This invention relates to radio receiving systems, and particularly to improved antenna arrangements for receiving purposes.

Among the objects of the invention are the following:

1. To approach as closely as possible the ideal, so far not closely approximated in practice, of a unidirectional receiving system;

2. To efficiently receive radio signals from a desired direction to the substantial exclusion of signals coming from a predetermined undesired direction.

3. To efficiently receive at a station of a two-way radio communication system, signals from a cooperating distant station without interference from waves radiated from the local transmitting station.

4. To achieve each and all of the above objects without sacrifice of protection against strays or, in a somewhat broader sense, to achieve each and all of the above objects and concomitantly to substantially prevent interference due to strays both from the desired direction and from other directions.

The word "strays" is used here and throughout the specification and claims, as in approved modern texts, to comprehend all signal simulating phenomena not falling within the category of signals, and therefore to include phenomena having artificial, as well as natural origin. It is intended specifically to include both "static" and "atmospheric".

An embodiment of the present invention is incidentally disclosed but not claimed in U. S. Patent 1,668,757, granted May 8, 1928, and assigned to the American Telephone and Telegraph Company.

A specific object of the invention is to improve the operation of long antenna known as Beverage or wave antenna, and in particular to improve the methods of eliminating one or more of the minor lobes of its polar reception diagram, the presence of which lobes tends to cause the antenna to be merely preponderantly, instead of strictly, unidirectional.

By the improved means of this invention, the elimination is accomplished without adding, to a harmful extent, new areas to the reception diagram. The presence of these additional areas would connote an increased susceptibility to the influence of strays, a susceptibility that is measured both by the size of the area and its angular extent.

In accordance with prior practice, as represented by the practice of the Radio Corporation which developed this type of antenna and is its principal user, the wave antenna is in effect arranged for simultaneous operation in the two opposite axial directions, so as to have similar but relatively reversed reception diagrams. After adjustment to provide the proper equality relation of the ordinates of the respective diagrams corresponding to a certain direction of interfering waves, the currents due to waves incident upon the antenna are superposed in the receiving circuit. It is apparent that this prior method is inherently adapted for the elimination of the axial minor lobe only since the reception diagrams must be unvaryingly 180 degrees apart. The lateral lobes, or certain of them, can be eliminated only by relatively enormously increasing the size of the reception diagram representing the compensating circuits with the production of a corresponding enormously increased additional reception area along the reverse axis.

Specifically, in the method of the present invention, the compensating wave is picked up by an entirely independent antenna, the reception diagram of which has such a configuration as to readily lend itself to combination with the corresponding diagram of the principal antenna, if superposed in a particular angular relation, to produce the desired resultant diagram. This independent or auxiliary antenna is dirigible and is so oriented that its actual reception diagram assumes this desired angular relation with that of the principal antenna. The currents are then simply combined in such relation as to be...
equal and opposed over the region of the lobe to be eliminated.

Because the wave antenna is normally so nearly unidirectional, the auxiliary antenna may be relatively small, since the area of its reception diagram is of the order of that of the particular minor lobe to be compensated or eliminated. Although perhaps a substantially unidirectional auxiliary antenna would, on theoretical considerations, be preferred, it has been found that a simple dirigible loop, having a bidirectional reception diagram resembling the shape of a figure 8 well answers every practical purpose. By means of this invention any one of the minor lobes of the reception diagram of the principal antenna may be substantially wholly eliminated with the production of a very small additional reception area which will be distributed partly in the general direction of that lobe and partly in substantially the reverse direction. If, under special conditions, the additional expense would be justified, the ordinary dirigible loop could be replaced by a dirigible antenna having a unidirectional, for example a cardiod, characteristic with a resultant improvement in the way of decreasing the additional reception area.

The novel features which are believed to be characteristic of the invention are set forth in the appended claims. The invention itself, however, both as to its organization and method of operation will best be understood by reference to the following description taken in connection with the accompanying drawings in which:

Fig. 1 is a circuit diagram of one embodiment of the system of the invention.

Fig. 2 is a polar reception diagram illustrating the operating characteristics of the wave antenna which constitutes a portion of the system of Fig. 1.

Fig. 3 is a polar reception diagram illustrating the operating characteristics of the loop antenna which constitutes another portion of the system of Fig. 1; and

Fig. 4 is a polar reception diagram illustrating the operating characteristics of the system of Fig. 1 as a whole including both antennas.

Before entering on the description of the specific arrangement of the invention, which may make use of any one of several forms of wave antenna circuits, the general theory of the operation of wave antenna will be developed. This plan, as providing a background for the specific invention that is to be described, will tend to aid one in looking back of the specific disclosure illustrated in the drawing to determine the real nature and extent of the invention.

The following references comprise in their disclosures substantially all of the learning and practice in this art available to the public up to this time. They, or some of them, may be studied to advantage in connection with this specification:

(1) A paper by Beverage, Rice, and Kelllogg, printed in three parts in the Journal of the American Institute of Electrical Engineers, in the March, April and May 1923, numbers. The physical theory is well described in the first of these three parts.

(2) Beverage U. S. Patents 1,351,081, June 7, 1921, 1,434,985, November 7, 1922, 1,434,985, November 7, 1922 and 1,434,986, November 7, 1922.


A wave antenna may be simply any substantially straight current conducting circuit, having a length of the order of the wave length of the ether wave, extending substantially horizontally, along which wave energy impressed upon it may be propagated at a velocity comparable with that of the same wave in ether. The last requirement may be satisfied by inserting condensers in series at uniform intervals throughout the length of the antenna, which may otherwise have the form of an ordinary transmission line of one or more conductors grounded at each end. The same effect, that of increased velocity of propagation, may be secured by inserting inductances between the antenna and ground.

In accordance with the most easily explainable theory of operation, a wave generated at one end of the antenna, hereinafter called the near end, by an ether wave which travels in the direction of extension of the antenna, is propagated along the antenna. The ether wave also generates a wave in each of the other elemental lengths into which the antenna may be considered divided, and these waves are similarly propagated along the antenna. The effect, practically, is that the wave generated at the end of the antenna absorbs energy from the accompanying ether wave and therefore increases in amplitude as it progresses along the antenna, attaining a maximum at the opposite end, hereinafter called the remote end, where the receiver is located. By parity of reasoning there would be no energy at the receiving end absorbed from a wave proceeding in the opposite direction, although an additional receiver at the opposite end could effectively receive such a wave. In order that the above operation may not be complicated by reflection effects, and accordingly that the unidirectional character of the antenna may be preserved, the ground lead at the end opposite to the receiver, and therefore at both ends if two receivers are to be used, may be caused to have an impedance equal to the surge impedance of the antenna. Means such as this have, in practice, been sufficient to nearly but not quite eliminate the axial minor lobe. Instead of placing the receiver at the remote end, as in the ground
lead, a reflection transformer can be placed in this ground lead if a two-conductor antenna is used and the antenna can then be used like an ordinary transmission line (current flowing in opposite directions in the two conductors) to transmit the energy back to the near end where the receiver may be placed. This permits the element which determines the surge impedance to be placed near the receiver where the impedance of the element can be most conveniently adjusted. If two receivers are to be used, the requisite surge impedance for the operation of the additional channel can be placed in the ground lead as in the usual way and in series with the reflection transformer. Beverage U. S. Patent 1,434,984, supra, illustrates that arrangement.

If the velocity of propagation is equal to the velocity of the ether wave, the wave in the antenna continues to build up until limited only by the antenna losses, that is, the benefits of an extra long antenna can be secured by high velocity (so long as it is not higher than that of light) and low attenuation. If the two velocities are not the same, there will be a cyclical variation of amplitude of the wave along the antenna as the relative phases of the two waves vary through successive conditions of coincidence and opposition, and an extra long antenna is not of advantage, so far as it affects the maximum signal strength.

It has been found that, in general, the directivity as determined principally by the area of the axial minor lobe increases as the velocity of propagation approaches the velocity of light (compare Figs. 36, 38, and 39 of the above mentioned American Institute paper). The decrease in the width of the major lobe as the propagation velocity decreases is favorable but is not sufficient to compensate for the more important effect of change of area of the minor lobe. Also, as appears from a comparison of Figs. 35, 37 and 38 of the same paper the directivity improves somewhat as the length of antenna increases principally on account of the decrease in the width of the major lobe. In practice, it has been found that in order to obtain maximum strength of signals the length of the antenna should be at least half the length of the ether wave and preferably several times this length.

It should be noted that, if the antenna design is such that the propagation velocity is not equal to the velocity of light, the antenna necessarily must have a certain frequency-velocity characteristic. Practical use can be made of this characteristic in order to obtain frequency, as well as directional, selectivity.

This may be done by positioning receivers, intended for reception of waves of different frequencies, at different positions along the antenna. Similarly this method of positioning the receivers may be used to avoid the effect of systematic stray interference. For the purposes of this invention the velocity should be as nearly that of light as possible and the attenuation should be as small as possible.

The above discussion treats of the mode of operation when an ether wave is incident on the antenna in the direction of its axis. The described mode of operation accounts for the presence of a pronounced major lobe of the reception diagram. Considering now the effects of ether waves incident on the antenna at an angle to its axis, it is evident that one of the effects is to shorten the distance the ether wave has to travel between its incidence on successive elemental lengths as compared with the case where the wave travels in a coaxial direction and as compared with the distance the propagated wave has to travel along the antenna. This effect is somewhat the same as if the two velocities were caused to be unequal. It is evident that for certain angles these differences in distance, translated into differences in phase, have simple integral multiple relations that result in a reinforcement substantially like that where the ether waves and antenna waves are travelling along the antenna in parallel. This at least qualitatively explains the existence of the lateral minor lobes.

The number, size and angular relation of these lobes can be caused to differ greatly by adjustments of the length, propagation velocity, and attenuation of the antenna. For example if the antenna is an integral multiple of half the wave length and if the propagation velocity equals that of light (a coincidence of conditions difficult to realize in practice) the axial minor lobe will be absent. The polar diagram illustrated in Fig. 2 is as nearly typical as any and is the one assumed to result from the operation of the system of Fig. 1 now to be described. Except perhaps as to the relative values of the ordinates, it is the same as Fig. 35 of the American Institute paper above mentioned.

The foregoing explanation should be kept in mind in considering the following description of a specific embodiment. Referring to Fig. 1, the antenna 1 is of the wave type and, as used in this system, receives most efficiently waves coming from the right. The antenna comprises a two-conductor line extending from the near end (near with respect to the ether waves) to the reflection transformer 2. The ground circuit at the near end contains impedance 3 adjusted to control the surge impedance of the antenna to prevent reflection of waves propagated along the antenna from the other (the remote) end. These waves, if reflected, would be superposed on and be indistinguishable from, the desired waves. The other end is grounded through the reflection transformer 2 which transduces the energy there received back to the antenna which accordingly serves as an ordinary transmission
line (currents flowing in opposite directions in the two conductors) to transmit the energy to the near end. If the antenna were not so used, the receiver could, and conveniently would, be placed in the ground lead at the remote end. This ground lead does not contain an element the primary function of which is to match the surge impedance, since the reflection transformer is designed to effect this result.

The disclosure of the antenna itself is diagrammatic only. Accordingly the antenna may actually consist simply of a two-conductor line, if the distributed inductance and capacity are small enough to give a propagation velocity comparable with that of light, or such a line varied by the inclusion of series condensers or shunt inductances, or both, as has been explained.

At the near end, the desired energy is again transduced by transformer 4 to circuit 5. The two halves of the primary of transformer 4 are related to the secondary winding, and to each other, in such a manner that magnetic effects resulting from undesired waves propagated simultaneously along both wires of the antenna from the remote to the near end, are balanced out in the secondary winding. That is, this balanced circuit arrangement prevents such undesired waves from directly affecting the receiving circuits connected to circuit 5, while the surge impedance element 6 prevents these waves from being reflected and thereby later entering circuit 5 through transformer 4.

The receiving circuits connected to the circuit 5 include an amplifier AM and a radio receiver RR. The amplifier, of course, may be omitted on occasion, and the transformers 6 and 7, whereby energy is transferred to the related circuits, may be replaced by well known equivalents.

The radio receiver may comprise any one of the well known circuit arrangements in which the impressed modulated carrier wave is demodulated to reproduce the low frequency modulating component, as in radio telephony, or rectified to reproduce radio telegraphic signals. The demodulated component is impressed on low frequency circuit 8. The radio receiver may include a filter, to eliminate the undesired frequency components resulting from demodulation so that only the low frequency signal currents are transmitted to circuit 8.

A loop antenna 9, here diagrammatically illustrated, may be of any one of the conventional forms now known and may be caused to be dirigible also in accordance with conventional practice, as by a simple rotatable mounting. Fig. 3 illustrates the polar reception diagram of a loop antenna, the axis drawn through the diameter of the two lobes corresponding to the direction of the plane of the loop. Since this direction can be varied at will there is no special significance to the position of the axis in this figure.

The other waves incident on the loop antenna are amplified by amplifier AM, and are then caused to flow through a phase shifter 10, potentiometer 11, another amplifier AM, and circuit 12 to the input of the radio receiver RR on which they are impressed by coil 13 which is coupled with the secondary of transformer 6.

The function of the phase shifter is to adjust the phase of the waves derived from the loop antenna so that they are in opposite phase to those derived from the wave antenna, with respect to the waves incident on the system from the direction corresponding to the lobe which is to be eliminated. The potentiometer functions to equate the amplitudes of the two waves for this direction.

In order that the function of the loop antenna system, as related to the wave antenna system, may be better understood, reference is made to Fig. 4. In this figure, polar diagrams corresponding to Figs. 2 and 3 are shown respectively in light full, and broken lines. The heavy full lines illustrate the resultant polar reception diagram. This resultant diagram indicates the current impressed upon the input of the radio receiver resulting from the superposition of the two component currents. The resultant diagram may be plotted, as it was in drawing this figure, by superposing the two component diagrams, dividing the field into as many lines representing directions as is practically possible, adding the ordinates of the two diagrams for each line while taking into account the differences in phase, laying off these difference values from the origin and along the same directions, and connecting the points thus obtained.

It is mentioned above that account must be taken of differences in phase. This results from the fact that the phase of the current, at the input of the radio receiver, derived from the wave antenna progressively varies with a corresponding variation of the angle of the incident waves with respect to that antenna. This variation of phase is indicated directly by the quantities in the last column of table III of the above mentioned American Institute paper, which assumes a set of conditions similar to those assumed here. There is no corresponding phase variation for the loop antenna except where the rotating vector passes from an angle corresponding to one side of the plane of the loop to an angle corresponding to the other side. The relations of the two superposed currents can be obtained very easily by merely superposing a curve taken from the last column of table III on a rectangular curve for the loop antenna, adjusting these curves (as is practically accomplished by phase shifting device 10) until there is opposition of phase at the center.
of the lobe to be eliminated and picking off the corresponding differences of phase for the other angles. The details of this method are not disclosed in the drawing since they would tend to unnecessarily complicate it and because the qualitative relations, which are all that are required to teach the essential principles that are involved, are sufficiently apparent without recourse to rigid geometrical methods of proof. The important thing to notice is that, beginning with the central line of the minor lobe there are four substantially equally spaced angles at which there is exact phase opposition and four symmetrically located intermediate angles at which there is phase coincidence.

For the assumed case, it was desired to eliminate the lobe indicated in Fig. 2 as a. For example, this lobe might point in the general direction of the local transmitting circuit of a two-way radio telephone station, of which the circuits of Fig. 1 constitute the receiving circuits.

The loop antenna would be accordingly oriented to a position such that the combination of currents in accordance with the method explained in the above paragraph results in an elimination of this lobe as possible. The position of the polar diagram for the loop antenna in Fig. 4 indicates the best position of this antenna to satisfy this condition.

The potentiometer 11 would also be adjusted so as to contribute to the satisfaction of this condition. That it has been so adjusted in the assumed case is indicated by the equality of the ordinates of the two component diagrams of Fig. 4 for a direction corresponding to the center of the lobe. The resultant heavy full line diagram indicates that the lobe has been substantially eliminated.

The resultant diagram also indicates that very little additional area has been produced. This area is indicated by that part of the resultant diagram outside of the diagram for the wave antenna, i.e., light full line diagram.

In accordance with prior practice, the compensating wave would be obtained from the ground lead at the near end of the wave antenna instead of from a separate dirigible antenna. The compensating wave would therefore be the wave resulting from the use of the antenna for waves oppositely directed relatively to those called the desired waves in the description of this invention. The polar diagram for the compensating wave would be similar to that of Fig. 2 but relatively reversed. It would be invariable in position with relation to the diagram for the desired waves. Accordingly, such a diagram could be superposed on that of Fig. 2 in such a manner as to substantially eliminate the axial lobe 6 of Fig. 2, and this is its normally intended function. However, if it were attempted to eliminate the lobe a, as by greatly increasing the size of the compensating wave diagram, a stray area of relatively large dimensions would be added to the polar diagram for the antenna system.

What is claimed is:

1. A radio receiving circuit comprising in combination, a proponderantly unidirectional receiving antenna, a directive dirigible antenna, said antenna being of types such that the axes of their polar reception diagrams are relatively displaced as the dirigible antenna is moved, receiving apparatus, and means whereby electrical variations produced in said antenna when adjusted so that the axes of their polar diagrams are relatively displaced are superposed on said apparatus.

2. The combination recited in claim 1 in which the dirigible antenna is of the unidirectional type.

3. The combination recited in claim 1 in which the dirigible antenna comprises a loop aerial, and means for rotating said loop about a vertical axis.

4. The combination recited in claim 1 in which the unidirectional antenna is a horizontal wave antenna.

5. The combination recited in claim 1 in which the unidirectional antenna comprises a substantially horizontal wave conducting circuit grounded at each end, having a substantially aperiodic characteristic, a length of the order of the wave length of the waves incident thereon and a propagation velocity comparable with that of either waves, and in that the dirigible antenna comprises a loop aerial and means for rotating it about a vertical axis.

6. In a directive radio receiving circuit, in combination, a wave antenna, comprising a substantially horizontal wave conducting circuit extending in the general direction of the source of radio waves which it is desired to receive, said circuit being substantially aperiodic, having a wave length of the order of the waves incident thereon and a propagation velocity comparable with that of either waves, a circuit connecting the end nearest the distant source with ground and having an impedance substantially equal to the surge impedance of the conducting circuit; a radio receiving apparatus; means for impressing on said apparatus the waves propagated to the end of the wave antenna remote from said source; a dirigible antenna comprising an aerial loop and means for rotating it about a vertical axis; and means for impressing the waves received by said loop on said apparatus in any desired phase relation with respect to the propagated waves.

7. The method of eliminating a selected minor lobe of a polar reception diagram of a horizontal aperiodic antenna, using a horizontal aperiodic antenna and a rotatable loop antenna, which comprises rotating said loop antenna until the axis of its polar reception.
diagram substantially coincides with the axis of said minor lobe, receiving radio waves jointly with said antennas and superposing the resultant waves.

8. The method using a directive horizontal aperiodic antenna and a dirigible loop antenna, of receiving desired waves from a direction corresponding to the major lobe of the polar reception diagram of said horizontal aperiodic antenna, to the substantial exclusion of interfering waves from a direction corresponding to a selected minor lobe of said diagram, which comprises orienting said loop antenna so as to most efficiently receive waves from a direction corresponding to said minor lobe, receiving the desired and interfering waves on said horizontal aperiodic antenna and compensating waves on said loop antenna, and superposing all of said waves in such phase relation that the interfering waves are substantially balanced out by said compensating waves.

9. A radio receiving circuit comprising in combination, a fixed, preponderantly unidirectional, receiving antenna, a directive dirigible antenna, said antennas being of types such that the axes of their polar reception diagrams are relatively displaced as the dirigible antenna is moved, receiving apparatus, and means whereby the electrical variations produced in said antenna are superposed on said apparatus.

10. The combination recited in claim 9, in which the dirigible antenna is of a unidirectional type.

11. The combination recited in claim 9, in which the dirigible antenna comprises a loop aerial, and means for rotating said loop about a vertical axis.

12. The method of improving the directive receiving qualities of an antenna which is preponderantly unidirectional, using a rotatable loop antenna, which comprises rotating said loop antenna until the axis of its polar reception diagram substantially coincides with a region of the polar reception diagram of said unidirectional antenna which it is desired to at least partially eliminate, receiving radio waves jointly with said antenna, and superposing the resultant waves.

In witness whereof, I hereunto subscribe my name this 7th day of July, A. D. 1925.

CARL R. ENGLUND.