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Feb. 7, 1928.

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RADIO RECEIVING SYSTEM

Filed Nov. 21, 1922

1,658,740

3 Sheets-Sheet 2

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.

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by Alexander B. Scott
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My present invention relates to radio receiving systems and more particularly to systems for obtaining a high degree of selectivity in reception.

For the purpose of eliminating interference from stations and static it is now recognized that highly directive antennas are especially effective. One form of unidirectional antenna which has been found to be highly successful in practice is that now known in the art as the "wave antenna," such as described in Business Patent 1,381,089, June 7, 1921. The directivity of this antenna increases with its length, but not proportionally thereto. For example, taking the area of the directivity curve of a wave antenna having light velocity and zero attenuation one wave length or 100%, it can be calculated that for

\[
\text{Antenna length} = \lambda, \text{area} = 100 \text{ per cent.}
\]

\[
\text{Antenna length} = 2\lambda, \text{area} = 81 \text{ per cent.}
\]

\[
\text{Antenna length} = 4\lambda, \text{area} = 60 \text{ per cent.}
\]

It appears from the above that the area of the directivity curve decreases rather slowly with increased length. If, on the other hand, instead of adding new antenna on the end of the existing antenna in the same straight line the two antennas are placed side by side at some distance apart and the signals from the two combined, a much sharper directivity curve may be obtained. The relative areas of the directivity curves may then be as follows:

One wave antenna \( \lambda \) long, \( A = 100 \) per cent.

Two parallel wave antennae each \( \lambda \) long and spaced \( \lambda/2 \) apart, \( A = 52 \) per cent.

Three parallel wave antennae each \( \lambda \) long and spaced \( \lambda/2 \) apart, \( A = 34 \) per cent.

In this case it is seen that the areas of the directivity curves are roughly inversely proportional to the total length of the antenna used. It is therefore apparent that the latter arrangement is economically superior to the former.

As will be shown in the description that follows there are numerous other forms of receiving antennae which may be combined in various ways to produce correspondingly sharper directivity curves than can be obtained with a single antenna. In the description which follows I will refer to the wave antenna as an "end on" receiver since it receives signals with maximum intensity when pointing toward the transmitter, and I will refer to the arrangement consisting of a row of antennae placed perpendicular to the signal direction as a "broadside" receiver since it normally receives signals with a maximum intensity when a signal strikes the various elements simultaneously.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims; my invention itself, however together with certain of the objects and advantages thereof will best be understood by reference to the following description taken in connection with the accompanying drawings in which:

Fig. 1 is a diagrammatic representation of a receiving system employing three-wave antennae; Figs. 2 and 3 are diagrams illustrating the operation of such a receiver; Figs. 4, 5 and 6 are directive curves illustrating the increase in directivity which may be obtained by employing two or three parallel wave antennae; Figs. 7 and 8 are diagrammatic representations of other antenna arrangements which may be employed to obtain similar results to that which may be obtained with the arrangement of Fig. 1.

In Fig. 1 I have shown three-wave antennae \( 1, 2 \) and \( 3 \), each of which points in the general direction of the signal which it is desired to receive. The ends \( B_1, B_2, B_3 \) of these antennae are provided with the usual reflection transformers \( r_1, r_2, r_3 \) to permit of the reception at the ends \( A_1, A_2, A_3 \) of signals traveling in the direction from \( A_1 \) to \( B_1 \). At the ends \( A_1, A_2, A_3 \), there are provided output transformers \( T_1, T_2, T_3, S_1, S_2, S_3 \), as indicated, for supplying signaling and compensating currents to the balanced transmission lines \( l_1, l_2, l_3, m_1, m_2, m_3 \) by means of which the desired currents are transmitted to the receiving station. Damper resistances \( C \) may be inserted across the transmission lines to prevent undesired reflections. I have provided at the receiving station artificial lines \( N_1, N_2, N_3, O_1, O_2, O_3 \) or other time or phase adjusting circuits to which the currents conveyed over the transmission lines are supplied by a series of transformers \( 4, 5, 6, 7, 8 \) and \( 9 \). Currents from the artificial lines are supplied by means of intensity couplers \( I_1, I_2, I_3, K_1, K_2, K_3 \), to the input circuits of the coupling tubes \( 10, 11 \) and \( 12 \).

The output circuits of the coupling tubes...
10, 11 and 12 are connected through transformers 13, 14 and 15 to artificial lines \( P_1, P_2, P_3 \), and the currents may be supplied from these artificial lines through intensity couplers \( V_1, V_2, V_3 \), to the input circuit of a combining tube 16. Current may be supplied from the output circuit of this tube 16 to the tuned circuit 17 from which the desired signaling current is supplied to the receiver 18. It will be understood that the vacuum tubes indicated will be connected in the usual manner, part of the connections having been omitted from the drawing for the purpose of simplification.

In adjusting the systems described to obtain the desired results the sliding connections 19, 20, 21, 22, 23 and 24 on the artificial lines are first adjusted for each of the wave antenennae to give the best signal reception from that antenna alone. In order to combine the currents from the different units in such a way as to obtain the maximum directivity and reception, the slidess 25, 26 and 27 on the artificial lines \( P_1, P_2, P_3 \) may be adjusted to adjust the phases of the currents impressed upon the grid circuit of the combining tube so that these currents will all be in phase.

In order to understand the mode of operation of the system described, consider the case of a signal traveling in the direction of the arrow which strikes all three antennae simultaneously and sets up like currents in each of the antenna units. The signaling currents are conveyed over the transmission lines and finally appear as variations in the plate currents of the several coupling tubes 10, 11 and 12. In general, the currents will not arrive simultaneously or in phase in the plate circuits of these coupling tubes since the different antennae will be at different distances from the receiving station. By proper adjustment of phase adjustors \( P_1, P_2, P_3 \), the different currents may be brought in phase so that their effects add directly in the secondaries of the intensity couplers \( V_1, V_2, V_3 \), and therefore their effects are added in combining tube 16. For the case of equal intensities in the different units the total effect will then be three times that of a single unit.

Assume now that the adjustment which gives equal time transmission and equal amplitude from the several antennae is retained but assume that the signal from an angle instead from the direction of the arrow. The currents received by the different units will still be equal in value but will not arrive at the receiver simultaneously and therefore instead of adding all in phase they will add at certain phase angles and the resultant will be less than three times the current which would be produced in a single unit by the signal coming from the assumed angle.

To illustrate the method of calculating the directive curve, let us assume the case of a row of like units spaced equal distances apart.

Let \( \theta \) = Direction angle of signal.

\( d \) = Distance apart of the antenna in wave length units.

\( \beta \) = Phase angle corresponding to the antenna spacing \( "d" \).

\( L_0 \) = Current from single unit at angle \( \theta \).

\( b \) = Delay distance in wave length units.

\( \phi \) = Phase angle corresponding to the delay distance \( "b" \).

If "\( d \)" is expressed in wave length units, then since one wave length corresponds to a 360° phase displacement the phase angle \( \beta \) will be

\[ \beta = 360 \times d; \]

We then have from the triangle Fig. 2,

\[ \phi = \beta \sin \theta, \]

\[ \phi_0 = 360 \times d \sin \theta. \]

Having determined the phase angle \( \phi_0 \) for a given direction of the signal, we can lay off the several antenna currents with their proper magnitudes \( L_0 \) and each differing from the previous one by the phase angle \( \phi_0 \) as illustrated in Figure 3. The chord drawn between the first and last vector constitutes the resultant current for the particular angle under consideration. By this process as many points on the polar directive curve as desired may be calculated.

The directive curves Fig. 5 and 6 were derived from Fig. 4 by this process. The units assumed are wave antennae each one wave length long having light velocity and zero attenuation. Fig. 4 is the directive curve for the single wave antenna; Fig. 5 the resultant directive curve for two such antennae spaces \( \frac{3}{4} \lambda \) apart; Fig. 6 the directive curve of the combination of three of these wave antennae, each \( \frac{3}{4} \lambda \) apart.

The units of which the broad side rows are composed may instead of being made up of wave antennae consist of any of the well-known unidirectional combinations. In Fig. 7 I have shown two ground antennae in each unit, spaced apart, that is, one behind the other in signal direction and these may be adjusted to give zero reception from the direction opposite to that of the signal. The currents from the various antennae in this arrangement are conveyed to the receiving station over the transmission lines \( L_1, L_2, L_3, M_1, M_2, M_3 \), as in the arrangement shown in Fig. 1. The same station apparatus may be employed for any of these alternative antenna systems and the procedure of adjustment and operation will be the same for each.

While I have shown in Fig. 1 only the circuit connections necessary for receiving a single signal, the arrangement shown in Fig. 1 as well as the arrangement shown in Fig. 7 may equally well be employed for multiplex
reception of signals all of which come from one direction or part from one direction and part from the opposite direction, it being necessary in this case to provide additional sliders 28 to 33, inclusive, for securing the necessary phase adjustments, and a duplicate set of coupling tubes, combining tube and intensity couplers for each separate signal which is to be received.

In the arrangements thus far described I have considered only a broad side row made up of a number of separate units spaced an appreciable fraction of a wave length apart perpendicular to the signal direction, for example, \( \frac{3}{2} \) or more. Another convenient arrangement whereby highly directive results may be obtained is to use two multiple tuned or "infinite velocity" antennas spaced apart one back of the other. This method of producing a unidirectional broadside receiver is illustrated in Fig. 8. Antennas 37, 38 are of the multiple tuned type and therefore adjusted so that the currents in all of the down leads are in phase. An antenna of this type is the equivalent of a plurality of static antennas connected by an infinite velocity transmission line. Transmission lines \( L_1 \) and \( L_2 \) convey the signals from each antenna to the receiving station where the phase and intensity adjusting apparatus \( N_1 \), \( N_2 \) and \( I_1 \), \( I_2 \) is located. The effects of the desired signaling currents are then combined in series on the grid of the combining tube 39 and the receiving set 18 is supplied through the tuned circuit 17 from the plate circuit of the combining tube. One of these antennas alone consists of a highly directive bidirectional broadside receiver. The combination of the currents from two such units one placed behind the other so that the wave impulses coming from the direction opposite the arrow of Fig. 8 will cancel while the signal coming in the direction of the arrow will not cancel results in a highly directive unidirectional broadside receiver. The method of combining currents from different units employed in this case is the equivalent of that indicated in the system illustrated in Fig. 7 as it is immaterial whether the first combination is made of currents from a row extending in the direction of the signal and the second combination is made of currents from a plurality of such rows or the first combination is made of currents from a row extending at a right angle to the signal direction and the second combination is made of currents from a plurality of such rows.

While I have shown and described the preferred embodiments of my invention, it will be apparent that many modifications in the form, number and arrangement of the antennas employed as well as in the manner in which the currents from the different antennas are combined, may be made without departing from the scope of my invention as set forth in the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. The combination in a radio receiving system of a plurality of parallel unidirectional receiving antennas each having a horizontal length as great as the wave length of the signal to be received and separated from each other by a substantial fraction of a wave length of the signals to be received, a receiving apparatus and means for combining the currents received upon the different antennas in the receiving apparatus.

2. The combination in a radio receiving system of a plurality of parallel wave antennas each having a horizontal length as great as the wave length of the signal to be received separated from one another by at least a half wave length of the signals to be received in a direction substantially at right angles to that of the signal to be received, a receiving apparatus and means for combining the currents received upon the different antennas in the receiving apparatus.

3. The combination in a radio receiving system of a plurality of parallel horizontal antennas separated from one another by a substantial fraction of a wave length of the signals to be received in a direction substantially at right angles to that of the signal to be received, a receiving apparatus and means for combining the currents received upon the different antennas in the receiving apparatus.

4. The combination in a radio receiving system of more than two receiving antennas arranged in a row extending in a direction substantially at right angles to the direction of the signals to be received and separated from each other by a substantial fraction of a wave length of the signals to be received, a receiving apparatus and a pair of balanced transmission lines connecting each antenna with the receiving apparatus.

5. The combination in a radio receiving system of more than two receiving antennas arranged in a row extending in a direction substantially at right angles to the direction of the signals to be received and separated from each other by a substantial fraction of a wave length of the signals to be received, a receiving apparatus, a pair of balanced transmission lines connecting each antenna with the receiving apparatus, and means at the receiving apparatus for adjusting the phase and intensity of the currents impressed from each transmission line upon the receiving apparatus.

6. The combination in a radio receiving system of a plurality of directive receiving units, a pair of phase adjusting circuits associated with each of said units, a coupling tube for each unit having its input circuit.
adjustably coupled to both of said phase adjusting circuits, and means for impressing upon the receiving apparatus currents of adjusted phase and intensity from the output circuits of all of the coupling tubes.

7. The combination in a radio receiving system of a plurality of directive receiving units, a coupling tube associated with each receiving unit, means for effecting a desired neutralization of interfering impulses in the input circuit of each coupling tube comprising means for combining in selected phase and intensity two different currents derived from the corresponding receiving unit and produced by waves reaching the unit from different directions, and means for impressing upon receiving apparatus currents of adjusted phase and intensity from the output circuits of all of the coupling tubes.

8. The combination in a radio receiving system of a plurality of directive receiving units, a pair of phase adjusting circuits associated with each receiving unit, a coupling tube for each unit having its input circuit adjustably coupled to the two phase adjusting circuits associated with that unit, a phase adjusting circuit associated with the output circuit of each coupling tube, and means for adjustably coupling the phase adjusting circuits of all of the tubes to a receiving apparatus.

9. The combination in a radio receiving system of a plurality of directive receiving units, a coupling tube associated with each receiving unit, means for effecting a desired neutralization of interfering impulses in the input circuit of each coupling tube comprising means for combining in selected phase and intensity two different currents derived from the corresponding receiving unit, and means for impressing upon receiving apparatus currents of adjusted phase and intensity from the output circuits of all of the coupling tubes, and a receiving apparatus associated with the output circuit of the combining tube.

In witness whereof I have hereunto set my hand.

CHESTER W. RICE.