July 24, 1928.

S. W. DEAN

1,677,956

BROADSIDE ANTENNA ARRAY

Filed June 3, 1926

3 Sheets-Sheet 1

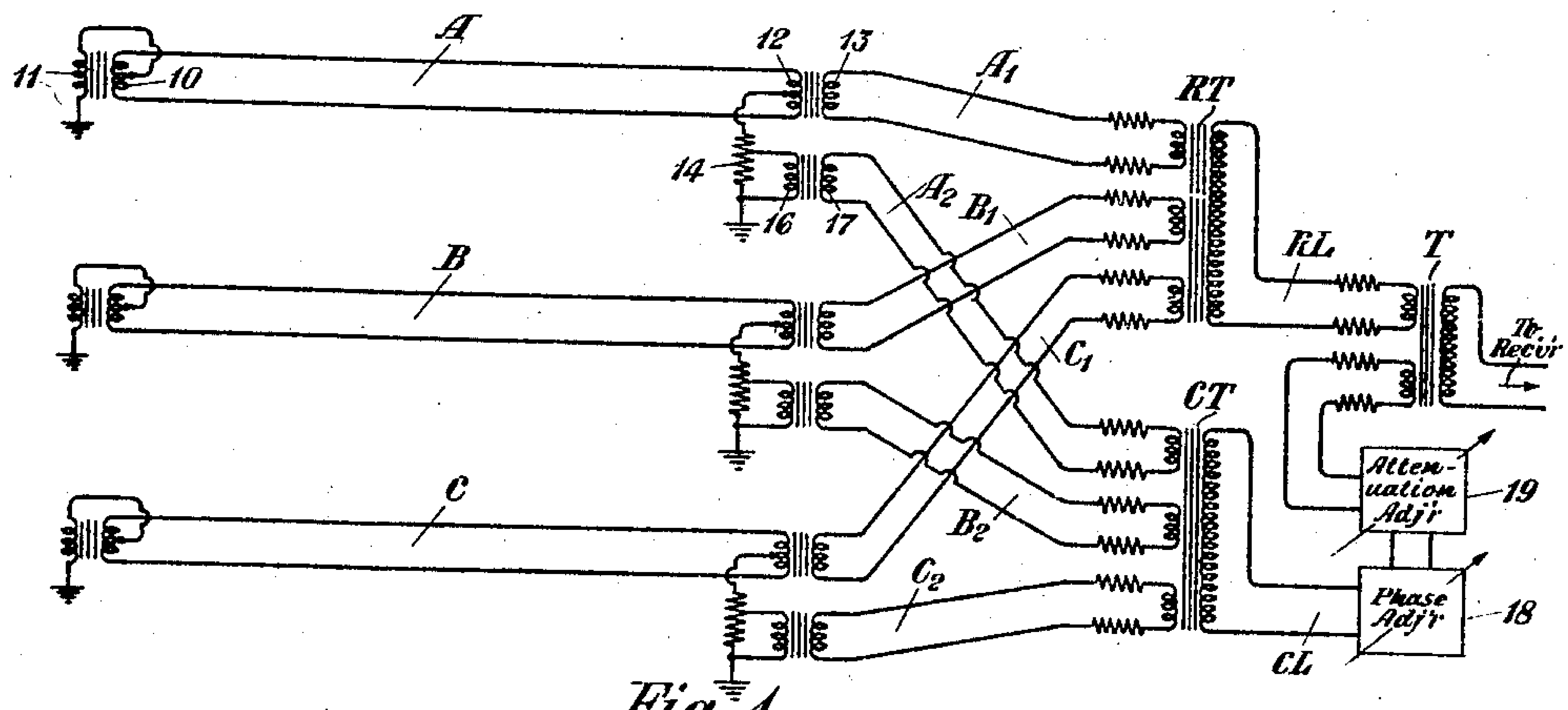

Fig. 1

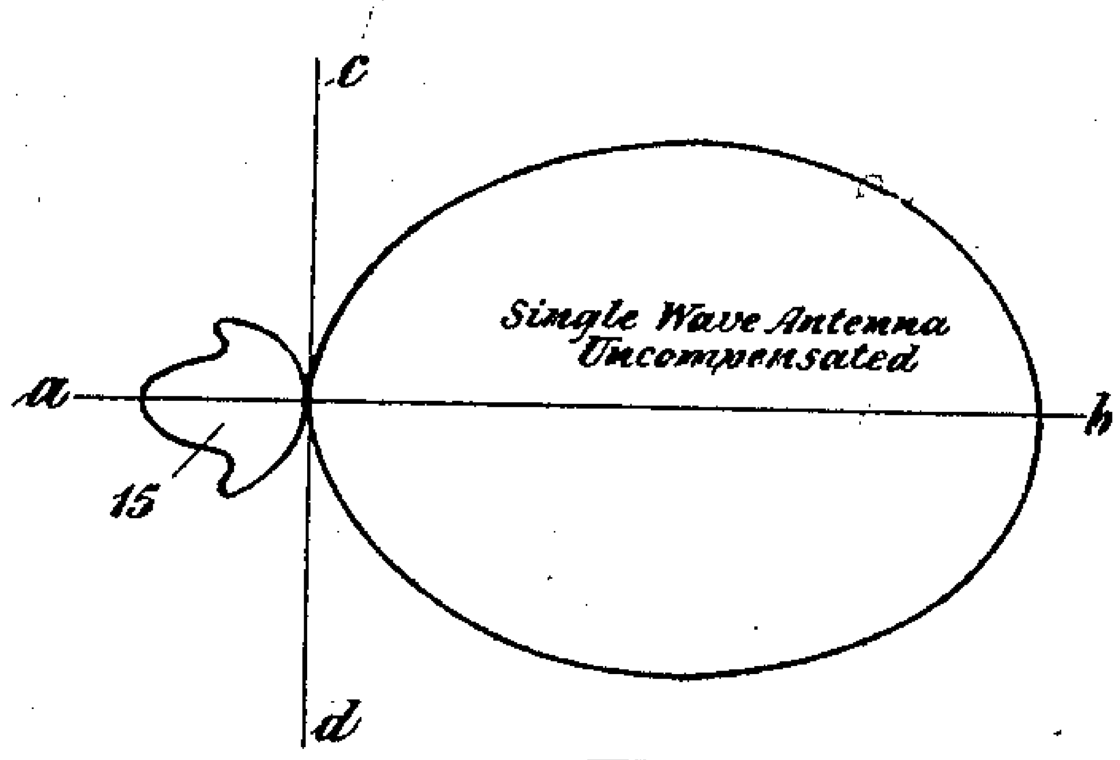

Fig. 2

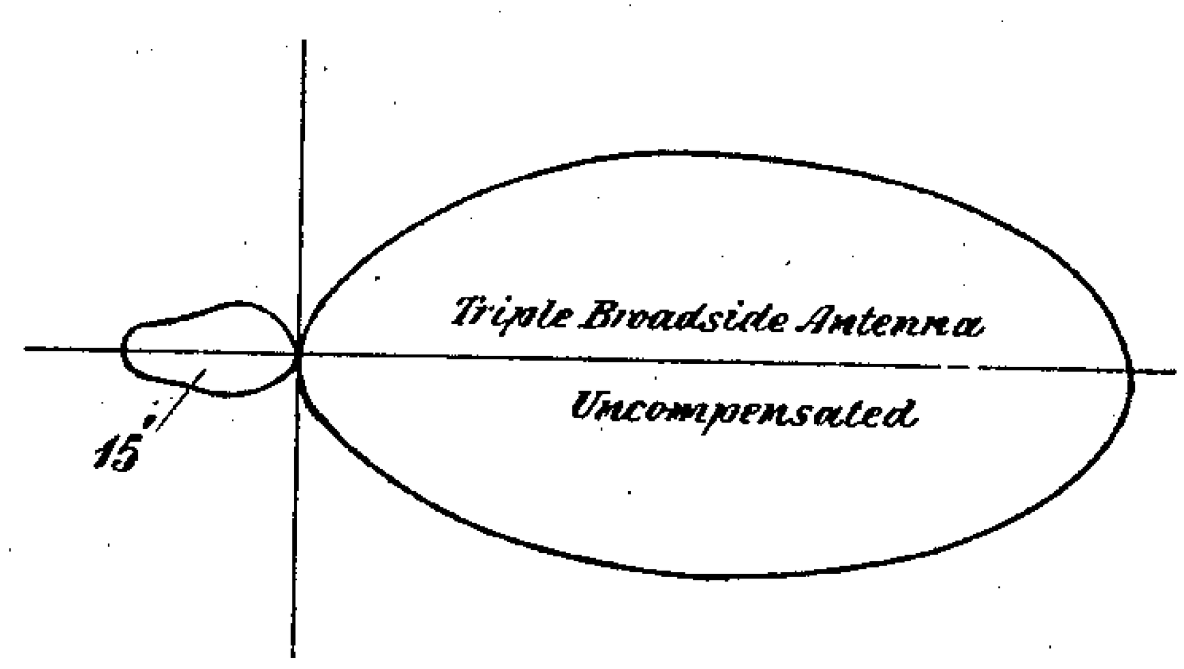

Fig. 3

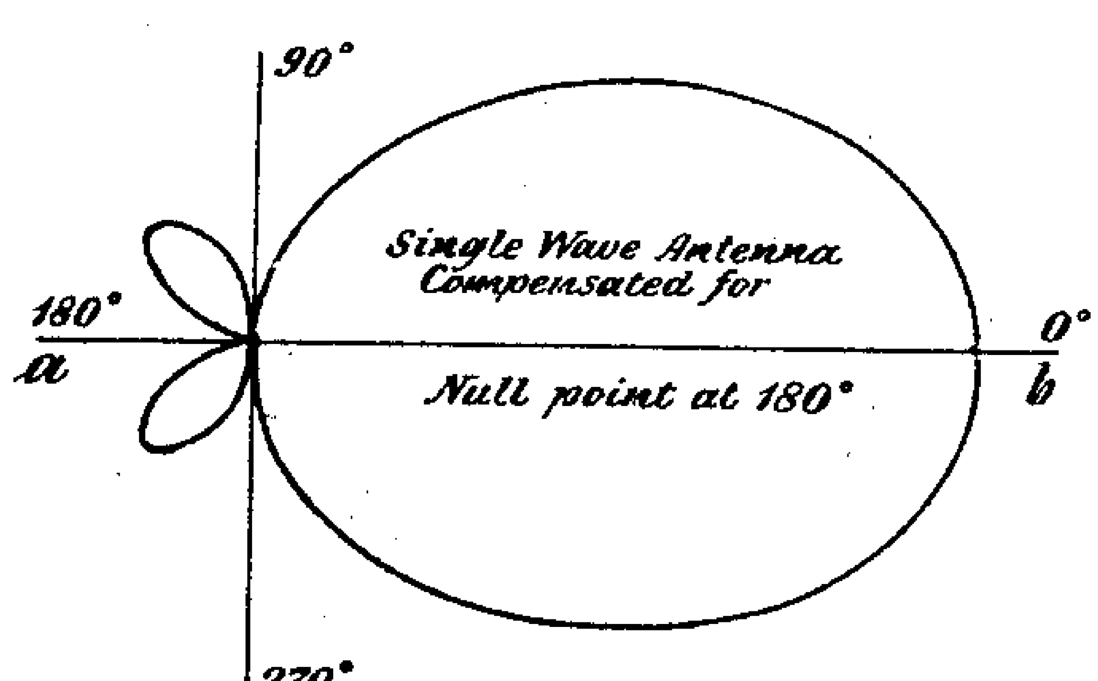

Fig. 4

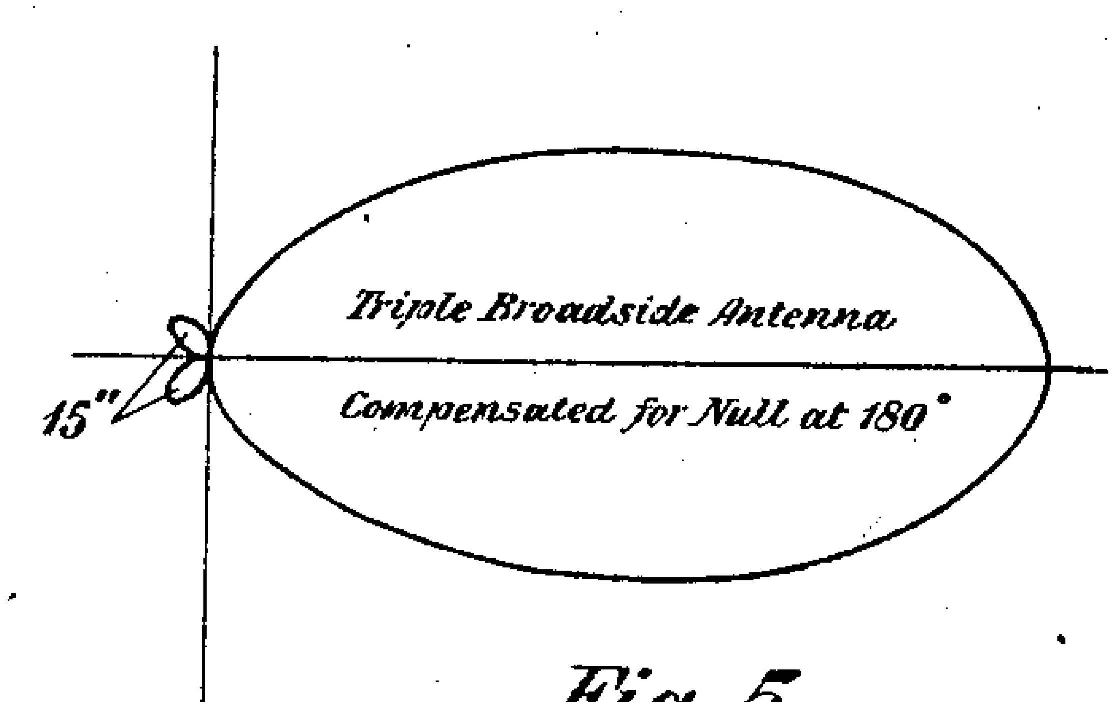

Fig. 5

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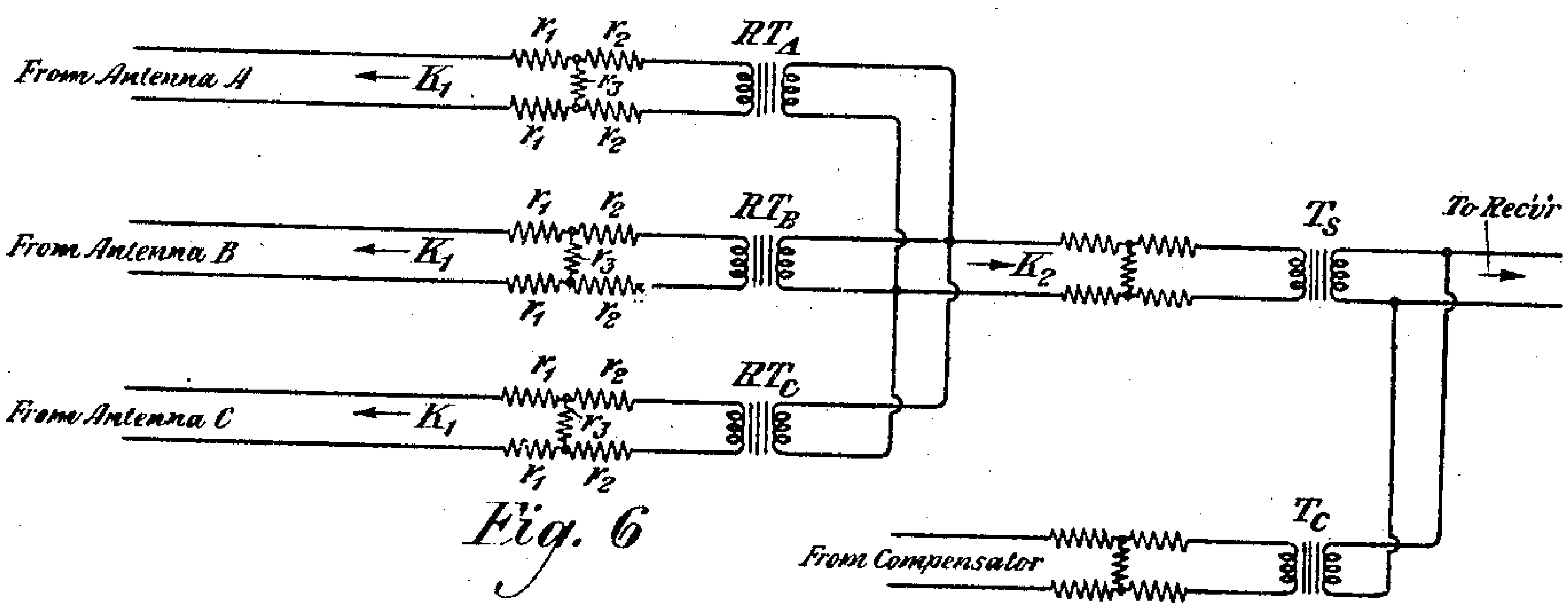

Fig. 6

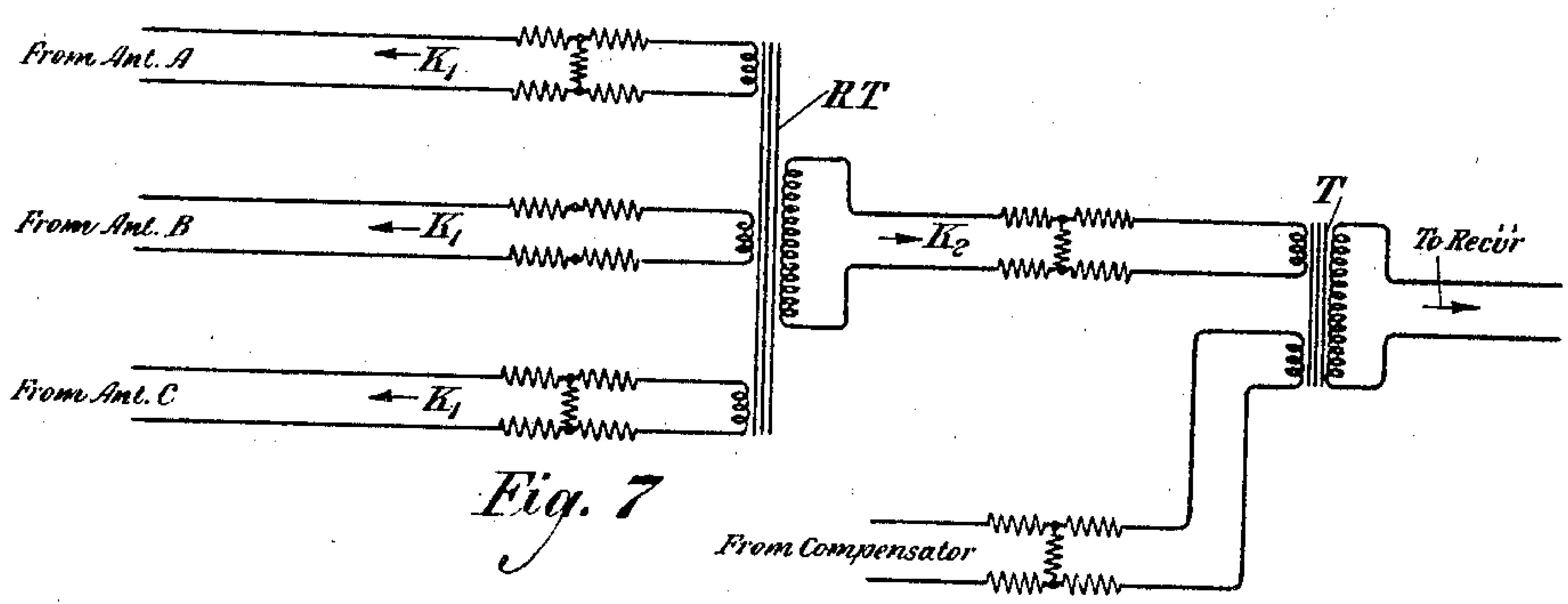

Fig. 7

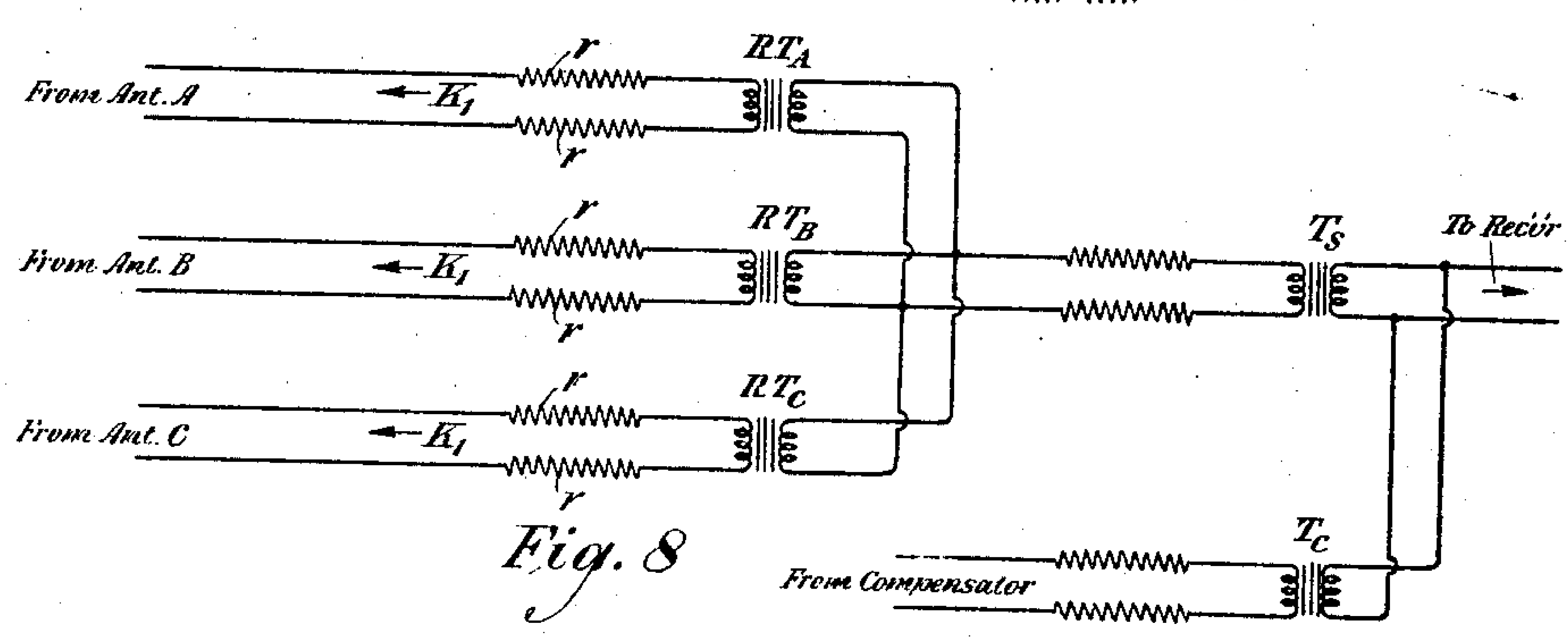

Fig. 8

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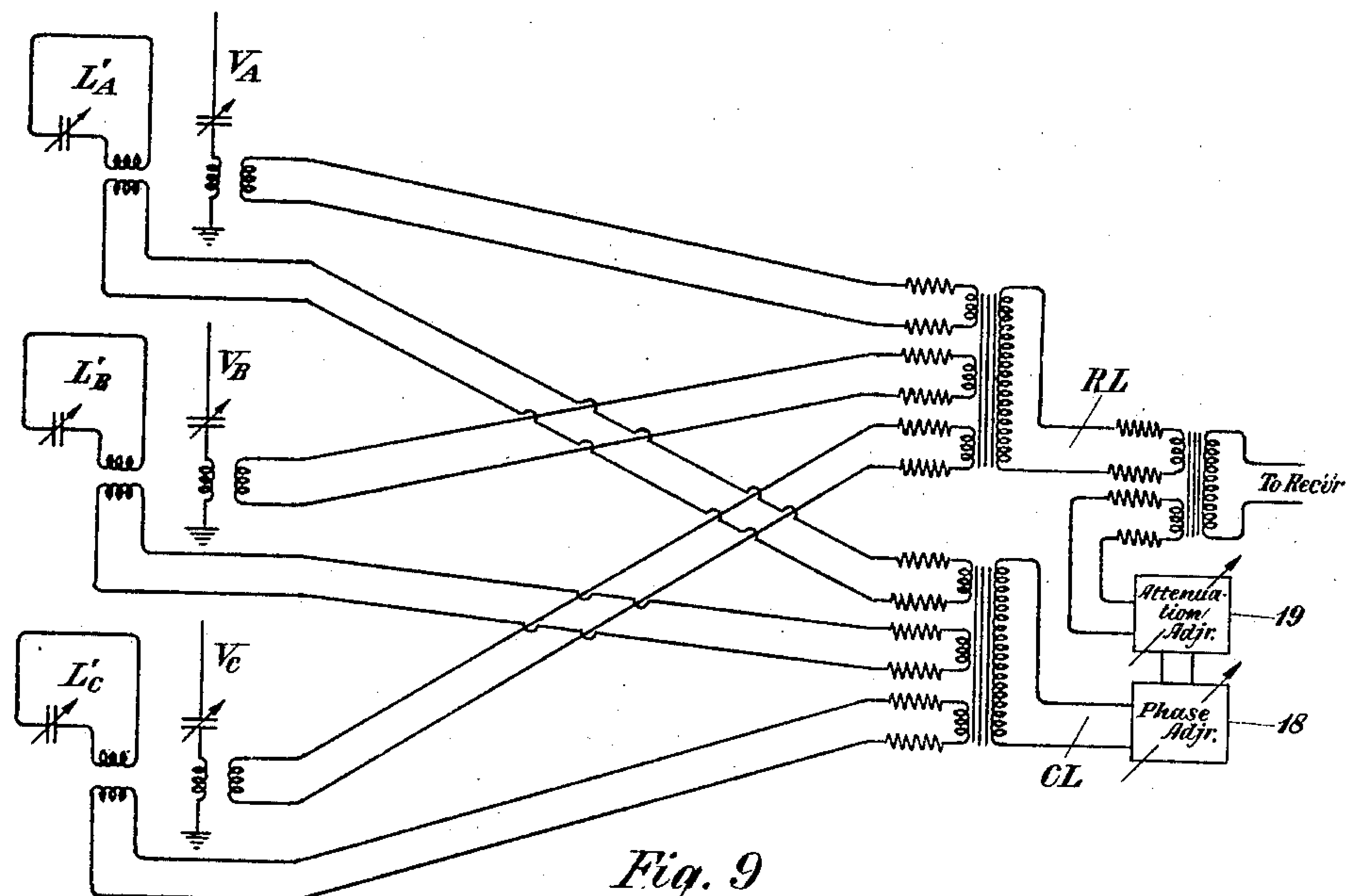

Fig. 9

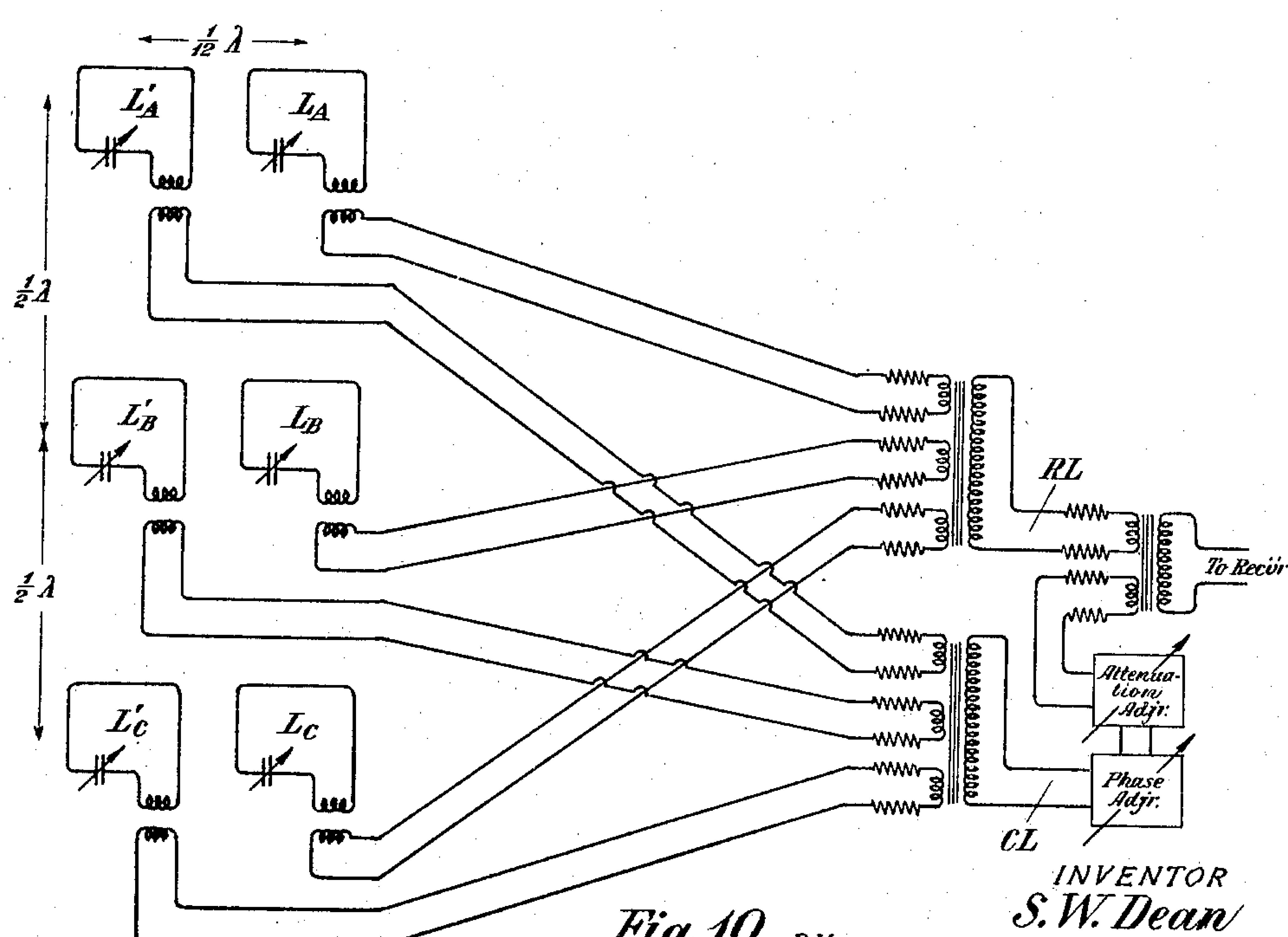

Fig. 10

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Patented July 24, 1928. 1,677,956

UNITED STATES PATENT OFFICE.

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BROADSIDE ANTENNA ARRAY.

Application filed June 3, 1926. Serial No. 113,506.

This invention relates to radio transmission systems, and more particularly to arrangements for connecting a plurality of antennæ in array formation.

When using a "wave antenna" it has been customary to make use of a small fraction of the interference or noise voltages developed in the surge resistance of the antenna to balance out undesired interference or noise received from a direction approximately opposite to that of the desired signal. Such a procedure is termed "compensation" and serves in effect to deform the normally directive curve of the antenna in such a manner as to produce zero reception at any desired angle "behind" the antenna, that is, at any angle greater than 90 degrees measured from the direction of the desired signal which is in line with the antenna. In particular, compensation is often used to produce zero reception at an angle of 180 degrees, or directly opposite to the direction of the desired antenna.

It is also known that the directivity may be increased by the use of a system of parallel wave antennæ spaced apart a certain fraction of a wave length in a direction at right angles to that of the desired signal, each wave antenna, however, extending in the direction of the desired signal. Such an arrangement is commonly called a "broadside wave antenna system". The effect of the "broadside" arrangement in general is to decrease the width of the directive curve as measured in a direction at right angles to the axis of transmission. In such a system compensation of the individual antennæ is capable of reducing to a considerable extent the size of the so-called "back-end" area of the directive diagram. In other words, the reception of interference and noise over the entire semi-circle to the rear of the antenna system is reduced with a corresponding improvement of the signal-noise or signal-interference ratio.

In the past this compensation has been accomplished by separate adjustments for each antenna of the broadside system, that is, each antenna has been compensated by itself as if it were to be used alone and the outputs of the antennæ have been subsequently combined in a suitable manner. In accordance with the present invention it is proposed to bring to a central point voltages derived from the surge resistances of the several antennæ of the broadside system and combine them in the same manner as the desired signal (derived from the so-called "front end" of the antennæ). Having thus combined these interference and noise voltages from the several antennæ it is proposed to utilize a portion of the resultant voltage to balance out noise and interference voltages coexistent with the desired signal in the circuit derived from the "front end" of the antennæ. In doing this the same general result is obtained as in the case of the individual compensating methods previously used, but the result is obtained in a simpler manner. Furthermore, the proposed compensation has the advantage that it permits of a very much more accurate adjustment of the balance than has ever been possible where it was attempted to balance each antenna separately.

Another feature of the present invention relates to the details of the circuits for combining the outputs of several antennæ connected in parallel. If, for example, lines from a plurality of wave antennæ are connected to the primaries of similar transformers whose secondaries are connected in parallel to a common receiver, or if the lines are connected to the primaries of a multiple winding transformer whose secondary is connected to the receiver, the lines will not be terminated in their characteristic impedances. For example, where we have three antennæ each line would be terminated in the impedances of the other two lines together with the input impedance of the receiving apparatus—all in parallel. This would obviously be considerably less than the characteristic impedance of the line. In accordance with the present invention it is therefore proposed to correct this difficulty by "building out" the transformers with impedance networks in such a manner as to terminate all of the lines in their characteristic impedances.

The method of compensation and impedance correction of the present invention are equally applicable to other types of directive antenna systems when arranged in "broadside", as will be described later.

The invention may now be more fully understood from the following detailed description when read in connection with the accompanying drawing in which Figure 1 shows the invention as applied to a system of wave antennæ connected in "broadside"; Figs. 2, 3, 4 and 5 are curves or directional diagrams illustrating the directive characteristics of wave antenna systems; Figs. 6, 7 and 8 are diagrams showing alternative methods of combining the outputs of a number of separate antenna systems; and Figs. 9 and 10 show the invention applied to "broadside" arrangements of typical directive antenna arrangements other than wave antennæ.

Referring to Fig. 1, a broadside connection, of three wave-antennæ A, B and C is shown although it will be understood that the principle is applicable to any number of antennæ connected in broadside. Each antenna is in the form of a pair of wires stretched across the country side in line with the direction from which signals are to be received. Assuming that the wires extend from east to west, for example, a signal coming from the east builds up by increments upon the wires of the wave antenna and reaches its maximum value at the west end of the antenna. It is usually desirable to have the receiving apparatus connected to the end of the antenna which points in the direction from which the signals arrive. Therefore each pair of wires comprising an antenna, such as A, terminates at the west end in a winding 10 of a transformer whose midpoint is connected to ground. The ground connection includes a primary winding 11 so related to the winding 10 that the two together constitute a transformer. The transformer impresses the received signal upon the two conductors constituting the antenna A in such a manner that the conductors function as a transmission line to transmit the signal from the west or "back" end of the antenna to the east or "front" end at which the receiving apparatus is located. At the front end the antenna, such as A, for example, is terminated in a similar transformer comprising primary winding 12 and secondary winding 13 for associating the antenna with a local line, such as A_1, leading to the receiver. The midpoint of the winding 12 is connected to ground through a surge resistance 14.

A wave antenna such as above described has a directive diagram of the general form indicated in Fig. 2, so the maximum signal is received in a direction along the axis *ab* from *b*—*a*. No signal is received from a direction along the axis *cd*. The wave antenna is not, however, purely unidirectional in its action but the directive curve has a small back-end area 15 of somewhat irregular form, as shown in Fig. 2. Consequently a certain amount of noise or interference in a direction from *a* to *b* or from a direction at an angle somewhat less than 90 degrees on either side thereof will be superposed on the signal received by the antenna A, for example, as above described. In order to compensate or balance out the noise which is picked up with the signal component due to the back-end area 15 of the directive curve, a transformer having a primary winding 16 is provided, the secondary 17 of the transformer being connected to a local line A_2 leading to a compensator consisting of a suitable phase adjuster 18 and attenuation adjuster 19. The noise from the directions represented by the back-end area 15 will be most efficiently picked up by the conductors on the antenna A, functioning as a wave antenna for the direction from west to east. These noise components attain their maximum value at the east or front end of the antenna and flow to ground through the surge resistance 14. By picking up these components through the transformers 16 and 17 and adjusting them with respect to phase by the phase adjuster 18 and with respect to amplitude by the attenuation adjuster 19 these noise components may be impressed upon the receiver in such phase relation and with such value as to oppose the components picked up along with the signal due to the back-end area 15 of the directive curve. When this compensation is properly effected for a single wave-antenna the directive diagram assumes the form shown in Fig. 4, the back-end area being reduced to zero in a direction from *a* to *b* but being somewhat increased for directions in the neighborhood of 45 degrees on either side thereof. It will be understood of course that by suitable phase adjustment the compensation may be made effective for noise arriving from any direction within the so-called back-end area, the curve of Fig. 4 merely showing the condition, where the noise arrives in a direction of 180 degrees from the desired signal.

So far the apparatus has been described for a single wave-antenna. When a plurality of antennæ are arranged in broadside the other wave antennæ, such as B and C, will be provided with equipment similar to that described in connection with the antenna A. The signal from the antennæ B and C will be transmitted from the back ends to the front ends thereof over the conductors of the antennæ connected as transmission lines, and the front ends of these antennæ will be connected to the receiver through lines such as B_1 and C_1. Similarly the balancing components will be taken from the surge resistance of antennæ B and C through transformers similar to transformers 16 and 17 and combined in the compensating circuit through lines B_2 and C_2.

The signal components from the several antennæ transmitted over the line circuits A_1, B_1 and C_1 may be combined in a common circuit such as RL by a compound transformer such as RT, having individual primary windings in the circuits A_1, B_1 and C_1 and a common secondary in the circuit RL. It is of course necessary that the signal components from the several circuits should be impressed upon the circuit RL in phase with each other. This result will be readily obtained where the line circuits A_1, B_1 and C_1 are of equal length. Where the geographical situation is not such that these lines would be normally of equal length they may be made of the same length by building the lines which would otherwise be short along indirect routes to the antenna terminals. As an alternative the shorter lines may be made electrically of the same length as the longest line by including in the shorter lines artificial line sections equivalent to the difference in length between any given line and the longest line.

In a similar manner the noise components taken from the surge resistances of the several antennæ may be combined in a compensating circuit CL through a compound transformer CT having primary windings associated with each of the lines A_2, B_2 and C_2 and a common winding in the circuit CL. Here again components taken from several antennæ must be impressed upon the common circuit CL in phase with each other. The lines A_2, B_2 and C_2 must therefore either be equal in length or be made electrically equal in length, as just described. The common circuit CL includes the phase adjuster 18 and attenuation adjuster 19, both of which are well known in the art. The former element serves the purpose of adjusting the phase of the compensating current due to noise arriving from a given direction in the back-end area so as to oppose the corresponding component received over lines A_1, B_1 and C_1. Similarly, the attenuation adjuster 19 may be adjusted until the compensating current is just equal in value to the noise current component in the circuit RL due to noise arriving from the particular direction for which compensation is to be made. As already stated the compensation will be for noise arriving from a sector in the neighborhood of 180 degrees from the direction of the signal.

As above described, the signal components are combined in a common circuit RL together with noise currents which are inherently picked up from the back-end area of the antenna system. The compensating noise components are combined in a common circuit CL. In order that the signal currents with their associated noise and the compensating noise currents from the circuits RL and CL, respectively, may be combined in the receiver, a compound transformer T may be employed. This transformer has separate primaries in the circuits RL and CL and a common secondary in the circuit leading to the receiver. The compensating current is therefore combined with the current to be compensated in the same manner, so far as electrical connections are concerned, as the several components of the signal were combined, except that the compensating current is 180 degrees out of phase with the current to be compensated.

Neglecting for the moment the compensation of a number of wave antennæ connected in broadside, the effect of the broadside array of wave antennæ is to reduce the width of the directivity diagram as shown in Fig. 3. If the curves of Fig. 2 and Fig. 3 be compared it will be seen that the front-end area of Fig. 3 is not so wide as the corresponding area of Fig. 2. The effect of the broadside connection upon the back-end area also results in reducing the width of the back-end area. As a result the effect of noise from a direction 135 degrees away from the signal will be decreased.

As has been previously stated, the practice heretofore has been to attempt to compensate each wave antenna separately. While such compensation can be made if sufficient time and trouble be taken, as a practical matter it has been found very difficult. This will be clear if we consider the form of the directional diagram of a single compensated wave antenna, as shown in Fig. 4. As has been previously pointed out such an antenna, when uncompensated, has a back-end area such as shown at 15 in Fig. 2. If the antenna be compensated for noise arriving from a direction 180 degrees away from the direction of the signal, the back-end area is as shown in Fig. 4. Now it will be obvious that if the only noise or interference is from a direction just 180 degrees away from the direction of the signal, the operator who makes the compensating adjustments can readily determine when the circuit is properly compensated at 180 degrees. Since the noise from that direction is the only noise present, the fact of its disappearance will be at once apparent.

In practice, however, the situation is not so simple. Static and other forms of noise and interference will usually be found coming from various directions throughout the entire back-end area. The operator listening on an uncompensated wave antenna hears all of these noises. If now the operator begins to make compensating adjustments the situation will be that when the circuit is properly adjusted for compensation the noise component arriving from a direction 180 degrees away from the signal will disappear but noise components from a direction 45 degrees on either side thereof, for example, will have been increased. In short, noise will be heard representing a large number of components even though the single wave-antenna is properly compensated. The result is that it is difficult, and under certain conditions practically impossible, for the operator to determine by the difference in the noise effects produced on the receiver, when a single wave-antenna has been properly compensated.

The effect of the broadside connection (neglecting compensation) is, as already stated, to make the diagram of less width. The back-end area, which assumed the form shown at 15 in Fig. 2 for a single wave antenna, becomes of the general shape shown at 15′ of Fig. 3 for an uncompensated triple broadside antenna. Where all of the noise components are combined in a single circuit, and phase and attenuation adjustments are made for all of the antennæ at the same time, as is the case with the present invention, the noise compenents arriving in a direction 180 degrees from the signal will disappear when the proper compensating adjustment has been made. The back-end area, which in the uncompensated condition has the form shown in 15′ of Fig. 3, will be reduced to two small loops, as shown at 15″ in Fig. 5. The operator will have no difficulty whatever in determining when the circuit is properly compensated because even assuming that noise is coming from a great many directions within the back-end area the total noise will be very materially decreased when the components in the neighborhood of 180 degrees away from the signal direction have been balanced.

In other words, an operator attempting to compensate a single wave-antenna would have great difficulty, when noise is coming in from a great many directions, in determining by hearing methods the difference between the back-end area 15 of Fig. 2 and the corresponding back-end area of Fig. 4 which represents the same antenna compensated. On the other hand, the same operator would have no difficulty whatever in determining the difference between the back-end area 15′ of Fig. 3 and the back-end area 15″ of Fig. 5. This sharpness and definiteness of the balance obtained in accordance with the present invention is due to the fact that there is one and only one adjustment of the compensation that markedly reduces the area of the so-called back-end diagram. Hence this adjustment is the only one which will materially reduce noise originating from a relatively broad sector behind the antennæ.

In using the system of the present invention it is possible to reach this adjustment with a minimum effort at times when with the older system it could only be reached by a laborious process of cut and try if indeed it could be reached at all. The present invention has the additional advantage that the adjustments for proper combination of the signal currents as well as for proper combination of the noise currents will be relatively stable and fixed in their nature, so that there only remains a single adjustment which need be made from time to time. Due to the varied direction of noise and interference waves it is necessary at intervals to readjust the compensating apparatus to preserve the desired degree of balance against these waves. In accordance with the present invention this is accomplished in a minimum of time, whereas in systems previously used the broadside array must be separated into its component antennæ and each antenna adjusted for proper balance by itself. This complicated procedure necessarily entailed an interruption of service involving a considerable length of time. Obviously of course the apparatus necessary to make the adjustments is in the present case materially simpler and cheaper than with the old system, particularly if a large number of antennæ are to be used in broadside.

The description of the invention up to this point has been concerned with the arrangements for effecting a balance against the interfering components impressed upon the receiver. The method of obtaining this result, above described, involves combining signal components from several antennæ arranged in broadside in a common circuit. Similarly interference components from the several antennæ are combined in a common circuit. These combinations are effected through parallel connections extending between the common circuit and each of the antennæ. One of the simplest parallel combination systems is that in which the lines from the several antennæ are connected to the primaries of a number of identical transformers whose secondaries are connected in parallel as shown in Figs. 6 and 8. An alternative is the use of a multiple winding transformer as described in connection with Fig. 1 and as illustrated in Fig. 7. The secondaries, or secondary, as the case may be, may supply energy to the receiving equipment which may or may not have a high input impedance, as is most convenient. A parallel system of this type is adapted to supply energy to a filter or similar device which has a characteristic impedance of the same order as an open-wire line, thus conforming to standard telephone practice. Of course other combining systems will readily suggest themselves and may be used if necessary.

If the lines from several antennæ are directly connected to the several primaries, however, they cannot be terminated in their characteristic impedances. For instance, take the case of three antennæ as shown in Fig. 6. Here the line from each antenna would be terminated in the impedances of the other two lines together with the input impedance of the receiving apparatus, all being in parallel. This impedance would obviously be considerably less than the characteristic impedance of the line.

In accordance with the present invention it is proposed to overcome this difficulty by "building out" the transformers with impedance networks in such a manner as to terminate all the lines in their characteristic impedances. In Fig. 6 the combination is effected by three transformers RT_A, RT_B and RT_C, in parallel. These transformers supply the receiving apparatus whose input impedance is K_2. The impedance networks for building out the transformers are shown as H networks comprising resistances r_1, r_2 and r_3. Since the characteristic impedance of most lines at radio frequencies is very nearly equal to pure resistance, only resistance components need be used in the networks in most cases. The characteristic impedances of the lines will be the same and equal to K_1. The values of the resistance elements of an H network which will satisfy the theoretical requirements may be obtained mathematically although the process is somewhat complicated. The adjustments of the resistance elements of such a network may also be obtained empirically within a fairly close approximation. For example, if the two resistance elements r_1 and the resistance element r_3 have a total value equal to the impedance K_1, the actual impedance of the networks as seen from the line will not materially vary from that of the line even though the combined impedances of the other two lines and the receiver be quite small, if the resistances r_2 be made very large. In other words, if the resistances r_2 are very large the shunting effect of these resistances upon the resistance r_3 will be relatively small.

The circuit in which the signal is combined and the circuit in which the compensating current is combined may be brought together through similar individual transformers T_S and T_C whose secondaries are connected in parallel, these transformers being built out by networks similar to those just described. Instead of using separate transformers for combining signals a single compound transformer, having a plurality of primaries and a secondary, may be used, as shown in Fig. 7. Other combining arrangements, of course, may be used. A similar type of transformer may be used for combining the total signaling current with the total compensating current. Here again H-type networks are used for building out the transformers in the individual lines.

In actual practice H networks or other forms involving shunt elements are not necessary, as simple series resistances r may be used for building out the transformers, as shown in Fig. 8. This figure is similar to Fig. 6 in the use of individual transformers for each line. The resistances r should have the value given by the equation,

$$2r = -\frac{n}{2}K_2 \pm \sqrt{K_1^2 + (n-2)K_1K_2 + \frac{1}{4}K_2^2n^2} \quad (1)$$

where n is the number of antennæ to be combined and the other symbols are as previously defined.

If K_2 and K_1 are the same this becomes

$$2r = K_1\left(-\frac{n}{2} \pm \sqrt{\frac{1}{4}n^2 + n - 1}\right) \quad (2)$$

If the common circuit in which the lines are combined works directly into a vacuum tube the impedance looking into the common circuit may be made very large. In this case K_2 approaches infinity and the equation for r becomes

$$2r = K_1\left(\frac{n-2}{n}\right) \quad (3)$$

Instead of separate transformers for each line, as shown in Fig. 8, the simple resistance elements r may be used for building out the transformer where the transformer is of the compound type having a plurality of primary windings and a single secondary winding. This case is shown in Fig. 9.

The invention, while above described as applicable to a broadside arrangement of wave antennæ, is equally applicable to broadside arrangements of other types of directive antenna systems. For example, Fig. 9 shows how the invention might be applied to a broadside combination of individual directive antennæ units each comprising a loop such as L_A' worked in connection with a vertical antenna such as V_A. The combination of a loop and a vertical antenna, as is well known, has a one-way directive effect somewhat similar to that of a wave antenna. If now we provide a number of such combinations side by side and separated from each other by a fraction of a wave length in a direction at right angles to the direction of maximum directivity, each vertical antenna of the broadside arrangements may be connected over a separate line through building-out resistances to a compound combining transformer such as described in connection with Fig. 1. Likewise, each of the loops of the broadside arrangement may be connected over separate lines through building-out resistances to a compound transformer. The outputs of the vertical antennæ are thus combined in a common circuit RL, and the outputs of the loops are thus combined in a common circuit CL. If a phase adjusting device 18 and an attenuation adjusting device 19 be included in the circuit CL the circuit may be so adjusted as to balance out noise arriving from a sector in the neighborhood of 180 degrees away from the direction of the desired signal.

It is true that in this arrangement the phase and attenuation adjustments affect both signal and interference components, for both signal and interference components are received by the loops and by the verticals. However, due to the reversal of phase of the loop current with reversal of signal direction it is possible, as is well known, to obtain a unidirectional characteristic as described above. The effect of such a broadside array of loop-and-vertical antenna groups is to secure a much sharper unidirectional characteristic than can be obtained by using a single group of this type.

It is also well known that two loops situated in tandem in the same plane and a fraction of a wave length apart may be made to have a one-way directional effect. If a plurality of such combinations are arranged in broadside along an axis at right angles to the planes of the loops the method of combining, heretofore described, may be applied, as shown in Fig. 11. Here the individual units comprise two loops, such as L_A' and L_A, separated from each other by a distance which may be, for example, about one-twelfth of the wave length in the direction of the plane of the loops. Each combination of this kind may be separated from the adjacent combination in a direction at right angles to the plane of the two loops by some fraction of wave length, such, for example, as one-half wave length. The loops, such as L_A, L_B and L_C, may be combined in a common circuit RL by means of separate lines including resistance building-out units through compound transformers of the type already described. Similarly the outputs of the loops L_A', L_B' and L_C' may be combined in a common circuit CL through similar individual lines leading to a compound transformer through building-out resistances. The circuit CL includes a phase adjuster and attenuation adjuster whereby the noise in the sector 180 degrees away from the signal direction may be balanced out without at the same time balancing out the signal from the desired direction. The principle in accordance with which this result occurs will be similar to that already disclosed in connection with Fig. 9. The result accomplished is a more sharply unidirectional characteristic than can be obtained from a single two-loop system, while retaining the facility of balance against interference and noise as disclosed above in connection with the application of the invention to wave antennæ.

In addition to the advantages already referred to the arrangements of the present invention have certain other advantages. The use of vacuum tubes and other more or less complicated apparatus which has been used or suggested heretofore in connection with other systems of combining the outputs of antennæ is eliminated. In this connection it is assumed of course that the proper phase and amplitude relations are obtained by means of suitable apparatus preceding the final combining apparatus. Aside from the question of simplicity it is of course desirable to eliminate all vacuum tubes previous to the selective circuits of the receiver. The reason for this is that such tubes are liable to be overloaded by interfering signals not in the frequency range of the receiving apparatus.

The system of the present invention may be extended to any number of antennæ and is adaptable for use with only one filter preceding the receiving apparatus.

It will be obvious that the principles herein disclosed may be embodied in many other organizations widely different from those illustrated without departing from the spirit of the invention as defined in the following claims.

What is claimed is:

1. In a transmission system, a plurality of substantially one-way directive antenna combinations arranged side by side a fraction of a wave length apart in a direction at right angles to the direction from which signals are to be received, a receiving circuit, a separate connection from each antenna combination to said receiving circuit over which the desired signal may be transmitted together with noise from a sector in the neighborhood of 180 degrees from the direction of the signal, means to combine the currents transmitted over said connections in substantially the same phase relation in said receiving circuit, a controlling circuit, separate connections from each antenna combination to said controlling circuit over which noise currents corresponding to noises from a sector in the neighborhood of 180 degrees from the desired signal may be transmitted, means to combine said noise currents in said controlling circuit, means in said controlling circuit to adjust the phase and amplitude of the currents combined therein until the noise currents are substantially equal in amplitude but opposite in phase to the noise currents in said receiving circuit, and means to impress the currents of said controlling circuit upon said receiving circuit.

2. In a transmission system, a plurality of wave antennæ arranged parallel to each other and a fraction of a wave length apart in a direction at right angles to the direction from which signals are to be received, a receiving circuit, a separate connection from each antenna to said receiving circuit over

which desired signal currents and noise currents from a sector in the neighborhood of 180 degrees from the direction of the desired signal may be transmitted, means to combine the currents transmitted over said connections in said receiving circuit in substantially the same phase relation, a conductor associated with each wave antenna over which flows noise currents originating from a sector in the neighborhood of 180 degrees from the desired signal, a controlling circuit, separate connections from each of said conductors to said controlling circuit, means for combining the currents flowing over said last mentioned connections in said controlling circuit, means to adjust the phase and amplitude of the currents in said controlling circuit so that the noise currents will be of substantially the same amplitude but opposite in phase to the corresponding noise currents in the receiving circuit, and means to impress the currents from said controlling circuit upon the receiving circuit.

3. In a transmission system, a plurality of wave antennæ arranged parallel to each other and a fraction of a wave length apart in a direction at right angles to the direction from which signals are to be received, each of said wave antennæ comprising a pair of conductors extending from its front end to its back end, means at the back end of each antenna to transmit to the conductors of the antenna acting as a transmission line the desired signal wave built up at that end of the antenna together with a residuum of noise from a sector in the neighborhood of 180 degrees from the direction of the desired signal, a receiving circuit, a separate line associated with the front end of each antenna in such manner as to act as a continuation of the antenna as a line, each of said lines extending to said receiving circuit, means to combine the currents from each of said lines upon the receiving circuit in substantially the same phase relation, a surge resistance associated with the front end of each antenna, a controlling circuit, separate connections from each surge resistance to said controlling circuit, means to impress a desired amount of noise currents flowing in such surge resistances upon said last mentioned connections, means to combine the noise currents thus transmitted over the connections in said controlling circuit, means to adjust the phase and amplitude of the combined current in said controlling circuit so that the noise currents will be substantially equal in amplitude but opposite in phase to the corresponding noise currents in the receiving circuit, and means to impress the current from said controlling circuit upon said receiving circuit.

4. In a transmission system, a plurality of directive antenna combinations arranged side by side and a fraction of a wave length apart in a direction at right angles from the direction in which signals are to be received, a common receiving circuit, a separate line extending from each antenna combination to said receiving circuit, a transformer arrangement for connecting said lines to said receiving circuit, means associated with each line for effectively building out the transformer so as to terminate each line in a combined impedance including that of the receiving circuit and other lines substantially equivalent to its own impedance.

5. In a transmission system, a plurality of directive antenna combinations arranged side by side and a fraction of a wave length apart in a direction at right angles from the direction in which signals are to be received, a common receiving circuit, a separate line extending from each antenna combination to said receiving circuit, a transformer arrangement for connecting said lines to said receiving circuit, and resistance combinations associated with each line having such values as to in effect build out the transformer arrangements so that each line is terminated in a combined impedance including that of the receiving circuit and other lines substantially equal to its own impedance.

In testimony whereof, I have signed my name to this specification this 2nd day of June, 1926.

SAMUEL W. DEAN.