

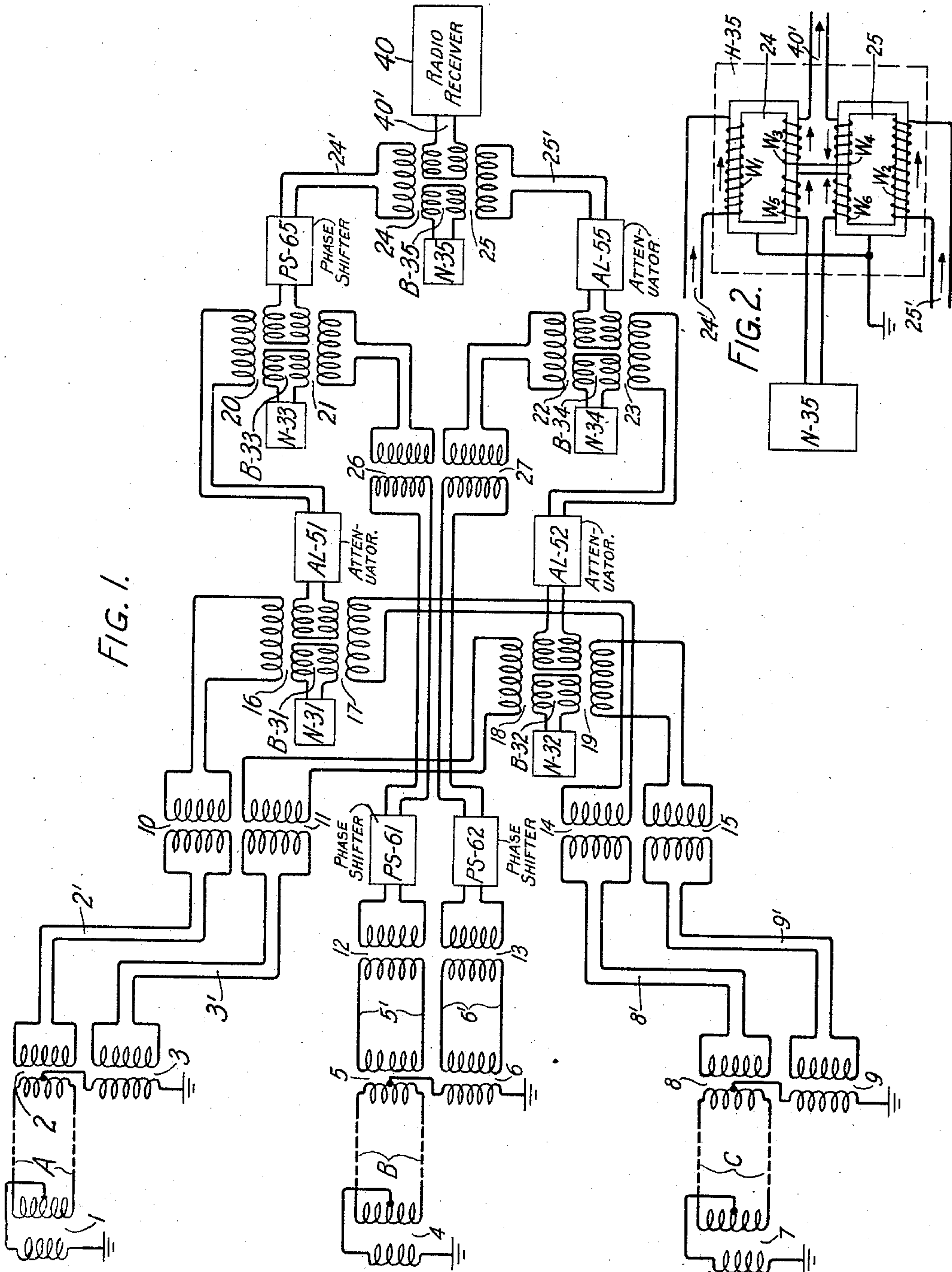
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TRANSFORMER SYSTEM

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TRANSFORMER SYSTEM

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This invention relates to electric wave transmission, and particularly to transformer circuits.

An object of the invention is to control phase shifts or phase relations of waves, especially of complex waves, for example for reducing deleterious effects of waves interfering with signaling, or for increasing directional selectivity of radio antenna systems. One specific aspect of the invention is a wave antenna circuit for receiving radio telephone signals from a given direction without undue disturbance from waves incident on the antenna from other directions. To balance out or neutralize the interference component in current having components due to signal energy and interfering energy received by the antenna, an interference compensating current derived from interfering energy received by the antenna is combined with the first current in phase opposition to its interference component. The two currents travel paths which differ as regards the transformers included in the two paths. In accordance with the invention, the relative phase shifts produced in the two paths by the transformers are properly adjusted; for otherwise there would result a relative phase shift in the interference current component and the compensating interfering current, and this relative shift would vary with frequency in such a manner that it could not be adequately compensated for, over the requisite frequency range, by adjustable phase shifting devices such as are customarily employed to adjust the phase relation of two single frequency currents.

If desired, the relative phase shift that the transformers produce may be made zero, over the frequency range of the signals so that the transformers are, together, substantially entirely self compensatory, as regards phase shift.

In an antenna system disclosed herein as embodying one specific form of the invention, the principle of relatively adjusting the phase shifts of the transformers in the paths of currents derived from antenna conductors to facilitate combination of the currents in

desired phase relations, is extended to a system including a plurality of antennae.

The general character of the system will now be indicated somewhat more specifically. The system includes three wave antennae, each of a general type disclosed for example in Kellogg Patent 1,487,339, March 18, 1924. Each wave antenna comprises two parallel wires extending in the direction from which the desired signal waves approach and terminating in a reflection transformer at the end farthest from the sending station. The other end of the antenna is connected to a radio receiver through a circuit including a signal transformer which has a connection from the midpoint of its primary winding to earth. The impedance of this earth connection is equal to the surge impedance of the antenna and includes the primary winding of a compensating transformer the secondary winding of which is included in a circuit leading to the input circuit for the radio receiver.

The secondary winding of the reflection transformer is connected between the antenna wires. The primary winding is connected from the midpoint of the secondary winding to earth.

Waves that approach the antenna from the direction from which it is desired to receive signals cause longitudinal currents to flow in the antenna toward the reflection transformer. These longitudinal currents pass from the antenna wires through the two halves of the secondary winding of the transformer to the midpoint of the winding, in such directions as to produce magnetic fields, which neutralize each other, and these currents flow from the midpoint of the secondary winding through the primary winding to earth. This current flow in the primary winding induces a voltage in the secondary winding which causes current to circulate in the loop formed by the secondary winding, the antenna wires and the primary winding of the signal transformer. This current flow in the primary winding of the signal transformer induces a voltage in the secondary winding, which causes current to flow in the circuit connecting the secondary winding to

the radio receiver. The primary winding of the compensating transformer receives very little of the longitudinal current flowing in the antenna wires due to waves from the direction of approach of the desired signals.

Waves that approach the antenna from the direction opposite that from which it is desired to receive signals, produce longitudinal antenna currents which pass through the two halves of the primary winding of the signal transformer in such directions as to produce magnetic fields which neutralize each other and induce no signal voltage in the secondary winding. Very little of these longitudinal currents flows through the primary winding of the reflection transformer, and consequently they have little tendency to cause interference currents to be received in the radio receiver.

Compensation is especially desirable for deleterious effects of waves that approach the antenna from directions other than the direction of the length of the antenna. For example, waves approaching at an angle of, say, 45 degrees to the direction of the desired waves may induce voltage in the antenna that result in a considerable current flowing through the primary winding of the reflection transformer. To compensate for the deleterious effects which this current tends to cause in the receiver, use is made of the current flowing through the primary winding of the compensation transformer, as a result of voltage induced in the antenna by these waves.

Interference waves reaching the radio receiver due to voltages applied to the primary winding of the reflection transformer suffer phase shift due to transformation in that transformer and further phase shift due to transformation in the signal transformer. Interference waves reaching the radio receiver due to voltages applied to the primary winding of the compensation transformer suffer phase shift due to transformation in that transformer. In accordance with the invention this phase shift is made substantially equal to the sum of the phase shifts in the reflection transformer and the signal transformer, over a frequency range including the frequencies of the wave components of different frequencies in the complex signal wave or waves to be received. When this equality of phase shifts obtains, the interfering waves from the secondary winding of the compensating transformer can be balanced against the interfering waves from the secondary winding of the signal transformer, to reduce the interference and increase the ratio of signal power to interference power in the radio receiver output. In order that the phase shift required for the compensating transformer may be sufficiently small to avoid undue difficulty in practical construction of the transformer,

the phase shift in each of the other two transformers is preferably made as small as is readily practicable.

In some cases the phase shift in the compensating transformer may differ from the sum of the combined phase shifts in the other two transformers in a desired manner over the frequency range of the signal components of the complex wave or waves to be received, and the difference be compensated for by phase shifting means. For example, the difference may be proportional to frequency, over the range mentioned, and may be compensated for by an adjustable phase shift network of the type known as a phase rotator, which is capable of producing phase shift proportional to frequency.

The three wave antenna are spaced apart a certain fraction of the wave length of the desired signals, in the direction perpendicular to the lengths of the antenna, and constitute an antenna array of the general form well known as a "broadside wave antenna system".

The circuits connecting the secondary windings of the signal transformers and the secondary windings of the compensating transformers to the input circuit of the radio receiver include bridge transformer networks, which have sometimes been termed hybrid coils, for combining the outputs from the signal transformers and combining the outputs of the compensating transformers and balancing this second combined output against the interference present in the first, to prevent the interference from reaching the receiver.

Each of the bridge transformer networks comprises two three-winding transformers. In accordance with the invention, the phase shifts in the two transformers of any given bridge transformer network may be equal, over the frequency band comprised in the signals to be received, so that proper phase relations between the waves transmitted through the transformers are preserved, as pointed out hereinafter.

Two two-winding transformers are connected respectively in two of the circuits connecting the antenna output transformers to the input circuit of the receiver. They introduce phase shifts equal respectively to those in two of the bridge transformer networks neither of which is included in either of these two connecting circuits but one or the other of which is included in each of the others of the connecting circuit; or the two-winding transformers may introduce respective phase shifts which differ in a desired manner from phase shifts in the two transformer bridge networks, over the frequency band comprised in the signals to be received, and the differences be then compensated for by phase shifting devices. For example, the differences may be proportional to

frequency, and the compensations for the differences be effected by phase rotators.

In accordance with the invention, a transformer that introduces a phase shift which balances a phase shift in one or more other transformers as described above, may have its impedance ratio different from that of one or more of the other transformers, or may have the impedance of its primary or secondary winding, or each, different from that of one or more of the other transformers.

Other objects and aspects of the invention will be apparent from the following description and claims.

Fig. 1 of the drawing is a circuit diagram of the system described above; and Fig. 2 represents a bridge transformer network of a type employed in the system of Fig. 1.

A wave antenna A has a reflection transformer 1, a signal transformer 2, and a compensating transformer 3. Wave antenna B has reflection, signal and compensating transformers 4, 5, and 6 respectively. Wave antenna C has reflection, signal and compensating transformers 7, 8 and 9. Each antenna extends from its reflection transformer toward the direction from which desired signals approach. The desired signals may be, for example, radio telephone signals. The antenna are spaced apart a certain fraction of the wave length of the desired signals, in the direction perpendicular to the lengths of the antennae, and form a broadside wave antenna system.

The secondary windings of transformers 2, 3, 5, 6, 8 and 9 are connected to the primary windings of sectionalizing transformers 10, 11, 12, 13, 14 and 15, respectively. The secondary windings of these sectionalizing transformers are connected respectively to the input windings of three-winding transformers 16, 18, 21, 22, 17 and 19.

Transformers 16 and 17 form a bridge transformer network B—31 which combines the signals from transformers 2 and 8 and transmits the combined signals to the input winding of a three-winding transformer 20. Transformers 20 and 21 form a bridge transformer network B—33 which combines the signals from transformers 2 and 8 with those from transformer 5 and transmits the combined signals to the input winding of a three-winding transformer 24.

Transformers 18 and 19 form a bridge transformer network B—32 which combines the compensating currents from transformers 3 and 9 and transmits the combined compensating currents to the input winding of a three-winding transformer 23. Transformers 23 and 22 form a bridge transformer network B—34 which combines the compensating currents from transformers 3 and 9 with those from transformer 6 and transmits the combined compensating currents to the input winding of a three-winding transformer 25.

Transformers 25 and 24 form a bridge transformer network B—35 which balances the compensating currents from coils 3, 6 and 9 against the signal currents from coils 2, 5 and 8, to reduce or eliminate interference in the signal currents before the signal currents reach radio receiver 40. The radio receiver may include means for demodulating or detecting carrier waves modulated by speech or other signal waves, and a telephone receiver or other signal indicator.

The bridge transformer networks B—31 to B—35 have associated therewith balancing networks N—31 to N—35 respectively, for balancing the impedances of the output circuits of the bridge transformer networks. The transformer bridge networks may all be alike. The bridge transformer network B—35 is shown in Fig. 2. Each of the transformers 24 and 25 has, upon its core, three windings each wound in a definite direction. The input winding W_1 of transformer 24 is connected to the input circuit 24' leading from bridge transformer network B—33. The input winding W_2 of transformer 25 is connected to the input circuit 25' leading from bridge transformer network B—33. The windings W_3 and W_4 of transformers 24 and 25, respectively, are connected to the output or receiving circuit 40' leading to radio receiver 40, while windings W_5 and W_6 of the respective transformers are in series with a balancing network N—35.

The windings of the transformers 24 and 25 are symmetrical, the corresponding windings of these transformers having the same values. Moreover, a balanced condition exists between the balancing network N and the receiving circuit 41. The transformer arrangement or bridge transformer network constitutes a combining circuit which is adapted to combine currents flowing from bridge transformer networks B—33 and B—34 for transmission to the radio receiver 40.

The manner in which a bridge transformer network such as B—35 functions may be explained as follows. Let it be assumed that energy is to be transmitted from circuits 24' and 25' into coil H—35, and that energy is to be transmitted from network B—35 to the output or receiving circuit 40'. Accordingly, the flow of currents in the windings W_1 and W_2 of transformers 24 and 25 may be assumed to be in the relative directions indicated by the arrows adjacent thereto. These currents in windings W_1 and W_2 will induce electromotive forces in windings W_3 and W_5 and W_4 and W_6 , respectively, which will tend to cause the flow of currents therethrough. The windings W_3 and W_4 are so arranged that the flow of currents therethrough due to the currents in circuits C_1 and C_2 as indicated, will aid each other, whereas windings W_5 and W_6 are differently arranged so that the flow

of currents therethrough will oppose each other under the same circumstances. The arrows adjacent to these windings represent the polarity of the electromotive forces across these windings, under the given circumstances. If the currents flowing in circuits 24' and 25' are of equal amplitudes and of the same phase, equal voltages will be induced in windings W_5 and W_6 which are oppositely directed so that there is no resultant effect in the circuit of the network N—35. Under the same conditions, the circuit 40' will receive all the energy from the circuits 24' and 25'. If, however, the current flowing in the circuit 24' is greater or less than the current flowing in the circuit 25', then the magnitudes of the potentials impressed across the windings W_5 and W_6 will be unequal, and current will flow through the balancing network N—35 of an amount proportional to the difference between the potentials impressed across these windings.

If the currents flowing in circuits 24' and 25' be of equal amplitudes but of opposite phases, the potentials set up across the terminals of windings W_5 and W_6 will be of equal magnitudes, but these currents will be substantially neutralized by virtue of their presence in the output or receiving circuit 40' in phase opposition. In this case the entire energy from circuits 24' and 25' will be dissipated in the network N—35. This property of the bridge transformer network is made use of when undesired signal or interference currents are combined in phase opposition, as is the case in the bridge transformer network B—35 in the system of Fig. 1. Furthermore, with the impedance of the network N—35 substantially equal to that presented by the receiving circuit 40', currents flowing in circuit 24' will not be transmitted to circuit 25', and vice versa. Therefore there is no interaction between circuits 24' and 25'.

It is desired that in the case of each of the bridge transformer networks B—31 to B—35 the two inputs to the network be in phase and be equal in magnitude, so that the waves from transformers 2 and 8 will be added cumulatively in network B—31 and will be augmented by the waves from transformer 5 in network B—33, and so that the waves from compensating transformers 3, 6 and 9 will similarly be cumulatively added by networks B—32 and B—34. Further, it is desired that the input to transformer 25 be equal in magnitude and opposite in phase to the interference component of the input to transformer 24, so that by the network B—35 the combined compensating waves will be opposed to the interference component of the combined waves from transformers 2, 5 and 8 to reduce or eliminate that component, with the result that the signal component alone will be transmitted to the radio receiver 40.

For interference waves from any given di-

rection other than the direction from which the desired waves approach, the desired equalities in magnitudes are obtained with the aid of attenuators, for example, artificial lines AL—51, AL—52 and AL—55, which may be adjustable. The attenuator AL—51 renders the input to transformer 20 equal in magnitude to the input to transformer 21. The attenuator AL—52 renders the input to transformer 23 equal in magnitude to the input to transformer 22. The attenuator AL—55 is adjusted to render the input to transformer 25 equal in magnitude to the interference component of the input to transformer 24, for interference waves from any given direction other than the direction from which the desired waves approach.

Phase-shifters PS—61, PS—62 and PS—65 assist in obtaining the desired phase relations. The transformers 2, 3, 8 and 9 are farther than the transformers 5 and 6 from the apparatus comprising the transformers 10 to 23. Each of the circuits 2', 3', 8' and 9' which connect transformers 2, 3, 8 and 9 to transformers 10, 11, 14 and 15 respectively is of the same length, but is longer than each of the circuits 5' and 6' which connect transformers 5 and 6 to transformers 12 and 13 respectively and which are of the same length. The phase-shifter PS—61 compensates over the frequency range of the desired signals, for the difference between the phase shift produced by line 2' or 8' with artificial line AL—51, on the one hand, and line 5' on the other hand. The phase-shifter PS—62 similarly compensates for the difference between the phase shift produced by line 8' or 9' and artificial line AL—52, on the one hand, and line 6' on the other hand. A transformer 26 produces in waves to be delivered to transformer 21 a phase shift equal, over the frequency range of the desired signals, to the phase shift produced by bridge transformer network B—31 in the waves to be delivered to transformer 20. A transformer 27 similarly compensates for the phase shifts in network B—32. For interference waves from any given direction other than the direction from which the desired waves approach, the phase shifter PS—65 is adjusted to compensate, over the frequency range of the desired signals, for the difference between the phase shifts which the antennae lines produce in the interference waves that the antennae transmit to the lines 2', 5' and 8', on the one hand, and the phase shifts which the antennae lines and the adjustable attenuator AL—55 produce in the interference waves that the antennae transmit to lines 3', 6' and 9', on the other hand.

The transformers included in the circuit are so constructed that the phase shifts which they produce over the frequency range of the desired signal waves are such as per-

mit the desired phase relations to be obtained. Transformers produce phase shifts so varying with frequency that in cases in which the range of signal frequencies is considerable, for instance in the case of a speech side band, adjustable phase shifters such as PS-61, PS-62 and PS-65 are incapable of adequately compensating for the phase shifts of the individual transformers. Moreover, in systems such as that of Fig. 1 it is desirable to employ in transmission channels which should have equal overall phase shifts, different numbers of tandem connected transformers. For example, antenna A transmits interference waves to line 2' through transformers 1 and 2 in tandem, but transmits compensating interference waves to the compensating circuit 3' through only the transformer 3. The phase shifts which the different numbers of transformers introduce in the channels which should have equal overall phase shifts can not be made equal by constructing the transformers alike, as they might be were the numbers not different; and moreover, it is sometimes desirable that the transformers in one of the channels, as for example the transformer 3', differ from those in another of the channels, as for example, the transformers 1 and 2, with respect to electrical characteristics such as impedance ratio or the impedance of one or more windings, for instance. Further, in systems such as that of Fig. 1, it is desirable to employ in transmission channels which should have equal overall phase shifts, or phase shifts which differ proportionally to frequency, transformers which differ for the different channels as to the general character of the transformers or their connection in the circuit. For example, as indicated above, a two winding transformer 26 is employed to produce a phase shift equal to, or differing proportionally to frequency from, the phase shifts produced by the three-winding transformers 16 and 17.

To obtain the desired phase relations in the system of Fig. 1, over the frequency range of the desired signals the following conditions as to relative phase shifts in the transformers are satisfied: The phase shift in transformer 3 is equal to the sum of the phase shifts in transformers 1 and 2; the shift in transformer 6 is equal to the sum of the shifts in transformers 4 and 5; the shift in transformer 9 is equal to the sum of the shifts in transformers 7 and 8; the shifts in transformers 1, 4 and 7 are equal; the shifts in transformers 2, 5 and 8 are equal; the shifts in transformers 3, 6 and 9 are equal; the shifts in transformers 10, 12 and 14 are equal; the shifts in transformers 11, 13 and 15 are equal; the shifts in transformers 16 and 17 are equal; the shifts in transformers 18 and 19 are equal; the shifts in transformers 20 and 21 are equal; the shifts

in transformers 22 and 23 are equal; the shifts in transformers 24 and 25 are equal; the shifts in transformer 26 is equal to the shift produced by transformers 16 and 17; the shift in transformer 27 is equal to the shift produced by transformers 18 and 19; and the shift produced by transformers 20 and 21 is equal to the shift produced by transformers 22 and 23. For disclosure of a manner in which the transformers may be constructed to give the requisite phase shifts, reference is made to Patent No. 1,759,332, issued May 20, 1930, on the copending application of Horace Whittle and D. G. Grimley, Serial No. 177,518 filed March 23, 1927. Of course the phase equalities expressed above are not exact as obtained in practice, but are substantial equalities. As an example of the closeness of approach to the absolute or exact equalities, which, in practice, may be made by constructing the transformers in accordance with the teaching of the application just mentioned, it may be stated that transformers have been constructed in which the phase equalities expressed above obtained to within less than 10 minutes of phase angle over any 5000 cycle band of frequencies between 45 and 65 kilocycles. Under these conditions of equality of phase shift, when the adjustable phase shifters in the system of Fig. 1 are set to balance out an unwanted signal or unwanted signals, the balance will hold over a frequency range of at least 5000 cycles.

In order to avoid any necessity for giving the compensating transformers, such as 3, 6 or 9, a phase shift so large that it would be unduly difficult to obtain in each of those transformers, the transformers 1, 2, 4, 5, 7 and 8 may each be made to have as small a phase shift as practicable, over the frequency range of the desired signals.

In the system of Fig. 1 instead of having the phase shift of transformer 3 balance the phase shift of transformers 1 and 2, it may differ from them in a desired manner over the frequency range of the signals to be received, and the difference be compensated for by phase shifting means. For example, the difference between the phase shift of transformer 3 and that of transformers 1 and 2 may be made substantially proportional to frequency over the frequency range of the desired signals and then may be compensated for by the adjustable phase shifter PS-65, which is capable of compensating for considerable differences in phase shift if the differences are substantially proportional to frequency. The transformers 4 and 7 may then be like transformer 1, the transformers 5 and 8 like transformer 2, and the transformers 6 and 9 like the transformer 3, so that the compensation introduced by phase shifter PS-65 for the transformers 1, 2 and

3 will be properly applicable to the transformers 4 to 9 also.

Similarly, the adjustable phase shifters PS—61 and PS—62 can be utilized to compensate for differences between the phase shift in transformer 26 and the phase shift in network B—31, and between the phase shift in transformer 27 and the phase shift in network B—32, if it is desired to have these differences proportional to frequency instead of equal to zero.

As explained in the copending application mentioned above, in order to give the transformers the desired characteristics it is sometimes desirable to employ such factors as inductances, capacity and resistance as effectively parts of the transformer construction although external to the core and windings. For example, it is sometimes desirable to employ series inductance or series capacity or shunt reactance which may be variable. The expression "transformer" as used in this specification and in the claims may include a transformer having such auxiliary impedances effectively portions thereof, as well as a transformer not dependent on such external impedances for its desired shunt and series impedances.

What is claimed is:

1. In combination, a circuit, one or more transformers in said circuit, and one or more other transformers so connected to said circuit and producing in waves transmitted therethrough phase shifts of such magnitude relative to the phase shifts produced by the first mentioned transformers in waves in said circuit as to compensate for the latter phase shifts, one of said first mentioned transformers having electrical constants substantially different from those of any one of said other transformers.

2. In combination, a circuit, one or more transformers in said circuit, and one or more other transformers so connected to said circuit and producing in waves transmitted therethrough phase shifts of such magnitude relative to the phase shifts produced by the first mentioned transformers in waves in said circuit as to compensate for the latter phase shifts, said first mentioned transformers differing in number from said other transformers.

3. In combination, a circuit, one or more transformers in said circuit, means for supplying waves of a given range of frequencies to said circuit, and adjustable phase shift means and one or more other transformers, said means and said other transformers being so associated with said circuit and having such frequency-phase shift characteristics relative to those of the first mentioned transformers as to compensate for phase shift, over said frequency range, produced by said first mentioned transformers in waves in said circuit, one of said first mentioned transform-

ers having electrical constants substantially different from those of any one of said other transformers.

4. In combination, a circuit, one or more transformers in said circuit, means for supplying waves of a given range of frequencies to said circuit, and adjustable phase shift means and one or more other transformers, said means and said other transformers being so associated with said circuit and having such frequency-phase shift characteristics relative to those of the first mentioned transformers as to compensate for phase shift, over said frequency range, produced by said first mentioned transformers in waves in said circuit, said first mentioned transformers differing in number from said other transformers.

5. In combination, two wave transmission channels, means for supplying waves of a given range of frequencies to each of said channels, and transformers in said channels, certain of said transformers being in one of said channels, and certain of said transformers being in said other channel, any difference between the sum of the phase shifts of the latter transformers and the sum of the phase shifts of said transformers in said one channel having a predetermined relation to frequency over the given frequency range, and one of said transformers in one of said channels having electrical constants substantially different from those of any one of said transformers in the other channel.

6. In combination, two wave transmission channels, means for supplying waves of the same frequencies to said channels, and transformers in said channels, certain of said transformers being in one of said channels, and certain of said transformers being in said other channel, the sum of the phase shifts of the latter transformers being substantially equal to the sum of the phase shifts of said transformers in said one channel at the frequencies of said waves, and one of said transformers in one of said channels having electrical constants substantially different from those of any one of said transformers in the other channel.

7. In combination, two wave transmission channels, means for supplying waves of the same frequencies to said channels, and transformers in said channels, certain of said transformers being in one of said channels, and certain of said transformers being in said other channel, any difference between the sum of the phase shifts of the latter transformers and the sum of the phase shifts of said transformers in said one channel having a predetermined relation to frequency over the frequency range of said waves.

8. In combination, two wave transmission channels, means for supplying waves of the same frequencies to said channels, and trans-

formers in said channels, certain of said transformers being in one of said channels, and certain of said transformers different in number being in said other channel, the sum of the phase shifts of the latter transformers being substantially equal to the sum of the phase shifts of said transformers in said one channel, at the frequencies of said waves.

9. In combination, two wave paths having portions separate and a part in common, said portions joining said part at the same point, and transformers in said separate portions, certain of said transformers being in one of said portions and certain of said transformers being in said other portion, any difference between the sum of the phase shifts of the latter transformers and the sum of the phase shifts of said transformers in said one portion being substantially proportional to frequency over a frequency range of substantial width, and one of said transformers in one of said channels having electrical constants substantially different from those of any one of said transformers in the other channel.

10. In combination, two wave transmission channels, means for supplying waves of the same frequencies to said channels, and transformers in said channels, certain of said transformers being in one of said channels, and certain of said transformers different in number being in said other channel, the sum of the phase shifts of the latter transformers being substantially equal to the sum of the phase shifts of said transformers in said one channel at the frequencies of said waves, and the phase shift of each of a plurality of said transformers in one of said channels being substantially smaller than the phase shift of one of said transformers in the other channel.

11. In combination, two wave transmission channels, wave receiving means for correlating effects of waves transmitted through said channels, and transformers in said channels, certain of said transformers being in one of said channels, and certain of said transformers different in number being in said other channel, the sum of the phase shifts of the latter transformers being substantially equal to the sum of the phase shifts of said transformers in said one channel, at the frequencies of said waves.

12. A radio receiving system comprising wave collecting means, a radio receiving circuit, two antenna transformers connected to said wave collecting means in tandem with each other for transmitting signals to said circuit, and a compensating transformer connected to said wave collecting means for transmitting interference compensating waves to said circuit, the phase shift of said compensating transformer being substantially equal to the phase shift of said two an-

tenna transformers in tandem, at the signal frequency.

13. A radio receiving system comprising wave collecting means, a radio receiving circuit, two antenna transformers connected to said wave collecting means in tandem with each other for transmitting signals to said circuit, and a compensating transformer connected to said wave collecting means for transmitting interference compensating waves to said circuit, said compensating transformer having a frequency-phase shift characteristic possessing a predetermined relation to the frequency-phase shift characteristic of said two antenna transformers in tandem, over the frequency range of said signals.

14. A radio receiving system comprising wave collecting means, a radio receiving circuit, two antenna transformers connected to said wave collecting means in tandem with each other for transmitting signals to said circuit, and a compensating transformer connected to said wave collecting means for transmitting interference compensating waves to said circuit, said compensating transformer having a frequency-phase shift characteristic possessing a predetermined relation to the frequency-phase shift characteristic of said two antenna transformers in tandem, over the frequency range of said signals, and the phase shift of each of said two antenna transformers being substantially smaller than the phase shift of said compensating transformer.

15. A radio telephone receiving system comprising wave collecting means, wave combining means, a radio telephone receiver connected to said combining means, two antenna transformers connected to said wave collecting means in tandem with each other for transmitting radio telephone signals to said combining means, a compensating transformer connected to said wave collecting means for transmitting interference compensating waves to said combining means, any difference between the phase shift of said compensating transformer and the phase shift of said two antenna transformers in tandem having a predetermined relation to frequency over the frequency range of said signals, and adjustable phase shifting means for equalizing the two phase shifts over said range.

16. In combination, two wave transmission channels having portions separate and a portion in common, a bridge transformer network including a three winding transformer, means connecting two of said windings in one of said separate portions, and a two winding transformer introducing in said other separate portion a phase shift equal to that introduced in said one portion by said network.

17. A radio receiving system comprising a

plurality of wave antennae arranged substantially broadside to an interfering source, a receiving circuit, a path for each antenna for currents corresponding to signal and interfering energy received by the antenna, means for combining the currents from these paths to produce a current having signal and interfering components, a path for each antenna for currents corresponding to interfering energy received by the antenna, means for combining the currents from the last mentioned paths to produce an interfering current, means for adjusting the relative phases of the combined currents so that the interfering current is in opposite phase to the interfering component, means for so combining the phase adjusted currents that the interfering component is neutralized, and means for transmitting the signal current from the last mentioned combining means to the receiving circuit, said paths comprising transformers different in number for the two paths, and the combined phase shifts of said transformers in each path being the same for each path.

18. A radio receiving system comprising an odd number of wave antennae arranged substantially broadside to an interfering source, a receiving circuit, a path for each antenna for currents corresponding to signal and interfering energy received by the antenna, means for combining the currents from these paths to produce a current having signal and interfering components, a path for each antenna for currents corresponding to interfering energy received by the antenna, means for combining the currents from the last mentioned paths to produce an interfering current, means for adjusting the relative phases of the combined currents so that the interfering current is in opposite phase to the interfering component, means for so combining the phase adjusted currents that the interfering component is neutralized, and means for transmitting the signal current from the last mentioned combining means to the receiving circuit, said paths comprising transformers and the combined phase shifts of said transformers in each path being the same for each path, certain of the transformers conjugately connecting certain of the paths.

19. In combination, two wave transmission channels, means for supplying waves of a given range of frequencies to each of said channels, and transformers in said channels, certain of said transformers being in one of said channels, and certain of said transformers being in said other channel, any difference between the sum of the phase shifts of the latter transformers and the sum of the phase shifts of said transformers in said one channel having a predetermined relation to frequency over the given frequency range, and one of said transformers in one of said

channels having an impedance ratio substantially different from that of any one of said transformers in the other channel.

20. In combination, two wave transmission channels, means for supplying waves of a given range of frequencies to each of said channels, and transformers in said channels, certain of said transformers being in one of said channels, and certain of said transformers being in said other channel, any difference between the sum of the phase shifts of the latter transformers and the sum of the phase shifts of said transformers in said one channel having a predetermined relation to frequency over the given frequency range, and one of said transformers in one of said channels having a winding impedance different from any corresponding impedance of any one of said transformers in the other channel.

In witness whereof, I hereunto subscribe my name this 25th day of August, A. D., 1927.

HORACE WHITTLE.