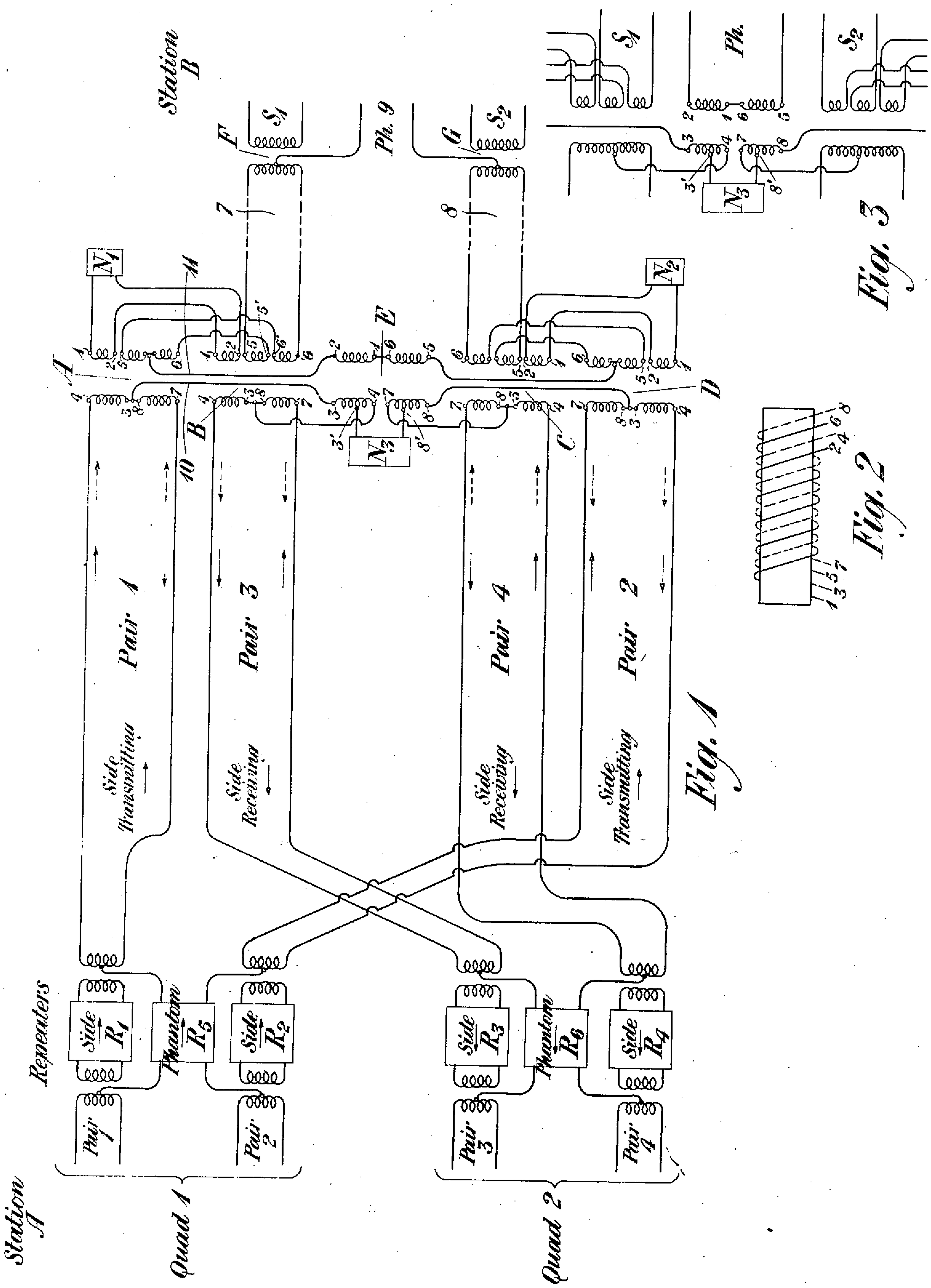
Dec. 29, 1925. 1,567,167

H. NYQUIST

FOUR-WIRE REPEATER CIRCUITS

Filed July 8, 1921 2 Sheets-Sheet 1



Inventor
H. Nyquist
By his Attorney
G E Folk

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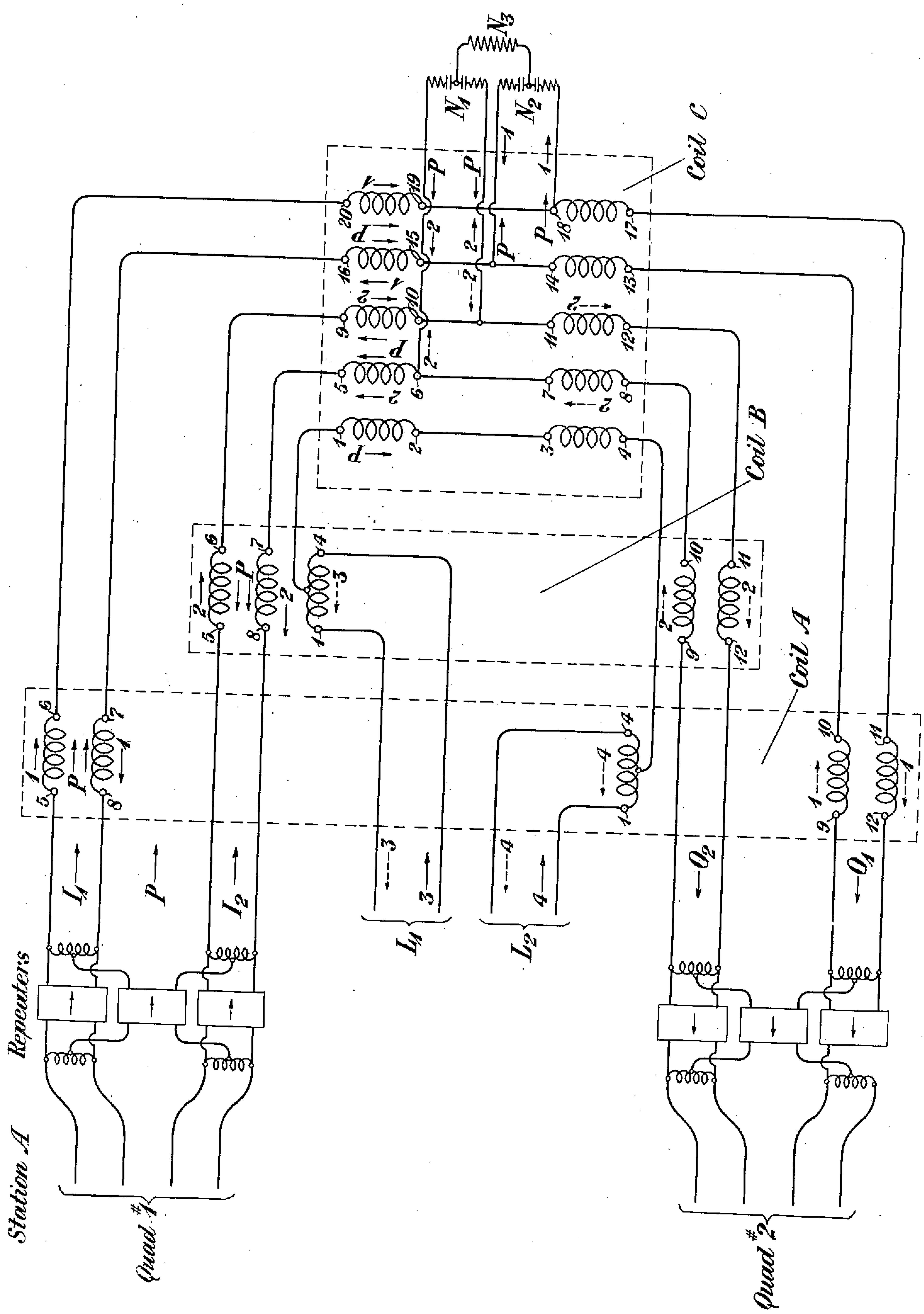

Fig. 4

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Patented Dec. 29, 1925. **1,567,167**

UNITED STATES PATENT OFFICE.

HARRY NYQUIST, OF ELMHURST, NEW YORK, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

FOUR-WIRE REPEATER CIRCUITS.

Application filed July 8, 1921. Serial No. 483,331.

To all whom it may concern:

Be it known that I, Harry Nyquist, residing at Elmhurst, in the county of Queens and State of New York, have invented certain Improvements in Four-Wire Repeater Circuits, of which the following is a specification.

This invention relates to four-wire repeater circuits, and especially to a circuit arrangement for terminating four-wire phantom circuits.

It is well known in the telephone art that a phantom circuit may be derived from two physical circuits by means of suitably balanced retardation coils or repeating coils bridged across each end of each physical circuit and having a tap taken from the midpoint of each retardation coil or from the midpoint of the line winding of each repeating coil. Such circuit arrangements are designed for the transmission of signals in both directions over each physical circuit and also over the phantom circuit.

The so-called four-wire circuit comprises two pairs of wires, each of which is arranged for unidirectional signaling. In such a circuit, the signaling currents created at and transmitted from one station will travel over one pair of wires to a second station, and similarly, the transmitted signals from the said second station will travel over a second pair of wires to the said first station. The term "four-wire phantom circuit" means a phantom circuit derived from two four-wire physical circuits. In such a phantom circuit, the signaling currents transmitted from one station will travel over one pair of wires to a second station and will return over a second pair of wires to the first station. The signaling currents transmitted from the said second station will travel over a third pair of wires to the said first station and will return over a fourth pair of wires to the said second station. It is necessary to have at each of the said stations connected with the four-wire circuits suitable terminating apparatus whereby the phantom circuit currents and the side circuit currents may be separated and directed into their proper terminal circuits at each of the said stations. It is also necessary that the terminating apparatus shall be so arranged that the currents arriving over certain pairs of the four-wire circuits will not be fed back into other pairs of the four-wire circuit, which would cause singing of the repeaters connected with the four-wire circuits and thereby reduce the efficiency of transmission.

My invention provides new arrangements for terminating four-wire phantom circuits, which arrangements are characterized by the use of the minimum number of coils, thereby making the arrangement cheap and efficient.

Other objects of this invention will be apparent from the following description, when read in connection with the attached drawing, of which Figure 1 shows one form of embodiment of the invention; Fig. 2 shows an arrangement of the windings of the coils shown in Fig. 1; Fig. 3 shows a variation in the mode of bringing out the phantom derived from two four-wire circuits, and Fig. 4 shows another form of embodiment of the terminal circuit having a single network adapted to balance both the four-wire side circuits and the four-wire phantom circuit.

In Fig. 1, pairs 1 and 3 constitute one four-wire circuit and pairs 2 and 4 constitute a second four-wire circuit. Pair 1 constitutes the conducting path of the first four-wire circuit in transmitting signals from station A to station B, and pair 3 represents the conducting path of the same four-wire circuit in receiving at station A signals transmitted from station B. For the purpose of brevity, these pairs will sometimes be referred to as the transmitting and receiving circuits, respectively, of the first four-wire circuit. Similarly, pair 2 represents the transmitting side of the second four-wire circuit and pair 4 represents the receiving side of the same four-wire circuit.

In the design of four-wire circuits, in order to minimize cross-talk, all of the circuits transmitting energy in one direction between stations are grouped together and likewise all of the circuits transmitting energy in the other direction are grouped together. Thus in Fig. 1, pairs 1 and 2, over which energy is being transmitted from left to right between the repeater points are grouped together, the two pairs forming what is designated as quad 1. In like manner, pairs 3 and 4, over which energy is being transmitted from right to left are grouped together in quad 2. Each quad constitutes one side of a four-wire phantom circuit and at the points where the four-wire circuit terminates, the phantom circuit currents and the side circuit currents are directed into their proper terminal circuits by means of a coil arrangement as shown in Fig. 1.

Associated with each quad is a group of repeaters adapted to amplify the currents of the physical and phantom circuits. Thus repeaters R_1, R_2 and R_5, associated with quad 1, are respectively adapted to amplify the currents traversing pair 1, pair 2 and the phantom transmitting circuit super-imposed upon the said pairs, and in like manner, repeaters R_3, R_4 and R_6 are respectively adapted to amplify the currents traversing pair 3, pair 4, and the phantom receiving circuit superimposed upon the said pairs. The repeaters associated with quad 1 are all adapted to transmit energy in one direction, and the repeaters associated with quad 2 are adapted to transmit energy in the opposite direction.

The terminal circuit shown at the right-hand side of Fig. 1 comprises five coils and three balancing networks. Coils A and B serve in part to connect the four-wire circuit comprising pairs 1 and 3 with a two-wire circuit 7, and similarly, coils C and D serve in part to connect the four-wire circuit comprising pairs 2 and 4 with a two-wire circuit 8. Coil E serves to connect what may be termed the four-wire phantom circuit with the two-wire phantom circuit, the latter made up of the two side circuits 7 and 8. The network N_1 is designed to balance the four-wire circuit 1—3 and similarly the network N_2 is designed to balance the four-wire circuit 2—4. The network N_3 balances the phantom circuit superimposed upon the said two four-wire circuits. By means of the repeating coils F and G, inserted in the physical circuits 7 and 8, the phantom circuit may be derived and terminated as the two-wire circuit 9.

The coils A and D, which are similar, are of the well-known type of phantom repeating coil comprising four windings 1—2, 3—4, 5—6 and 7—8, arranged as shown in the figure. The relative arrangement of the windings upon the core of these coils is shown in Fig. 2. The four windings are put on in the same direction and, consequently, it will be seen that if the current flows from the odd numbered terminals to the even numbered terminals of the windings, the resultant flux will be in the same direction. Coils B and C differ from coils A and D in that in coils B and C the windings 5—6 are divided in half, the reason for which will be made clear hereafter. The junction points between windings 3—4 and 7—8 of both coils A and D are connected with terminals 3 and 8, respectively, of coil E. In a similar manner, the junction points between windings 3—4 and 7—8 of coils B and C are connected with the terminals 4 and 7, respectively, of coil E. The midpoint of winding 5—6 of coil A is connected with the terminal 2 of coil E and the midpoint of winding 5—6 of coil D is connected with the terminal 5 of coil E. The network N_3 is bridged across the midpoints of windings 3—4 and 7—8 of coil E. Windings 1—2 of coils A and B are connected in series with the balancing network N_1. The terminals of winding 5—6 of coil A are connected to the inner terminals 5′, 6′ of the divided winding 5—6 of coil B. The outer terminals 5—6 of coil B are connected with the conductors of the two-wire physical circuit 7. In a similar manner, the windings of coil D are related to coil C, thereby bringing into association with the four-wire circuit the balancing network N_2 and the two-wire physical circuit 8.

Having in mind the foregoing description of the parts of this circuit, the invention will be apparent from the following description of the mode of operation of the circuit: let it be assumed that energy is being transmitted from left to right over pair 1, which is the condition when a voice signal is being transmitted from station A to station B. The current resulting therefrom may at any instant be assumed to be in the direction indicated by the solid arrows. Thus current will flow through the left-hand windings of coil A in the direction represented by the numerals 4, 3, 8, 7. It will be seen by reference to Fig. 2, that the flux resulting therefrom will induce in the windings 1—2 and 5—6 an electro-motive force such as to cause current to flow in the direction represented by the numerals 1, 2, 5, 6. The current flowing in winding 1—2 of coil A will likewise flow from terminal 1 to terminal 2 of winding 1—2 of coil B. The current flowing in winding 5—6 of coil A will flow through the two halves of divided winding 5—6 of coil B in such direction as to set-up a flux which will oppose and neutralize the flux set up by the flow of current through winding 1—2 of coil B. Consequently, no resultant current will be produced in pair 3, which constitutes the other side of the same four-wire circuit, and consequently singing around the circuit, with its consequent loss of transmission, is prevented. The current which is set up in winding 5—6 of coil A, flows through the divided winding 5—6 of coil B, and is in turn transmitted over the conductors 7 and actuates the receiving apparatus associated with the circuit S_1 at station B.

Voice signals originating at station B are impressed upon the circuit 7 and the currents resulting therefrom flow through the divided winding 5—6 of coil B, and also winding 5—6 of coil A. Let it be assumed that the direction of the flow of current in circuit 7 is such that the current will pass from terminal 6 to 6′ and from 5′ to 5. This will induce in winding 1—2 of coil B an electromotive force which will produce a flow of current from 1 to 2. The flow of current in winding 5—6 of coil A will be in such direction as to cause an induced flow of current from 2 to 1 of the winding 1—2 of coil A. Since the direction of the flow of current in winding 1—2 of coil A is opposite to that of winding 1—2 of coil B, there will result no flow of current through the circuit containing the network N_1. The current flowing through the divided winding 5—6 of coil B will induce a current in the left-hand windings of the said coil, which will be transmitted through the amplifier R_3 and, in turn, over pair 3 to station A. The current in winding 5—6 of coil A will also induce current in the left-hand windings of the said coil, but in view of the unidirectional characteristic of the vacuum tube amplifier, this current will not pass through the repeater R_1 and, consequently, will not pass over the line to station A. The four-wire circuit made up of pairs 2 and 4, over which voice signals are transmitted from and received at station A, operates in the same manner as the previously described circuit, and the voice signals originating at station A, transmitted over the pair 2, will be impressed upon circuit 8 in such a manner as to prevent reaction upon pair 4, so that singing around the circuit comprising repeaters R_2 and R_4 is prevented.

In the transmission of voice signals from station A to station B over the phantom circuit, the resultant current will flow toward station B over the two conductors of pair 1 in parallel, as indicated by the dashed arrows, and will return over the two conductors of pair 2 in parallel, as similarly indicated. The current resulting from the transmission of voice signals from station B to station A, will flow over the two conductors of pair 3 in parallel and will return over the two conductors of pair 4 in parallel, as indicated by the dashed arrows. The current flowing over the conductors of pair 1 in parallel will pass through the left-hand windings of coil A from 7 to 8, and from 4 to 3, which is in such direction as to prevent the induction of current in the right-hand windings of the said coil. The phantom current will flow from the junction point 3—8 over conductor 10 to terminal 3 of coil E, thence through winding 3—4. Part of the current will flow through the network N_3 to the midpoint 8′ of winding 7—8 and thence to the junction point 3—8 of the left-hand winding of coil D and over the conductors of pair 2 in parallel, to the source of current at station A. Since the direction of the flow of current from the left-hand windings of coil E is from the odd numbered to the even numbered terminals, current will be induced in the right-hand windings of the said coil in the direction of the even to the odd numbered terminals. Current will thus flow from terminal 5 of coil E to the mid-point of winding 5—6 of coil D, then in parallel and in opposite directions through the divided winding 5—6 of coil C and over the conductors of circuit 8 to the mid-point of coil G, thence to one side of the receiver associated with the phantom terminating circuit 9. The current will continue to flow through the receiver of said phantom circuit to the midpoint of the winding of coil F, and thence over the conductors of circuit 7 in parallel to the terminals 5 and 6 of the divided winding 5—6, then in an opposite direction through the said windings to the midpoint of winding 5—6 of coil A, and over the conductor 11 to the terminal 2 of coil E. It will be seen that the flow of current through the divided windings 5—6 of coils B and C is in such directions as to prevent induction of currents in the left-hand windings of coils B and C. Furthermore, there will be no flow of current over a circuit from the terminal 4 of coil E to the junction point 3—8 of coil B and over pair 3 and pair 4 to the junction point 3—8 of coil C, to the terminal 7 of coil E, for the reason that the current that might tend to flow over the latter traced circuit, due to its being in parallel with the circuit through the network N_3, is neutralized by the current induced in that portion of the windings 3—4 and 7—8 lying between 3′ and 4, respectively, and 8′ and 7, respectively, by the flow of current through the network N_3. An analysis of these circuits will show that the direction of flow of current in the portions of the left-hand windings of coil E stated above is such as to oppose the current which might tend to flow over the circuit represented by pairs 3 and 4, due to the difference in potential between the points 3′ and 8′.

It will be seen that by means of my invention, a four-wire phantom circuit may be terminated by means of a plurality of repeating coils of the well-known type, the windings of the said coils being so arranged by a reversal of one of the coils that currents traversing one pair of a four-wire circuit will set up currents of the same magnitude in the two-wire terminating circuit, and also in the balancing network circuit. These currents traverse the windings of the repeating coil of the other pair of the four-wire circuit in opposite directions and consequently, produce no resultant current in the said pair, thereby preventing singing around the circuit. This method of connection makes it easy to superpose the phantom circuit currents upon the two-wire phantom circuit made up of the pairs 7 and 8.

Fig. 3 shows an arrangement whereby the phantom circuit superimposed upon the two physical four-wire circuits may be connected directly with a physical two-wire circuit by means of the right-hand windings of coil E, instead of being continued as a phantom circuit upon the two-wire physical circuits 7 and 8 as shown in Fig. 1.

Fig. 4 shows an arrangement for deriving a phantom circuit from two four-wire repeater circuits, which employs three coils and a common balancing network instead of five coils and separate networks, as shown in Fig. 1. In the arrangement shown in Fig. 4, I_1 and I_2 represent two pairs of quad 1, and O_1 and O_2 represent two pairs of quad 2. I_1 and O_1 represent the two sides of one four-wire circuit and I_2 and O_2 represent the two sides of another four-wire circuit. I_1 and I_2 constitute one side of the phantom circuit and O_1 and O_2 constitute the other side of the phantom circuit superimposed upon the two four-wire circuits. Energy is transmitted in the same direction, as indicated by the arrows, over pairs I_1 and I_2 and also over the side of the phantom superimposed upon I_1 and I_2. In like manner energy is transmitted in the same direction over both pairs O_1 and O_2 and also over the side of the phantom super-imposed upon these two pairs, but the direction is opposite to that in which energy is transmitted over I_1 and I_2, and the side of the phantom super-imposed upon these two circuits. L_1 and L_2 represent two two-wire circuits which are related by means of windings of coils B and A respectively with the four-wire circuits, and in like manner the phantom superimposed upon L_1 and L_2 is related to the phantom superimposed upon the two four-wire circuits by means of windings of coil C.

Coil A, as may be seen, embraces five windings, two of which are connected in series with pair I_1, two with pair O_1 and one with pair L_2. In a similar manner coil B comprises five windings, two of which are connected in series with pair I_2, two with pair O_2 and one with pair L_1. Coil C embraces ten windings, four of which are arranged in series with pairs I_1 and O_1, four with pairs I_2 and O_2 and two with pairs L_1 and L_2. Connected with the windings of coil C, associated with pairs I_1 and O_1, is a network N_2 adapted to balance the said pairs, and similarly connected with the windings associated with the pairs I_2 and O_2 is a network N_1 adapted to balance the said pairs. Connected with the networks N_1 and N_2 is a third network N_3, which taken together with networks N_1 and N_2, is adapted to balance the phantom circuit.

Let it be assumed that a signaling wave is being transmitted over pair I_1 from station A, and this wave is to be impressed upon pair L_2 for transmission to a station connected therewith. Current will flow through the windings 5—6 and 7—8 of coil A in the direction indicated by the arrows marked 1. This current will also flow through windings 20—19 and 15—16 of coil C and through the network N_2 in the direction indicated by the arrows marked 1. The difference of potential across the network N_2 will of course tend to cause current to flow through the windings 18—17 and 13—14 of coil C. Since, however, windings 9—10 and 11—12 of coil A are inductively related to the windings 5—6 and 7—8 of the same coil, a difference of potential will be set up in pair O_1 which will neutralize the effect produced in windings 18—17 and 13—14 of coil C, thereby preventing the transmission of energy out over pair O_1 which prevents singing over the four-wire circuit represented by pairs I_1 and O_1. Current will however, be induced in winding 1—4 of pair L_2 and in this manner the energy of the voice signaling wave of pair I_1 will be transmitted to the station connected with pair L_2. Since the windings of coil C and coils A and B are arranged in the manner shown in Figure 2, in which the odd numbers represent one terminal of the windings and the even numbers represent the other terminal of the windings, current flowing in windings 20—19 and 15—16 will produce no effect in the other windings of this coil.

If the station connected with the pair L_2 desires to transmit, for example, a signal to the station A of the four-wire circuit current will flow over the pair L_2, which, for example, may be assumed to be in the direction represented by the arrow marked 4. This flow of current will induce a difference of potential in windings 5—6 and 7—8 connected with pair I_1, and also in windings 9—10 and 11—12 connected with pair O_1. Since the repeaters in pair I_1 are adapted to transmit energy only in the direction represented by the arrow, none of the energy caused by this induced potential can get through the repeaters. On the other hand since the repeaters connected with pair O_1, are adapted to transmit in the opposite direction, energy will be transmitted over pair O_1 to the receiving apparatus connected with the four-wire circuit at station A.

The transmission of signals in opposite directions over pairs I_2 and O_2 representing the other four-wire circuit is accomplished by means of the windings of coil B in the same manner in which energy is transmitted over the four-wire circuit represented by pairs I_1 and O_1.

Let it be assumed that a signal is to be transmitted from station A over the phantom circuit superimposed upon these two four-wire circuits. The current will flow over the two wires of pair I_1 in parallel as represented by the arrows marked P, and will return over the two wires in parallel of pair I_2 in the direction indicated by the arrows marked A. Since the direction of flow of current through the windings 5—6 and 8—7 is in opposite directions, no difference of potential will be induced in the other windings of coil A, and similarly no difference of potential will be induced in the windings of coil B by the flow of current through the windings 5—6 and 8—7. Since the phantom current flows in the same direction through windings 20—19 and 16—15 and returns in the same direction through windings 10—9 and 6—5, there will be induced a difference of potential across winding 1—2 of coil C which will cause a flow of current in the phantom circuit superimposed upon pairs L_1 and L_2. It will also be seen that in transmitting a signal from a station connected with the phantom circuit superimposed upon pairs L_1 and L_2 that no current will be induced in the side circuits of the four-wire circuits through the windings of coils A or B, but that current will be induced in the phantom circuit superimposed upon the two four-wire circuits by means of the windings of coil C. This energy of the signaling wave will tend to flow over the side of the phantom circuit superimposed upon pairs I_1 and I_2 and also over pairs O_1 and O_2. Since the phantom repeater associated with the side of the phantom superimposed upon pairs I_1 and I_2 is not adapted to transmit in the direction toward station A, the energy will not get through, consequently no detrimental effect will be produced. On the other hand, since the phantom repeater associated with the side superimposed upon pairs O_1 and O_2 is adapted to transmit in the direction of station, the signaling wave will be transmitted to the said station and will be received thereby.

The aforedescribed arrangement provides a four-wire phantom terminating arrangement requiring only three transformers having its balancing network so arranged as to be capable of balancing both the four-wire physical circuits, as well as the four-wire phantom circuit.

Although this invention has been disclosed as having a particular form, it will be understood that it may be embodied in many other organization widely different from those illustrated, without departing from the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. In a signaling system, the combination with one four-wire signaling circuit of a second four-wire signaling circuit, a two-wire circuit individual to each four-wire circuit, a network adapted to balance each of the said two-wire circuits, and a plurality of repeating coils having their windings so connected with the said four-wire circuits and with the said two-wire circuits and the balancing networks, as to derive a phantom circuit not only from the four-wire circuits but also from the two-wire circuits, the said phantom circuit being thereby rendered electrically continuous.

2. In a signaling system, the combination with one four-wire signaling circuit of a second four-wire signaling circuit, each four-wire circuit being of the type in which the signaling energy for transmission in one direction is carried by one pair of wires, and for transmission in the opposite direction is carried by the other pair of wires, and means to derive a phantom circuit from the said four-wire circuits.

3. In a signaling system, the combination with one four-wire signaling circuit of a second four-wire signaling circuit, and means to derive the phantom circuit from the said four-wire circuits, said means comprising a plurality of repeating coils the windings of which are so interconnected that the current in one branch of a four-wire circuit will not induce an E. M. F. in the other branch of the same four-wire circuit.

4. In a signaling system, the combination with two four-wire signaling circuits of two two-wire signaling circuits, a plurality of networks individual to and adapted to balance the said circuits, and a plurality of repeating coils connecting the said four-wire circuits with the said two-wire circuits and their networks, whereby a continuous phantom circuit may be superposed upon the said four-wire and the said two-wire circuits.

5. In a signaling system, the combination with two four-wire signaling circuits of two two-wire signaling circuits, a plurality of repeating coils adapted to connect the said four-wire circuits with the said two-wire circuits, whereby a phantom circuit may be superposed upon both the four-wire and the two-wire circuits and rendered electrically continuous, and a balancing network adapted to balance the two-wire circuits with respect to their use as physical circuits and as a phantom circuit.

6. In a signaling system, the combination with a four-wire repeater circuit comprising two pairs of conductors adapted for the propagation of signals thereover in opposite direction, of a two-wire circuit, means to balance the said two-wire circuit and a plurality of repeating coils for connecting the said four-wire and the said two-wire circuit and said balancing means, the said connecting repeating coils being so arranged as to prevent singing over the four-wire circuit.

7. In a signaling system, the combination with two four-wire repeater circuits, each

having a two-wire terminal circuit individual thereto, of networks adapted to balance the said two-wire circuits, repeating coils adapted to connect each four-wire circuit with its respective network and its two-wire circuit, and another repeating coil and balancing network connected with both of said four-wire circuits and said two-wire circuits for effectively deriving a phantom circuit from the said four-wire circuits.

In testimony whereof, I have signed my name to this specification this 7th day of July, 1921.

HARRY NYQUIST.