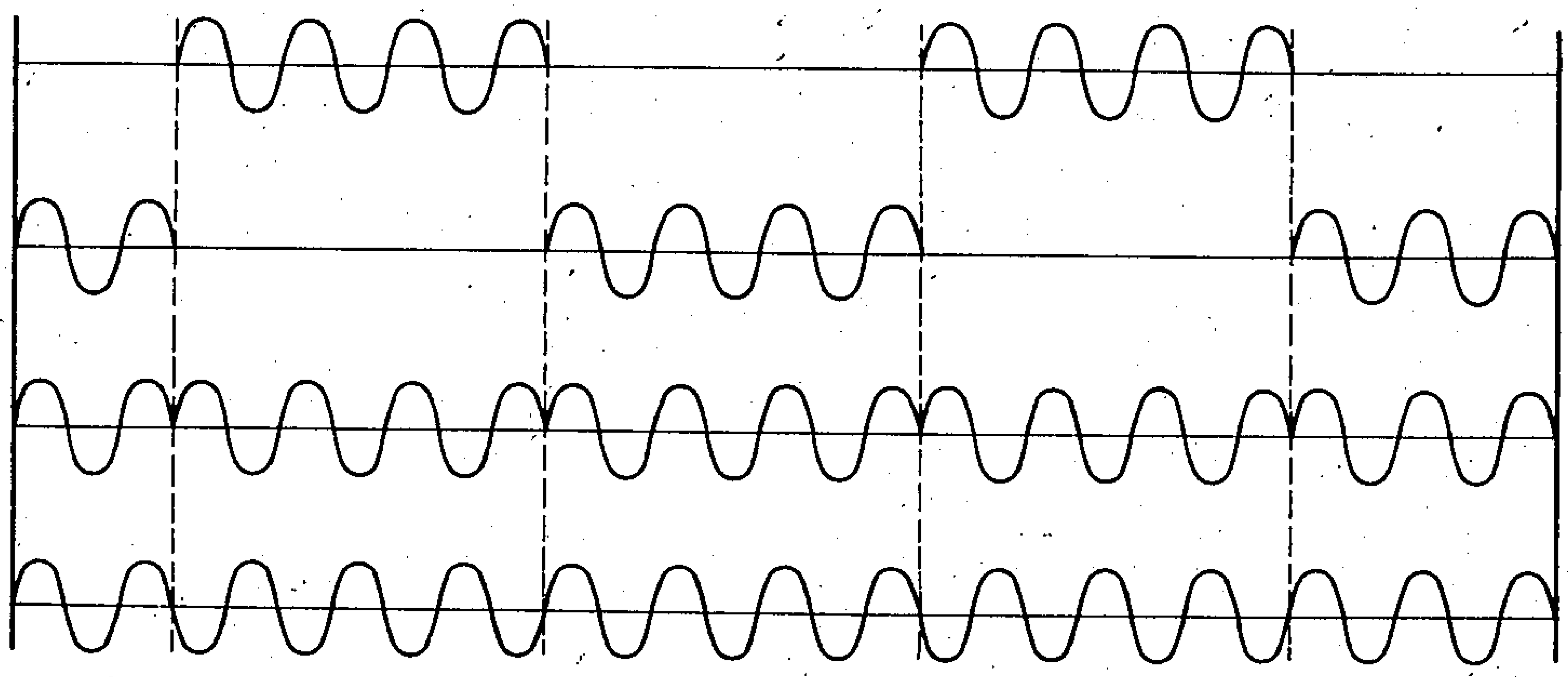
Nov. 3, 1925. 1,559,641

H. NYQUIST

SIGNALING WITH PHASE REVERSALS

Filed Aug. 28, 1923 4 Sheets-Sheet 1



Curve a represents letter "I" when current in line corresponds to marking
Curve b represents letter "I" when current in line corresponds to spacing
Curve c represents letter "I" when signals are formed by reversing circuit
Curve d represents a sine wave when the line is not reversed.
By combining Curves c and d, curves like a and b may be obtained having amplitudes twice as great as a and b

Fig. 1

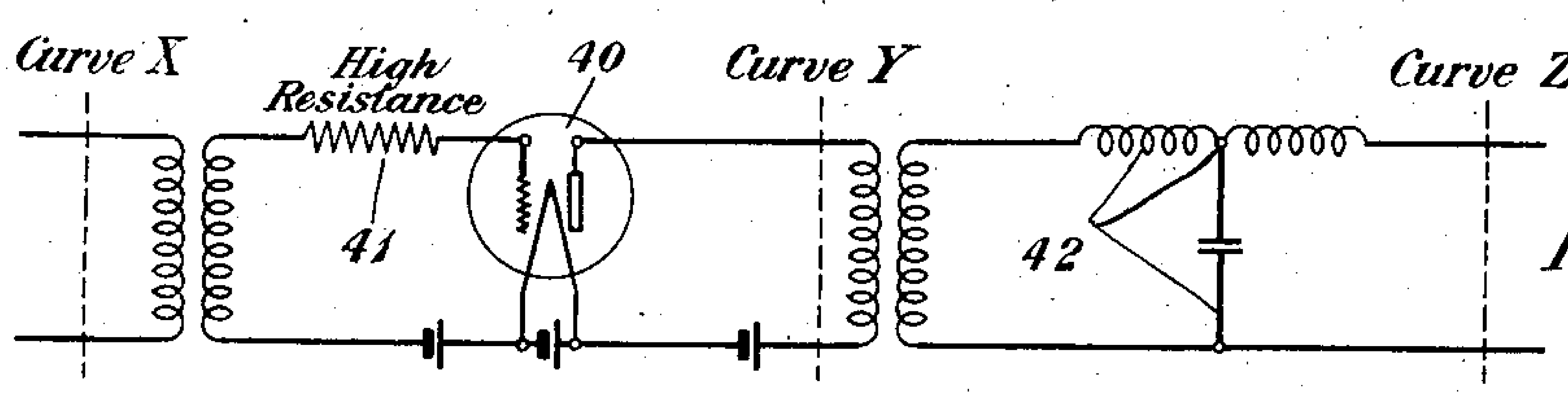


Fig. 7

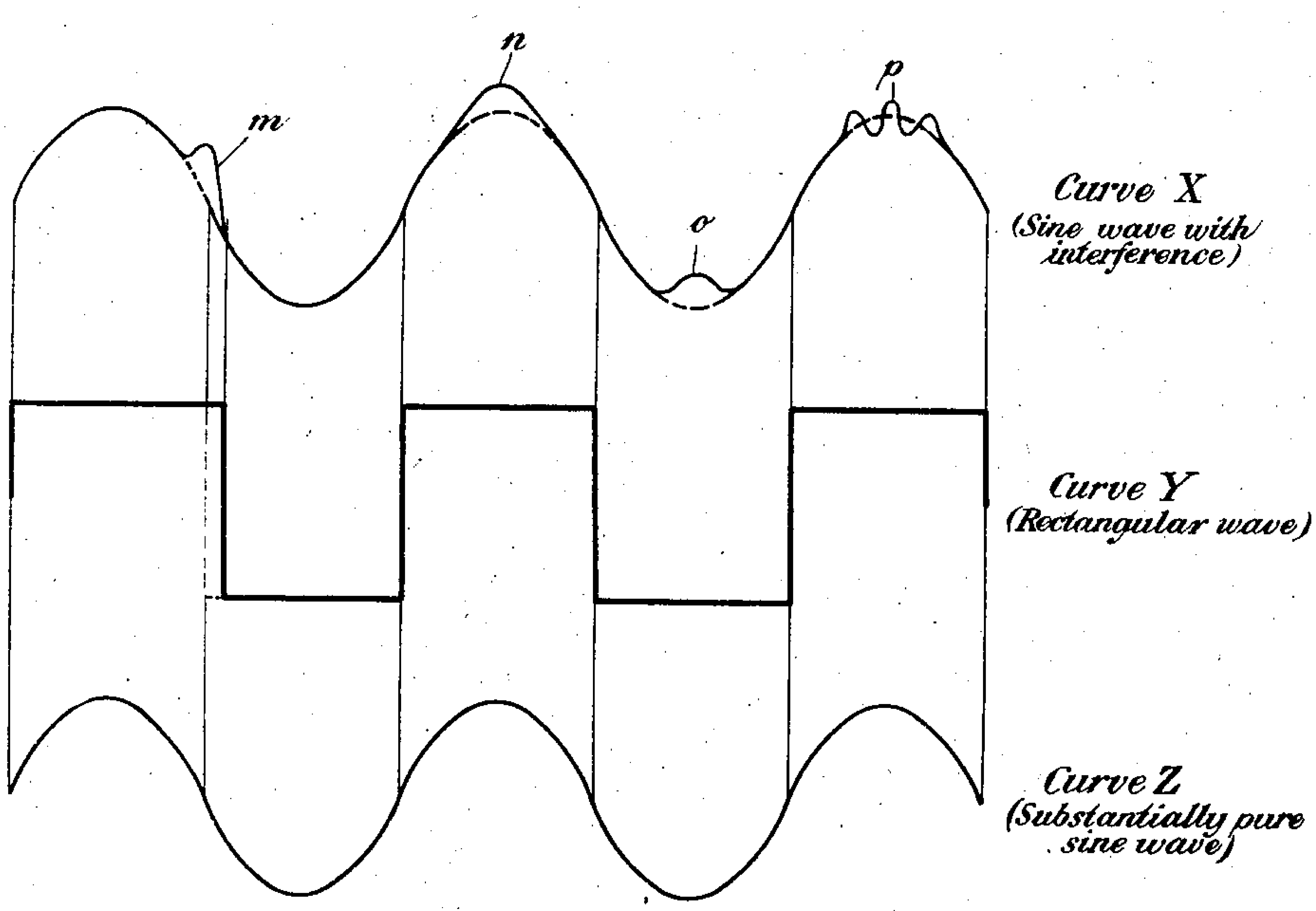


Fig. 8

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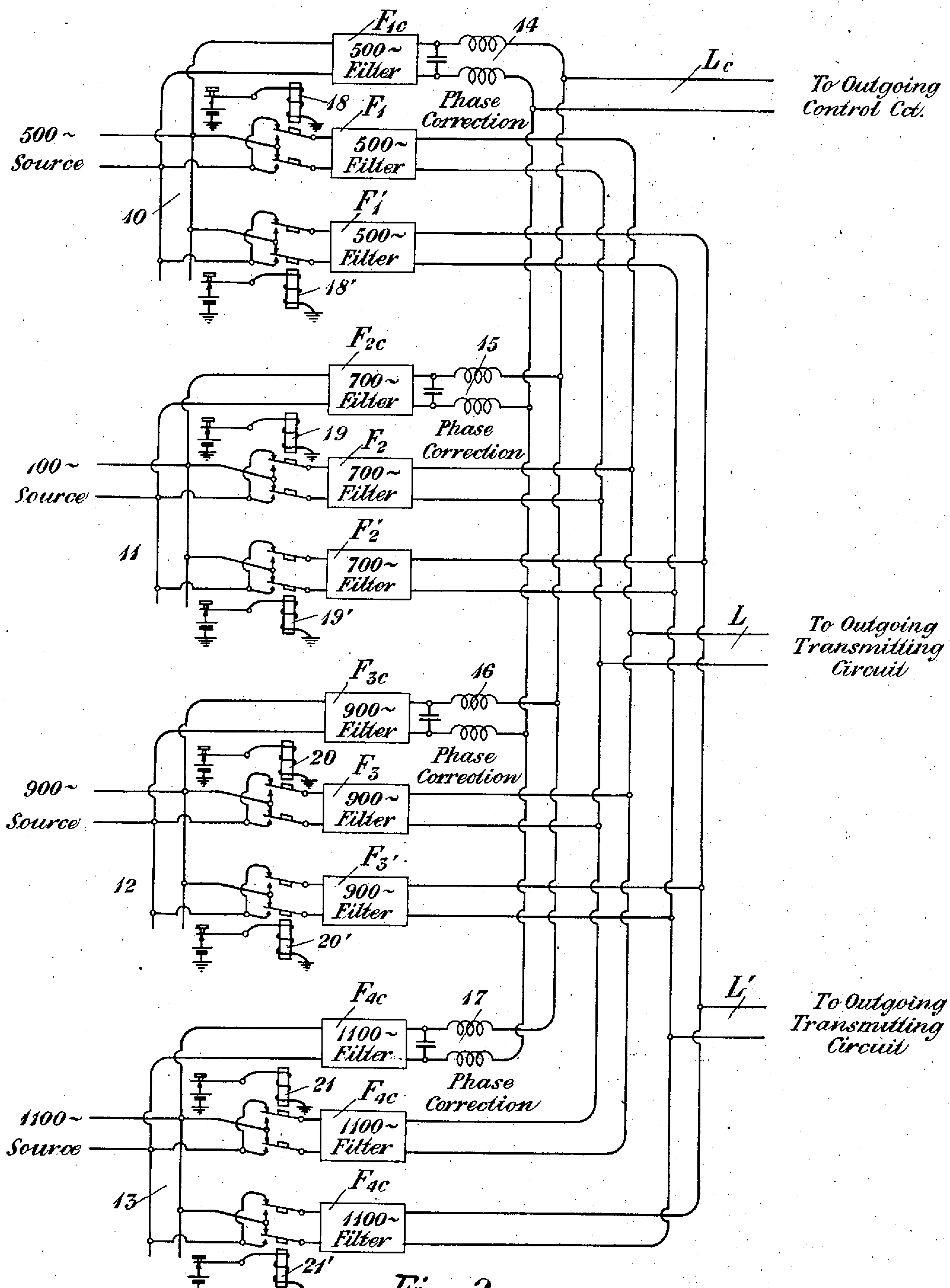

Fig. 2

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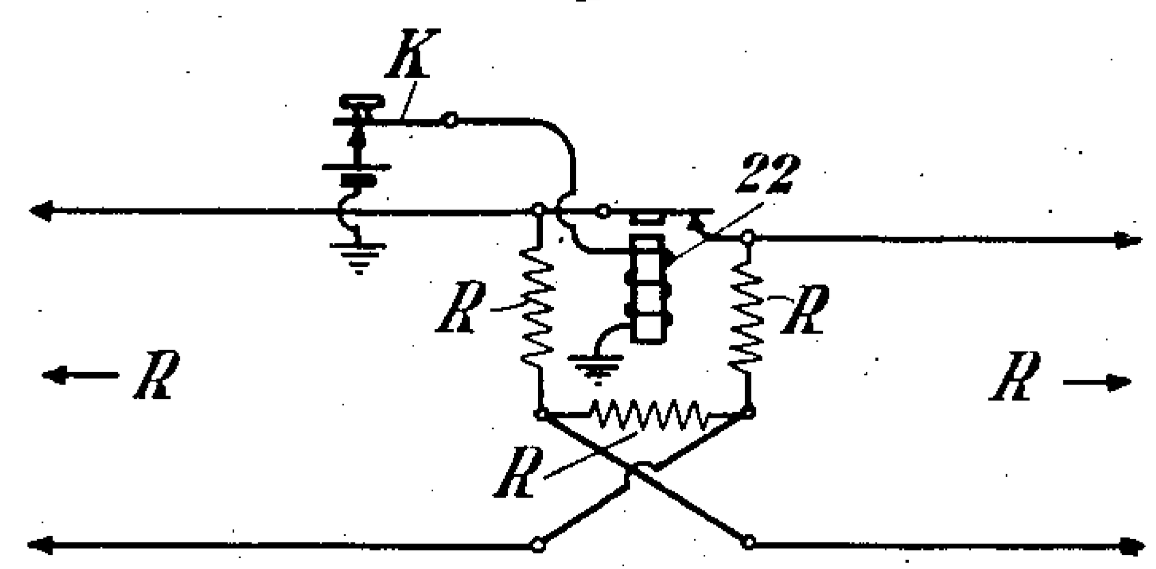

Fig. 5

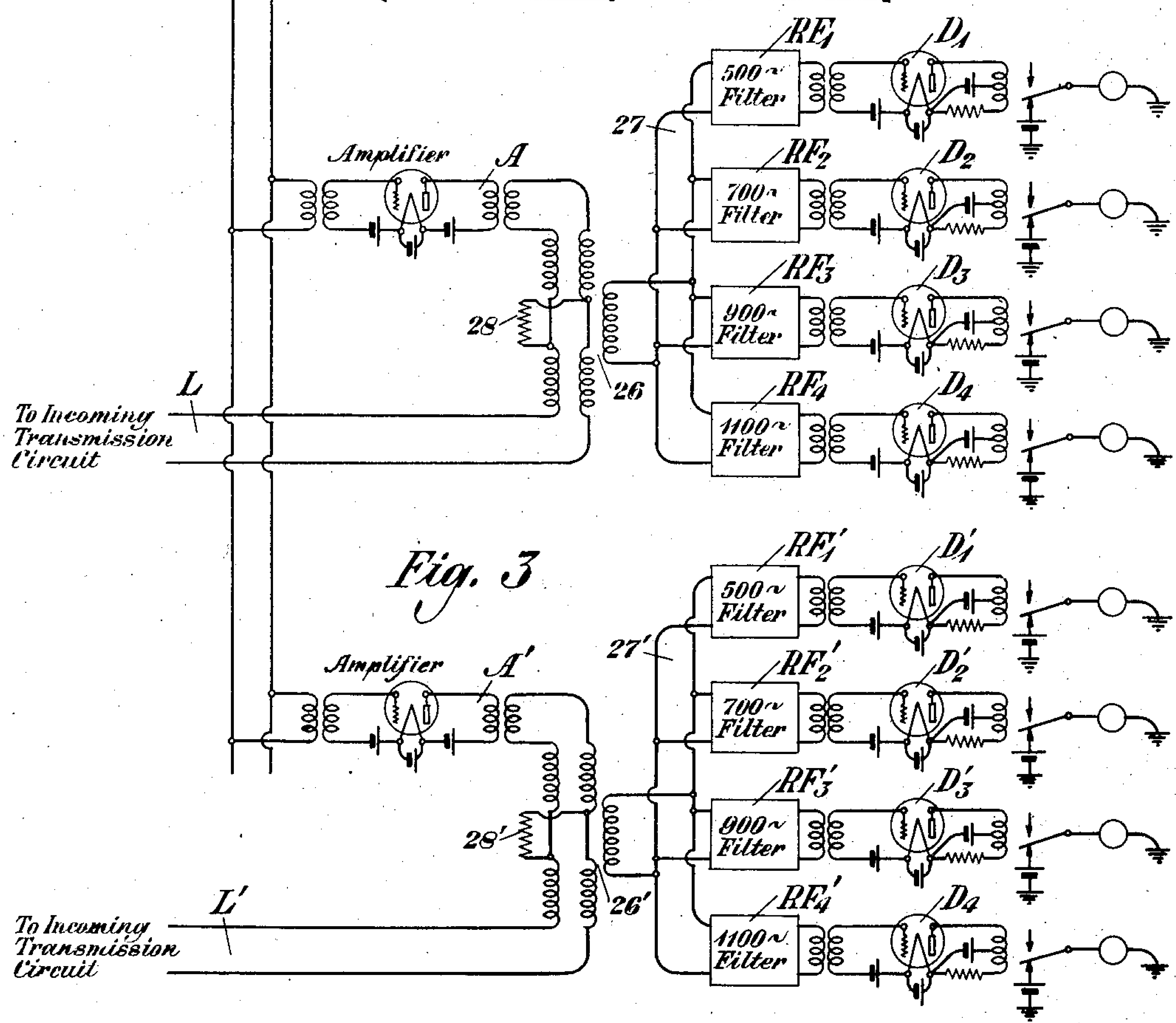

Fig. 3

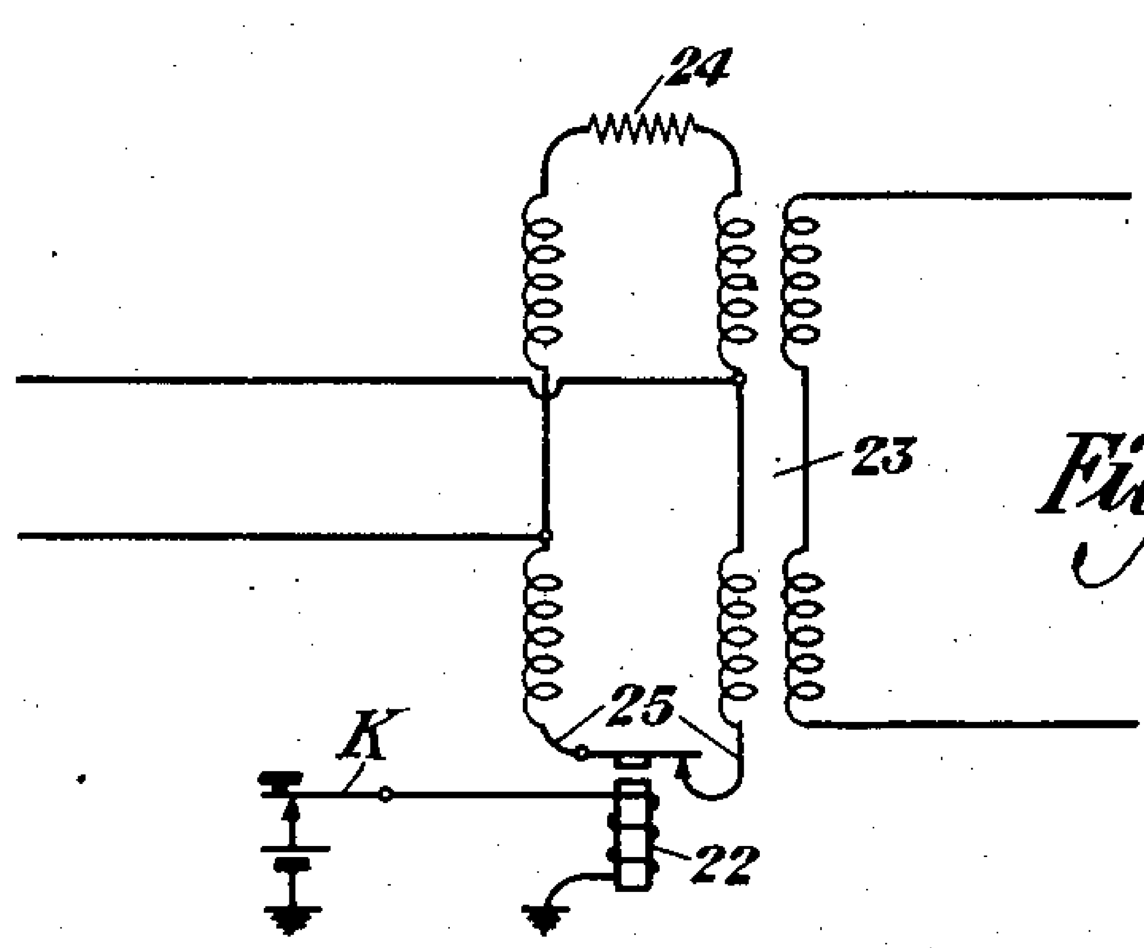

Fig. 6

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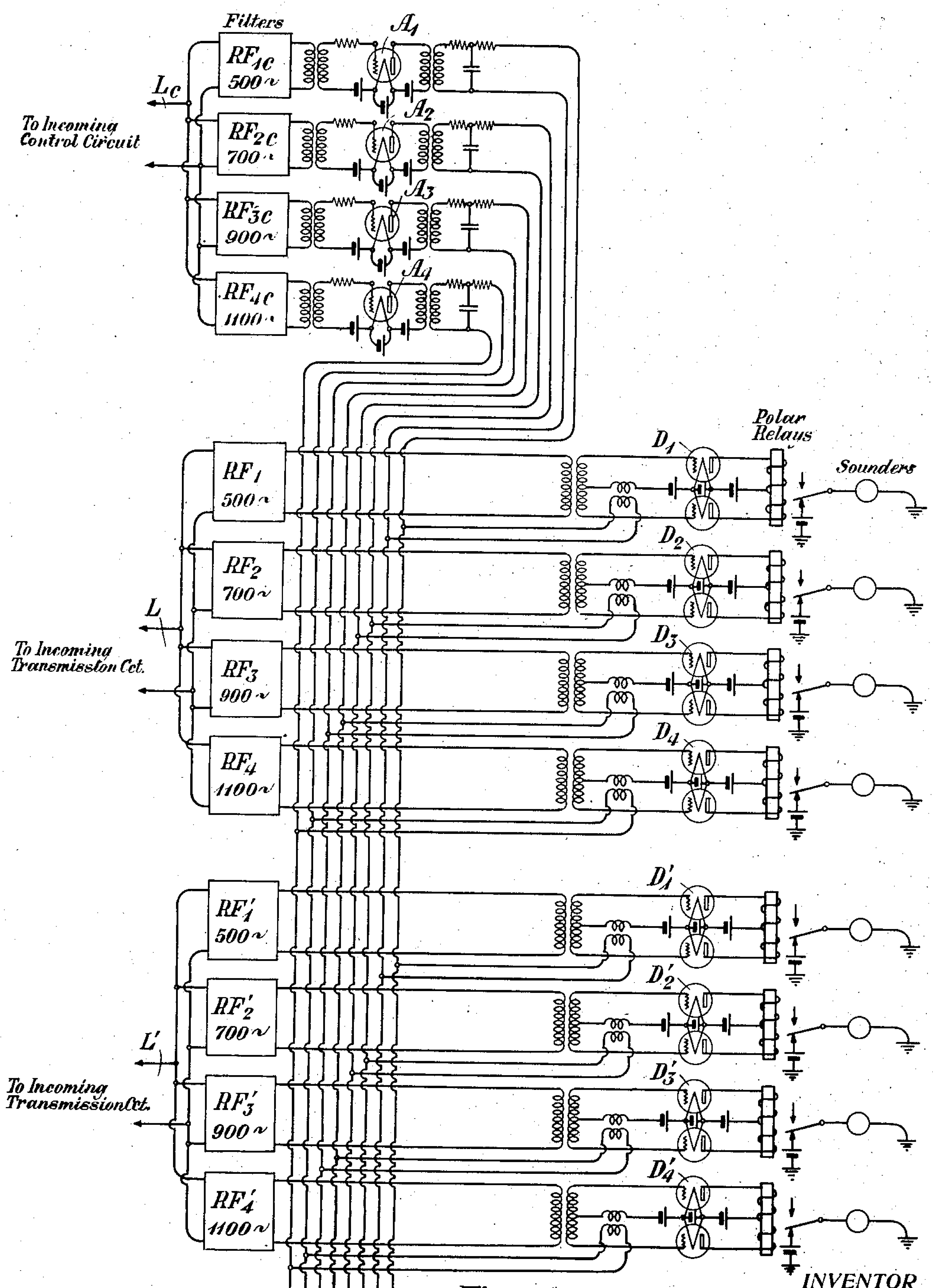

Fig. 4

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Patented Nov. 3, 1925. **1,559,641**

UNITED STATES PATENT OFFICE.

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

SIGNALING WITH PHASE REVERSALS.

Application filed August 28, 1923. Serial No. 659,754.

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 Signaling with Phase Reversals, of which the following is a specification.

This invention relates to the art of signaling, and more particularly to the transmission of telegraph signals.

It is one of the objects of the present invention to provide a telegraph system having one or more channels transmitting over the same circuit, the channels being so arranged that by the transmission of an alternating current of given magnitude, a signal response of greater amplitude will be produced. Another object of the invention is to provide a circuit of the type above described, in which the effect of foreign interference will be reduced. Another object of the invention is to provide a multiplex telegraph system so arranged that the mutual interference between different channels will be a minimum. A still further object of the invention is to provide a telegraph system in which the biasing effect of the received signals caused by variations in the transmission equivalent of the circuit will be practically eliminated.

These objects, together with other objects of the invention, are accomplished by transmitting an alternating current of constant frequency and amplitude and by reversing the phase of the transmitted current in response to the marking and spacing signals. At the receiving station, the transmitted current will be combined with another current of equal amplitude and of the same frequency but with its phase constant. While, in general, this controlling current may be either generated at the transmitting station and transmitted to the receiving station, or generated at the receiving station under the control of the current source at the transmitting station, the specific embodiment of the invention herein disclosed illustrates only the former of these methods.

The invention may now be more fully understood from the following detailed description thereof, when read in connection with the accompanying drawing, Figure 1 of which illustrates a number of curves showing the form of wave transmitted in accordance with the present invention; Fig. 2 of which shows a schematic circuit diagram embodying the transmitting apparatus of the present invention; Figs. 3 and 4 of which illustrate two different types of receiving arrangements to be employed in connection with the present invention; Figs. 5 and 6 of which illustrate two different circuit arrangements for producing phase reversals; Fig. 7 of which illustrates a piece of apparatus adapted to reduce the effect of interference at the receiving station; and Fig. 8 of which illustrates curves showing the operation of the apparatus of Fig. 7.

Referring to Fig. 1, the curve designated *a* illustrates the current condition in the line of an alternating current telegraph system in which the marking signal is produced by transmitting current in the line and the spacing signal corresponds to the no-current condition of the line, the particular signal illustrated being the letter "I". Curve *b* represents the same letter when current in the line corresponds to the marking condition. The curve designated *c* represents the same letter formed in accordance with the present invention by simply reversing the phase without altering the magnitude of the current. It will be seen that if a signaling wave such as is illustrated by the curve *c* is combined at the receiving end with the simple sine wave of the same frequency and constant amplitude as shown by the curve marked *d*, the resultant wave will be identical either with curve *a* or *b*, depending upon whether the constant sine wave be made to correspond in phase to the marking condition or the spacing condition of the signal wave. Inasmuch as the received signal is the result of two waves *c* and *d*, the signal will have an amplitude twice as great as the signal produced by waves such as shown at *a* or *b*. A signal wave such as that illustrated at *c* will be advantageous (provided a wave similar to *d* can be supplied at the receiving end) either from the standpoint of producing a stronger signal at the receiving station, or from the point of view of obtaining as strong a signal as can be at present attained, but with a line current only half as great as that required for signaling methods of the prior art.

Fig. 2 illustrates the apparatus necessary at a transmitting station where the present invention is applied to a multiplex carrier telegraph system. For purposes of illustration, two signaling lines L and L′ are provided, each having four channels transmitting thereover at different carrier frequencies. The number of channels transmitting over each line may, of course, be made either greater or less in number than that illustrated. The carrier currents for the four lines may be supplied, for example, from four sources of 500, 700, 900 and 1100 cycles, respectively, and the several sources may supply as many signaling lines as are necessary to carry the desired traffic. Common to each of the signaling lines is a control line L_c, the purpose of the latter being to transmit the control frequencies corresponding to each of the channels of each signal line. Where, for example, four carrier channels are provided for each signal line, there will be four different signaling frequencies transmitted over each of the lines and four constant amplitude, constant phase and constant frequency currents will be transmitted over the control circuit L_c. But one control circuit will be necessary, regardless of the number of signaling lines involved in the system, and consequently, the provision of the control circuit will, in general, represent but a small additional expense over and above that of the transmission lines themselves when the important advantages in operation are taken into consideration.

Each of the carrier frequency sources, as, for example, the 500 cycle source, is connected to common bus-bars as illustrated at 10, and from the bus-bars connections lead through suitable filters or other selecting devices F_{1c}, F_1 and F_1' to the control circuit L_c and the various transmitting lines such as L and L′. Each of the other sources will be connected to the control circuit L_c and the various transmission lines such as L and L′ through similar groups of filters as illustrated. A phase correcting or controlling device of well-known character is illustrated at 14 in connection with the control circuit for the purpose of adjusting the phase of the control frequency to the desired relation with the signaling current, as will be described later, one of these phase controllers being provided in connection with each carrier source.

For the purpose of simplicity of illustration, the signaling mechanism for producing the current reversals in the signaling frequencies applied to the circuits L and L′ are shown as being simple pole changers such as 18, 18′, etc. Simple pole changers of this type are not, however, well adapted for producing the phase reversals in practice for the reason that a certain amount of time must elapse for the armature of the pole changer to pass from one contact to the other. During this time there will be a hiatus during which no current will be on the line and there will not actually be a sharp reversal from one phase to the other. Accordingly, it is preferred that some arrangement such as is illustrated in Fig. 5 be utilized for producing the phase reversals.

Fig. 5 illustrates a bridge arrangement comprising three arms, each of resistance R, and a fourth arm including the contact of a relay 22, whereby when the contact is closed, the resistance of the fourth arm will be zero, and when it is opened, the resistance will be infinite. Circuit connections extend from two opposite corners of the bridge to the carrier supply source (not illustrated) and circuit connections from the other two corners of the bridge extend through suitable apparatus (not illustrated in Fig. 5) to the signaling line. Preferably, the impedance looking towards the source and looking towards the signaling line should have the same value R as the arms of the bridge. It will be obvious from this circuit arrangement that if the key K controlling the circuit of the relay 22 is closed, so that the fourth arm of the bridge is of zero resistance, the bridge will be unbalanced to transmit current of a definite amplitude to the line, while if the key is opened, so that the contact in the fourth arm of the bridge is opened, the bridge will be unbalanced in the opposite sense, thereby causing a current of equal amplitude to flow in the opposite direction. In the case of an alternating current supply, it will be obvious that this will produce a change in phase of 180° in current supplied to the line. Since this change in the phase is instantaneous upon the making or breaking of the contact, there will be no hiatus between reversals.

A modified arrangement is illustrated in Fig. 6. In this figure, a balancing arrangement comprising a hybrid coil 23 and a balancing resistance or network 24 and a circuit 25 is provided. The current supply may be connected, for example, to the midpoints of the windings of the hybrid coil, the circuit to be supplied being in turn connected to the secondary of the hybrid coil, although the circuit will work equally well if the current source is connected to the secondary and the circuit to be supplied be connected to the midpoints of the hybrid coil. If the impedence of the circuit 25 be made just equal to that of the network 24, it will be apparent that no current will be transmitted from the source to the circuit to be supplied. The circuit 25, however, contains the contact of a relay 22 and when the contact of the relay is closed, the circuit 25 has zero resistance, while with the contact open, the circuit 25 has infinite resistance. In the one case, the circuit will be unbalanced in one direction, and in the other case, the circuit will be unbalanced in the opposite direction, so that by manipulating the key K to open and close the contact of the relay 22, reversals in phase of the alternating current supplied will occur, and these reversals will occur instantly upon the making or breaking of the circuit.

It will be noted in connection with the circuit of Fig. 2 that inasmuch as the controlled currents transmitted over the line L_c come from the same source as the signaling currents transmitted over the lines L, L′, etc., they will be of the same frequency as the signaling currents themselves. Furthermore, inasmuch as the controlled currents pass over a circuit substantially the same as the signaling circuits, they will be subject to the same phase changes and hence suitable for combination in proper phase relation with the signaling currents received at the receiving station. In connection with the phase relation, it will be noticed that the phase relation of the arriving currents at the receiving station may be adjusted by means of the phase correction device connected in series with each source supplying the control circuit, and once the phase is fixed for each frequency, it will remain properly adjusted without further attention. It will further be observed that apart from the addition of the control circuit, the arrangement shown at the transmitting station involves substantially the same units of apparatus as are provided for ordinary multiplex carrier telegraph systems except that the transmitter consists of a reversing arrangement instead of the usual device for opening and shorting the circuit. The waves of each frequency resulting from the operation of the transmitting key will correspond in form to the wave shown at *c* in Fig. 1.

Fig. 3 illustrates one arrangement whereby the signals may be received. The signaling lines such as L and L′ terminate at the receiving station in hybrid coils such as 26 and 26′, the opposite terminals of the hybrid coils being connected to common bus-bars leading to the incoming control circuit L_c. It is, of course, desirable that the control currents supplied to the terminals of the hybrid coil be equal in amplitude to the signaling currents supplied to the opposite terminals. Since, however, the current transmitted over the control circuit L_c supplies a plurality of receiving circuits and will, in general, be substantially no greater in amplitude during transmission over the line than the current transmitted over each signaling circuit, it is necessary to supply amplifying arrangements such as A and A′ between the terminals of each hybrid coil and the bus-bars of the control circuit. By a suitable adjustment of the amplifiers (which may be of any type well known in the art), the control current supplied to the hybrid coil may be made equal in amplitude to the signaling current.

The secondary winding of each hybrid coil is connected to bus-bars such as 27 and 27′, to which the individual receiving channels are connected. The signaling channels corresponding to the signaling line L include filters such as RF_1, RF_2, RF_3 and RF_4, each selective of the particular carrier frequency assigned to the channel, each receiving channel also including a detector such as D_1, D_2, etc. The detectors may be of any well-known type, such as ordinary vacuum tube detectors, and as is usually the practice in carrier telegraph circuits, the receiving element associated with the detector comprises a polar relay having one winding in the plate circuit and another winding in an auxiliary circuit including a resistance properly proportioned with respect to the plate resistance of the tube, the latter circuit being also supplied with current from the plate source. The circuit of the detecting tube is so adjusted that when no signal is being received, no current flows through the upper winding and the current in the lower winding produces a pull tending to shift the armature of the relay in one direction with a given force. When a normal signaling current is being received, however, sufficient current flows in the plate circuit to energize the upper winding of the polar relay to produce a force substantially twice as great, tending to shift the armature in the opposite direction. This results in a properly unbiased polar relay action for a received signal of given amplitude.

Returning to the hybrid coil 26, it will be observed that balancing resistances or networks 28 and 28′ are associated with the hybrid coils. These networks are so proportioned with respect to the impedance looking into the receiving channels that the circuits leading to the signaling line and the control circuit are conjugate with respect to each other. By means of this arrangement, the incoming signal wave of the form shown in curve *c* of Fig. 1 is superposed upon the control wave of the form shown by the curve *d* to produce in the secondary circuit of the hybrid coil a wave of either the type illustrated by curve *a* or the type illustrated by curve *b*, depending upon the phase relation of the control wave to the signal wave. At the same time, a complementary wave will be produced in the network 28 or 28′, as the case may be. That is to say, if the wave in the secondary assumes the form of curve *a*, the wave in the network will assume the form of curve *b*, and vice versa.

This may be readily understood by considering that if the wave *c*, during the marking interval, is transmitted through the lower windings of the hybrid coil to the terminals of the network in opposite phase relation to the wave *d* transmitted through the upper windings of the coil, a wave such as *b*, having twice the amplitude of the signal wave, will be produced in the network during the marking period but no wave will be induced in the secondary of the hybrid coil because the waves oppose each other. During the spacing period, the signal wave and the control wave will be series-aiding in the hybrid coil and will consequently produce a wave of double amplitude in the receiving circuit. No current will, however, be transmitted to the network during the spacing period. On the other hand, if the phase of the control wave be changed 180°, the opposite effect will be produced, no current being transmitted to the network during the marking and a double marking current being transmitted to the receiving terminal. During the spacing period, no current will be transmitted to the receiving terminal but a double current will be transmitted to the network. In short, the operation of the hybrid coil arrangement is such that the signaling wave such as *c*, transmitted over a signal line, will be transformed at the receiving terminals into a wave either of type *a* or of type *b*, having twice the amplitude of the transmitted signaling wave. As the received wave is of the ordinary type, it is consequently detected after being selected into the proper receiving channel by a detector of the ordinary type. Consequently, the only additional feature required by the receiving circuit over and above the apparatus used in ordinary carrier telegraph systems is the hybrid coil for translating the signal current from a wave of type *c* to a wave of type *a* or *b*, as the case may be.

It will be observed that the signals received by means of the arrangements shown in Fig. 3 vary in amplitude as the transmission equivalent of the circuit varies. This introduces a bias into the received signals due to the fact that the detected signaling current flowing through the upper winding of the polar relay will not necessarily be twice as great as normal current flowing in the lower winding. Since it is not, in general, practicable to vary the biasing current in the lower winding to correspond to the change in the amplitude of the detected signaling current, it follows that the arrangement of Fig. 3 from the standpoint of bias is no better than an ordinary carrier telegraph circuit of the usual type. The operation in this respect, however, may be greatly improved by supplying the biasing current from the signal. For example, it will be obvious that if marking currents are transmitted through the filters illustrated to the detectors to operate the upper winding of the polar relay, the spacing currents which are transmitted to the network might be selected by similar filters and transmitted through similar detector tubes to energize the lower winding of the polar relay, thereby avoiding any biasing effect due to change in the transmission equivalent. As this is not a very practicable method owing to the duplication of filters and detectors, it is preferred to use an arrangement such as shown in Fig. 4 for accomplishing the same result.

In accordance with Fig. 4, duplex balanced vacuum tube detectors are employed instead of single vacuum tube detectors such as shown in Fig. 3. The signaling current having the form of wave *c* is led through filters such as RF_1, RF_2, etc., in the various receiving channels to the input circuits of the detectors as indicated, in such a manner as to produce opposite potentials upon the grids of the tubes. The several control frequencies are selected by receiving filters such as RF_{1c}, RF_{2c}, etc., and transmitted over a circuit inductively connected to the common conductor of the input circuits of each duplex detector. As a consequence of this connection, the control wave potential will be added to the signal wave potential upon the one grid, while the two waves will oppose each other upon the other grid. Depending upon the phase of the control wave, it is possible by a proper adjustment of the detecting tubes to impress only marking currents upon the upper tube, for example, and only spacing currents upon the lower tube. The detected component of the marking current will then energize the upper winding of the polar relay to shift the armature in the one direction, while the detected component of the spacing current will energize the lower winding to shift the armature in the opposite direction. No biasing effect will take place with this arrangement, because the current in each winding of the polar relay depends to the same extent upon the transmission equivalent of the signaling and control circuits.

While the methods of signaling above discussed result in doubling the amplitude of the received signal, it should be noted that with the system disclosed we will have foreign interference from two sources, namely the foreign interference which is introduced through the signaling circuit, and also the foreign interference which is introduced in the control circuit. While at first thought it might seem that these two interfering currents would tend to combine in the same manner as the signal currents to produce a greater interference in the receiver, it will be found upon closer analysis that such is not the case. Owing to the fact that the signaling and control currents are controllable in phase, the phase relations of these two currents will be fixed to produce the maximum amplitude of the signal. The two interfering components obtained from the control and signaling circuits, respectively, continually vary in phase with respect to each other and will, on the average, tend to neutralize each other in part. For example, if we consider two interfering waves received in the control circuit and a signaling circuit, it will be apparent that the relative phases of the two components will vary from zero to 180° and that, on the average, the two components will be separated in phase by 90°. The resultant of the two components will, therefore, not be the sum of the two but will be the square root of the sum of their squares. Consequently, while the effective magnitude of the signal is double, the interference is only increased in the ratio of 1.4, and the net effect is a relative reduction of the interference to .7 of its original value.

Fig. 7 illustrates an arrangement whereby it becomes possible to eliminate most of the interference which is introduced in the control circuit. The arrangement consists of a vacuum tube distorting device 40 having a high rsistance 41 in its input circuit and a sharply tuned circuit or filter 42 in its output circuit. If we consider a simple sine wave applied to the input circuit of the vacuum tube, the effect is to cut off the top and bottom of the wave, thereby tending to produce in the output circuit a more or less square-topped wave. (See curve Y of Fig. 8.) The square-topped wave, as is well-understood, is equivalent to a wave of the original frequency having superposed thereon various harmonics of the original frequency. The tuned circuit or filter 42 will then have the effect of selecting the fundamental frequency and eliminating the harmonics, so that the wave finally transmitted will be substantially a pure sine wave. Suppose now the sine wave impressed upon the input circuit is subjected to interference of such a nature as to vary the form of the wave to that illustrated by the curve X of Fig. 8. Obviously, any interference such as that shown at *n*, *o* and *p*, which tends to increase or decrease the amplitude of the wave, will be to a large extent eliminated by passing it through the distorting tube, since the interference will be cut off when the top and bottom of the wave are cut off by the distorting circuit. Interference such as that shown at *m*, tending to slightly widen the wave, will, however, result in a slight widening of the square-topped wave so that in this particular pulse there will be a slight distortion as indicated. Even this distortion, however, to a large extent disappears upon passing the square-topped wave through the filter and substantially a pure sine wave will be transmitted as indicated by the curve Z.

In the arrangement of Fig. 4, it is, of course, necessary to provide in each channel leading from the control circuit an amplifier such as A_1, A_2, A_3, etc., for the purpose of making the control current equal in amplitude to the received signaling current. While this amplifier may be a simple vacuum tube amplifier of the ordinary type, it is preferred to modify the circuit as illustrated in Fig. 7 to produce a distorting effect upon the applied wave at the same time that it is amplified, thereby to a large extent eliminating the interference components from the control wave and producing as the effective control wave a wave such as is shown by the curve Z of Fig. 8.

It will be obvious that the general 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. The method of signaling, which consists in transmitting a wave of constant amplitude and frequency but reversed in phase at intervals to indicate signals, and combining at the receiving station with the wave thus transmitted, a wave of substantially the same amplitude and frequency but unreversed in phase.

2. The method of signaling, which consists in transmitting a wave of constant amplitude and frequency but reversed in phase at intervals to indicate signals, transmitting to the receiving station a similar wave except that it is unreversed in phase, and combining the two waves at the receiving station.

3. The method of signaling, which consists in generating a wave of constant amplitude and frequency, applying a portion of the energy of said wave to each of two circuits, reversing the phase of the wave applied to one circuit at intervals, and combining the wave reversed in phase with the unreversed wave at the receiving station.

4. The method of signaling, which consists in generating a wave of constant amplitude and frequency, applying a portion of the energy of said wave to each of a plurality of circuits, transmitting the wave over one of said circuits without phase reversals, producing phase reversals corresponding to signals in the components of said wave transmitted over others of said circuits, and separately combining the unreversed wave at the receiving station with each of the waves transmitted over the other circuits to produce signals corresponding to each circuit.

5. In a signaling system, means for transmitting a wave of constant amplitude and frequency, means for producing phase reversals in said wave in accordance with signals, means at the receiving station to com-

bine with the transmitted wave a wave of substantially the same amplitude and frequency but unreversed in phase.

6. In a signaling system, means for transmitting a wave of constant amplitude and frequency, means to produce phase reversals in said wave in accordance with signals, means to transmit to the receiving station a wave of substantially the same amplitude and frequency but unreversed in phase, and means to combine the two waves at the receiving station.

7. In a signaling system, means for generating a wave of constant amplitude and frequency, means to apply a portion of the energy of said wave to each of two circuits, means to reverse the phase of the wave applied to one circuit in accordance with signals, and means at the receiving station to combine the wave reversed in phase with the unreversed wave.

8. In a signaling system, a plurality of signaling circuits and a control circuit, means for generating a wave of constant amplitude and frequency, means to apply a portion of the energy of said wave to each of the signaling circuits, means to produce phase reversals in the wave applied to each signaling circuit, means to apply a portion of the energy of said wave to said control circuit, and means at the receiving station to separately combine the wave transmitted over said control circuit with the waves transmitted over the signaling circuits.

9. In a signaling system, a plurality of signaling circuits and a control circuit, means to generate a plurality of constant amplitude waves of different frequencies, means to apply a portion of the energy of each of said waves to said control circuit without phase reversals, means to apply a portion of the energy of all of said waves to each of said signaling circuits, means associated with each signaling circuit for producing phase reversals in each of the waves applied thereto in accordance with separate signals, means at a receiving station to select from each signaling circuit the individual waves with their phase reversals, and means to combine with each selected wave of each circuit a corresponding wave received from the control circuit which is unreversed in phase.

10. In a signaling system, means to transmit to a receiving station a wave of constant amplitude and frequency reversed in phase at intervals in accordance with signals, means to transmit to said receiving station a wave of similar amplitude and frequency but unreversed in phase, means to separate interference components from the latter wave comprising a distorting device for rendering the wave substantially square-topped, selective means for selecting a wave of sine form from the distorted wave, and means to combine the selected wave with the wave which is reversed in phase to produce a signal.

11. In a signaling system, a transmitting device comprising a balanced type of circuit, a single source of current supply for said circuit and a contact in said circuit so arranged that when the contact is opened the circuit will be unbalanced in one sense with respect to said source and when the contact is closed the circuit will be unbalanced in the opposite sense with respect to said source.

12. In a signaling system, a transmitting arrangement comprising a single source of current, a circuit to which current from said source is supplied, a balanced type of circuit interconnecting said first mentioned circuit with said source, and a contact so associated with said balanced type of circuit that when the contact is opened current from said source will be transmitted to said first mentioned circuit in one phase relation and when said contact is closed current from said source will be transmitted to said first mentioned source in opposite phase relation.

13. In a signaling system, a transmitting arrangement comprising a source of alternating current, a circuit to be supplied with current from said source, a balanced type of circuit associated with said first mentioned circuit, connections from said source to neutral points of said balanced type of circuit, and a contact in said balanced type of circuit so arranged that when the contact is opened the circuit will be unbalanced in one direction and when it is closed it will be unbalanced in the opposite direction.

14. In a signaling system, means to transmit an alternating signaling current of constant amplitude and frequency in which marking and spacing intervals are differentiated by reversals in the phase of the current, a detecting device comprising two detecting elements, means to actuate one element with currents of one phase and means to actuate the other element with currents of the opposite phase.

15. In a signaling system, means to transmit an alternating signaling current of constant amplitude and frequency in which marking and spacing intervals are differentiated by reversals in the phase of the current, a detecting arrangement comprising a pair of detecting elements, a polar relay having a winding in circuit with each detecting element, means to transmit a detected current through one winding of said relay in response to currents of one phase, and means to transmit a detected current through the other winding of said relay in response to currents of the opposite phase.

16. In a signaling system, means to transmit a signaling current of constant amplitude and frequency in which marking and spacing intervals are differentiated by reversals in the phase of the current, means to

combine said current with a current of substantially the same amplitude and frequency but without phase reversals to produce resultant current components, one of which has constant amplitude current during a marking interval and no current during the spacing interval and the other of which has no current during the marking interval and constant amplitude current during the spacing interval, a pair of detecting devices, means to impress one of said components upon one detecting device and means to impress the other component upon the other detecting device.

In testimony whereof, I have signed my name to this specification this 27th day of August, 1923.

HARRY NYQUIST.