May 22, 1928. 1,670,376

H. NYQUIST

HIGH SPEED SIGNALING SYSTEM

Filed May 13, 1926 4 Sheets-Sheet 1

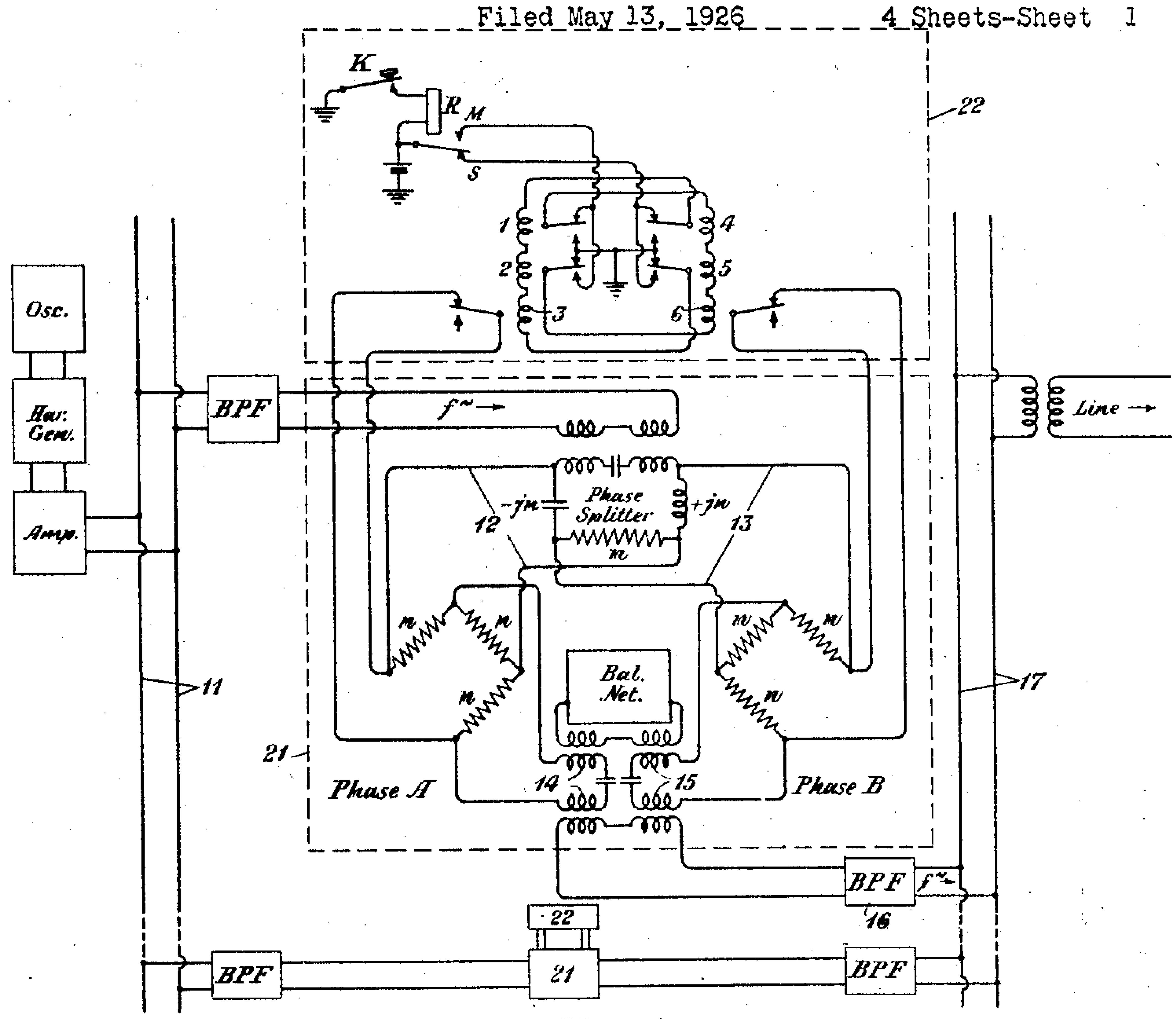

Fig. 1

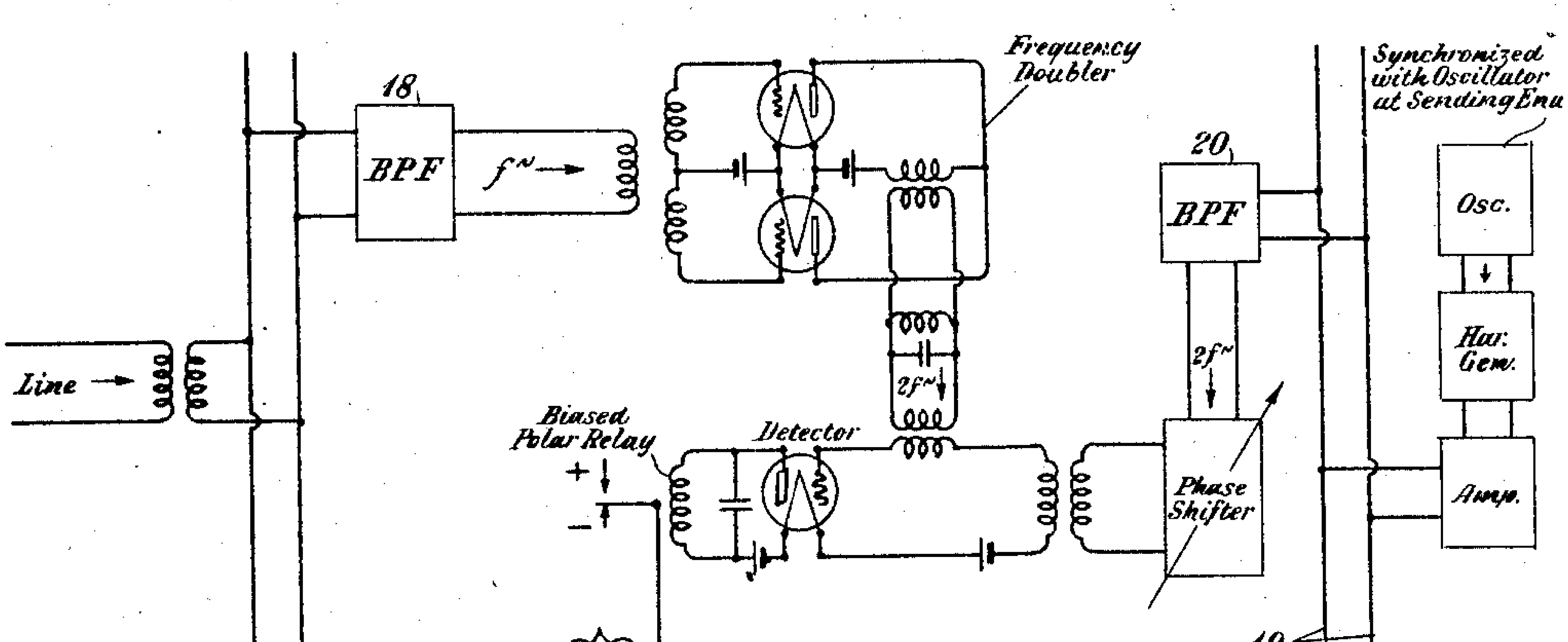

Fig. 2

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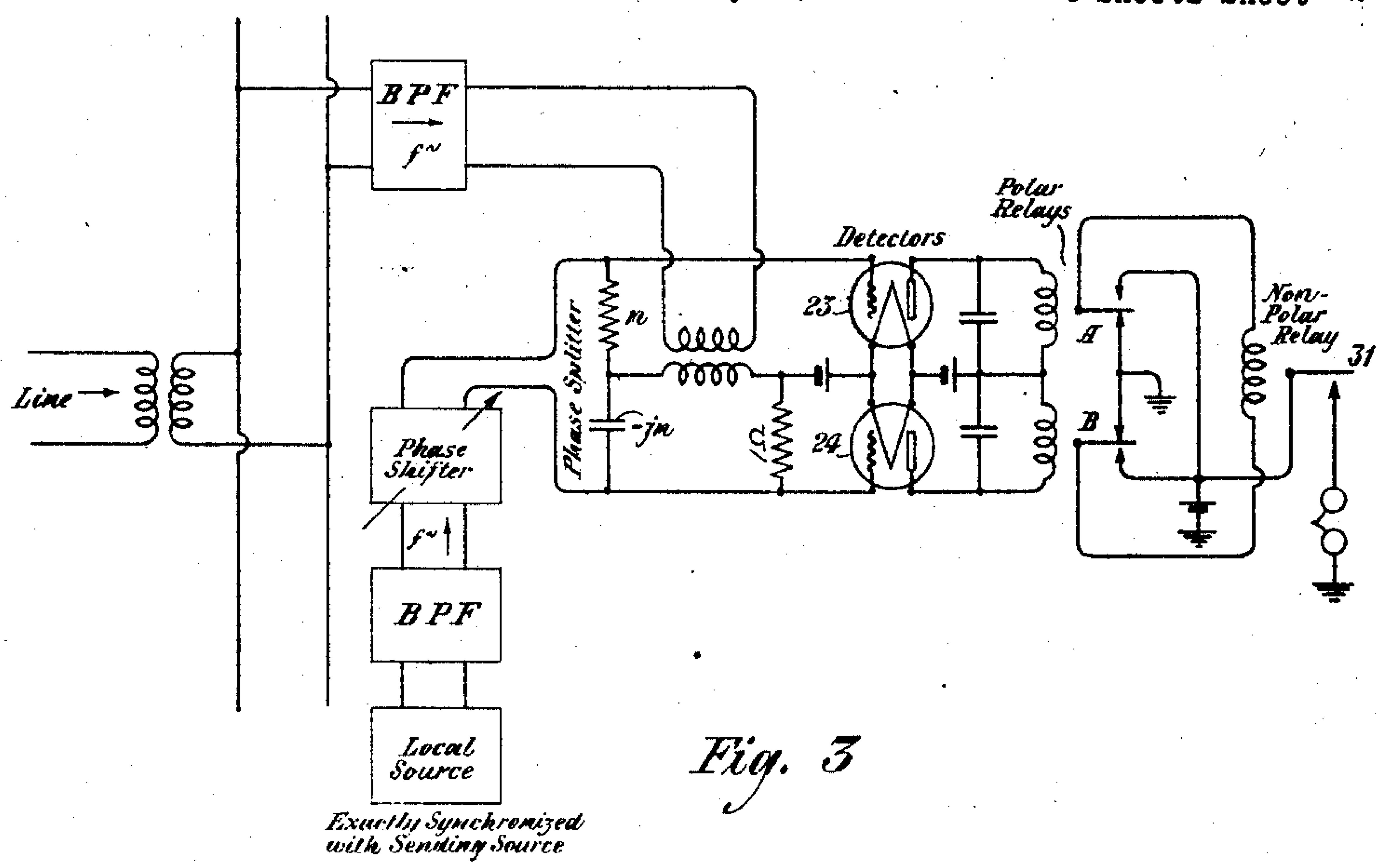

Fig. 3

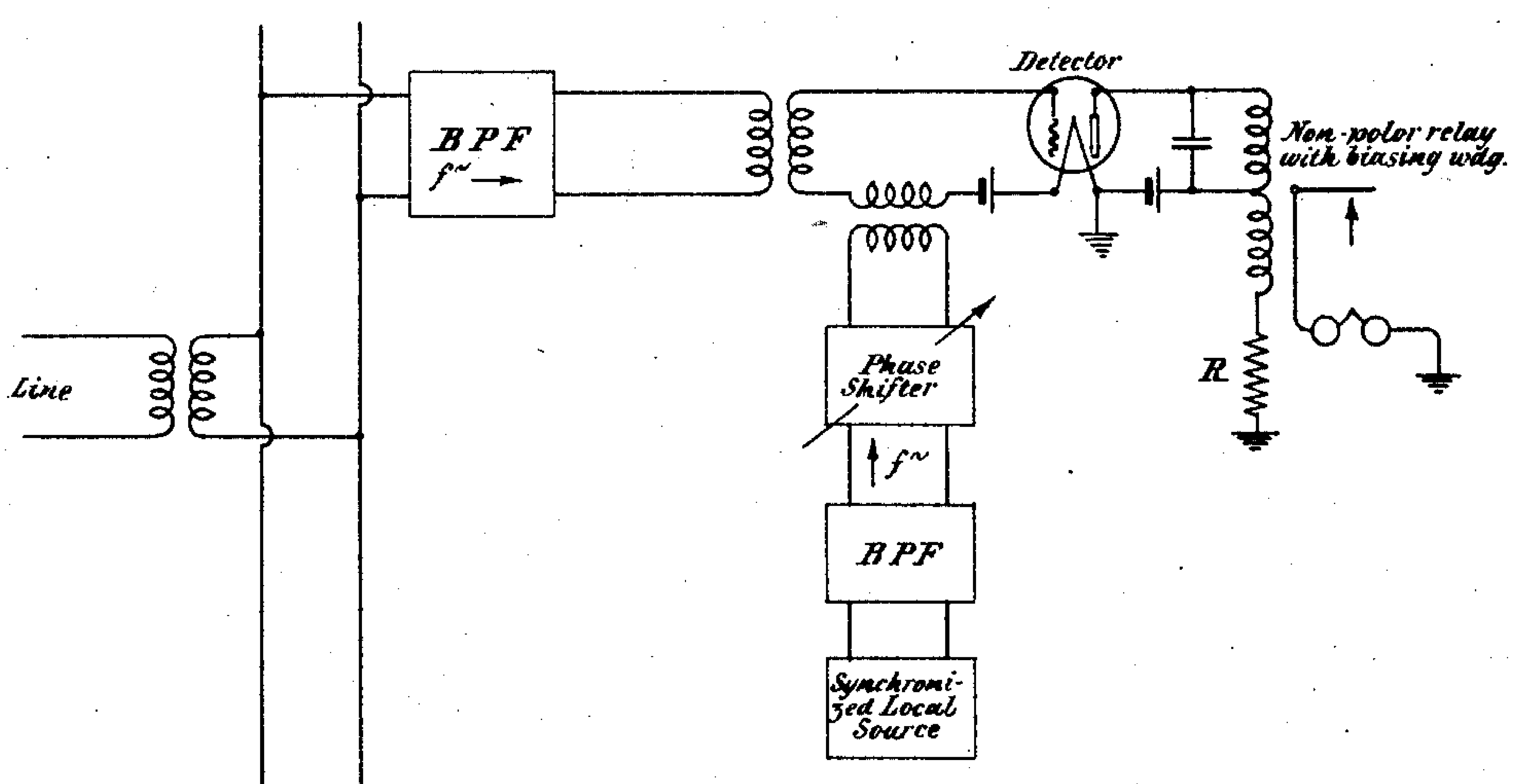

Fig. 4

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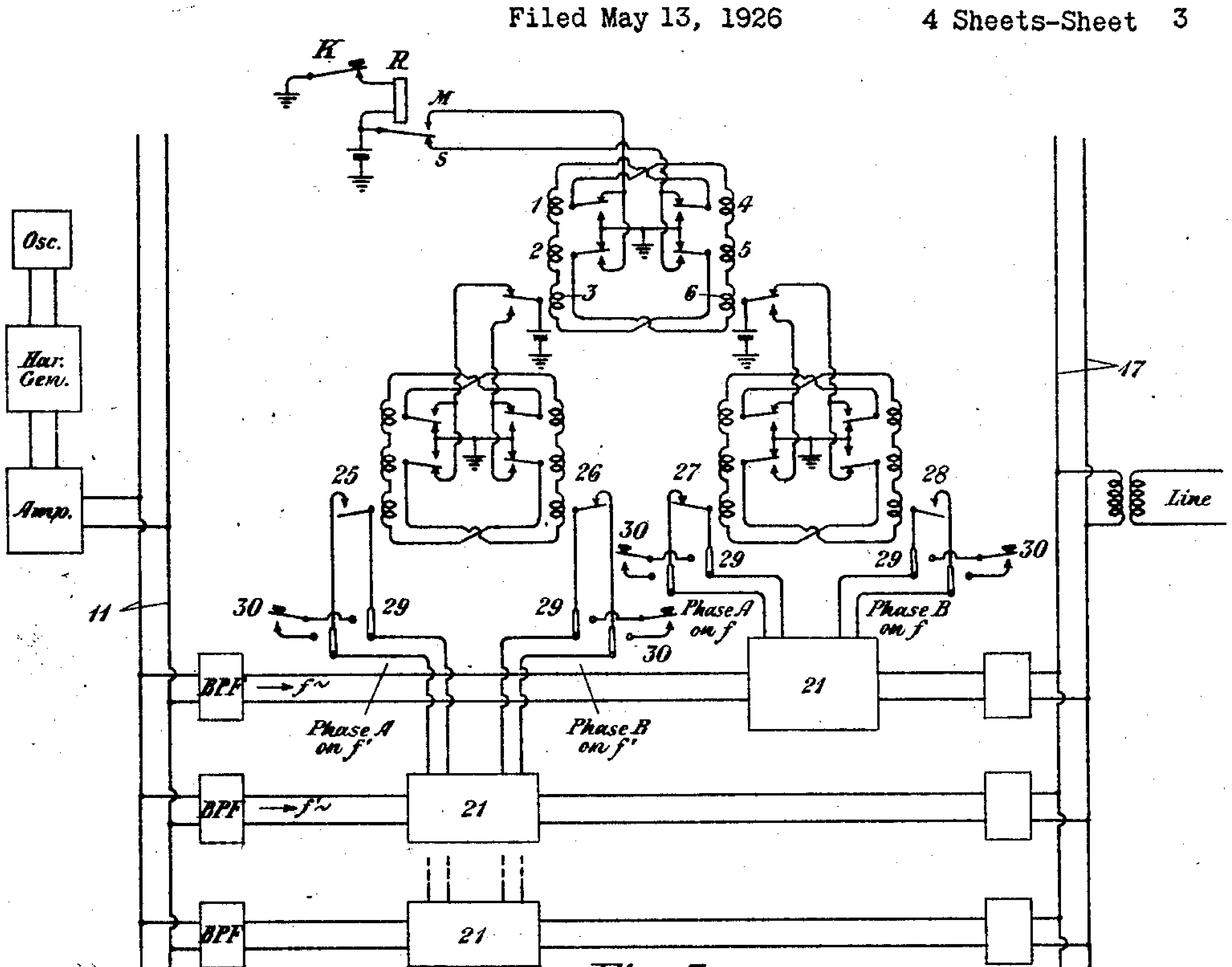

Fig. 5

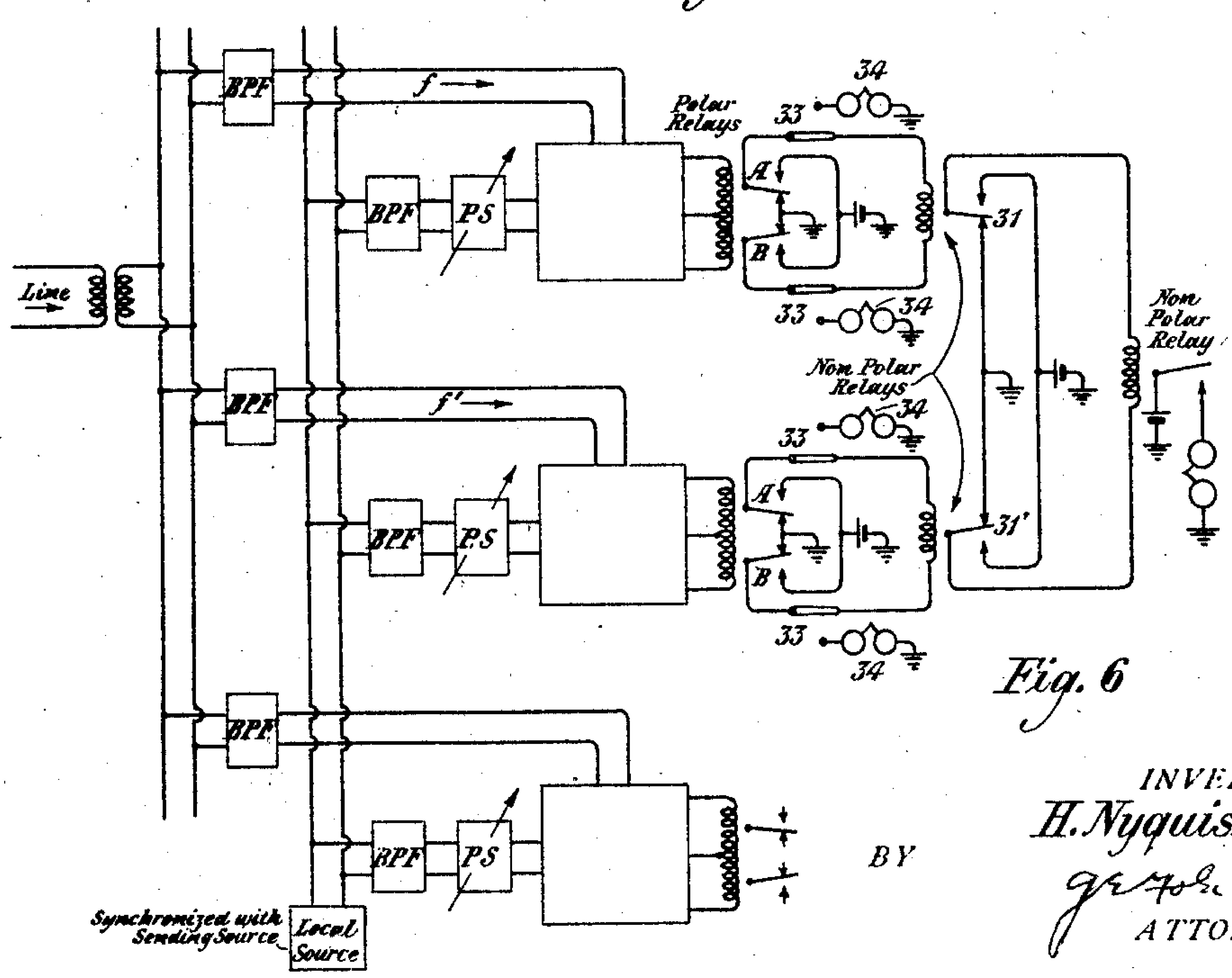

Fig. 6

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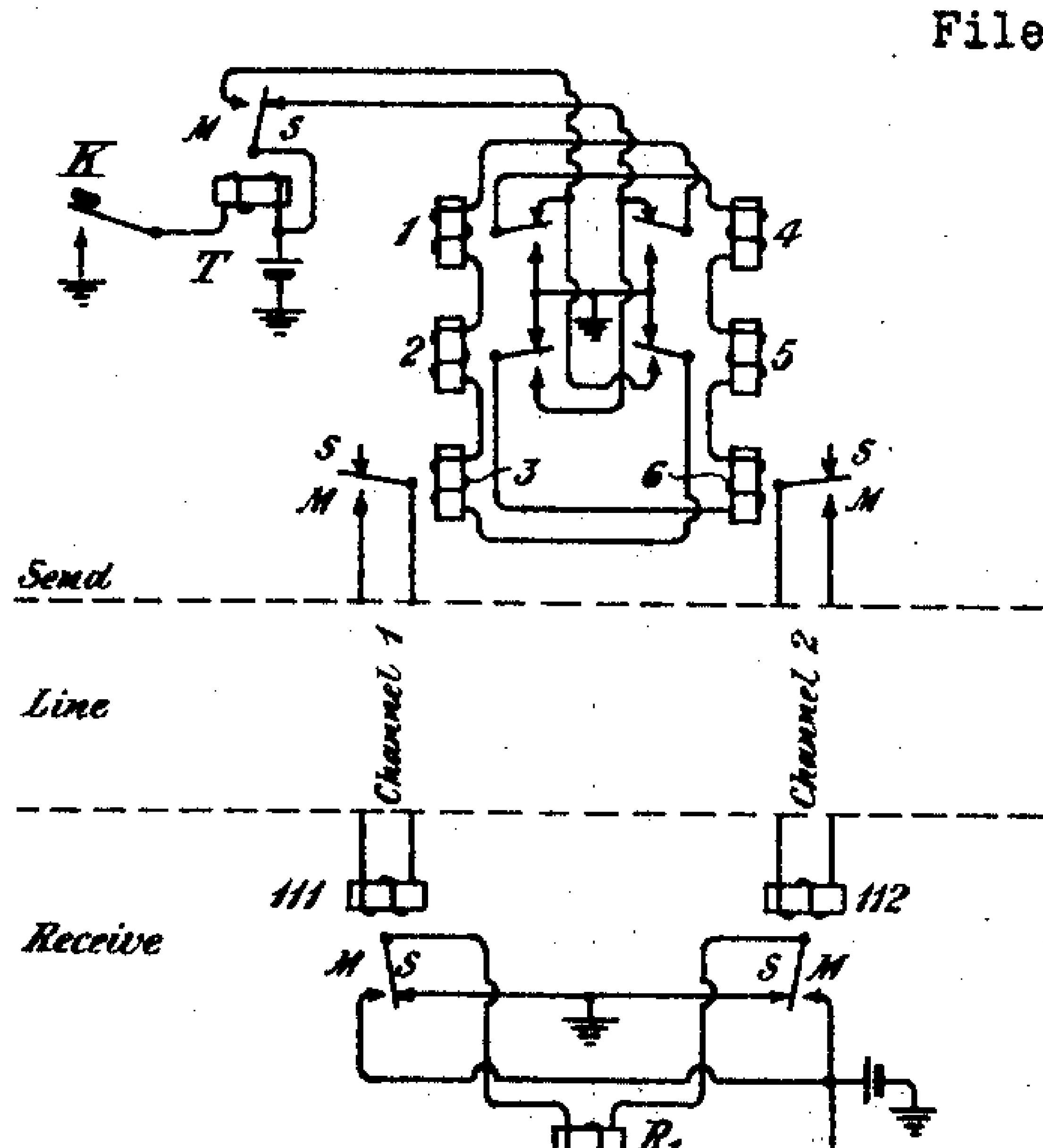

Fig. 7

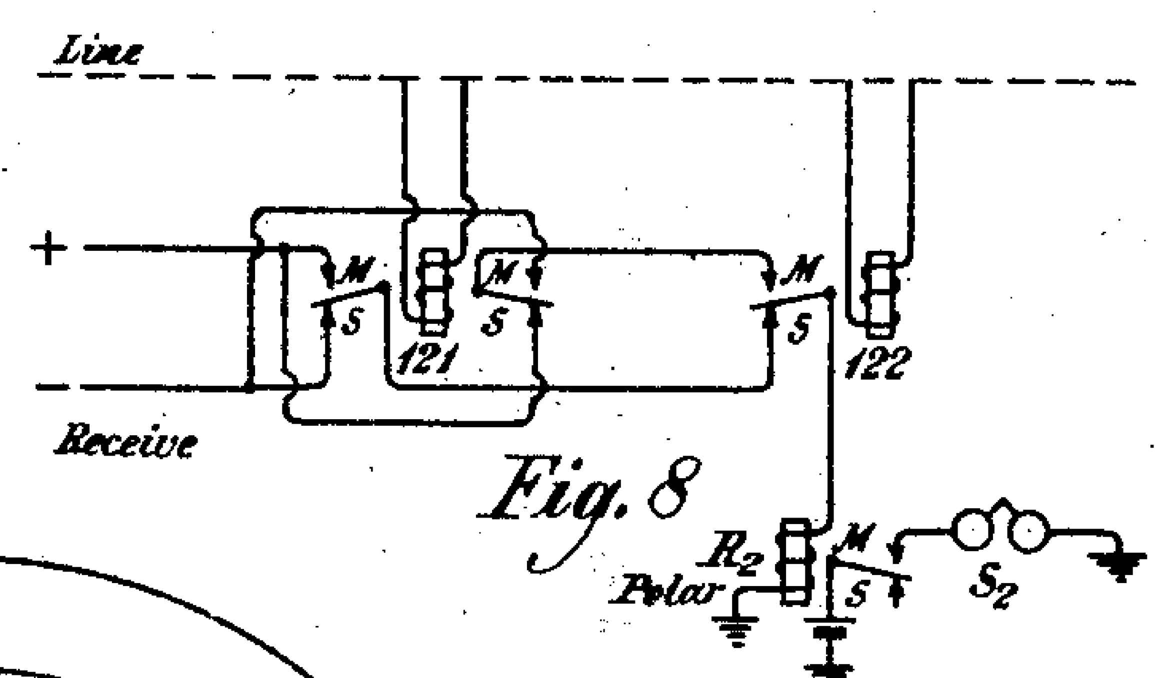

Fig. 8

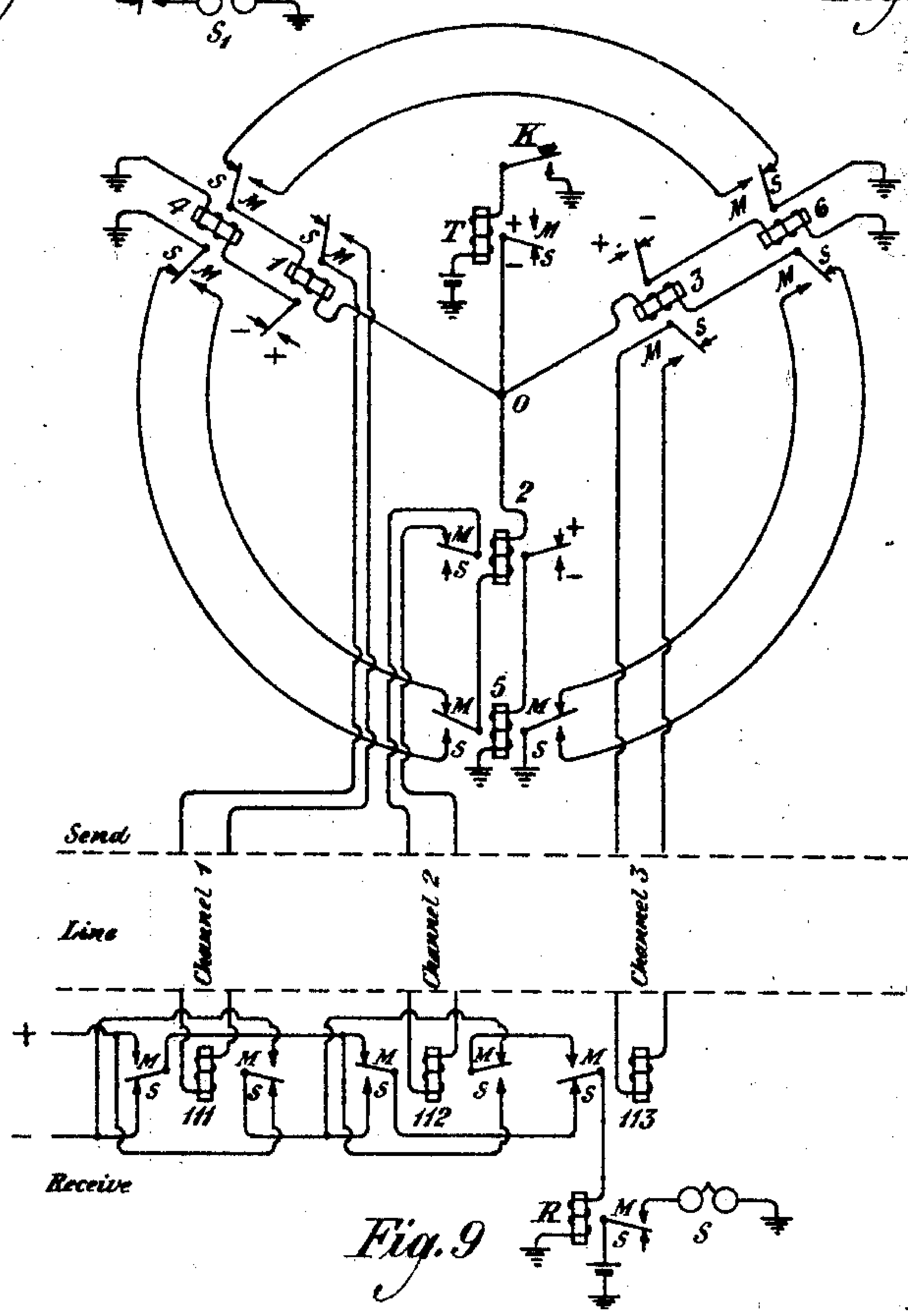

Fig. 9

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Patented May 22, 1928. **1,670,376**

UNITED STATES PATENT OFFICE.

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

HIGH-SPEED SIGNALING SYSTEM.

Application filed May 13, 1926. Serial No. 108,940.

An object of my invention is to provide for increasing the speed of transmission of message signals by utilizing simultaneously two or more physically distinguishable transmitting channels. Another object of my invention is to provide for utilizing several channels for respective messages or alternatively for utilizing all these channels simultaneously for the transmission of one message at greater speed. Another object of my invention is to provide for splitting the phase of a carrier current and transmitting "marking" changes on one component and "spacing" changes on the other component so as to increase the speed of transmission as compared with sending both kinds of changes on a single component. These objects and other objects of my invention will become apparent on consideration of a limited number of specific examples of practice according to the invention which I now proceed to disclose in this specification. It will be understood that the following disclosure relates to these particular examples of the invention and that the invention will be defined in the appended claims.

Referring to the drawings, Figure 1 is a diagram of sending apparatus for one message on a carrier current of a certain frequency decomposed into two components 90 degrees apart in phase; Fig. 2 is a diagram of corresponding receiving apparatus involving the use of a frequency doubler; Fig. 3 is a diagram of alternative receiving apparatus employing two polar relays; Fig. 4 is a diagram of another alternative form of receiving apparatus employing a single biased relay; Fig. 5 is a diagram indicating how more than two physically distinguishable transmitting channels can be utilized at the transmitting end for respective message channels or alternatively as a single message channel at correspondingly increased speed; Fig. 6 is a diagram for the receiving end corresponding to Fig. 5; Fig. 7 is a diagram of a system in which one channel of relatively high speed message sending and receiving apparatus is employed with two relatively low speed transmitting channels between them; Fig. 8 is a diagram of receiving apparatus alternative to that shown in Fig. 7; and Fig. 9 is a diagram of a system in which one channel of relatively high speed message sending and receiving apparatus is employed with three relatively low speed transmitting channels between them.

Referring to Fig. 1, the oscillator at the left generates an alternating current of a certain fundamental frequency which is delivered to the harmonic generator whose output is accordingly a composite current of various frequencies all having harmonic relation to the fundamental. This composite current goes to the amplifier as shown in the drawing, and its output goes to the busses 11 from which respective branches go to the inputs of the various band-pass filters designated B. P. F. Each of these filters passes a respective band of frequencies such as the band on the frequency f as indicated in the drawing.

The "phase splitter" shown in Fig. 1 is a network having resistances and reactances of the magnitudes given by the legends in the drawing, n being a positive real number. The current from the phase splitter in the conductor pair 12 referred to as "phase A" will differ by 90 degrees from that in the conductor pair 13, referred to as "phase B". Each pair of conductors leads to a pair of opposite vertices of a bridge having three of its four sides each formed by a resistance n, the fourth side being open or closed as determined by the position of the armature of the relay 3 or 6. The remaining two vertices of each bridge are connected as shown to the windings 14 and 15, respectively, of a hybrid coil arrangement with a balancing network on one side and a circuit to the band-pass filter 16 on the other side. The output from this filter goes to the bus-bars 17 and thence to the line.

The relays 3 and 6 have already been mentioned. They are controlled by the key K through the relay R and the circuits as shown in the drawing.

The armatures of the polarized relays 1, 2, 3, 4, 5 and 6 are all designed to remain on whichever contact they are resting when the windings are deenergized. As shown in the drawing, current is flowing from the battery through the contact S down through relays 1, 2 and 3, and this direction of current has moved the corresponding armatures up as shown. Closure of the key K energizes relay R and moves its armature to the marking contact M, which puts current down through relays 4, 5 and 6, causing their armatures to shift down from the positions shown in the drawings. This opens the previously short-circuited arm of the bridge in phase B and also reverses the circuit for relays 1, 2, and 3.

When the key K is released and current again flows through the spacing contact S, it will go through the relays 3, 2 and 1 in the reverse direction to that previously considered, causing their armature to go down, but the armatures of relays 4, 5 and 6 will remain down. The shift of the armature of relay 3 opens the previously short-circuited fourth arm of the bridge on phase A and the shift of the armatures of relays 1 and 2 reverses the circuit for relays 4, 5 and 6.

The next depression of the key K sends current through contact M and through relays 6, 5 and 4 in reverse direction to that of their previous energization. Accordingly, their armatures go up but the armatures of relays 1, 2 and 3 remain down. The movement of the armature of relay 6 again closes the fourth arm of the bridge for phase B and the movement of the armatures of relays 4 and 5 again reverses the circuit for relays 1, 2 and 3.

The next time the key K is released, current flows through the spacing contact S down through the relays 1, 2 and 3 causing their armatures to move up; it will be seen that this completes a cycle and brings the armatures of relays 1, 2, 3, 4, 5 and 6 all back to their positions as assumed at the outset and shown in the drawings.

It will be seen that two cycles of movement of the key K give only one cycle of movement for each of the armatures of the relays 1, 2, 3, 4, 5 and 6. The order of operations is as follows, referring to the opening and closing of the fourth arm of the bridge for the phases A and B;

First mark—opens on phase B;
Space thereafter—opens on phase A;
Second mark—closes on phase B;
Space thereafter—closes on phase A.

The current in the coils 14 reverses in phase when the fourth arm of the bridge for phase A is changed from open to closed or from closed to open. Thus each shift of an armature or relay 3 or 6 causes a phase reversal of one of the two 90-degree components of current in the input to the filter 16. The composite current in the input to this filter, being the sum of the two phases, changes by 90 degrees when one of its phases is reversed. Therefore, the effect on this composite current produced by repeated operation of the key K is each time to shift the current progressively 90 degrees in phase as indicated by the diagram of Fig. 7.

It will be seen that in the repeated operations of the key K all the marking is initiated by phase reversals of one of the two 90-degree components, and all the spacing is initiated by reversals of the other component of current. Hence whatever the limiting speed for reversing one of these two components, the message speed will be twice as great as it would be if one message were sent on one such component.

Other messages may be sent in the same way on other frequencies by the use of similar apparatus as indicated symbolically in Fig. 1 at 21 and 22, all such frequencies being superposed on the line. The reactances in 21 will have different values, appropriate to the respective frequencies.

The line currents may be received with apparatus corresponding to the diagram of Fig. 2. The band-pass filter18 passes the band of current of the carrier frequency f and applies it to a frequency doubler whose output is accordingly a current of frequency 2^f. It has already been mentioned in connection with Fig. 7 how each shift of the sending key K causes a 90-degree phase shift in the composite transmitted current. In the frequency doubler such a phase shift in its input will cause a phase reversal in its output current.

The oscillator shown at the right of Fig. 2 is synchronized by methods well known in the art, so that its frequency corresponds with the frequency of the generating oscillator at the sending end. Its current output goes to a harmonic generator whose output in turn goes to an amplifier, and from this amplifier component currents of all harmonic frequencies are put on the bus-bars 19. The band-pass filter 20 takes off current of the frequency 2^f and passes it through the adjustable phase shifter shown in the drawing.

The outputs from the frequency doubler and the phase shifter are superposed in the input of the detector. It has already been mentioned how the output from the frequency doubler reverses in phase for each signal change from spacing to marking or from marking to spacing. In one of these states the two inputs to the detector will be in phase and in the other state they will be in phase opposition. When they are in phase, the detector output current will be greater than when they are in phase opposition and the armature of the biased polar relay in the detector output circuit will be shifted accordingly and the messages will be indicated in the sounder controlled by the armature of this relay.

An alternative receiving system is shown in Fig. 3. Two detectors 23 and 24 are arranged as shown, and their grids are supplied with electromotive forces from a local source of frequency f and 90 degrees apart in phase. Superposed alike in the grid circuits of the two detectors 23 and 24, electromotive forces are also applied corresponding to the received signal currents of frequency f.

Of the two components received over the line through the band-pass filter, both of frequency f and differing in phase 90 degrees, one of them will be in phase with the local electromotive force to one of the detectors or in phase opposition, and similarly, the other received component will be in phase with the local electromotive force to the other detector or in phase opposition. When received phase A agrees with the local source on detector 23, the corresponding relay armautre A will be operated one way, but if the relation is a phase opposition, the said armature will be operated the other way. Thus the polar relay armature A responds to the reversals on phase A and the polar relay armature B responds to the reversals on the other phase B.

By the circuit shown in Fig. 3, these two armatures control the non-polar relay 31, which in turn controls the sounder.

Remembering the character of the transmitted current and that its two components reverse alternately, it will be seen that the armatures A and B are operated alternately. When they are both on ground or both on battery, the sounder circuit will be open, but when one armature A or B is on battery and the other on ground, then the sounder circuit will be closed. Thus the operation will correspond to the operation of the key K at the sending end.

Still another alternative receiving system is shown in Fig. 4. In this case a single detector is employed and the phase of the local source is adjusted so that the corresponding electromotive force on the detector grid is in phase or phase opposition with the line electromotive force when a "mark" is being transmittted. When they are in phase, the resultant detected current is of sufficient magnitude to operate the relay in the detector plate circuit and close the sounder circuit. On the next "space", the line current is shifted 90 degrees relative to the local source and the detector plate circuit current is reduced. The resistance in series with the biasing winding of the relay is so adjusted that the biasing current neutralizes the effect of the plate circuit current under this condition and the receiving relay releases its armature and opens the sounder circuit. On the next "mark", the line and local currents are 180 degrees out of phase and the detector plate circuit current is still further reduced, so that the relay is again operated because of the current in the biasing winding. On the next "space", the phases are again 90 degrees apart and the relay armature is released. This cycle of operations repeats, the relay operating on every "mark" and releasing on every "space" transmitted from the sending station.

In the foregoing examples of practice according to my invention, two physically distinguishable channels have been utilized for a single message, so that for a given limiting speed in each channel, the message speed is twice as great as if the message were transmitted in only a single channel. If still greater speed is desired, more than two physically distinguishable impulse transmitting channels can be employed for one mesage channel. In Fig. 5 I have shown one message channel associated in this way with four physically distinguishable impulse transmitting channels. The key K controls the armatures of relays 3 and 6 exactly the same as in Fig. 1. Each of these armatures in turn controls two others in the same way, that is, the armature of relay 3 controls armatures 25 and 26, and the armature of relay 6 controls armatures 27 and 28.

The two armatures 27 and 28 control the two phases on frequency f just the same as the armatures of relays 3 and 6 of Fig. 1 control the two phases on frequency f in that figure. Similarly, the two armatures 25 and 26 control the two phases of current of frequency f'. It will readily be seen that the arrangement is such that when the key K is operated from the position shown in Fig. 7;

First mark reverses phase A on frequency f;

Following space reverses phase A on frequency f';

Second mark reverses phase B on frequency f;

Following space reverse phase B on frequency f';

Third mark restores phase A on frequency f;

Following space restores phase A on frequency f';

Fourth mark restores phase B on frequency f;

Following space restores phase B on frequency f'. For further operation of the key K this cycle repeats. Thus it will be seen that four channels are utilized and that these channels are affected in cyclic order by the operation of the signaling key so that each channel is affected only once in a cycle of four operations of the key. Accordingly, for a given limiting speed in each channel, the message speed will be four times as great with the system of Fig. 5 as if the transmission were wholly on one channel.

By throwing the four pairs of switches at 29 and using the four keys 30, four independent messages can be sent on respective channels, but in this case the limiting speed in each channel will make the signaling speed only a fourth as much as when the four channels are used for one message.

A receiving system is shown in Fig. 6 for cooperation with the sending system in Fig. 5. It will be seen that it comprises two receiving units like the system of Fig. 3, but whereas the armature of relay 31 of Fig. 3 directly controls a sounder circuit, the two corresponding armatures of relays 31 and 31′ of Fig. 6 cooperate in the control of another relay 32, which in turn controls a sounder. The combined operation of the armatures of relays 31 and 31′ in control of the armature of the relay 32 in Fig. 6 is the same as the combined operation of armatures A and B in control of the armature of relay 31 in Fig. 3.

When the switches 29 are thrown at the sending end (Fig. 5) thus providing for use of the four keys 30, then at the same time the switches 33 will be thrown at the receiving end (Fig. 6), so that the four keys will control the four sounders 34 respectively.

Referring to Fig. 7, this shows a system corresponding in some respects to Figs. 1 and 2, but Fig. 7 uses two distinguishable line circuits designated "channel 1" and "channel 2", whereas Figs. 1 and 2 depend on phase discrimination for two channels on one circuit. In Fig. 7, at the sending terminal, the transmitting relay T in the high speed channel is operated by the subscriber's key K. Relays 1 to 6 are polar relays so adjusted that with no current in the windings the armature will remain on the contact on which it is placed. The windings of 1, 2 and 3 are connected in series as are also those of 4, 5 and 6; 3 and 6 are signaling relays on the two independent channels, respectively. Relays 1 and 2, together, act as a double-pole, double-throw switch and reverse the windings 4, 5 and 6 in the circuit on each operation; 4 and 5 act similarly on 1, 2 and 3. Batteries and grounds are connected as shown in the drawing. At the receiving terminal, the receiving relays 111 and 112 follow the signals sent over channels 1 and 2 by relays 3 and 6, respectively. The armatures of these receiving relays, with batteries and grounds shown, operate the receiving relay R_1 in the high-speed channel and this in turn operates the subscriber's sounder S_1. It can be seen that R is on "space" when the two-channel receiving relays are both on "mark" or both on "space" and on "mark" when only one of the receiving relays is on "mark". The action of this system is best understood by following the sequence of operations through a complete cycle of changes. At the start, it is assumed, as shown on the drawing, that K is open, T is on "space", 1 to 6 are up, say, putting 3 and 6 on "space" so that 111 and 112 are accordingly on "space" with R and S consequently on "space". The following table gives the positions of the various relays as K is successively closed and opened. (M denotes "mark" and S "space".)

Signal	K	T	1 and 2	3 and 111	4 and 5	6 and 112	R_1 and S_1
Start	Open	S	Up	S	Up	S	S
1st M	Closed	M	Up	S	Down	M	M
1st S	Open	S	Down	M	Down	M	S
2nd M	Closed	M	Down	M	Up	S	M
2nd S	Open	S	Up	S	Up	S	S

The second space after the start returns the system to its original condition, completing the sequence of the operations. It can be seen that S follows K exactly, but that relays 3 and 111 and 6 and 112 complete only one cycle for two on K and S, thus establishing a channel from T to R twice as fast as either of the line channels 1 and 2. As previously exemplified, a continuation of this process allows the use of any power of two channels (that is, 2, 4, 8, 16 and etc. channels) with the consequent gain in speed for the derived channel.

The receiving apparatus shown in Fig. 8 is alternative to that of Fig. 7 and its resultant operation is the same, as will be readily understood from the drawing.

As has been remarked, the principle of the foregoing described systems can be extended to utilize 2, 4, 8 or any power of 2 channels for one message channel. Fig. 9 shows a system that is good for utilizing 3 channels and it will be seen that its principle can be extended to utilize 5, 7 or any odd number of channels.

At the sending terminal, T is operated by K as before and puts positive battery for "mark" and negative battery for "space" on the star terminal O of the high-speed channel. Polar relays 1—6 are connected as shown in the drawing and it is understood that any of them is operated to "mark" by current from positive battery and to "space" by current from negative battery. Relays 1 to 3 are so adjusted that any of their armatures remains on the contact on which it is placed with no current in the winding. Relays 1 and 4, 2 and 5, and 3 and 6, work together in pairs. Relays 1 to 3 are signaling relays on the three channels 1 to 3, respectively, use being made of the M and S contacts on one of the armatures for this purpose. Relays 4 to 6 serve to distribute the signals transmitted by T to the three channels in order, the first "mark" going to channel 1, say, the first "space" to channel 2, the next "mark" to 3, etc. This arrangement may be easily extended for use on a larger number of channels; and if the number used is odd, the signal sent to any signaling relay on successive cycles of distribution is always such as to operate it to its uncoupled contact and so maintain the distribution. At the receiving terminal, the three-channel receiving relays 111 to 113 follow the signals sent on channels 1 to 3 by relays 1 to 3, respectively. These are connected, as shown, to R and S in the high-speed channel in such a way that a reversal of either channel relay causes a reversal of R and S. The following table gives the positions of the various relays during a complete cycle of operation of the system, the starting condition being assumed as shown in the drawing. (M denotes "mark" and S "space" as before.)

Signal	K	T	1, 4, 111	2, 5, 112	3, 6, 113	R and S
Start	Open	S	S	M	S	S
1st M	Closed	M	M	M	S	M
1st S	Open	S	M	S	S	S
2nd M	Closed	M	M	S	M	M
2nd S	Open	S	S	S	M	S
3rd M	Closed	M	S	M	M	M
3rd S	Open	S	S	M	S	S

The third space after starting returns the system to its original condition, completing a cycle of operations. It is seen that S follows K exactly, but the line channels are operated at only one-third of the speed used on the high-speed channel between K and S. As pointed out above, this system of distributing signals over channels can be easily extended to include any odd number of channels. The receiving system can be enlarged to include any number of channels.

A proper combination of the two methods of signaling indicated in Figs. 7 and 9 allows the distribution of the signals on one telegraph channel over a group of channels of any desired number with a corresponding gain in the limiting signal speed of the original channel.

I claim:

1. The method of high speed signaling, which consists in transmitting successive signal impulses over different physically distinguishable channels in cyclic order.

2. The method of high speed signaling, which consits in transmitting successive signal impulses over different physically distinguishable channels in cyclic order, and at the receiving end applying these impulses as received over the different channels in the same cyclic order to operate a message receiving indicator.

3. The mehod of high speed signaling, which consists in transmitting a plurality of different wave trains, and varying these wave trains in cyclic order by successive signal changes.

4. In combination, means to transmit energy over several physically distinguishable channels, and signaling means to affect these channels in cyclic order.

5. In combination, means to transmit energy over several physically distinguishable channels, signaling means to cause energy changes in these channels in cyclic order, and at the receiving end a message receiving indicator and means to actuate it by all of these changes in the same order.

6. In combination, means to generate a carrier current of a certain frequency, means to split it into two components differing in phase, a signaling key, means operated by said key to effect phase reversal of said components alternately at successive operations of the key, means to transmit energy corresponding to said carrier current components as affected by the operation of said key, means at the receiving end to detect the phase reversals on each component, and means to indicate therefrom the message corresponding to the operation of the key.

7. In combination, means to generate a carrier current of a certain frequency, means to split it into two components differing in phase, a signaling key, means operated by said key to effect phase reversals of said components alternately at successive operations of the key, means to transmit said current components as affected by the operation of the key from the transmitting station to the receiving station, a synchronized source at the receiving station for electromotive forces in phase or in phase opposition with the respective components of the transmitted current, detecting means responsive conjointly to the received current, and the current from the local source, and a signal indicator controlled by said detecting means.

8. In combination, a line, means to generate carrier currents of various frequencies and superpose them on the line, means to split each such current into two components 90 degrees apart in phase, phase reversing means for each component, a key, and means operated by the key to actuate the said phase reversing means alternately at each key operation for each component.

9. The method of high speed signaling, which consists in sending successive signaling impulses on different channels in cyclic order, whereby the speed on each channel is less than if all the impulses were sent on one channel.

10. In combination, means for transmitting energy in a plurality of channels, respective means at the sending end for changing the energy in each channel, means at the receiving end for detecting these changes, a plurality of independent keys respective to said means at the sending end, a single key, means to operate said means at the sending end cyclically by said single key, and switches alternatively to connect said plurality of keys or said single key in operative relation to said means at the sending end.

11. In combination, means for transmitting energy in a plurality of channels, respective means at the sending end for changing the energy in each channel, means at the receiving end for detecting these changes, a plurality of independent keys respective to said means at the sending end, a single key, means to operate said means at the sending end cyclically by said single key, a plurality of respective signal indicators at the receiving end, a single signal indicator at the receiving end, means to actuate the single signal indicator by the received energy changes in cyclic order, and switches operatively to connect said plurality of signal indicators or said single indicator.

12. A multi-channel energy transmitting system and alternative means to send and receive one message utilizing all the channels in cyclic order or to send and receive independent messages on the respective channels.

13. The method of high speed signaling, which consists in transmitting successive signal impulses over different physically distinguishable channels in cyclic order, each signal impulse persisting in a transmitting channel till the arrival of the next cyclic turn of that channel.

14. The method of high speed signaling, which consists in transmitting successive signal impulses over different physically distinguishable channels, each signaling impulse persisting in a channel till the next occasion for using that channel.

In testimony whereof, I have signed my name to this specification this 6th day of May, 1926.

HARRY NYQUIST.