Sept. 18, 1928. 1,684,455

H. NYQUIST

MULTIPLEX CARRIER CURRENT SIGNALING

Filed May 13, 1926 3 Sheets-Sheet 1

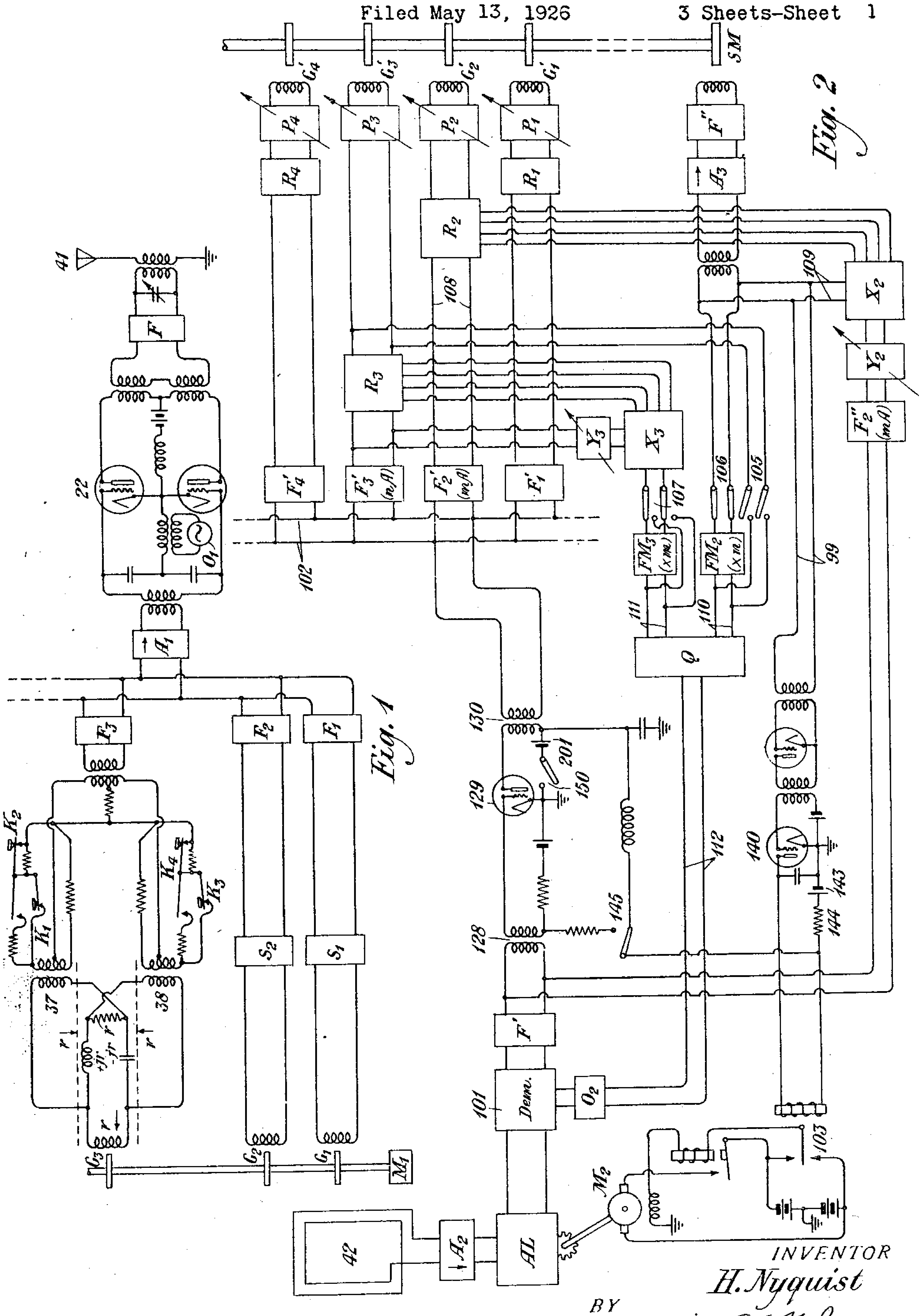

Fig. 1

Fig. 2

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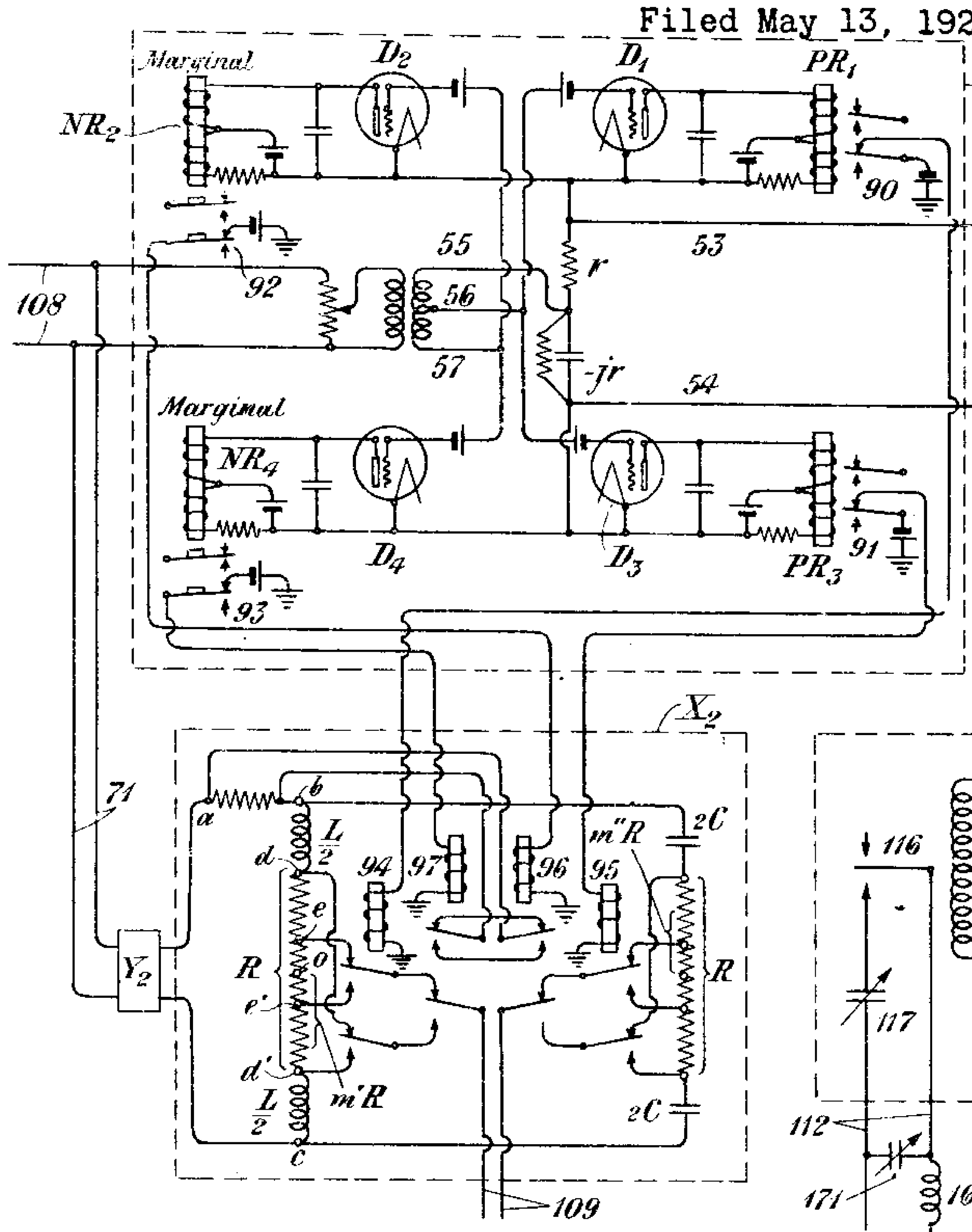

Fig. 3

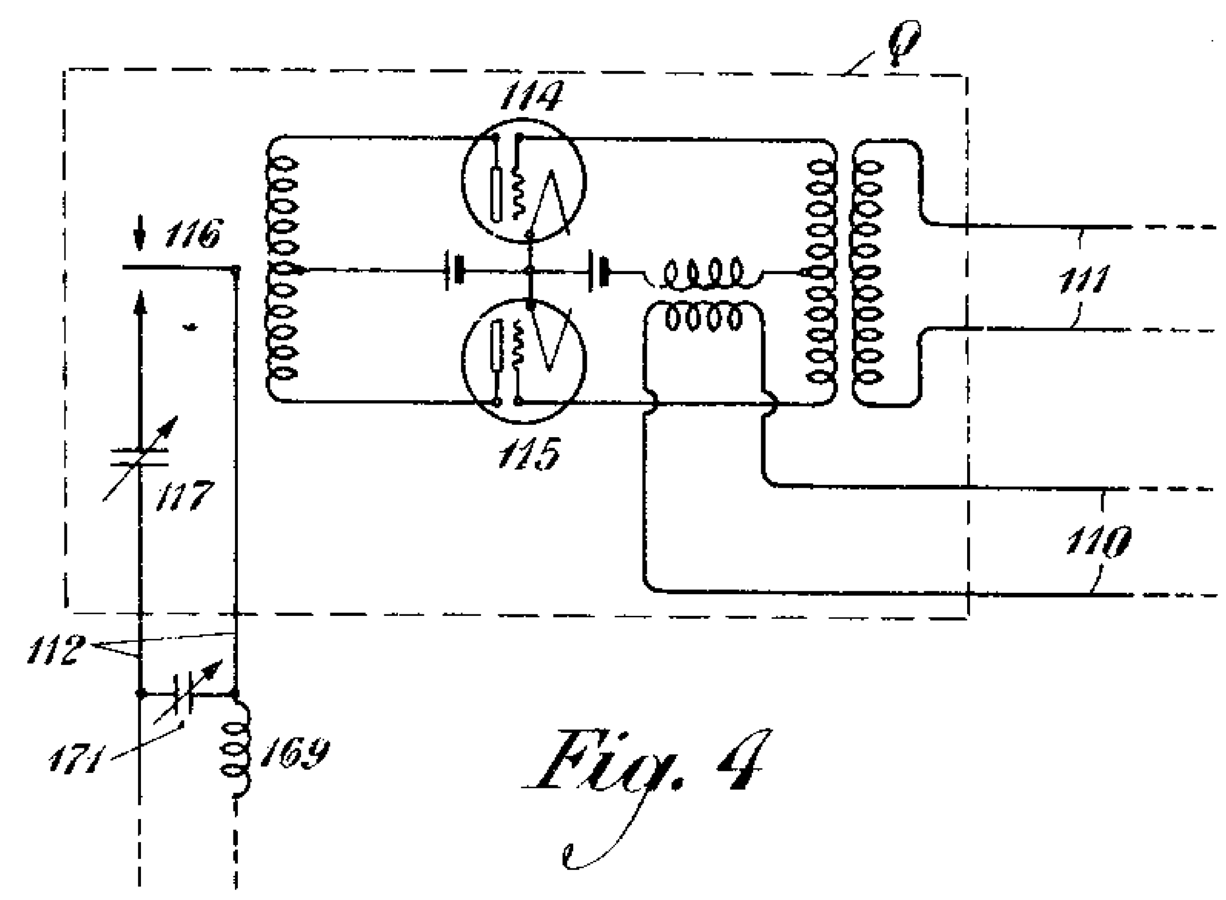

Fig. 4

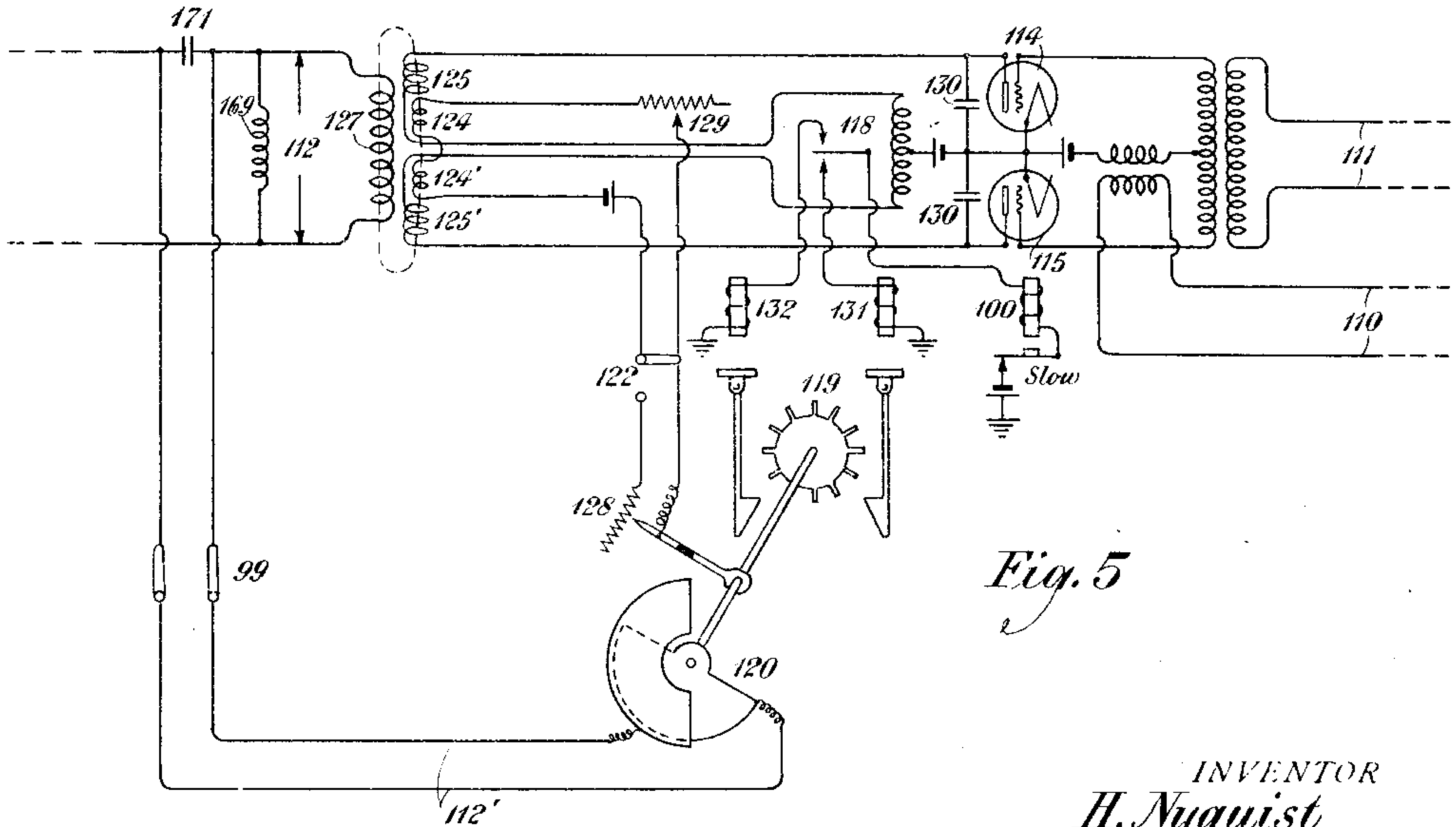

Fig. 5

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MULTIPLEX CARRIER CURRENT SIGNALING

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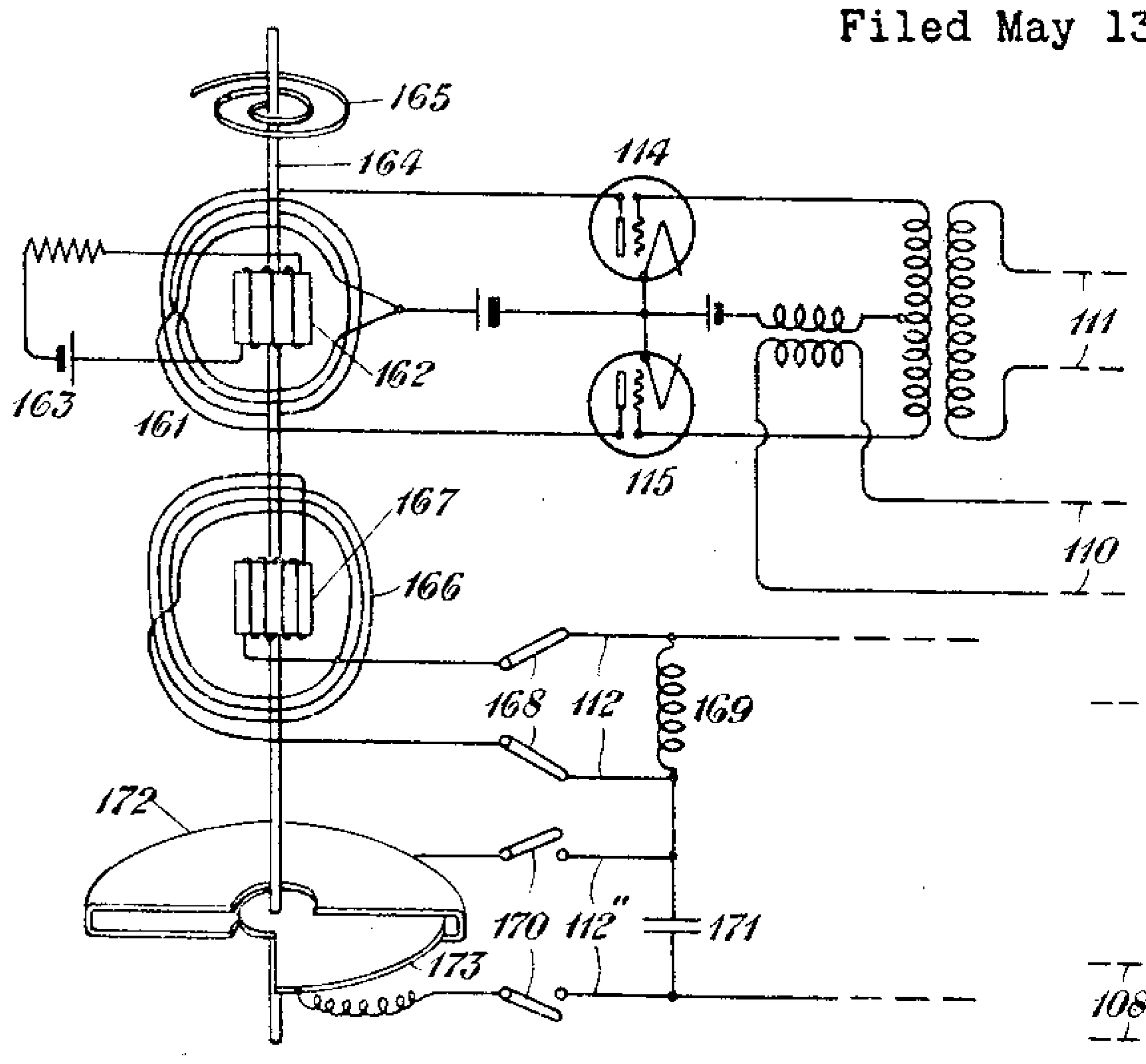

Fig. 6

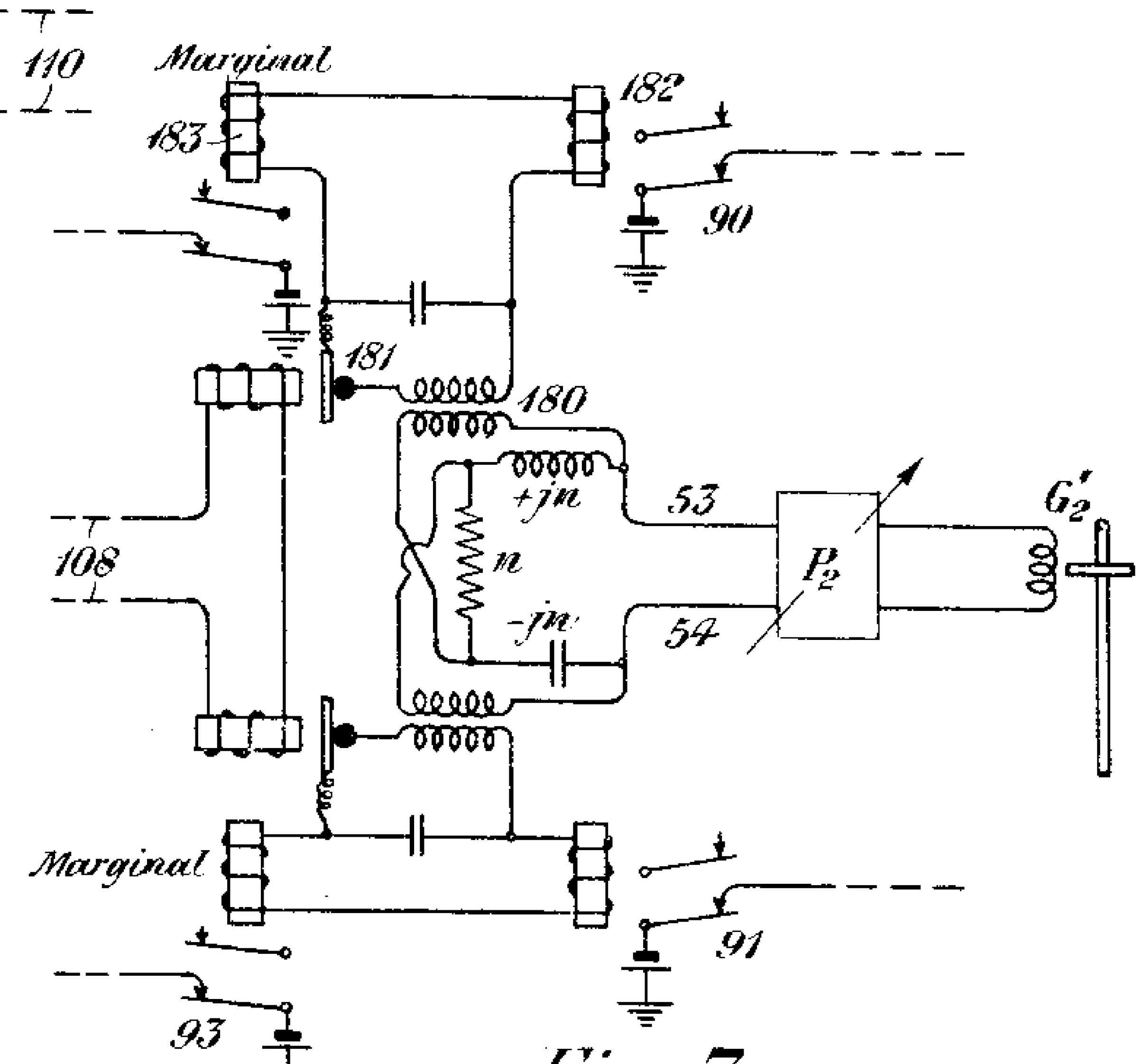

Fig. 7

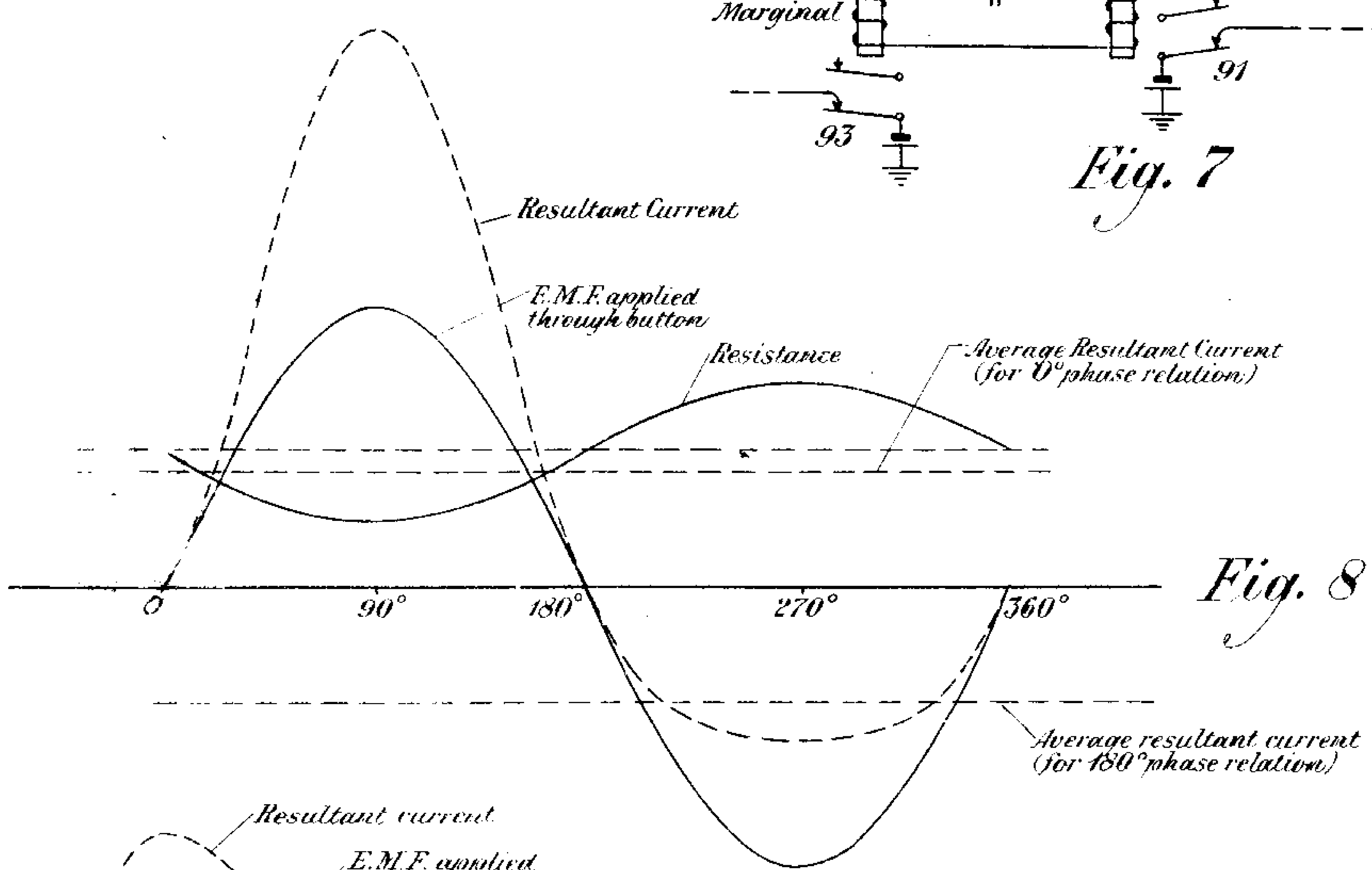

Fig. 8

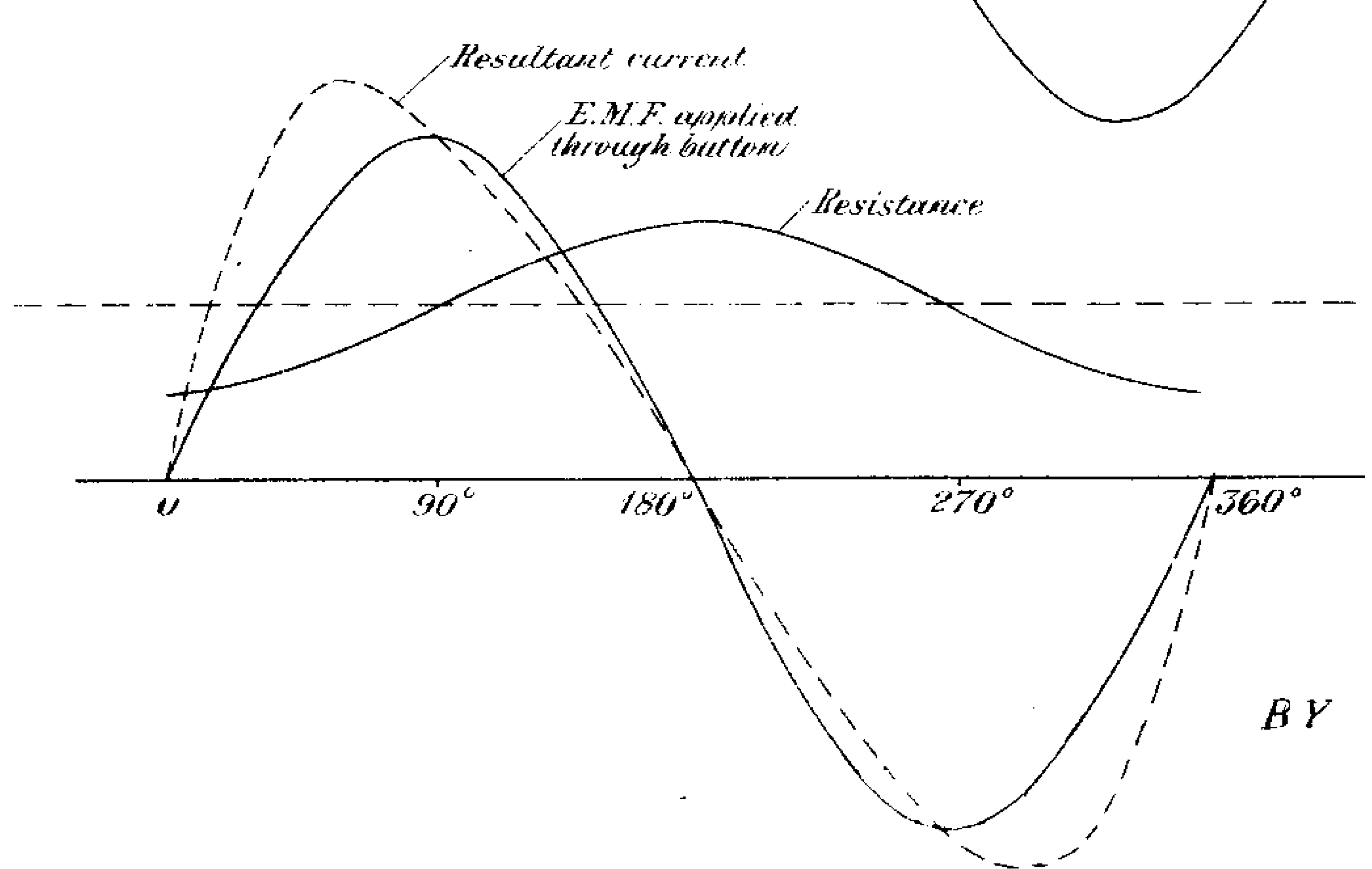

Fig. 9

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Patented Sept. 18, 1928. 1,684,455

UNITED STATES PATENT OFFICE.

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

MULTIPLEX CARRIER-CURRENT SIGNALING.

Application filed May 13, 1926. Serial No. 108,839.

An object of my invention is to provide a new and improved method and corresponding apparatus for multiplex signaling over a limited range or band of carrier current frequencies. Another object of my invention is to utilize such a band of frequencies advantageously for telegraph signal channels. Other objects of my invention relate to automatic adjustment to compensate for changes of transmission equivalent; generation at the receiving end of a current of the same frequency as the carrier current or currents, these currents being suppressed in transmission; and distinguishing message channels by phase and magnitude discrimination within the same frequency range.

In one aspect, my invention involves multiplex transmission by the use of two stages of carrier current, one of intermediate frequency and the other of relatively high frequency. There are various different channels afforded by different neighboring frequency bands on the intermediate frequency stage, and there is a further multiplication of channels by phase and magnitude discrimination on each of these intermediate frequencies. The invention relates largely to deriving the proper intermediate frequency currents all of exact frequency value and in proper phase relation at the receiving end from the high frequency currents that are received there.

These and other objects of my invention will become apparent on consideration of an example of practice according to the invention which I will disclose in this specification, together with a few modifications of certain features. It will be understood that the following disclosure relates to these particular examples of practice according to my invention and that the invention will be defined in the appended claims.

Referring to the drawings, Figure 1 is a diagram of a radio transmitting station; Fig. 2 is a diagram of the corresponding radio receiving station; Fig. 3 is a diagram of receiving apparatus and signal-compensating apparatus shown symbolically in Fig. 2; Figs. 4, 5 and 6 are diagrams of alternative forms of synchronizing or frequency-determining apparatus shown symbolically in Fig. 2; Fig. 7 is a diagram of receiving apparatus alternative to that shown in the upper part of Fig. 3; and Figs. 8 and 9 are curve diagrams that will be referred to in explaining Fig. 7.

Referring to Fig. 1, the constant speed motor M_1 drives the generators G_1, G_2, G_3, etc., to produce currents of respective frequencies such, for examples, as A, mA and nA, when m and n are odd integers. The output circuit of the generator G_3 comprises resistance and reactance elements having their related values indicated by the legends in Fig. 1, r being a certain resistance value, and j standing for $\sqrt{-1}$. It follows that the electromotive forces applied through the transformer primaries 37 and 38 are 90 degrees apart in phase. The current of one of these phases is controlled by the two keys K_1 and K_2. The key K_1 operates to reverse the phase of the component current put through the filter F_3 from the transformer primary winding 37; this is done without changing the magnitude of this current. On the other hand, the key K_2 operates to change the magnitude of this component of current without affecting its phase; when key K_2 is closed down or marking, the magnitude is about three times what it is when this key is open or spacing.

Similarly, the keys K_3 and K_4, respectively, reverse the phase and change the magnitude of the component of current put through the filter F_3 from the transformer primary winding 38. The filter F_3 is a band pass filter of intermediate frequency, the same as the frequency of the generator G_3.

The sending network that has just been described is somewhat similar to the sending network shown in Fig. 1 of my Patent 1,620,735, granted March 15, 1927, and fully described in the specification of that patent.

The boxes S_1 and S_2 represent other sending networks corresponding to the sending network shown in the upper part of Fig. 1, and the filters F_1 and F_2 are band pass filters of intermediate frequencies corresponding, respectively, to the generators G_1 and G_2.

The three or more currents from the generators G_1, G_2, etc., each decomposed into two components 90 degrees apart, and each component varied by phase reversals and by magnitude changes for respective message signaling, are all superposed in one pair of conductors and put through the amplifier A_1.

A balanced modulator is shown at 22, comprising two three-electrode vacuum tubes in push-pull relation. The generator or oscillator O_1 of radio frequency B furnishes the carrier current input for the balanced modulator 22, and the superposed currents from the output of the amplifier A_1 of lower frequency are applied to modulate this carrier current.

Since the modulator 22 is balanced, the carrier current is suppressed from its output and only the upper and lower side bands are present. The band filter F passes only the upper side band of frequencies B+A, B+3A, B+5A, etc. The currents of these frequencies are put on the antenna 41 and radio waves of corresponding frequencies are transmitted from the antenna 41.

Referring to Fig. 2, these radio waves are received on the loop aerial 42, and the corresponding currents generated therein are amplified in the amplifier A_2 and passed through the adjustable artificial line AL and the demodulator 101 and the filter F′ to the transformer 128. This transformer is connected on the input side of the amplifier 129 whose output goes through the transformer 130 to the bus-bars 102.

The demodulator 101 is also supplied with high frequency current from an oscillator O_2, governed in a manner presently to be described, so that its frequency is kept accurately at the value B. For the present, let it be assumed that the frequency of the oscillator O_2 is C, a value nearly equal to B, and it will be shown in due course how regulation is effected so that C is made accurately equal to B.

The output current from the demodulator 101 comprises two side bands lying, respectively, far above and far below the neighboring frequencies C and B+A, B+3A, etc. The band filter F′ passes only the lower of these side bands so that the currents put on the conductors 102 are of the frequencies B+A−C, B+3A−C, B+5A−C, etc.

Relying on the assumption already stated that the adjustment of the oscillator O_2 is such as to make B and C nearly equal, it will be seen that the currents referred to have nearly the frequencies A, 3A, 5A, etc. These components are separated into respective branch circuits by the band filters such as F_1', F_2', F_3' and F_4', and these components of the respective frequencies go to the corresponding receiving networks such as R_1, R_2, R_3 and R_4.

One of these receiving networks R_2 is shown in the upper part of Fig. 3. A similar receiving network is shown in Fig. 2 of my Patent 1,620,735, granted March 15, 1927, and fully described in the specification of that patent. The input current on the conductors 108 is some odd multiple frequency of A, say mA (assuming, as will be established presently, that B=C). It will be remembered that the current of this frequency comprises two components 90 degrees apart, each affected by phase reversals and magnitude changes. This current goes through the transformer whose secondary 55—57 has an intermediate tap at 56. The full output voltage from this transformer goes to the input of the detector D_2, but the less output voltage determined by the tap 56 goes to the input of the detector D_1. Superposed on these inputs is an electromotive force from the generator G_2'. The output of this generator goes through a phase adjuster P_2 and then through conductors 53, 54 to a phase splitter by which two 90-degree components are separated, and it is one of these that is superposed on the inputs for the detectors D_1 and D_2. The generator G_2' is of frequency mA, as determined by means and method presently to be described, (and subject to the provisional assumption already stated, that B=C), and the phase of the component applied to the detectors D_1 and D_2 is the same as for one of the two components coming in on the conductors 108, provided the key K_1 for that component at the sending station is in its marking position. Since the input electromotive forces to these detectors from the local sources are in phase with one component and in quadrature with the other, the detectors will give no response for the other component but only for the one component for which there is phase agreement. With the keys K_1 and K_2 closed down, both detectors D_1 and D_2 will give substantial output currents energizing, respectively, the polar relay PR_1 and the neutral relay NR_2 and holding their armatures at marking position.

The relay NR_2 is marginal, and as soon as the key K_2 is opened at the sending station and the magnitude of the corresponding component of current is decreased, the relay NR_2 will drop its armature to the spacing position independently of whether the phase of the component is the same as for the local source, or reversed. The armature of relay NR_2 is slow acting so it does not drop for a reversal of magnetism in the relay core.

On the other hand, the polar relay PR_1 and associated parts are so adjusted that its core would be deenergized if subject to the local source alone; accordingly, its operation is dependent only on the phase of the superposed incoming received voltage; and when the resultant voltage to the detector D_1 comprises two components in phase, the relay PR_1 will be operated at marking position, but when the incoming voltage comprises a component opposite in phase to the local source, the relay PR_1 will reverse and be at spacing position. Accordingly, raising the key K_1 at the sending end causes the armature of relay PR_1 to reverse, irrespective of the magnitude of the current component involved.

The foregoing description for the operation of detectors D_1 and D_2 for one of the 90-degree components on conductors 108 applies similarly to the remaining detectors D_3 and D_4 and their associated relays PR_3 and NR_4 which operate on the other 90-degree component on the conductors 108.

Having described the receivers shown symbolically as at R_2 in Fig. 2 and in detail in Fig. 3, attention will now be given to the matter of determining the frequency of the oscillator O_2 in Fig. 2. Bridged across the output conductors from the filter F' is a band filter F_2'' which passes the band of frequencies on the carrier of the same intermediate frequency mA as passed by band filter F_2'. The output from filter F_2'' goes through an adjustable delay-network Y_2. This network Y_2 is merely a transducer that gives an output corresponding to its input but with a time delay or lag according to its adjustment. The output goes to the signal compensating network X_2, shown in detail at the lower part of Fig. 3, where its structure is apparent without the necessity for verbal exposition at this point. The currents at the input of X_2 from Y_2 are of the approximate frequency mA, but having each 90-degree component affected by magnitude changes and by phase reversals. Each of these magnitude changes and each of these phase reversals determines the position of the corresponding relay armature 90, 91, 92, or 93 in the receiving network R_2, and the positions of these armatures determine the energization of the respective magnets 94, 95, 96 and 97, in the network X_2. The armatures of these last mentioned magnets shift to change connections within the network X_2 so as to compensate for the phase and magnitude changes referred to.

For example, if the key K_1 at the sending end is raised from its marking to its spacing position this will reverse the phase of one component of the current on the conductors 108 and will cause the relay PR_1 to drop its armatures, thus deenergizing the magnet 94 and causing it to drop its armatures. This will change the connections within the network X_2 so that the output on the conductors 109 will be the same after as before the phase reversal of the said one component, assuming that delay in Y_2 is so adjusted that the change in the current from Y_2 to X_2 is held up until relay 94 operates. Similarly, a phase change in the other component of the current on conductors 108 will be compensated in the network X_2; and magnitude changes of these components will be compensated in the network X_2 so that the output on the conductors 109 will be a pure sine-wave current without phase reversals of a component and without magnitude changes of a component.

The output from the network X_2 of Fig. 2 on the conductors 109 will be a current of the frequency $B+mA-C$ and this will go to the frequency multiplier FM_2 where its frequency will be multiplied by the factor n, nA being the intermediate frequency for the band pass filter F_3'. Accordingly, the output from the multiplier FM_2 will be a current of the frequency $nB+mnA-nC$.

The frequency of the current passed by the band filter F_3' to the receiving network R_3 is $B+nA-C$. By a branch circuit, current of this frequency is sent through a delay network Y_3 and signal compensator X_3 to the frequency multiplier FM_3 where its frequency is multiplied by the factor m, giving an output of frequency $mB+mnA-mC$. These two output currents from the frequency multipliers FM_2 and FM_3 go to the apparatus shown symbolically at Q in Fig. 2 and in alternative detail in Figs. 4, 5 and 6. Q is a device which operates to increase or decrease the natural frequency of the connected oscillator O_2 according to departures from equality of frequency of the two input currents on the respective conductor pairs 110 and 111. Connection between Q and O_2 is made by the conductor pair 112.

Referring to Fig. 4, 169 and 171 are, respectively, the inductance and the capacity of the frequency-determining circuit of the oscillator O_2 in Fig. 2. In shunt to the condenser 171 is another condenser 117, and they are so adjusted that the frequency of the oscillator is a little too high with condenser 171 alone in circuit, and a little too low with condenser 117 in parallel. The parallel branch for condenser 117 is controlled by the armature 116 of a polarized relay.

Within apparatus Q in Fig. 4 two three-electrode vacuum tubes 114 and 115 are arranged as shown with the respective inputs from the conductor pairs 110 and 111. Accordingly, when the currents in 110 and 111 are in quadrature, the output currents will be balanced and the armature 116 will be open. Any departure from the quadrature relation for the currents in 110 and 111 will be in the sense to close the circuit of the condenser 117, and this action keeps frequencies equal in circuits 110 and 111.

Comparing the output frequencies $mB+mnA-mC$ and $nB+mnA-nC$ expressed above for the two frequency multipliers FM_2 and FM_3, it will be seen that these are equal if the frequency C of the oscillator O_2 is made equal to B. Accordingly, the oscillator O_2 is adjusted so that with the condenser 171 in its frequency-determining circuit and with the switch 116 open, the frequency of oscillator O_2 will be slightly greater than B, but with switch 116 closed and condenser 117 in parallel, the frequency of oscillator O_2 will be slightly less than B.

It will also be seen that any departure from equality of B and C causes a corresponding departure from equality of the output frequencies $mB+mnA-mC$ and $nB+mnA-nC$ from the two frequency multipliers FM_2 and FM_3. Therefore, whenever the frequency of the oscillator O_2 tends to depart from the value B, it produces a tendency to a corresponding inequality between the outputs of the two frequency multipliers, and their departure from the quadrature relation effects a compensating adjustment in the oscillator O_2 so that its frequency is held accurately at the value B.

By the control of the oscillator O_2 as heretofore described, the output of the signal compensator X_2 is held accurately at frequency mA and the current of this frequency goes by a branch circuit through amplifier A_3 and filter F'' to drive the synchronous motor SM which in turn drives the generators G_1', G_2', etc., at frequencies corresponding respectively to G_1, G_2, etc. at the sending end. The output currents of these frequencies go through the adjustable phase shifters P_1, P_2, etc. to the receiving networks R_1, R_2, etc. and are there applied as described heretofore in connection with Fig. 3.

The apparatus Q of Fig. 2 may be energized to control the frequency of the oscillator O_2 in another way by throwing the switches 105, 106 and 107. This cuts out the two frequency multipliers FM_2 and FM_3 and puts the current of frequency $B+nA-C$ on the input conductor pair 111 to the device Q. The current to the synchronous motor SM will be of frequency $B+mA-C$, and the generators G_1', G_2', etc. are arranged so that their frequencies are all harmonics of the fundamental having the frequency l/m $(B+mA-C)$ and accordingly the frequency of generator G_3' is n/m $(B+mA-C)$. The current of this frequency goes through switches 105 and through the input conductor pair 110 to device Q. Any departure from equality of these two input frequencies $B+nA-C$ and n/m $(B+mA-C)$ in device Q causes it to regulate oscillator O_2 to hold these frequencies equal. For the condition that

$$B+nA-C=n/m\ (B+mA-C),$$

B must equal C. This condition $C=B$ also establishes the fundamental frequency A for the harmonics generated by G_1', G_2', etc.

A modified frequency controlling system Q is shown in Fig. 5. The output circuits of the vacuum tubes 114 and 115 comprise iron cored inductance windings 125 and 125′, as shown. In inductive relation with windings 125 and 125′ are the further windings 124 and 124′, energized by a direct current. In the circuit of this direct current, resistance 129 is adjusted to the value for which there is the greatest change of inductance of the coils for a given small change of magnetizing force. The condensers 130 serve to close the circuits of coils 125 and 125′ as seen from the oscillator O_2 connected through conductors 112. In the output circuit of tube 114 the current has a tendency to aid the direct current coil 124 in magnetizing effect, but in the output circuit of the tube 115 there is opposition. Accordingly, any departure from equality of the output currents from the tubes 114 and 115 will increase or decrease the magnetization of the cores of the windings referred to and change the effective inductance of the circuit of the associated winding 127. This coil 127 is in parallel with the inductance 169 for the frequency-determining circuit of the oscillator O_2. Hence in the case of Fig. 5 as described thus far, the adjustment of frequency is by adjustment of the inductance instead of the capacity as in Fig. 4.

The adjustment effected by the foregoing methods may be of limited range and a wider but slower adjustment will be effected automatically by the differential voltmeter relay 118. As long as the output currents from the two tubes 114 and 115 are equal, both circuits will be open at 118, but whenever either current exceeds the other to a certain degree, one of the circuits will be closed correspondingly and one or the other of the magnets 131 or 132 will operate the ratchet wheel 119 one way or the other to correspond. As long as the closure of one circuit remains at 118, the slow relay 100 will open and close, thus causing the ratchet wheel 119 to take progressive steps in the same direction.

The ratchet wheel 119 governs an adjustable condenser 120 which varies the capacity in shunt to the main condenser 171 of the frequency-determining circuit of the oscillator O_2. Hence in the case of Fig. 5, large adjustments are made comparatively slowly by automatic adjustment of the condenser 120, and smaller quicker adjustments are made by varying the effective inductance through the winding 127 in parallel with the main inductance 169 of the frequency-determining circuit of the oscillator O_2.

By opening the switches 99 and throwing the switch 122, the adjustable condenser 120 is thrown out of service and the slow adjustment is effected by means of the rheostat 128, which now becomes a part of the direct current circuit through the coils 124 and 124′. In this case, the slow adjustment, by varying the direct current through the windings 124 and 124′, changes the magnetization of their cores to values at which the inductance will be greater or less as required.

Still another modification for the frequency-determining apparatus is shown in Fig. 6. Here the output currents from the two tubes 114 and 115 go through opposed windings 161 within which is an armature 162 on the shaft 164 held at a certain position by the spring 165. The armature 162 is energized by direct current from the battery 163, and hence turns one way or the other when the current in the output circuit of either tube 114 or 115 exceeds the current in the other such circuit.

The coils 166 and 167, with one of them mounted to rotate with the shaft 164, constitute an adjustable industance in shunt to the main inductance 169 of the frequency-determining circuit of the oscillator O_2. Accordingly, the frequency of this circuit is adjusted one way or the other by excess of output current from one tube over the other of the two tubes 114 and 115.

By opening the switches 168 and closing the switches 170, adjustment of the frequency of the oscillating circuit of the oscillator O_2 may be effected by adjustment of the capacity of the condenser whose plates are 172 and 173, and which is connected in parallel with the main condenser 171 of the frequency-determining circuit.

The intensity of the received currents in the receiving loop 42 (Fig. 2) will vary over a wide range from time to time according to common experience in radio receiving. But it is important that the intensity of the input currents to the receiving networks R_1, R_2, etc. shall be substantially constant; this is especially requisite for the proper operation of the marginal relays such as NR_2 and NR_4 of Fig. 3. While radio transmission may be subject to necessity for adjustment to keep the proper transmission level at the receiving end, on the other hand, it will generally be unnecessary to provide adjustment for phase distortion, because all frequencies are transmitted through the ether with the same velocity.

From the output of signal compensator X_2, a conductor pair 99 conducts received current of frequency mA to an amplifier and the detector 140. In the output circuit of this detector 140 is the polarized relay 103 which is adjusted so that at a certain desired strength of output current, its armature will be open between two opposed contacts, but a slight increase of current strength will close it on one contact and a slight decrease will close it on the other contact. Such closure either way will cause motor M_2 to rotate in a corresponding direction and adjust the artificial line AL to compensate the increased or decreased intensity and restore the armature of relay 103 to its neutral position.

The adjustment effected as described above by means of relay 103 may be somewhat slow or delayed and a supplemental quick adjustment over a narrow range is afforded by means now to be described. Referring again to Fig. 2, the plate voltage for the amplifier 129 is supplied from the negative end of the resistance 144 in the plate circuit of the detector 140. Any change in the received transmission level on conductors 99 results in a corresponding change in the output current of the detector 140, as already explained. Due to the resistance 144, this change in detector current will vary the plate voltage on amplifier 129 in the opposite direction and change the gain of the amplifier accordingly, thus tending to maintain the level delivered to the bus-bars 102 constant. An alternative method of controlling the gain of amplifier 129 may be used by closing the switch 150 and throwing switch 145 to its other position. The plate voltage on amplifier 129 is now supplied by the battery 201 and is constant. However, the effective bias grid voltage applied to amplifier 129 will now vary with the output current in detector 140, inasmuch as the current from the negative side of 144 through the resistances to ground on the filament of 129 will vary; e. g., an increase in output current of 140 will give an increased negative voltage on the grid of 129 and so reduce the gain of the amplifier. It is evident that this change in gain of the amplifier is the same as that in the alternative case described first.

The receiving network such as R_2 in Figs. 2 or 3 connected to the input conductors 108 may be replaced by the apparatus shown in Fig. 7. The local generator G_2' of the current of low frequency mA is the same as for Figs. 2 and 3, and the current of this frequency is split in two components 90° apart as in those figures. One of these two components is applied through transformer 180 to the terminals of the carbon button 181. The incoming signal currents on conductors 108 go through a magnet winding that varies the pressure on this carbon button 181, and varies its resistance correspondingly. It will be remembered that this incoming current has two components 90° apart, each modified by amplitude changes and by phase reversals for signals. With proper adjustment of the phase shifter P_2, one such component is either in phase or at 180° with the applied electromotive force through button 181 and the other such component is in quadrature. The variation of resistance of the component of incoming current in phase is shown in Fig. 8. The resultant current component, being determined by electromotive force divided by resistance, is readily plotted. Its positive half wave is obviously of much greater value than its negative half wave and the average resultant current has a substantial positive value as shown by the appropriately labeled horizontal dotted line. But when the incoming current component is at 180° with the locally applied electromotive force, instead of in phase, the resultant current will be modified so its direct current component will be reversed as shown by the lowermost dotted line in Fig. 8.

On the other hand, the variation of resistance of the component of the incoming current in quadrature is shown in Fig. 9; the two half waves of resultant current are equal and the current component has zero average value.

The direct current relays 182 and 183 of Fig. 7 will not be influenced by the current of Fig. 9 but they will be influenced by the current of Fig. 8 if it be of sufficient magnitude. The relay 182 is a polarized relay and shifts its armature when the current of Fig. 8 changes from one dotted line value to the other, that is, when the incoming current changes 180° in its relation to the electromotive force applied through the button. On the other hand, the relay 183 is neutral and marginal and operates only for more pronounced variation of the resistance through the carbon button 181, that is, it operates only for strong currents in the windings supplied by conductors 108 as determined by closure of key K_2 at the sending end. Each relay 182 or 183 controls a circuit at 90 or 92, respectively, for the signal compensator X_2 as in Fig. 3.

Just as relays 182 and 183 operate on one 90° component of incoming current on conductors 108, so the other pair of relays at the bottom of Fig. 7 operate on the other 90° component of incoming current.

I claim:

1. In a carrier current signal receiving system, a demodulator, a generator to supply current of carrier frequency to said demodulator, frequency controlling means for said generator, and means to compare two different harmonic currents in the modulator output and to actuate the said controlling means thereby.

2. In a carrier current signal receiving system, a demodulator, a generator to supply current of carrier frequency to said demodulator, frequency controlling means for said generator, means to separate two components of different freqencies in the demodulator output, means to derive therefrom two currents that will be equal in frequency when and only when the said generator operates at the correct frequency, and means to compare said derived currents and by their departure from equality of frequency to make compensating adjustment through said frequency controlling means.

3. In carrier current signaling, the method of synchronizing a current of carrier frequency generated locally at the receiving end for demodulation, which consists in separating out two harmonic currents in the demodulation product, multiplying each by the harmonic number of the other so as to get currents of equal frequency provided the locally generated current is of the proper frequency, and applying the currents so obtained to make compensating adjustment of said locally generated current by their departure from the equality relation if the locally generated current is not of the proper frequency and phase.

4. In a carrier current signal receiving system, a demodulator, a generator to supply current of carrier frequency to said demodulator, frequency controlling means for said generator, means to separate two harmonic components of different frequencies in the demodulator output, means to multiply each by the harmonic number of the other to get product currents of equal frequency provided the said generator is operating at the correct frequency, and means to actuate said controlling means by departure of said product currents from the equality relation.

5. In a multiplex carrier current signal receiving system, a demodulator, a generator to supply current of carrier frequency to said demodulator, frequency controlling means for said generator, means to separate signal modified component currents of different frequencies from the demodulator output, local generators of currents of corresponding frequencies to cooperate in detecting the signals on these component currents, means to synchronize the local generators by one such component, and means to actuate said controlling means by frequency comparison of another such component and the locally generated current corresponding thereto.

6. In multiplex signaling, the method of discriminating between received current components differing in phase, which consists in applying the received current to vary a resistance and applying through the resistance an electromotive force in phase with the component to be received, whereby the current through the resistance will correspond with the desired component of the received current.

7. The method of detecting signals on each of two components of received current 90° apart in phase, which consists in applying the received current to vary two resistances and applying through these resistances respective locally generated electromotive forces 90° apart in phase and corresponding to the said components of received current, whereby the currents through said resistances vary in accordance with the signal changes on the respective components.

8. In combination, a microphone, an electromagnet in operative relation to it, means to apply to one of these elements a current having signal modifications on each of two components thereof differing in phase, and means to apply to the other element an electromotive force corresponding in phase

with one such component, whereby the current through said element will correspond to the signal modifications on the corresponding component.

9. In combination, two microphones, respective electromagnets, a circuit to apply thereto received signal currents each of two components 90° apart in phase and each component affected by signal modifications, means to apply to the microphones electromotive forces in phase with said components, respectively, and current indicators in series with said microphones to indicate the signals carried by the respective received current components.

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

HARRY NYQUIST.