Oct. 5, 1926. 1,601,808

H. NYQUIST

MULTIPLEX SIGNALING SYSTEM

Original Filed Feb. 29, 1924 3 Sheets-Sheet 1

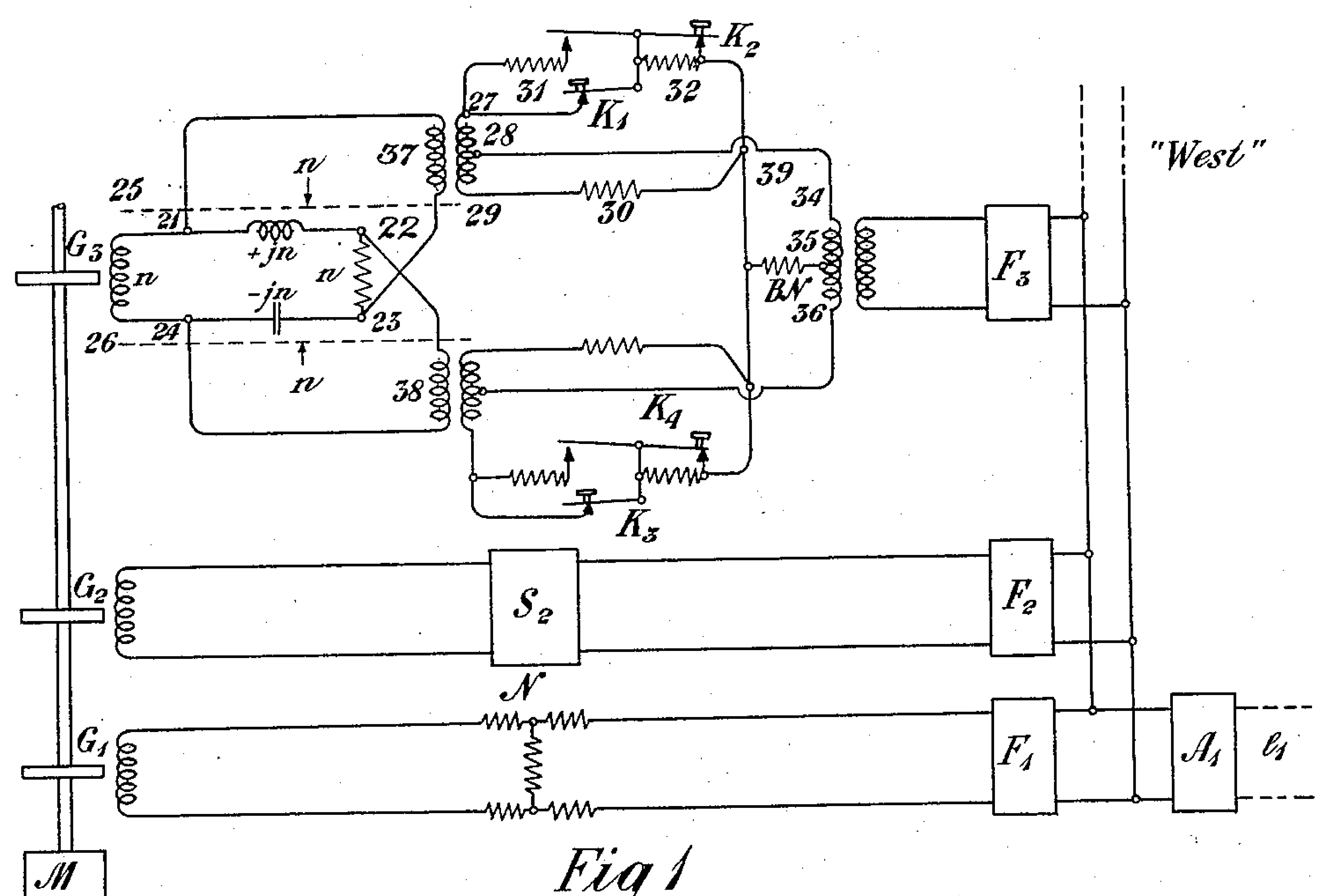

Fig 1

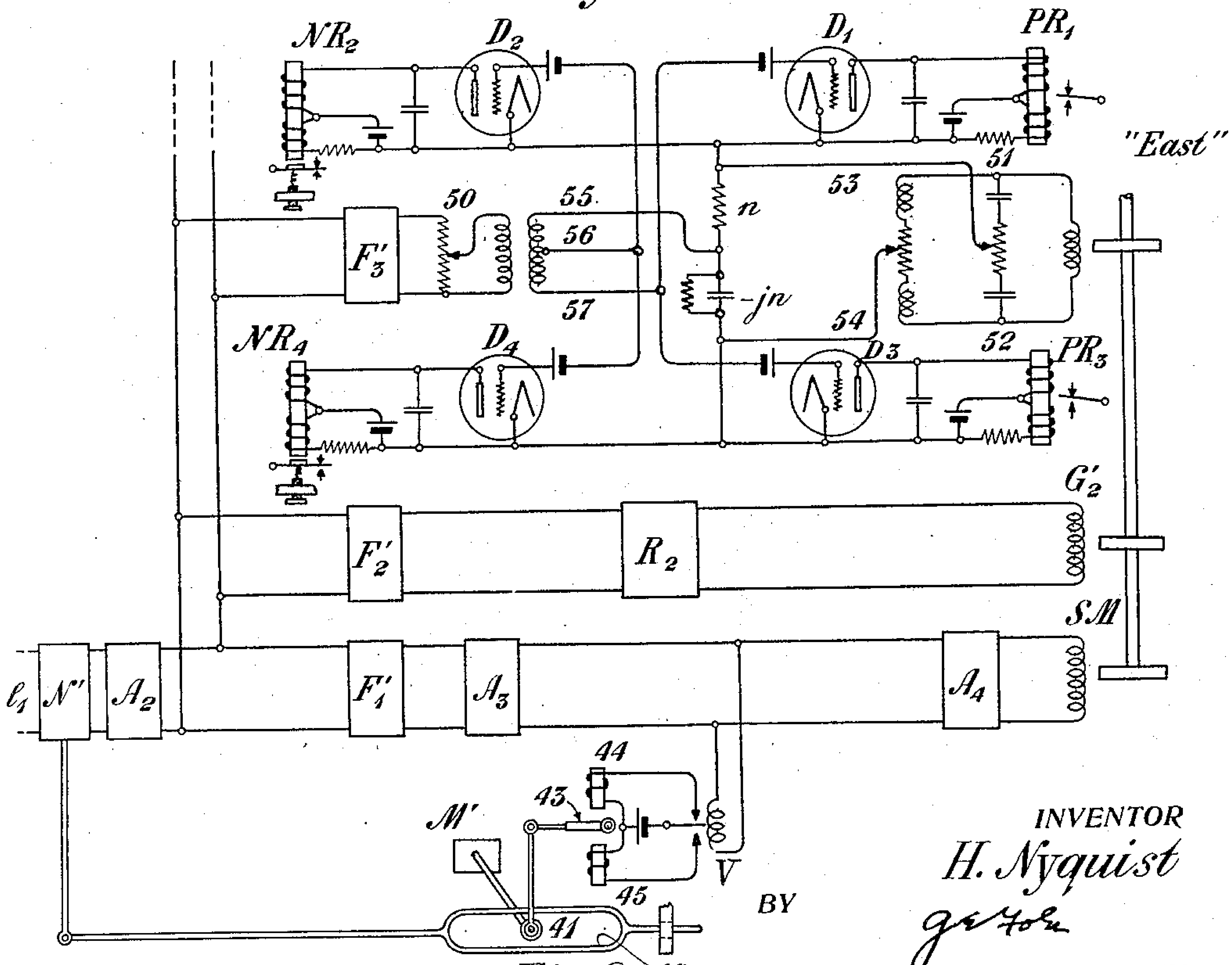

Fig. 2

INVENTOR
H. Nyquist
BY
ATTORNEY

H. NYQUIST

MULTIPLEX SIGNALING SYSTEM

Original Filed Feb. 29, 1924 3 Sheets-Sheet 2

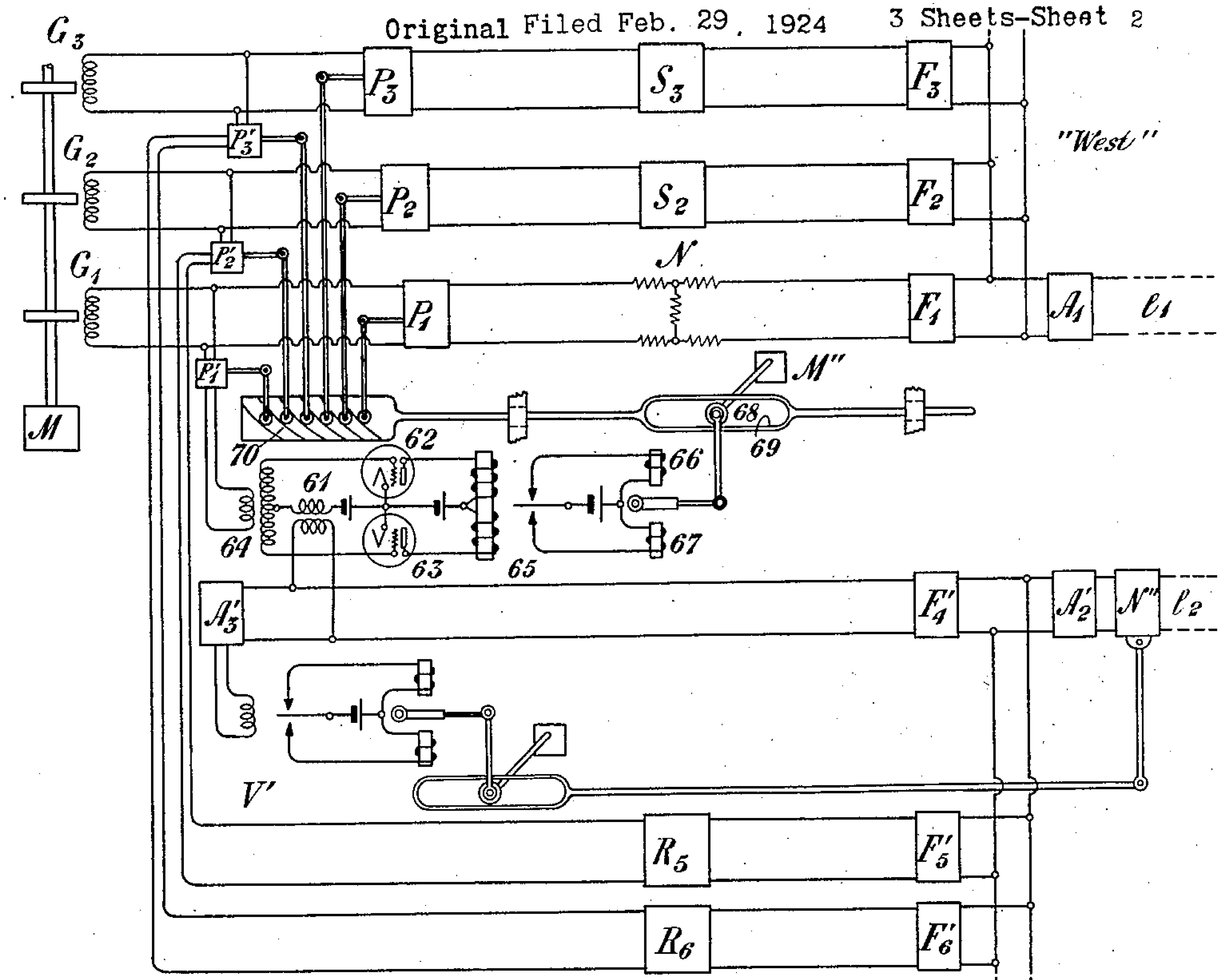

Fig. 3

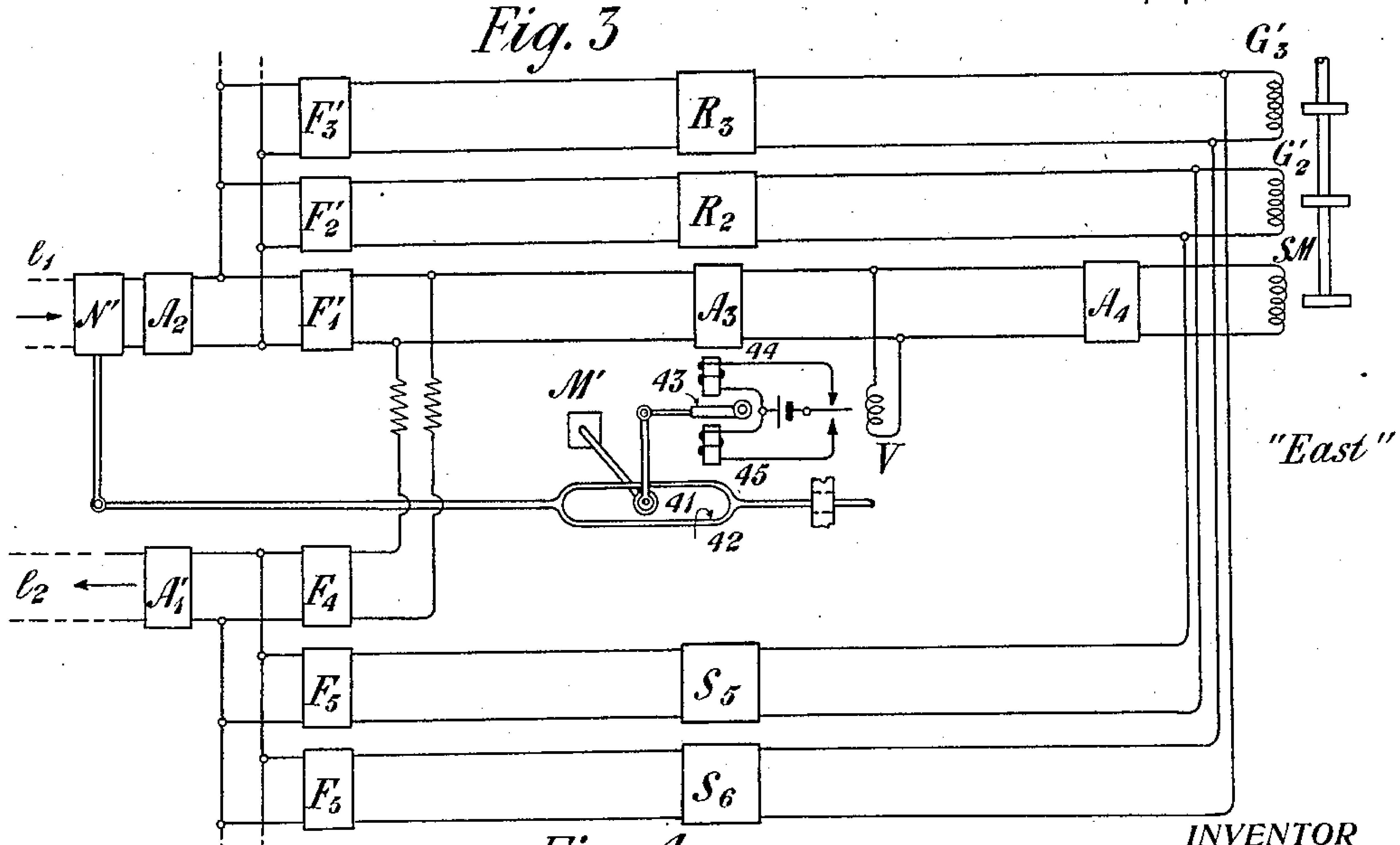

Fig. 4

INVENTOR
H. Nyquist
BY
[signature]
ATTORNEY

Oct. 5, 1926. 1,601,808

H. NYQUIST

MULTIPLEX SIGNALING SYSTEM

Original Filed Feb. 29, 1924 3 Sheets-Sheet 3

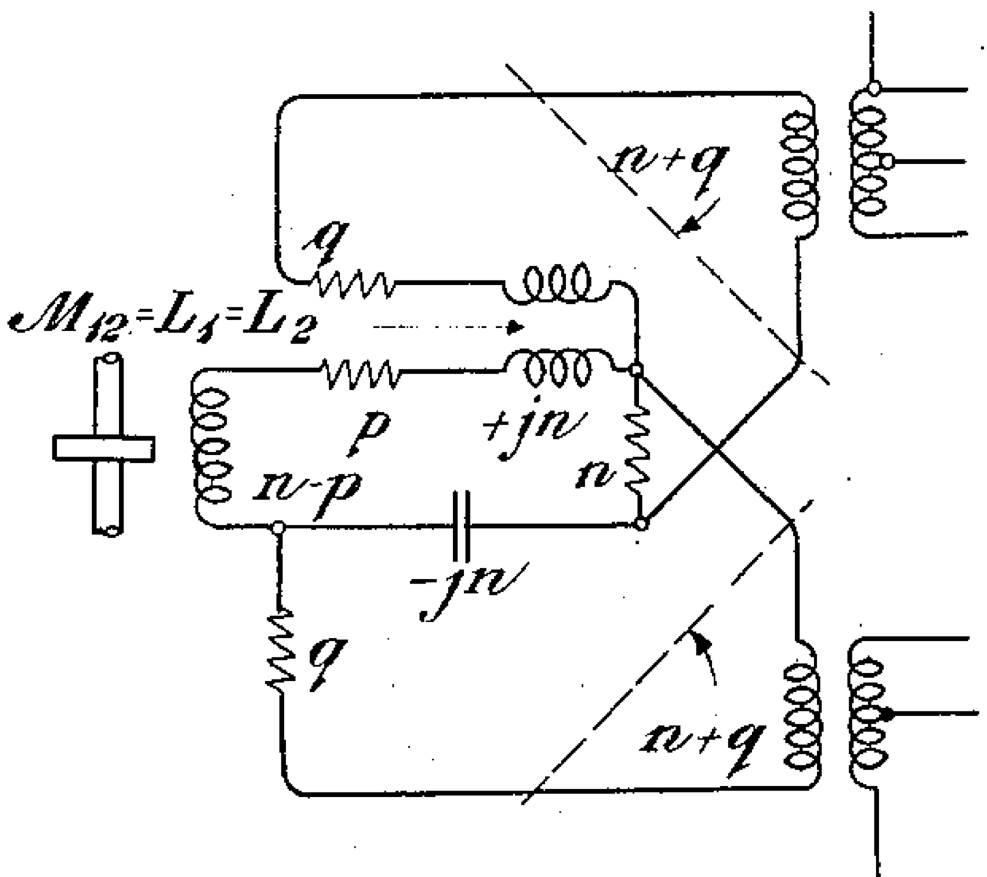

Fig. 5

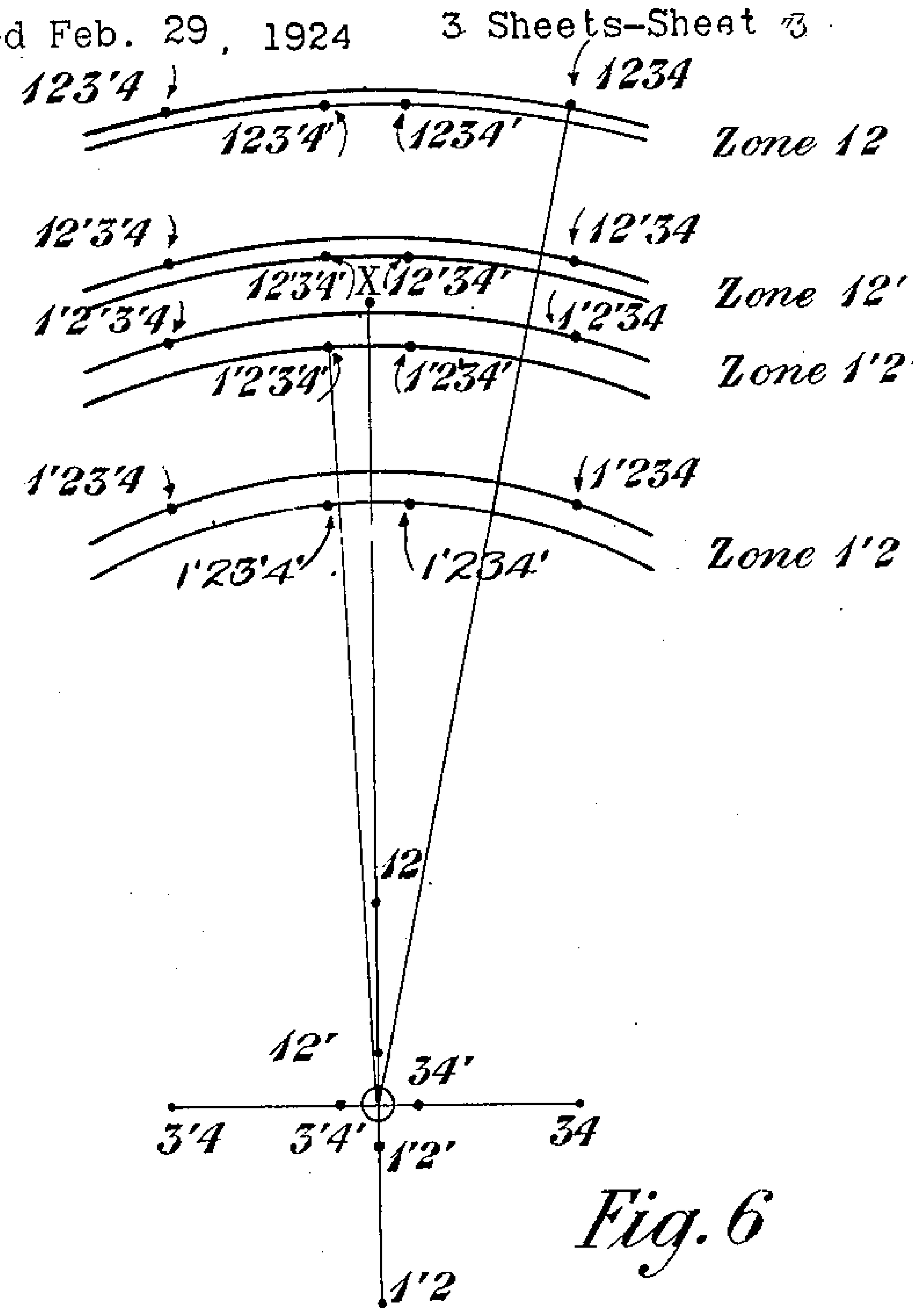

Fig. 6

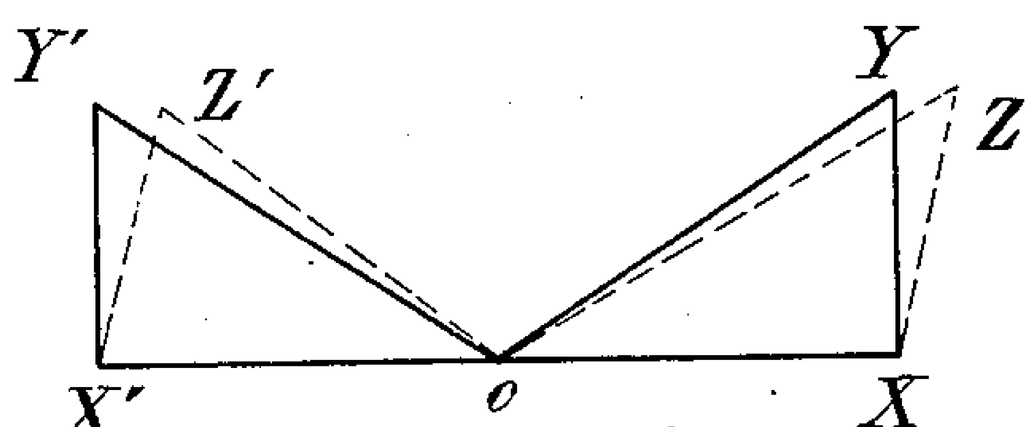

Fig. 7

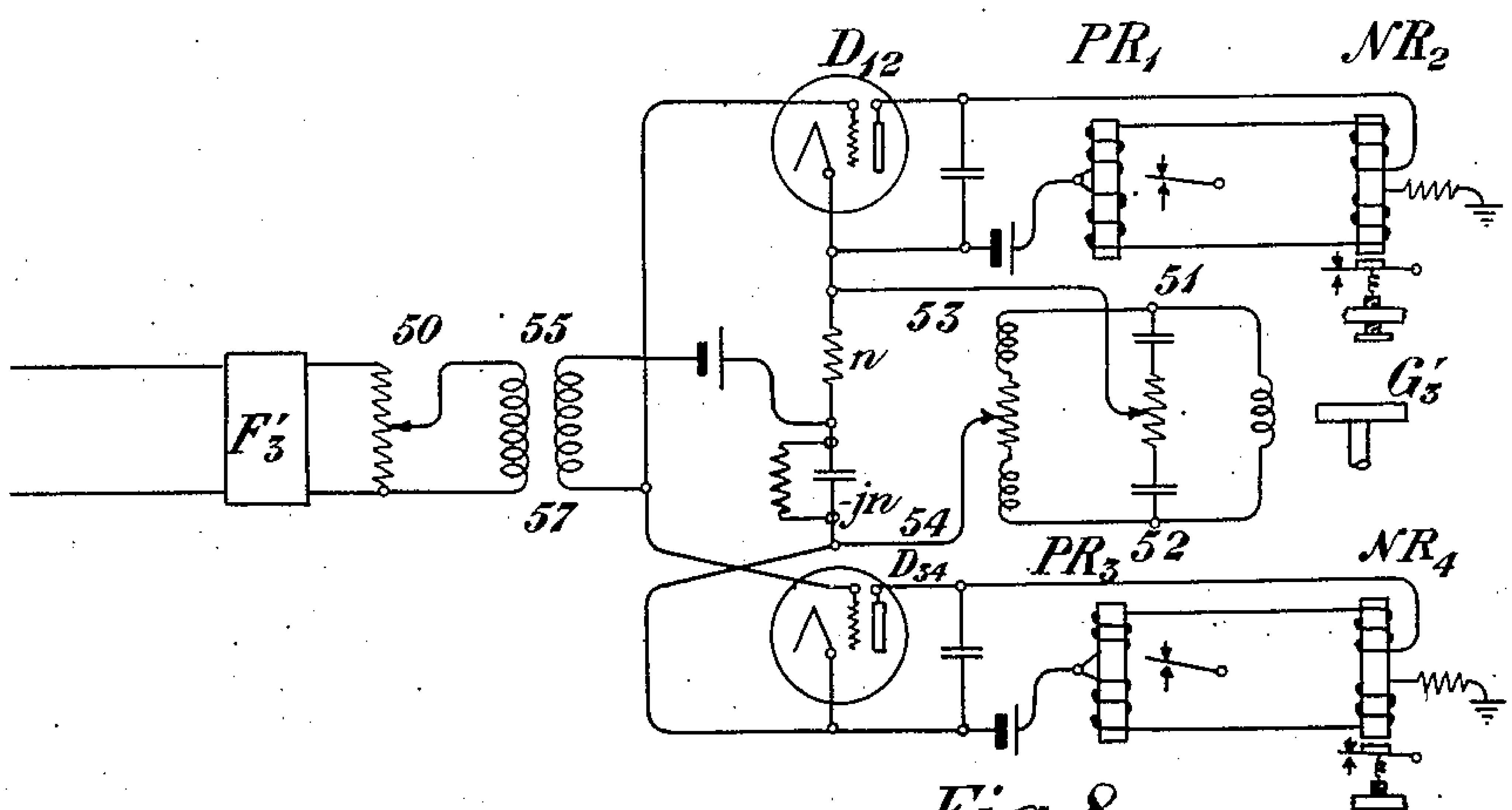

Fig. 8

INVENTOR
H. Nyquist
BY
ATTORNEY

Patented Oct. 5, 1926. **1,601,808**

UNITED STATES PATENT OFFICE.

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

MULTIPLEX SIGNALING SYSTEM.

Application filed February 29, 1924, Serial No. 696,048. Renewed March 18, 1926.

The principal object of my invention is to provide a new and improved method and suitable apparatus for utilizing a line for the simultaneous transmission of a number of messages. Another object of my invention is to provide for a system of multiplex telegraphy with discrimination by difference of phase between messages in the same frequency range. Still another object of my invention relates to providing for magnitude discrimination as well as for phase discrimination between different messages transmitted within the same frequency range. Other objects of my invention have to do with providing for accurate synchronization at the transmitting and receiving ends by means of a pilot channel; for regulating the absolute magnitude of the received signals so as to facilitate magnitude discrimination; for phase adjustment between the sending and receiving ends to facilitate phase discrimination; and for relative phase adjustment in the different frequency ranges. These and various 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 have chosen to illustrate and describe in this specification. With the understanding that the following specification is a disclosure of these particular examples of the invention and that the scope of the invention will be indicated in the appended claims, I now proceed to describe the structure and operation of the apparatus shown in the drawings.

Figure 1 is a diagram of multiplex sending equipment; Fig. 2 is a diagram of the corresponding receiving equipment; Fig. 3 is a diagram of a sending and receiving equipment with provision for automatic phase adjustment; Fig. 4 is a diagram of a station at the opposite end of the lines from the station of Fig. 3; Fig. 5 is a diagram of a detail modification in Fig. 1; Figs. 6 and 7 are vector diagrams that will be referred to in explaining operation of the apparatus shown in the other figures, and Fig. 8 is a modification corresponding to the upper part of Fig. 2.

At the station "West" shown in Fig. 1, the constant speed motor M drives the inductor alternators, of which three are shown, G_1, G_2 and G_3, of different "carrier current" frequencies. The output current from the generator G_3 goes over the circuit 21—22—23—24 through an inductance coil of impedance $+jn$, a resistance n and a condenser of impedance $-jn$ in series, where n has any suitable value, say 600 ohms. The value n is the resistance of the generator G_3 looking into it across the points 21, 24 and it is important in the particular example illustrated that the impedance of the generator should be substantially a pure resistance as seen from its output terminal. The network 21—22—23—24 is a balanced Wheatstone bridge because the product of the impedances of one pair of opposite arms is equal to the corresponding product for the other pair of opposite arms. Hence there is no interference in the transformer winding 37 due to electromotive force in the winding 38, nor vice versa. This is true for the particular frequency of the generator G_3. It is also true for other frequencies because with a variation of frequency the impedance of the coil and the impedance of the condenser will vary inversely and, therefore, their product will be constant, and equal to $(+jn)\ (-jn)=n^2$.

Looking across the circuit at 25 in the direction of the arrow, the impedance is n; this is true because the circuit of the coil 38 may be considered open on account of the bridge balance, and it follows that the impedance between the points 21 and 23 is

$$\frac{(n+jn)(n-jn)}{(n+jn)+(n-jn)}=n.$$

The currents in the windings 37 and 38 are 90 degrees apart in phase. To prove this, notice that if a given voltage is impressed across the points 21 and 23, the current into the generator will lead by 45 degrees. The design is such that the impedance across the terminals of the coil 37 is effectively a pure resistance. This being the case, it follows that the current in the winding 37 due to a voltage from the generator G_3 will lead by 45 degrees. Similarly, it can be shown that the current due to the generator G_3 in the winding 38 will lag 45 degrees, and hence the currents in the windings 37 and 38 are 90 degrees apart.

Thus far it has been assumed that the resistance of the coil marked with the impedance value $+jn$ is negligible. Fig. 5 is a modified diagram to take care of the case when the resistance of this coil is not neglected. Assume that its resistance is p and associate another coil with a close inductive coupling whose self-inductance is the same and whose resistance is q. Then with the modified impedance values written on Fig. 5, it may readily be shown that the bridge is in balance as before.

To explain the operation of the keys K_1 and K_2 in Fig. 1, first assume that the keys and the resistances 31 and 32 are removed and that the points 27 and 39 are connected by a resistance equal to the resistance 30. The points 28 and 39 will then be neutral points, no matter what current flows in the winding 37, and there will be no transmission. It will readily be seen that while the key K_2 remains closed, the key K_1 gives zero resistance from 27 to 39 when it is closed for marking and infinite resistance when it is open for spacing. As is well known, when two unequal resistances are joined it is permissible and often convenient to look at the point of junction as a point of reflection and to consider that there is a reflected current wave at the point of junction. In the case here under consideration, the reflected wave from point 27 is transmitted in part into the line. It is also well known that in the limiting case when one of the resistances is made zero and the other is left finite the reflected current is equal to and in phase with the incident current, whereas in the limiting case when one of the resistances is made infinite and the other is made finite the reflected current is equal to and in phase opposition to the incident current. If, therefore, the impedance at 27 is changed from zero to infinity the effect is to reverse the current transmitted to the line. Now if a resistance artificial line is connected between point 27 and the point of reflection and if this artificial line is so designed that there is no reflection at point 27, then the incident wave will traverse the network and be attenuated, moreover, the reflected wave will traverse the line also. The net result of the artificial line is that the current transmitted to the transmission line is attenuated by twice the loss of the artificial line. While the function of the key K_1 is to open and close the circuit and thus to reverse the phase of the transmitted current, the function of key K_2 is to add or remove artificial line and thus to change the magnitude without changing the phase.

Thus it will be seen that the key K_1 transmits by phase reversal of the carrier current and the key K_2 transmits by changing the magnitude of one component of the carrier current from generator G_3.

In a similar manner, the keys K_3 and K_4, respectively, transmit by phase reversal and magnitude change in the other carrier current component which differs 90 degrees in phase from that controlled by the keys K_1 and K_2. These two carrier current components of the same frequency, differing 90 degrees in phase and varying in magnitude as determined by the operation of the keys K_2 and K_4, are superposed in the input of the band filter F_3 whose output goes in multiple with the outputs from other similar filters to the line l_1. These filters are confluent band filters each with relatively narrow band width and with the carrier frequency near the middle of its range so as to produce no serious phase shift during the building up of the signals. The currents to the line l_1 are amplified by the amplifier A_1.

The box S_2 represents a network similar to that between the generator G_3 and the filter F_3. Accordingly, four more messages will be carried in the channel from the generator G_2 through the network S_2 and the filter F_2 and added in multiple on the line l_1.

Alternating current of still another frequency from the generator G_1 is passed through the artificial line or network N, by which it is reduced to the proper intensity to be put on the line. The simple unmodulated current of desired intensity goes from the network N through the filter F_1 and terminal repeater or amplifier A_1 to the line l_1.

As shown in Fig. 1, three frequency channels are provided in the line l_1. Two of these, identified respectively, with the generators G_3 and G_2, each carry four messages. The frequency in the third channel, identified with the generator G_1, may be called a pilot frequency and the channel may be called a pilot channel. As will be pointed out presently, this channel is utilized to provide for synchronism at the receiving end.

Referring to Fig. 2, this shows the receiving station which may be called "East." The currents coming in over the line l_1 pass through the adjustable artificial line or network N′ which is controlled automatically in a manner to be described presently. This network N′ attenuates the currents so as to give a uniform magnitude in its output for the same signal elements from one time to another. The currents, thus attenuated to a standard magnitude, pass through the amplifier or terminal repeater A_2 to the filters F'_1, F'_2, and F'_3 in multiple. These filters correspond in their frequency ranges, respectively, with the filters F_1, F_2 and F_3 at station "West."

The current of pilot frequently goes through the filter F'_1 to the amplifier A_3 and thence to a power tube amplifier A_4 whose output goes to the synchronous motor SM. This motor drives the two generators G'_2 and G'_3 of the same frequency, respective. as G_2 and G_3 at station "West."

The voltmeter relay V is connected across the output from the amplifier A_3 and normally holds its index at a certain position corresponding to a certain voltage. Whenever this voltage changes a little either way, the index closes one or the other of the circuits for the magnets 44 and 45 causing the armature 43 to move and bring the wheel 41 into contact with one side or the other of the yoke 42. The wheel 41 is rotated continuously by the motor M′, so that the artificial line N′ is adjusted one way or the other to adjust the attenuation therethrough. Thus it will be seen that by means of the voltmeter relay V and the associated apparatus, the current of pilot frequency is kept at uniform voltage as delivered to the input of the amplifier A_2. This insures that for the same signal elements in the other channels, the voltages delivered to the input of the amplifier A_2 will be uniform. Even if the attenuation on the line l_1 varies from time to time, as may be the case due to weather conditions, etc., there will be no corresponding variation of the current and voltage magnitudes in the output from the network N′ at station "East." If the received currents at "East" were to vary from time to time, it might happen that signals of low magnitude would sometimes be strong enough to affect the high magnitude receiving apparatus, or that high magnitude would sometimes be too weak to affect the high magnitude receiving apparatus. By the adjustment at N′, any such outcome is prevented.

The modulated current of carrier frequently determined by the generator G_3 at station "West" will, accordingly, find its way through the filter F'_3 and the potentiometer 50 to the primary of the transformer whose secondary is 55—57 with an intermediate tap at 56.

Current of the same frequency as the carrier frequency in the channel considered will be generated locally by the generator G'_3 whose output is applied across the points 51 and 52. The network between these two points is associated with the adjustable taps 53 and 54 so that at these taps an electromotive force of the proper phase and intensity may be drawn off and applied through the resistance n and the condenser of impedance value $-jn$ in series therewith. The electromotive forces across the resistance n and the condenser will be 90 degrees apart. Thus there will be applied to the grids of the detectors D_1 and D_2 locally generated electromotive force from the terminals of the resistance n of the same or opposite phase with the received carrier current component controlled by keys K_1 and K_2, and there will be applied to the grids of the detectors D_3 and D_4 locally generated electromotive force from the terminals of the condenser whose impedance value is $-jn$, of the same phase as the receiver carrier current component controlled by the keys K_3 and K_4. The electromotive forces due to these received carrier current components will be superposed in the secondary windings 55—56 and 55—57 on the locally generated electromotive force.

Let the voltage on the grids of tubes D_1 and D_2 due to the generator G'_3 be represented by the vector OX in Fig. 6. The superposed electromotive force due to the received currents on the line will comprise two components 90° apart. One of these will be

O12 when both keys K_1 and K_2 are marking
O12′ when key K_1 is marking and key K_2 is spacing
O1′2 when key K_1 is spacing and key K_2 is marking
O1′2′ when both keys are spacing

(As will be seen, unprimed numerals are used when the corresponding detectors are marking, primed when they are spacing). Similarly, keys K_3 and K_4 will determine a component O–34, O–3′4, O–34′ or O–3′4′. These two components, combined with the locally generated electromotive force OX give one of 16 different resultants from O to a point which may readily be identified by the notation on Fig. 6. For example, when all four keys are marking the resultant is the vector from O to the point 1234; for another example, when all four keys are spacing the resultant is the vector from O to the point 1′2′3′4′. It will be seen that four substantially different vector magnitudes may be put on each of the detectors D_1 and D_2. These may be classed as lying in the four zones 12, 12′, 1′2 and 1′2′, as shown in Fig. 6. Detector D_1 and its associated elements of apparatus are adjusted so that when the grid voltage has the magnitude OX of Fig. 6, the core of the polar relay PR_1 will be substantially deenergized. But when key K_1 is marking whatever the condition of the other keys K_2, K_3 and K_4, the resultant electromotive force on the grid of detector D_1 will have a magnitude greater than OX and the polar relay PR_1, controlled by detector D^1, will be on the marking side. On the other hand, when key K_1 is spacing, whatever the condition of the other three keys, the resultant electromotive force on the grid of detector D_1 will be of magnitude less than OX and the relay PR_1 will be on the spacing side.

The relay NR_2 is a neutral relay and is adjusted to be marginal in its operation. The adjustments of this relay NR_2 and the associated detector D_2 and their circuits are such that the relay NR_2 is deenergized when the voltage on the grid of the corresponding detector D_2 has the magnitude OX in Fig. 6. When the magnitude of this voltage changes either way, the magnetism in the core of relay NR_2 departs correspondingly one way or the other from zero. Because of its marginal character the relay NR_2 will not operate for a change of voltage to zone 12′ or to zone 1′2′, but it will operate for a change to zone 12 or zone 1′2. Its armature is made slow enough in release so that on a reversal of the magnetism in the core it will not drop; in other words, the armature of the relay NR_2 will not drop for a change in the key K_1, by which the grid voltage goes from one to the other of zones 12 and 1′2.

To recapitulate briefly, key K_1 causes shifts between zones 12 and 12′ on the one hand and zones 1′2 and 1′2′ on the other hand and actuates polar relay PR_1 accordingly, whereas key K_2 causes shifts between zones 12 and 1′2 on the one hand and zones 12′ and 1′2′ on the other hand, and operates neutral relay NR_2 accordingly.

The operation of detectors D_3 and D_4 and their corresponding relays is closely similar to that described for detectors D_1 and D_2 and their relays and need not be repeated in detail.

Fig. 8 shows a modification of the part of Fig. 2 associated with filter F'_3 and generator G'_3. In this case the functions of the pair of detectors D_1 and D_2 are performed by the single detector D_{12} and similarly D_{34} takes the place of D_3 and D_4.

The system of Figs. 1 and 2 is adapted for operation in a case in which the phase shift involved in transmission over the line l_1 is substantially the same from time to time. This being the case, adjustment made by the taps 53 and 54 will be lasting and will not have to be changed from time to time. In case the properties of the line are such that the phase shift over the line changes from time to time, the system shown in Figs. 3 and 4 may be employed. At station "West" shown in Fig. 3, the constant speed motor M, the generators G_1, G_2 and G_3, the adjustable network N, the sending networks S_2 and S_3 and the respective filters F_1, F_2 and F_3 are the same as for Fig. 1. Interposed between each generator G_1, G_2 or G_3 and the respective network N, S_2 or S_3 is an adjustable phase shifter P_1, P_2 or P_3.

In the system of Figs. 3 and 4, two lines are employed, l_1 for transmitting from west to east and l_2 for transmitting from east to west. These may be the wires of a four-wire system. Reception at the station "East" on the line l_1 is the same as explained heretofore for Fig. 2, and the upper part of Fig. 4 is the same as Fig. 2 with the addition that branch circuits in multiple are taken from the output of the filter F'_1 and from the outputs of the generators G'_2 and G'_3, as will now be explained.

The output from the filter F'_1 is the pilot received from the line l_1. This goes through the sending filter F_4 and back from east to west over the line l_2. The branch circuits from the generators G'_2 and G'_3 go, respectively, to the sending networks S_5 and S_6 and the respective filters F_5 and F_6 to the line l_2 from east to west. Thus it will be seen that the apparatus at the lower part of Fig. 4 is very similar to that of Fig. 1, the pilot carrier frequency current being that received from station "West" on the line l_1 and sent back over line l_2.

At station "West" shown in Fig. 3, the incoming currents on the line l_2 are adjusted automatically for magnitude in the adjustable network N″ by the voltmeter relay V′ and associated apparatus like that shown in the lower part of Fig. 2. The received pilot frequency current not only goes to the voltmeter relay V′ but a multiple branch carries this same frequency to the primary of the transformer 61 whose secondary is connected to apply the resulting electromotive forces alike to the grids of the two three-electrode vacuum tube detectors 62 and 63.

The output from the pilot frequency G_1 goes from a branch circuit through the phase shifter P'_1 to the primary of the transformer 64 and develops an electromotive force which is applied in opposite phase to the grids of the two three-electrode vacuum tube detectors 62 and 63. The normal adjustment of the phase shifters P_1 and P'_1 will be such that the electromotive forces developed in the secondaries of the transformers 61 and 64 will be 90 degrees apart. Accordingly, under such normal conditions, the full line vector diagram of Fig. 7 will apply. On one grid, the electromotive force will be OY, the sum of OX and XY. On the other grid, it will be OY′, the sum of OX′ and X′Y′.

But suppose there is a slight departure from the 90-degree relation between the two electromotive forces in the secondaries of the transformers 61 and 64. The vector diagram shown in dotted lines in Fig. 6 will then obtain and the electromotive forces on the grids of the two tubes 62 and 63 will become, respectively, OZ and OZ′.

When the electromotive forces on these grids were equal, namely OY and OY′, the output currents of the detectors 62 and 63 were equal and hence the armature of the relay 65 stood at neutral. But with the unequal electromotive forces OZ and OZ′ on the grids of the two tubes, the output currents are unequal and the armature of the relay 65 will close on one contact or the other, energizing one or the other of the magnets 66 and 67. The result will be to push the wheel 68 against one side or the other of the yoke 69. This wheel 68 is turned constantly by the motor M″ so that the cams 70 are shifted to the right or the left. These cams engage respective rollers which are mechanically connected so that their displacements adjust the phase shifters P_1, P_2, P_3, P'_1, P'_2 and P'_3. The adjustment of the phase shifter P_1 and P'_1 restores the 90-degree relation between the electromotive forces in the secondaries of the transformers 61 and 64. The adjustments are opposite and equal for P_1 and P'_1, likewise for P_2 and P'_2, and likewise for P_3 and P'_3, and in each of the three round trip channels of different carrier current frequency, the currents are made to arrive at the receiving apparatus in proper phase relation with the locally generated currents.

I claim:

1. In a carrier current telegraph system, the method of transmitting a plurality of messages on each frequency, which consists in establishing two currents of that frequency in quadrature and modulating each current by phase reversal for one message and by magnitude change for another, whereby four messages will be carried on current of one frequency.

2. In a multiplex carrier current system, means to generate two currents of the same frequency 90° apart, means to modulate each of these currents in two ways according to respective messages, and means to superpose the modulated currents on the line.

3. In a carrier current telegraph transmission system, means to generate two component currents of each frequency 90° apart and to modulate each of these components by phase reversals for one message and by magnitude changes for another and to put these modulated currents on the transmission line, means at the receiving station to generate currents 90° apart corresponding in frequency and phase with the carrier components, two detectors at the receiving station to which one locally generated current of the carrier frequency is applied and two other detectors to which the other component of that frequency is applied, polar relays associated respectively with one of each pair of detectors and neutral relays associated respectively with the other detector of each pair.

4. In a multiplex carrier current system, means for generating carrier currents of various frequencies and superposing them upon a transmission line, means to modulate all of these carrier currents except one in accordance with messages to be transmitted and phase adjusting means controlled by the unmodulated carrier component.

5. In a multiplex carrier current transmitting system adapted for two-way transmission, means to generate a plurality of currents of different frequencies and to modulate them according to messages and put them on the transmission line, means to generate another current of another frequency and send it over the line one way and back the other way, means at the generating station to compare this current in phase before and after the two-way transmission, and phase shifters associated with all the generators controlled by said comparing means.

6. The method of maintaining definite phase relations among the alternating currents of various frequencies in a multiplex carrier current system, which consists in appropriating one channel each way to an unmodulated current of a particular frequency, sending that current over the line and back and adjusting the phase in each channel as determined by the phase displacement in the channel of unmodulated current referred to.

7. The method of transmitting four messages on one frequency of carrier current, which consists in transmitting two current components of that frequency 90 degrees apart in phase, and modulating each component by phase reversal for one message and by magnitude change for another, whereby four messages will be carried on current of the one frequency.

8. In a carrier current system, means to generate two component currents of the same frequency 90 degrees apart in phase and to modulate each of them in two ways and put them on a line, means at the receiving end to generate two currents locally agreeing in frequency and phase with the said carrier components and to combine them therewith, and detectors respectively responsive to the current of each phase and also to the currents as modulated in each of the different ways at the sending station.

9. In a carrier current system, receiving means for a carrier current of two components 90 degrees apart each modulated by phase reversal for one message and by magnitude change for another message, said receiving system comprising means to generate two currents locally each agreeing with one of the carrier components in phase, two pairs of detectors to all of which the received currents from the line are applied and to which the locally generated currents are applied in respective pairs, neutral relays respectively associated with one detector of each pair and polar relays respectively associated with the other detector of each pair.

10. In a multiplex carrier current system, means for generating carrier currents of various frequencies and superposing them on a transmission line, means to modulate the currents of each frequency with a plurality of messages, a receiving station, means at the receiving station to generate

currents corresponding to the carrier currents for reception by the homodyne method, means to generate and transmit an unmodulated current of a certain frequency, and means actuated by said last mentioned current to adjust the system for variations of propagation on the line.

11. In a multiplex carrier current system, phase shifters, means to compare a current before and after transmission to test changes in the phase displacement on the line, and means automatically to adjust said phase shifters to compensate therefor.

12. In a two-way multiplex carrier current transmission system, means to generate and transmit unmodulated current of one frequency once to and fro, means to compare the input and output currents of this frequency, and phase adjusting means automatically actuated by said comparing means.

13. The method of compensating for variation of phase relations in a multiplex carrier current system, which consists in transmitting unmodulated current of one frequency once to and fro, comparing its input and output for phase, and adjusting the phase for all frequencies by means of this comparison.

14. Means to compensate for variation of phase relations in a multiplex carrier current system, comprising means to transmit unmodulated current of one frequency once to and fro, means to compare its input and output for phase, and phase adjusters for all frequencies controlled by said phase comparing means.

15. The method of regulating the phase and magnitude of the currents in a multiplex carrier current signaling system which consists in applying the carrier current of one particular frequency to make automatic adjustments for phase and magnitude of the currents of the other frequencies.

16. In a multiplex carrier current signaling system, means to transmit carrier currents of various frequencies, means to modulate certain of them and to detect such modulations, and means governed by the current of one particular frequency to effect automatic adjustment of the phase and magnitude of the currents of other frequencies.

17. In a multiplex carrier current signaling system, an adjustable phase shifter, and automatic means to adjust said phase shifter to compensate for variations of phase shift in transmission from time to time.

18. In a multiplex carrier current signaling system, means to test one component of the current for phase shift, and an adjustable phase shifting network governed by said means.

19. In a multiplex carrier current signaling system having channels of different frequency, means to separate out the current of one frequency, means to test this current for phase shift, and an adjustable phase compensating network controlled by said means.

20. In a multiplex carrier current signaling system, means for generating carrier currents of various frequencies and superposing them upon a transmission line, means to modulate at least several of these carrier currents in accordance with messages to be transmitted, and phase adjusting means controlled by one of the said carrier currents.

21. The method of maintaining definite phase relations among the alternating currents of various frequencies in a multiplex carrier current signaling system, which consists in sending the carrier current of one frequency over the line and back and adjusting the phase at each frequency as determined by the phase displacement of the carrier current of the one frequency referred to.

22. In a two-way multiplex carrier current transmission system, means to generate and transmit currents of various frequencies and to transmit one of these currents once to and fro, means to compare the input and output currents of this particular frequency, and phase adjusting means automatically actuated by said comparing means.

23. The method of compensating for variation of phase relations in a multiplex carrier current signaling system, which consists in transmitting one of the frequency components of the system once to and fro, comparing its input and output for phase, and adjusting the phase for all frequencies by means of this comparison.

24. In a multiplex carrier current signaling system, means for generating carrier currents of various frequencies and superposing them on a transmission line, means to modulate certain of these carrier currents in accordance with messages to be transmitted, and means to apply one of these carrier currents for phase regulation of the system.

25. In a multiplex carrier current signaling system, means for generating carrier currents of various frequencies and superposing them on a transmission line, means to modulate certain of these carrier currents in accordance with messages to be transmitted, and means to apply one of these carrier currents to effect phase regulation for all of said currents.

26. In a multiplex carrier current system, means for generating carrier currents of various frequencies and superposing them on a transmission line, means to modulate certain of these carrier currents in accordance with messages to be transmitted, means to apply one of these carrier currents to synchronize the receiving apparatus of the

system, and means to apply current of the same frequency to compensate for phase variations of transmission on the line.

27. A conductor system for transmitting currents of various frequencies, said system being subject to changes of condition tending to change the phase relations among the various frequencies, means responsive to such changes, and automatically adjustable compensating means controlled thereby to keep the said phase relations constant.

28. A conductor system for transmitting currents of various frequencies, said system being subject to changes of condition tending to change the phase relations among the various frequencies, means responsive to such changes and compensating means controlled thereby to keep the said phase relations constant.

29. A conductor system for transmitting an alternating current of several components, said system being subject to changes of condition tending to change the phase relations of said components at the receiving end, means responsive to such changes and compensating means controlled thereby to keep the said phase relations constant.

30. In a multiplex carrier current system subject to changes of condition tending to change the phase relations among the elementary currents of the system, means responsive to such changes, and automatically adjustable compensating means controlled thereby to maintain the phase relations unchanged at the receiving end.

31. In a carrier current signaling system requiring a local generator at the receiving end to generate a current of carrier frequency to cooperate in receiving, means to synchronize the local generator, means to regulate the transmission level of the system, and means to sift out and apply a particular component of the transmitted current to govern said synchronizing means and said regulating means.

32. In a multiplex carrier current system, adjustable means to vary a component of the propagation constant of the system, means to compare a current before and after transmission to test changes in a component of the propagation constant, and means operated by such comparison to actuate said adjustable means.

In testimony whereof, I have signed my name to this specification this 27th day of February 1924.

HARRY NYQUIST.