March 1, 1927. H. NYQUIST 1,619,085

CARRIER CURRENT SIGNALING SYSTEM

Filed Feb. 29, 1924 3 Sheets-Sheet 1

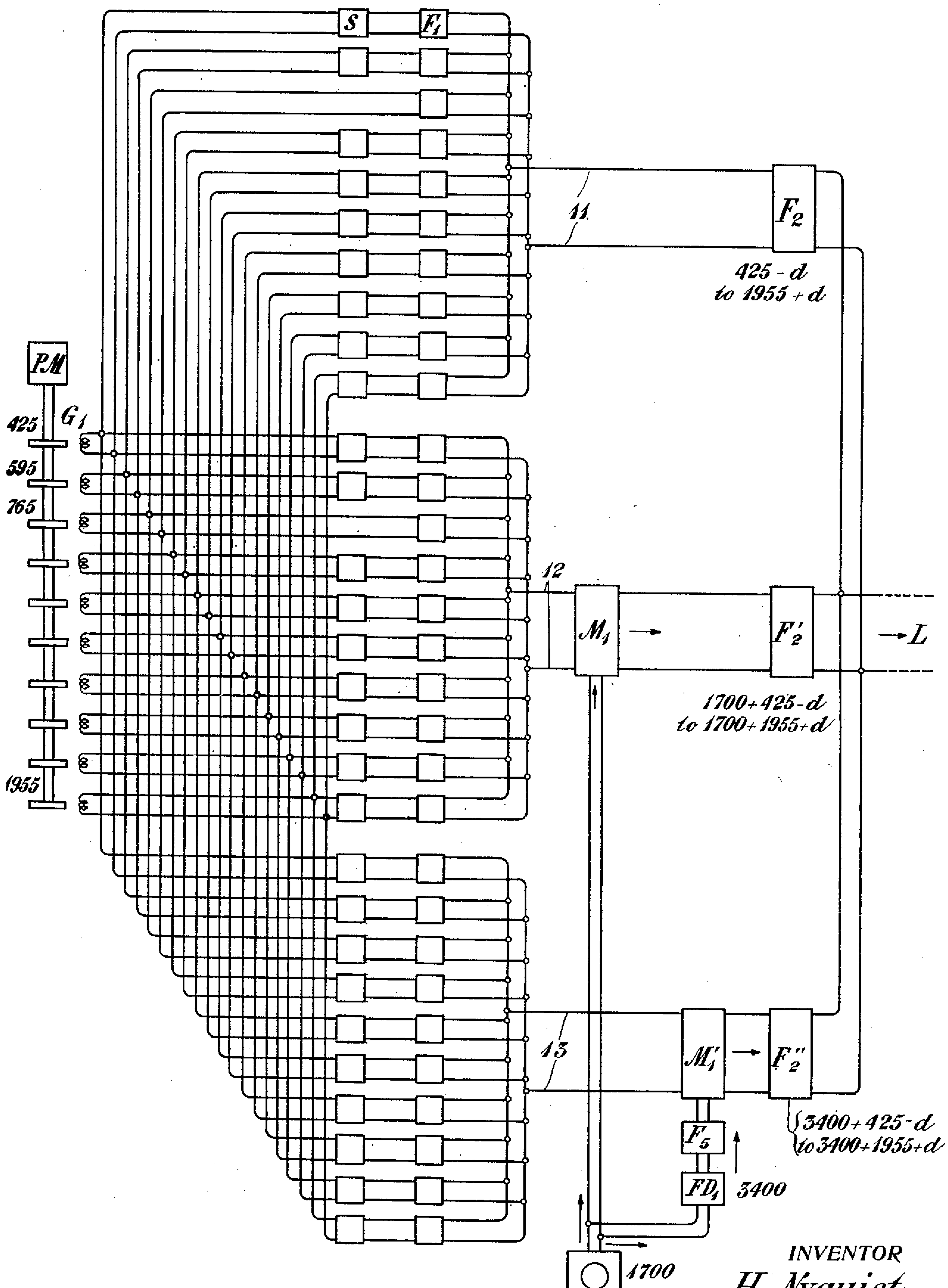

Fig. 1

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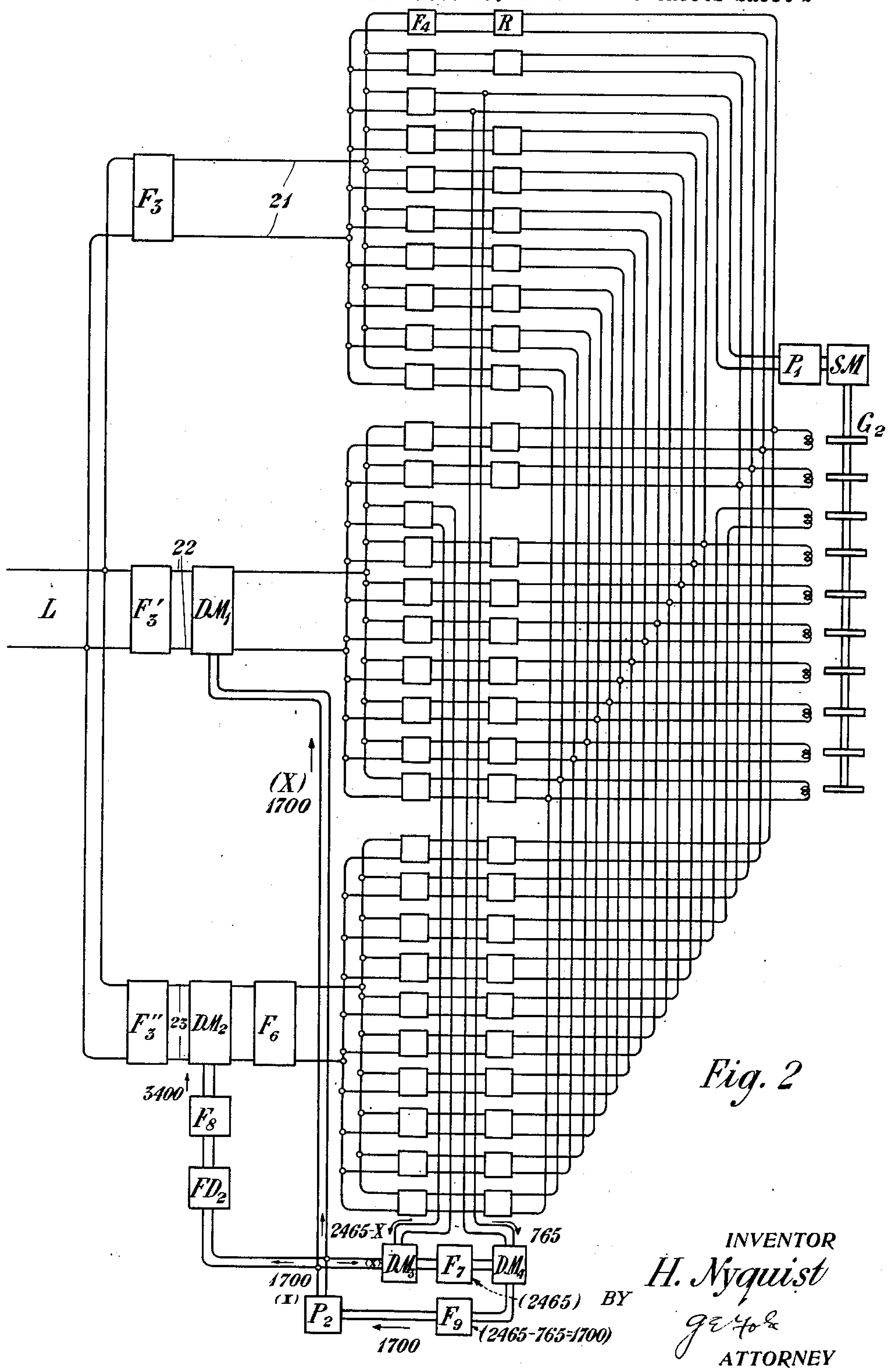

Fig. 2

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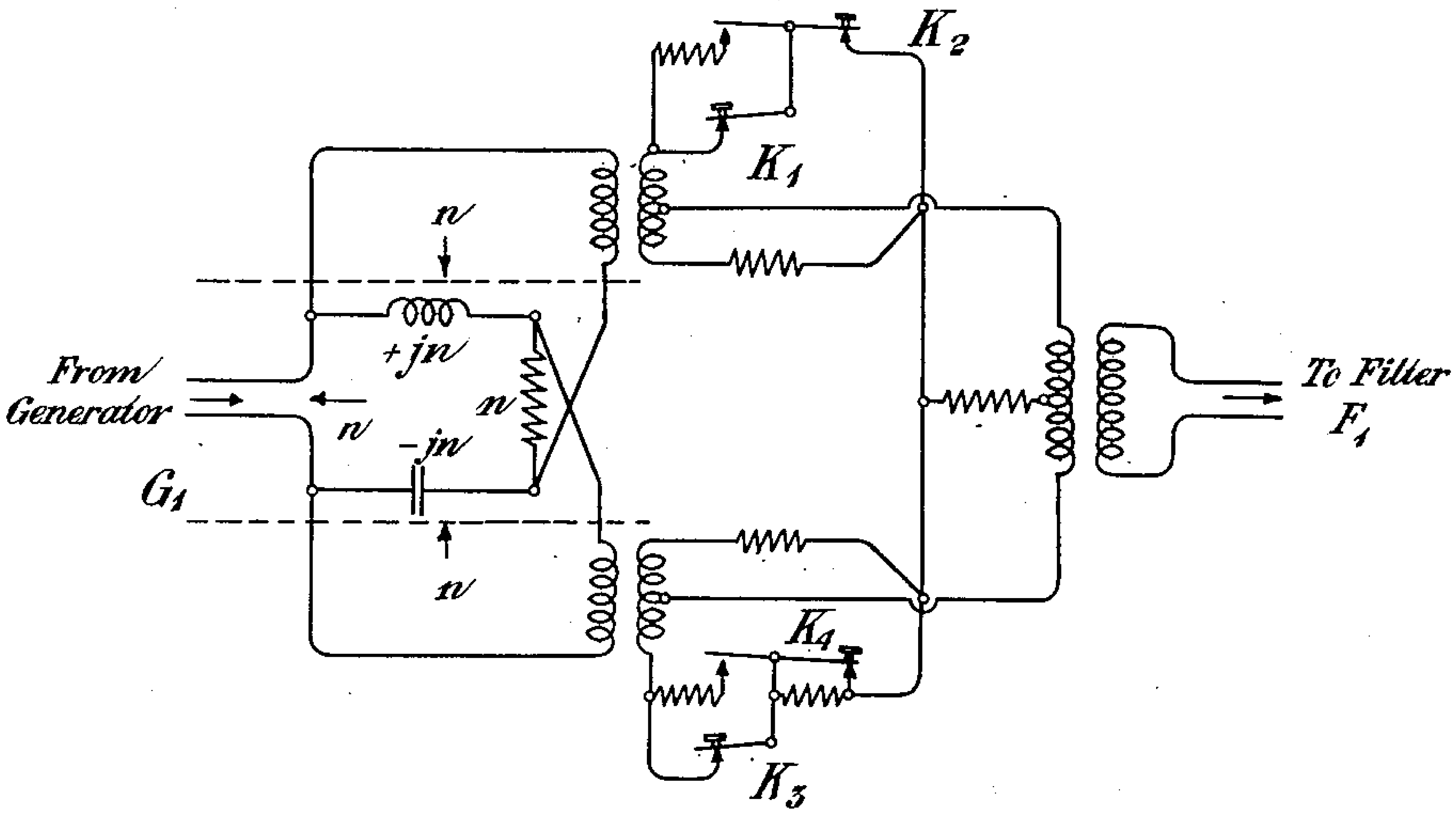

Fig. 3

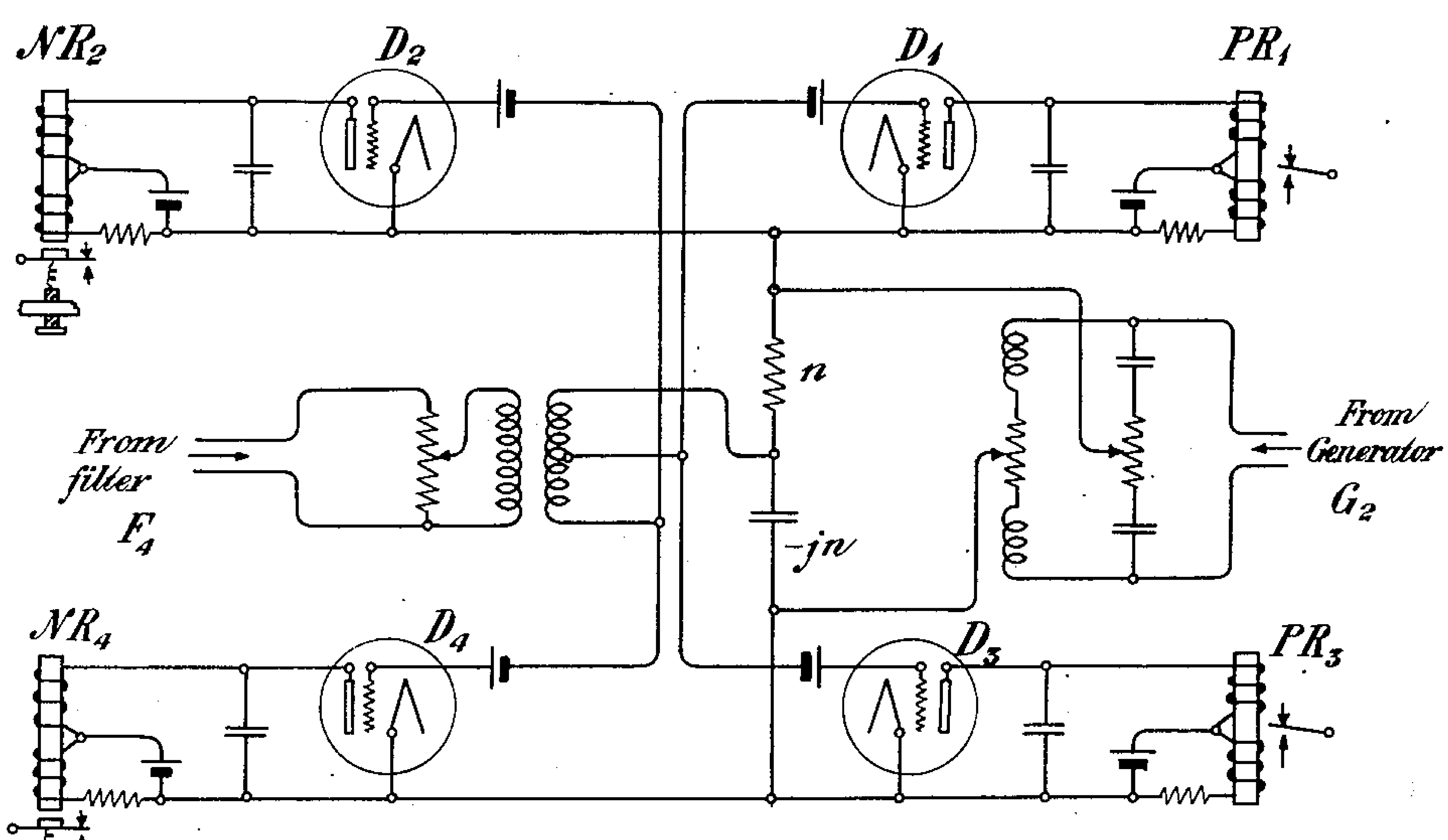

Fig. 4

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Patented Mar. 1, 1927. **1,619,085**

UNITED STATES PATENT OFFICE

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CARRIER-CURRENT SIGNALING SYSTEM.

Application filed February 29, 1924. Serial No. 696,050.

An object of my invention is to provide a new and improved system for the transmission of a plurality of messages on a single circuit. Another object of my invention is to provide for accurate and effective synchronization of the apparatus at the sending and receiving stations in a multiplex carrier current signaling system. Another object of my invention is to provide for definitely distinguishing the different carrier frequencies over a wide frequency range. These and various other objects of my invention will become apparent on consideration of the specific example which I have chosen to illustrate the invention and which I now proceed to disclose in the following specification, taken with the accompanying drawings. It will be understood that this disclosure relates to this particular example of the invention and that the scope of the invention is to be determined by the appended claims.

Referring to the drawings, Figure 1 is a diagram of a transmitting station, Fig. 2 is a diagram for a corresponding receiving station, Fig. 3 is a diagram of a sending network, and Fig. 4 is a diagram of a receiving network.

At the sending station shown in Fig. 1, the constant speed motor PM drives ten alternating current generators G_1, which may be inductor alternators. These generate currents of frequencies 170 cycles apart so that with the first generator giving 425 cycles per second, the next gives $425+170=595$ cycles per second, and so on up to $425+9\times170=1955$ cycles per second. From each of these generators G_1 (with one exception presently to be noticed), conductors lead in multiple to three sending networks S. One of these networks is shown more fully in Fig. 3. In this network the received current is resolved into two components 90 degrees apart, and each of these components is modulated by two keys K_1 and K_2 or K_3 and K_4, one of them to reverse the phase of the corresponding component and the other to change its magnitude. Thus, each sending network S corresponds to a single carrier frequency which is modulated in four respects so as to carry four messages.

It will be seen that there would be 30 of these sending networks S in Fig. 1, except that two of them, the third and the thirteenth from the top, are omitted for a purpose which will be explained presently. The respective output currents from these sending networks S go through sending filters F_1, whose output terminals are connected in parallel to the respective conductor pairs 11, 12 and 13. The currents gathered in conductors 11 are passed through the sending filter F_2, which passes frequencies $425-d$ to $1955+d$, where d is half of the band width for each of the filters F_1. Evidently, d has a value somewhat less than half of 170.

An oscillation generator O is provided, whose output frequency is as nearly as practicable 1700 cycles per second. Its output current of frequency 1700 goes to the modulator M_1, where it is combined with the currents of frequencies within the range from $425-d$ to $1955+d$ in the conductors 12. The output from the modulator M_1 goes to the filter F'_2, which passes the upper side band of frequencies, that is, from $1700+425-d$ to $1700+1955+d$.

The output from the oscillator O also goes to the frequency doubler FD_1 and its output goes through the filter F_5, which passes the frequency 3400 to the modulator M'_1. Here, the 3400 frequency is combined with the currents gathered in the conductors 13, and the corresponding filter F''_2 passes the upper side band of frequencies, namely, those from $3400+425-d$ to $3400+1955+d$.

The output currents from the three filters F_2, F'_2 and F''_2 go to the line L, which may be a loaded line with amplifying repeaters at suitable points. Transmission on this line is only one way, and the line may be one pair of a four-wire system.

At the receiving station shown in Fig. 2, the currents coming in on the line L are separated into three frequency ranges by the respective filters F_3, F'_3 and F''_3 these being band-pass filters with ranges corresponding respectively to those of the filters F_2, F'_2 and F''_2 at the sending end. Under some circumstances the filters F_2 and F_3 may be omitted. It will be understood that coming in over the line L are 30 carrier currents, of which 28 are modulated in such a way that each of these may carry as many as four different messages. Ten of these carrier currents go through the filter F_3, whose output conductors are 21, ten more go to the filter F'_3, whose output conductors are 22, and the remaining ten to the filter F''_3, whose output conductors are 23. The conductors 21 lead by multiple branches to the filters F_4, each of band width 2d and each corresponding to a single carrier current and to one of the sending filters F_1. To receive the output from each of the 30 filters F_4 is a receiving network R, except that for two of the thirty channels, such networks are omitted, as will be explained presently.

Each receiving network R also receives from a local source a pure sine wave alternating current of the corresponding carrier frequency, and reception is by the homodyne method. Each such receiving network may have four relays and four respective detectors, all as shown in Fig. 4. Each of the four detectors D_1, D_2, D_3 and D_4 responds to one, and one only, of the four messages carried on the carrier current of the corresponding frequency, as determined by the respective key K_1, K_2, K_3 or K_4 at the sending end. PR_1 and PR_2 are polar relays and NR_2 and NR_4 are marginal neutral relays.

It is important that accurate frequency and phase relations shall be maintained between the sending station of Fig. 1 and the receiving station of Fig. 2. The generators G_2 at the receiving station are driven by the synchronous motor SM, which receives its current from a power tube generator P_1. The input current that controls the frequency of the power tube generator P_1 is the received carrier current of frequency 765 cycles per second. It will be seen that the receiving network for this frequency is omitted and that the current goes directly from the filter F_4 to the power tube P_1. At the sending end, the corresponding network is also omitted so that the current of this frequency 765 cycles per second goes on the line as a pure sine wave current, unmodulated by any message.

In relation to the receiving system of Fig. 2, we have thus far traced only the output of the filter F_3 in the output conductors 21. The outputs from the other two filters F'_3 and F''_3 on the respective conductors 22 and 23 go to demodulators DM_1 and DM_2, in which they are combined with locally generated currents of respective frequencies 1700 and 3400 cycles per second. The 1700 cycle current at the receiving station is generated by a tube P_2. In the drawing, the output of the tube P_2 is also marked x as well as 1700 to facilitate discussion of how this output frequency is determined.

It will be seen that at the sending station the sending network has been omitted at the thirteenth position from the top, that is, for the frequency 765 in the second group. By means of the modulator M_1 at the sending station this frequency of 765 is raised to $1700+765=2465$, and put on the line, and it will readily be traced that this particular frequency is present as a pure sine wave component in the currents in the conductors 22. In the demodulator DM_1 this frequency is combined with the frequency x from the power tube P_2 so that the frequency appearing in the output of the corresponding filter F_4, the thirteenth from the top in Fig. 2, is $2465-x$. This goes to the demodulator DM_3, where it is combined with the frequency x from the power tube P_2, so that one component of the output of the demodulator DM_3 is the pure frequency 2465. This is passed by the filter F_7 to the demodulator DM_4, where it is combined with the frequency 765 received directly through the third filter F_4 from the top in Fig. 2. The output from the demodulator DM_4 comprises a component of the frequency

$$2465-765=1700,$$

which is passed by the filter F_9 and goes therefrom to control the frequency of the power tube P_2. Thus, it is determined that the output from power tube P_2 has the frequency 1700, in other words, $x=1700$. Accordingly, in the demodulator DM_1 1700 is subtracted from the frequencies coming in from the line, and the resulting frequencies passed by the corresponding filters F_4 range from $425-d$ to $1955+d$.

The 1700 cycle output from the power tube P_2 also goes to the frequency doubler FD_2 and thence through the filter F_8, giving a frequency of 3400 for the demodulator DM_2. From what has gone before, it will readily be seen that the frequencies in the conductors 23 range from $3400+425-d$ to $3400+1955+d$ and are all reduced by 3400 and then delivered to the corresponding filters F_4 and receiving networks R.

This explains how the tube P_2 is made to supply the proper frequency during the operation, but does not account for its starting initially. To insure this the tube P_2 is equipped with a feed back circuit such as is common in vacuum tube oscillators and which is so adjusted that when there is no current delivered from F_9 the tube oscillates gently at approximately 1700 cycles. This is enough to start the cycle described above and when it is once started the frequency is determined by the frequencies delivered from the line.

In the system which is here disclosed it will be seen that I make use of phase discrimination at all frequencies within the range of the system. Phase discrimination becomes increasingly difficult as the frequency is increased on account of the difficulty of providing a synchronous source at the receiving end. This difficulty is overcome by the system shown, in which the synchronous motor SM at the receiving end and the power tube P_2 at the receiving end are kept accurately in step respectively with the motor M_1 at the sending end and the oscillation generator O at the sending end.

It will be seen that the filters F_1 at the sending end and F_4 at the receiving end are of narrow band width. When a filter of narrow band width is employed for a high frequency, it is somewhat difficult to secure accurate adjustment. For example, it is easier to adjust a filter to a band width of 170 when the mean frequency is 1955 than when the means frequency is 3400+1955. It will be seen that in the system here disclosed, the filters mentioned F_1 and F_4 run no higher in mean frequency than 1955 at the sending end and likewise at the receiving end. At each end there are three groups of filters, with ten in each group, and the groups are alike. Thus, the difficulty is obviated of attempting to secure adjustment for the narrow band width filters at high mean frequencies.

I claim:

1. The method of generating and transmitting a plurality of currents of different respective frequencies, which consists in generating the currents of lower frequency in primary generators and delivering them to at least three multiple branch circuits and in certain of the multiple branches from each generator applying them to modulate other currents of different respective frequency values and separating out by filters the modulation product currents of frequency higher than those generated at the outset, and superposing the currents in all said multiple branches in a transmission line.

2. The method of multiplex carrier current transmission, which consists in modulating low frequency alternating currents, more than two of each frequency, according to respective messages, applying one set of these currents of different frequency directly to the line and applying other sets to modulate other currents different from each other in frequency and then filtering out the higher frequency components and applying them also to the line.

3. In combination, a plurality of alternating current generators of different frequency, at least three branch circuits from each, means to modulate one set of currents according to messages to be sent and to put the modulated currents on a transmission line, means to modulate other similar sets similarly and then to step them up in frequency of different amounts and also put them on the same line.

4. A transmission line, a plurality of generators of comparatively low frequency alternating current, at least three branch circuits from each such generator, means to modulate one set of currents of different frequency in one set of branch circuits according to messages to be sent and put such currents on the line, means similarly to modulate the currents in other similar sets of branch circuits, and means further to apply such currents collectively to modulate other currents of different frequencies and filter out from the modulation product currents, a higher range of frequencies than that delivered by the generators and put them also on the line.

5. In combination, alternating current generators of a variety of comparatively low frequencies, at least three multiple branch circuits from each, similar means to modulate these currents in each branch, a transmission line, means to put one set of modulated currents corresponding to the various generators directly on the line, and means to step up each other similar set of modulated currents to respective different higher frequencies and also put them on the line.

6. In a multiplex carrier current transmission system, a transmission line, at least three receiving filters to separate the various modulated carrier currents into as many groups with a plurality of different frequencies in each group, means to step the currents down to lower frequency in each group of higher frequency, and respective detectors for the respective carrier channels at these lower frequencies.

7. The method of multiplex carrier current transmission, which consists in generating currents of various definitely related frequencies, modulating them in accordance with messages to be transmitted, generating another current, modulating this with the output message bearing currents, filtering and transmitting a range of frequencies higher than those generated initially, also transmitting two unmodulated frequencies, and at the receiving end applying one of these to determine the local generation of a set of currents corresponding in frequency to those initially generated at the sending end and also at the receiving end applying the other unmodulated current to determine the frequency of a local generator corresponding in frequency to the single generator at the transmitting end.

8. The method of multiplex carrier current transmission, which consists in modulating low frequency alternating currents, at least three of each frequency, according to respective messages, applying one set of these currents of different frequency directly to the line and applying the other such sets to modulate other different frequency currents and then filtering out the higher frequency components and applying them also to the line, and at the receiving end separating these sets of currents by filters and stepping down the frequencies of the currents of higher frequency and applying all said currents to respective detectors.

9. In combination, a plurality of alter-

nating current generators of different frequency, at least three respective branch circuits from each, means to modulate one set of currents according to messages to be sent and to put the modulated currents on a transmission line, means to modulate each other similar set similarly and then to step them up in frequency by different amounts and also put them on the same line, and at the receiving end filters to separate the said sets of currents, means to step down the currents of the set of higher frequency, and respective detectors for the currents.

10. The method of signaling, which consists in simultaneously stepping up each of a plurality of signaling bands in the frequency spectrum from substantially the same level by respectively different amounts to different levels and then combining the resultant bands at such different levels.

11. The method of signaling, which consists in transmitting a band of frequencies corresponding to a signal but elevated in the frequency spectrum with respect to the normal signaling range, transmitting with said band other signaling bands likewise elevated but to different levels of the frequency spectrum, filtering said bands at different levels into different circuits, and stepping down simultaneously all said bands to the same orignal normal signaling range.

12. The method of multiplex telegraph signaling, which consists in generating carrier currents of various frequencies, distributing such currents to a plurality of groups of sending networks, each frequency of current being distributed to a respective network in each group, modulating these currents in said networks each according to four messages distinguished by phase and by magnitude, superposing and transmitting the output currents from one group, stepping up the frequencies of the output currents of the other groups by a different amount for each such group and superposing and transmitting these currents of stepped-up frequency along with the others, and at the receiving end separating the groups by filtering, further separating the frequencies of the said one group by filtering and delivering the filtered output currents to respective receiving networks, stepping down the frequencies of the other groups by the amounts by which they were stepped up at the sending end, separating the frequencies of these groups by filtering and delivering the filtered output currents to other respective receiving networks.

13. The method of multiplex telegraph signaling, which consists in generating carrier currents of various frequencies, distributing such currents to a plurality of groups of sending networks, each frequency of current being distributed to a respective network in each group, modulating these currents in said networks each according to four messages distinguished by phase and by magnitude, superposing and transmitting the output currents from one group, stepping up the frequencies of the output currents of the other groups by a different amount for each such group and superposing and transmitting these currents of stepped-up frequency along with the others.

14. The method of carrier current signaling, which consists in message-modulating respectively each of at least three currents of the same low frequency, simultaneously stepping all but one of them up to different levels of frequency, transmitting them, separating them at the receiving end by filters according to the frequency levels, stepping down those of higher frequency level to the original level, and detecting the messages in each corresponding message channel.

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

HARRY NYQUIST.