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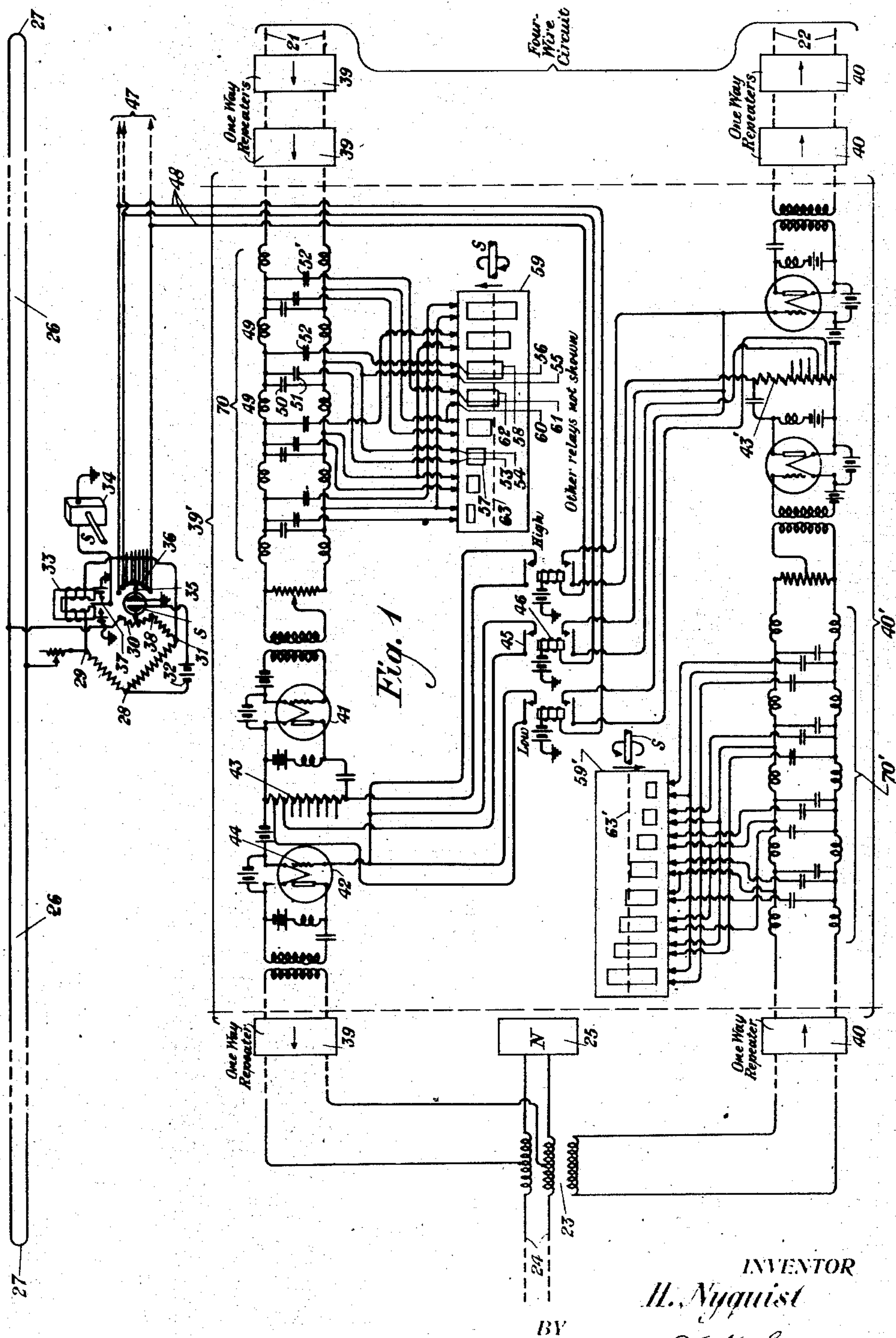
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**H. NYQUIST**

## PHASE REGULATING SYSTEM

Filed March 26, 1926

2 Sheets-Sheet 1



**INVENTOR**

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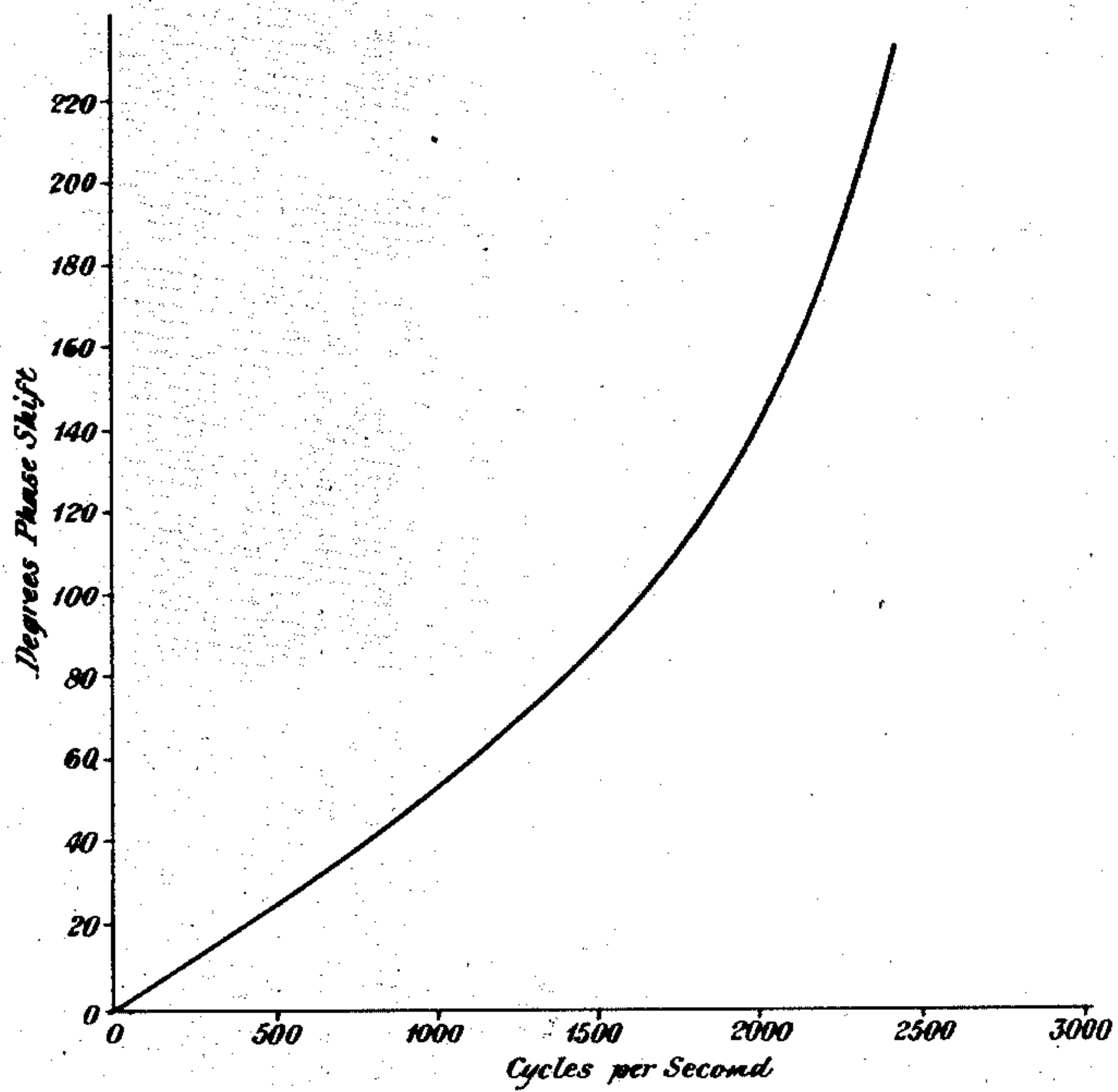
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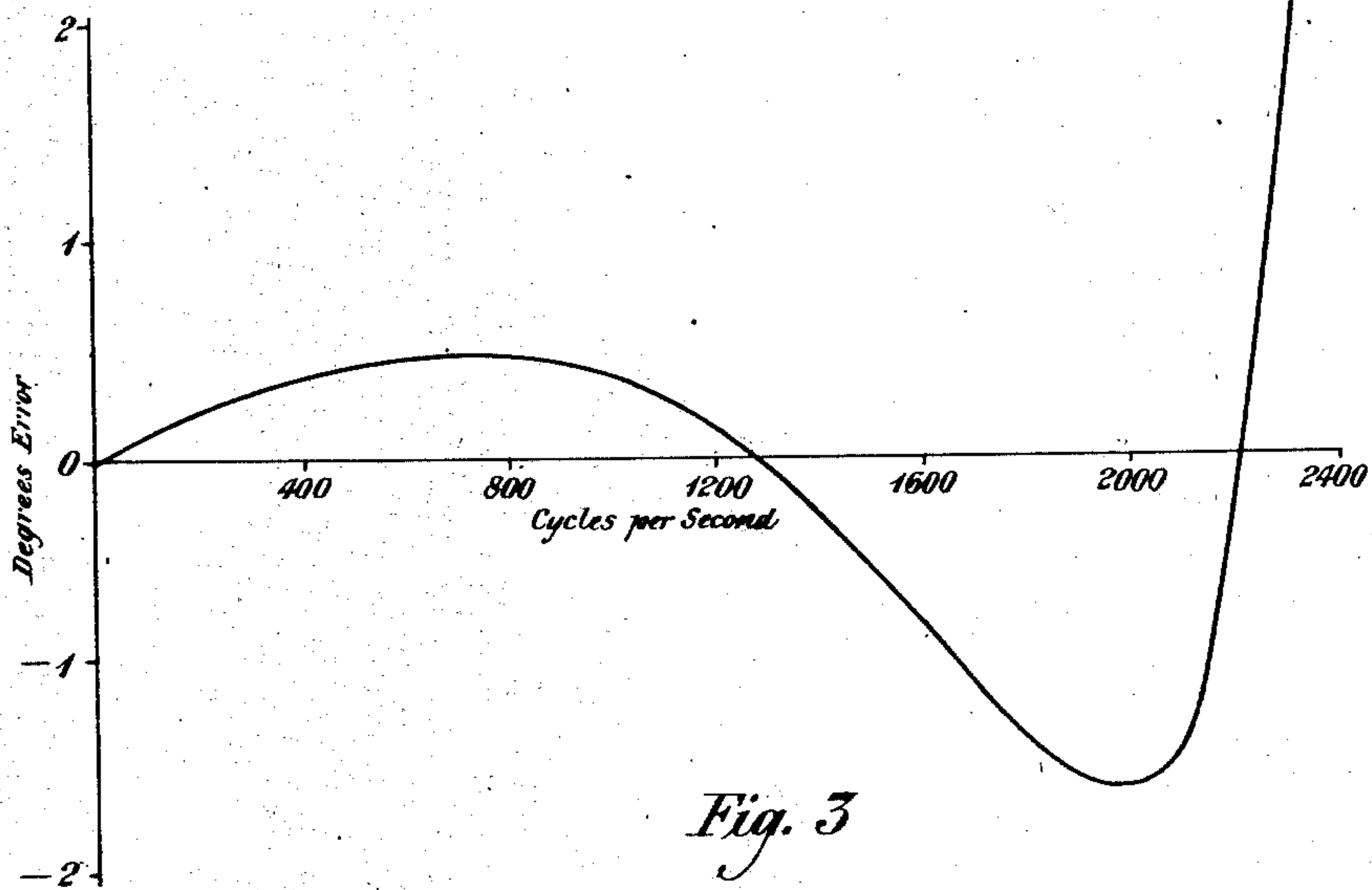
PHASE REGULATING SYSTEM

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2 Sheets-Sheet 2



*Fig. 2*



*Fig. 3*

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# UNITED STATES PATENT OFFICE.

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## PHASE-REGULATING SYSTEM.

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It is an object of my invention to provide apparatus and method for compensating relative phase shift among various carrier current components in a multiplex signal system. Another object of my invention is to provide compensation for phase shifts due to changes in the distributed capacity along a transmission line; such changes of capacity may be caused by changes of temperature along the line. Another object of my invention is to provide compensation for both resistance changes and capacity changes caused by temperature changes along a transmission line. Another object of my invention is to provide a network system at a repeater station on a multiplex signal transmission line and to provide automatic adjustment thereof to compensate relative phase shifts caused by resistance and capacity changes along the line caused in turn by temperature changes along the line. These objects of my invention and others will become apparent on consideration of an example of practice according to the invention which I have chosen to disclose in this specification. It will be understood that the following description relates to this particular example of the invention and that the invention will be defined in the appended claims.

Referring to the drawings, Figure 1 is a general diagram showing a system with which my invention may be practiced; and Figs. 2 and 3 are curve diagrams that will be referred to in explaining the principles involved in this connection.

For a specific example of a situation in which my invention may be employed advantageously, consider a plurality of loaded line circuits extending a long distance and comprised within one cable. In addition to the loading coils at proper intervals, there will be repeaters in these lines at greater intervals. Some of the conductor pairs will be appropriated to respective signaling circuits with 22-type repeaters, and other conductor pairs will be employed in "four-wire circuits". Since the circuits are all loaded lines, they will all cut off at frequencies somewhat above the essential voice frequency range. Some of these circuits of voice frequency range may be employed for multiplex telegraph signaling. In this case, various different frequencies throughout the range will afford respective message channels, and these different frequencies will all be super-

posed in one conductor pair. Each component current of a single frequency may be split into two components  $90^\circ$  apart in phase, and signals may be transmitted on each component by phase reversals thereof. Locally generated currents at the receiving end will be employed, corresponding in frequency and in phase with the various current components received on the line. To maintain this correspondence of phase between the received currents and the locally generated currents, it will be important to prevent relative phase shifts from time to time in the received currents.

The circuits in the cable will be subject to temperature changes from time to time, and these changes will have two effects on the electrical characteristics of any circuit in the cable. An increase of temperature will increase the resistance of the circuit and will also increase the distributed capacity between the conductors of the circuit. Such changes will tend to produce relative phase shifts among the component currents of various frequencies. By my invention it becomes possible to compensate such changes, so that there shall be no substantial change in attenuation nor in relative phase shift of the received currents on the circuit referred to.

Referring to Fig. 1, this shows a four-wire circuit on the right consisting of the two conductor pairs 21 and 22. These are connected through the usual hybrid coil arrangement 23 with the two-wire circuit 24 on the left, which is balanced by the network 25.

These circuits 21, 22 and 24 are all loaded lines comprised with many other circuits in a single cable. Also in the same cable is a circuit comprising another pair of conductors 26, like the ordinary conductors of the cable. At distant points on each side, perhaps several repeater stations away, the ends of the conductors 26 are joined as at 27 to form loops.

The two loops in parallel form one side or arm of a Wheatstone bridge between the vertices 29 and 30. The opposite side of the bridge is the resistance 28—31, and the two remaining sides of the bridge are 28—29 and 31—38—30. The energy of the battery 32 is applied across the two opposite vertices 28 and 30. It will be seen that the point 30 is a contact arm which is adjustable by the rotation of the shaft S. The output bridging member extending across the vertices 29 and



31 comprises the polarized relay 33 whose armature 37 shifts one way or the other to apply positive or negative battery to the motor 34 that rotates the shaft S.

5 This shaft S carries the contact arm 30, as already mentioned, and also a contact arm 35 that engages some one of a row of contact points 36.

10 An increase of temperature on the line increases the resistance of the pilot wire circuit 26 and unbalances the bridge. The resulting current from the battery 32 in the relay 33 shifts its armature 37 and applies positive or negative battery to the motor 34 which rotates the shaft S and shifts the contact 30 in a suitable direction to reestablish the bridge balance, upon the occurrence of which condition the armature 37 opens its contact and stops the operation of the motor 20 34. The direction of rotation of the shaft S for an increase of temperature is clockwise, looking at the contact arms 30 and 35 in Fig. 1.

25 The four-wire circuit comprising the two conductor pairs 21 and 22 is equipped with the usual one-way repeaters 39 and 40. The regulator now being described is associated with one pair of such repeaters 39' and 40' at a single station. The one-way 30 repeater 39' comprises the amplifier of two stages 41 and 42. At the input of the amplifier 42 is a potentiometer 43, and connection is made from one or another of its various contact points to the grid 44, through 35 the closure of a corresponding relay armature 45. The armatures, such as 45, are controlled by respective relays such as 46, and the circuit conductors 48 for these relays extend respectively therefrom to the respective 40 contact points 36 that have already been mentioned in connection with the contact arm 35 of the shaft S. The set of relays such as 45 and the conductors 48 are for the particular four-wire circuit 21, 22; branch 45 conductors 47 go to corresponding relays for regulating other circuits in the same cable.

In tandem in the line 21 is an artificial line 70 comprising series inductances 49 and alternately disposed shunt capacities 50. 50 Each pair of inductance coils 49 on the two sides of the lines has substantially the same inductance value as in a load coil on the line, and each shunt condenser 50 has a capacity somewhat less than the shunt capacity of a 55 section of the line between load coils. Associated with each shunt condenser 50 are two other condensers 51 and 52, and the capacity of condenser 50 and one of these two condensers 51 or 52 in parallel across the 60 line is substantially the same as the normal shunt capacity of a section of the line between load coils at an ordinary intermediate temperature, but the capacity of all three condensers 50, 51 and 52 in parallel is 65 greater than of such a line section. As will

be seen from the drawing, the condenser 50 stands permanently across the line, but each of the condensers 51 and 52 is operatively connected across the line only when its contacts 53, 54 or 55, 56 rest on the corresponding plate 57 or 58 of the controller 59. This controller 59 is on the same shaft S that carries the contact arms 30 and 35 and is turned by the motor 34. The shaft S carries similar controllers for other circuits in the same 75 cable.

Associated with line 22 are a potentiometer 43', an artificial line 70' and a controller 59' corresponding respectively to the elements 43, 70 and 59 associated with line 21. 80

It has already been pointed out that an increase of temperature along the cable increases the resistance of the pilot wire loops 26 and causes the shaft S to rotate clockwise as viewed where it carries the contact arms 85 30 and 35. This same clockwise direction of rotation is indicated by the arrows adjacent to the controllers 59 and 59'.

The contacts such as 53, 54, 55 and 56 for the controller 59 and the corresponding con- 90 tacts for the controller 59' are assumed to be positioned along the horizontal dotted lines 63 and 63' shown across those controllers. The increase of temperature along the cable already referred to and the corresponding 95 increase of the resistance of the pilot wire circuit 26 and the resulting clockwise rotation of the shaft S will carry the pair of contacts 60, 61 off the controller plate 62 and thus remove the condenser 52' from across 10 the line, decreasing by so much the shunt capacity of the sectional artificial line. Thus it will be seen that the increased capacity across the line due to the increase of temperature is compensated by the decrease 15 of capacity in the sectional artificial line.

At the same time the clockwise rotation of the shaft S shifts the contact arm 35 from one point to the next of the series of contact points 36 and takes the current off from one 1: relay 46 and puts it on the next relay 46, thus effectively changing the connection of the grid 44 to the next lower point of the potentiometer 43. This puts a higher electro- 1 motive force on the grid 44 and gives an increased over-all amplification factor for the repeater and compensates the attenuation and phase shift due to the increased resistance on the line caused by the increase of 1 temperature.

The steps of the potentiometer 43 are shown symbolically in the figure, and for accuracy in maintaining the phase shift unchanged they will each be properly designed resistance and reactance networks, and not 1 mere simple resistances, though approximate compensation for attenuation may be effected if these potentiometer steps are all mere ohmic resistances, and approximate compensation for phase shift can also be se-



cured even though the only reactance is in the end step of the potentiometer.

An inspection of Fig. 1 will show that with increase of temperature on the line and clockwise rotation of the shaft S from the position indicated by the dotted line 63 the condensers such as 52 will be cut off successively from right to left. On the other hand, with decrease of temperature on the line and consequent counterclockwise rotation of the shaft S the condensers such as 51 will be operatively connected in succession from right to left.

As a reasonable example for illustrative purposes, it may be assumed that the capacity across a conductor pair of a cable increases five parts in 10,000 for every degree centigrade rise in temperature. The resultant relative phase shift will be greater in a medium heavy loaded cable than in an extra light loaded cable, and the medium heavy loaded cable will be assumed for illustrative purposes. Assume that the circuit in this cable is being operated for multiplex telegraphy on channels given by frequencies from 425 to 2295 cycles per second in odd multiples of 85, that is, the channel frequencies run 425, 595, 765 . . . 1275 . . . 1955, 2125 and 2295. Assume further that the current of intermediate frequency, 1275 cycles per second, is applied at the receiving end to synchronize the local source at that end. It follows that there will be no relative phase shift for this particular frequency however the temperature may change on the line; the local source will be in synchronism with the received current of this frequency, because such received current determines the synchronism.

The adjustment is intended to be such that at an intermediate temperature all the other frequencies will be in appropriate synchronism. At this intermediate temperature all the condensers 51 will be connected across the artificial line, but the condensers 52 will be disconnected. Each pair of condensers 50 and 51 has a combined capacity equal to the capacity of a line section between load coils.

As the temperature along the line departs from the assumed intermediate value, there will be a relative phase shift among the component carrier currents on the line, but of course the temperature change along the line will not have any effect on the phase relations of the locally generated currents at the receiving end.

By my invention the relative phase shifts of the currents on the line will be compensated, so as to keep the received currents in an unchanging phase relation.

As to the magnitude of the relative phase shift that may be caused by considerable temperature changes, attention is directed to the curve of Fig. 2. This is based on an as-

sumed line of medium heavy loaded side circuit with 159 load coils. According to the data that have been set forth earlier in this specification, a temperature change of 55° Fahrenheit will cause a change of 1.528 per cent in the capacity across the two conductors of this line. Fig. 2 shows the phase shift in degrees for the currents of various frequencies in this line caused by such a capacity change due to a temperature change of 55° Fahrenheit. For example, it will be seen that the current component of 765 cycles per second will have its phase shifted about 39° by this change of temperature; also the current component of 1955 cycles per second will have its phase shifted about 137°. Such changes are seen to be considerable and to require compensation.

Fig. 3 shows the resultant or residual relative phase shifts for this assumed example after compensation as compared with Fig. 2 before compensation. These figures are drawn to different scales. Whereas the relative phase shift without compensation may be as much as +143° at frequency 2000, it is only -1.6° with compensation at the same frequency, and less at all other frequencies within the essential voice range. Fig. 3 is computed for 10.5 sections of artificial line and with each capacity reduced to  $\frac{7}{10}$  its normal value, this normal value being the line capacity between consecutive loads at the normal temperature from which the 55° temperature change was reckoned. A fractional number of sections would not be practicable but 10 or 11 sections would give nearly the same result, provided the total capacity change is kept the same.

I claim:

1. The method of compensating at a repeater for temperature changes on a transmission line equipped with repeaters, and with tandem artificial lines, which consists in increasing the amplification ratio as the temperature rises, and also at the same place decreasing the artificial shunt capacity as the temperature rises, and varying these magnitudes in the opposite direction as the temperature lowers.

2. The method of compensating relative phase shift due to increase of resistance and increase of capacity on a line caused by increase of temperature which consists in increasing the amplification ratio at a repeater station, and at the same place making a decrease in the shunt capacity corresponding to the increase at another place along the line.

3. In combination, a transmission line exposed to temperature changes, and means to compensate for phase shifts due to such changes, said means comprising a potentiometer across the line, a tandem sectional network in the line with shunt capacities, and automatic means to increase the poten-



tiometer output and decrease the shunt capacities as the temperature rises, and vice versa.

4. In combination, a transmission line exposed to temperature changes, a pilot circuit exposed to the same changes, a bridge having this pilot circuit in one arm thereof, and means controlled by the bridge to compensate for phase shifts due to such temperature changes, said means comprising capacities to be cut in or out of parallel connection to the line to compensate for the changes of capacity along the line.

5. In combination, a cable, a circuit and a pilot wire therein, an artificial network comprising shunt capacity connected to said circuit, and means operated by resistance changes in said pilot wire and controlling said shunt capacity to compensate for corresponding capacity changes in the circuit.

6. In combination, a cable, a circuit and a pilot wire therein, an artificial shunt

capacity connected to said circuit, means operated by resistance changes in the pilot wire to compensate for resistance changes in the circuit, and further means controlled by said resistance changes to vary the artificial shunt capacity in accordance with the resistance changes.

7. In combination, a transmission line exposed to temperature changes, a pilot circuit exposed to the same changes, a repeater and a variable capacity associated with the line, a bridge having the pilot circuit in one arm thereof, and means controlled by the bridge to change the amplification ratio and to vary the associated capacity, both in accordance with the resistance change of the pilot circuit.

In testimony whereof, I have signed my name to this specification this 22nd day of March, 1926.

HARRY NYQUIST.