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H. NYQUIST

ARTIFICIAL LINE

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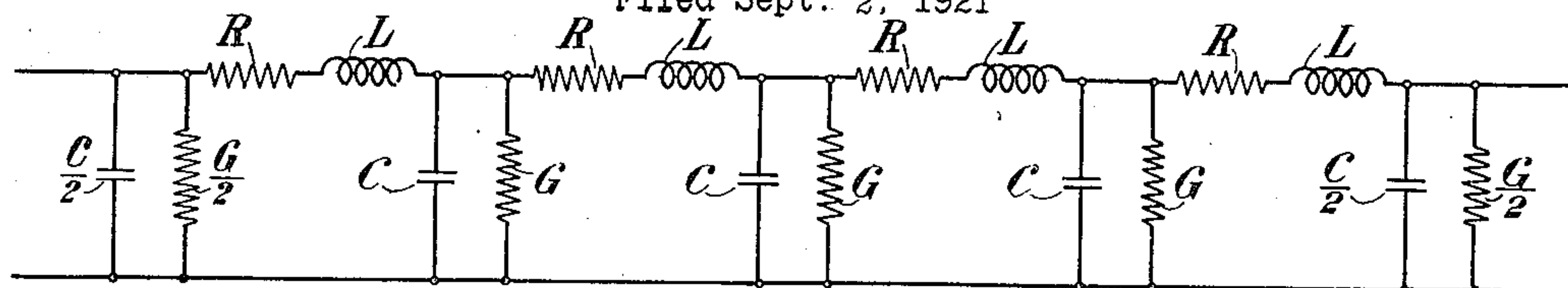


Fig. 1

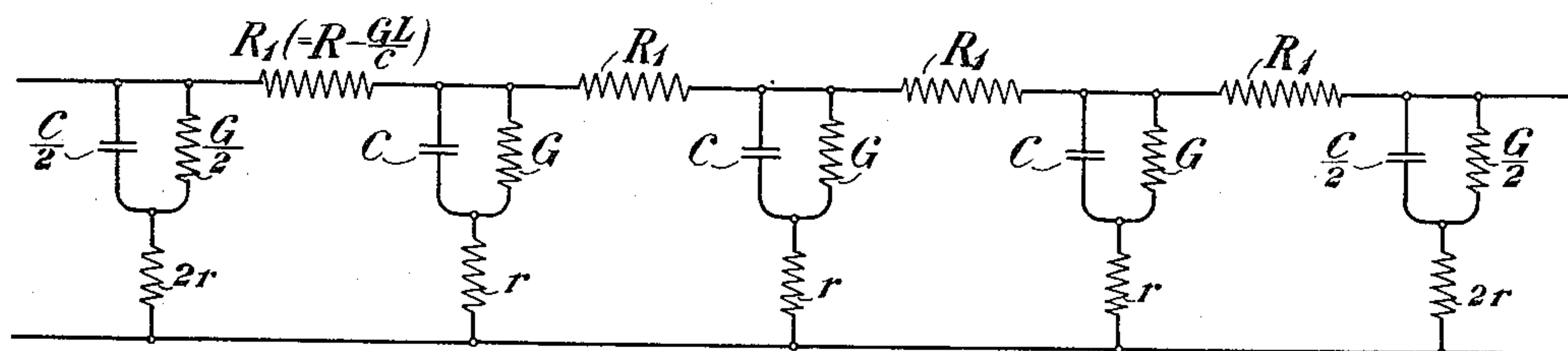


Fig. 2

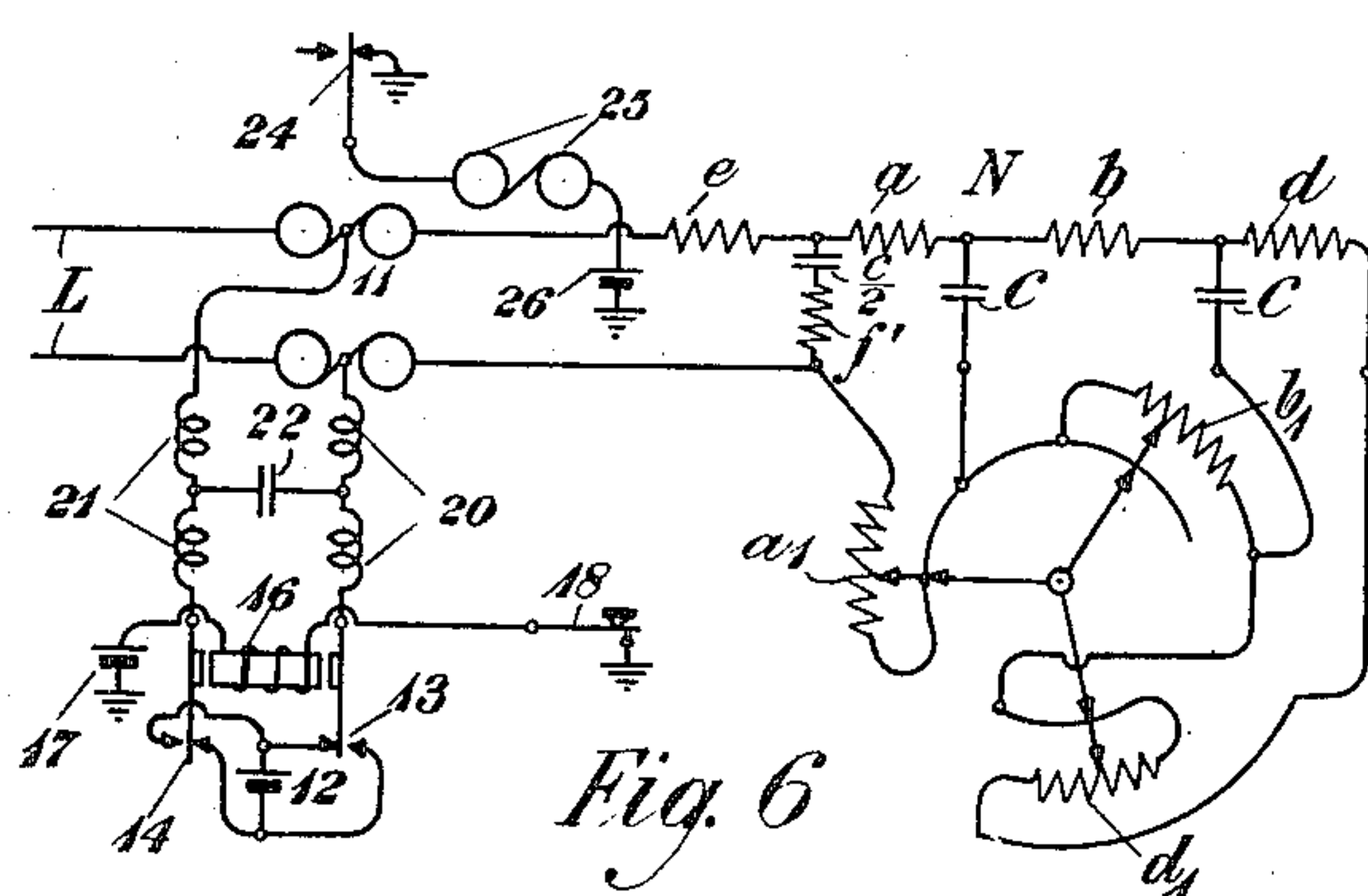


Fig. 6

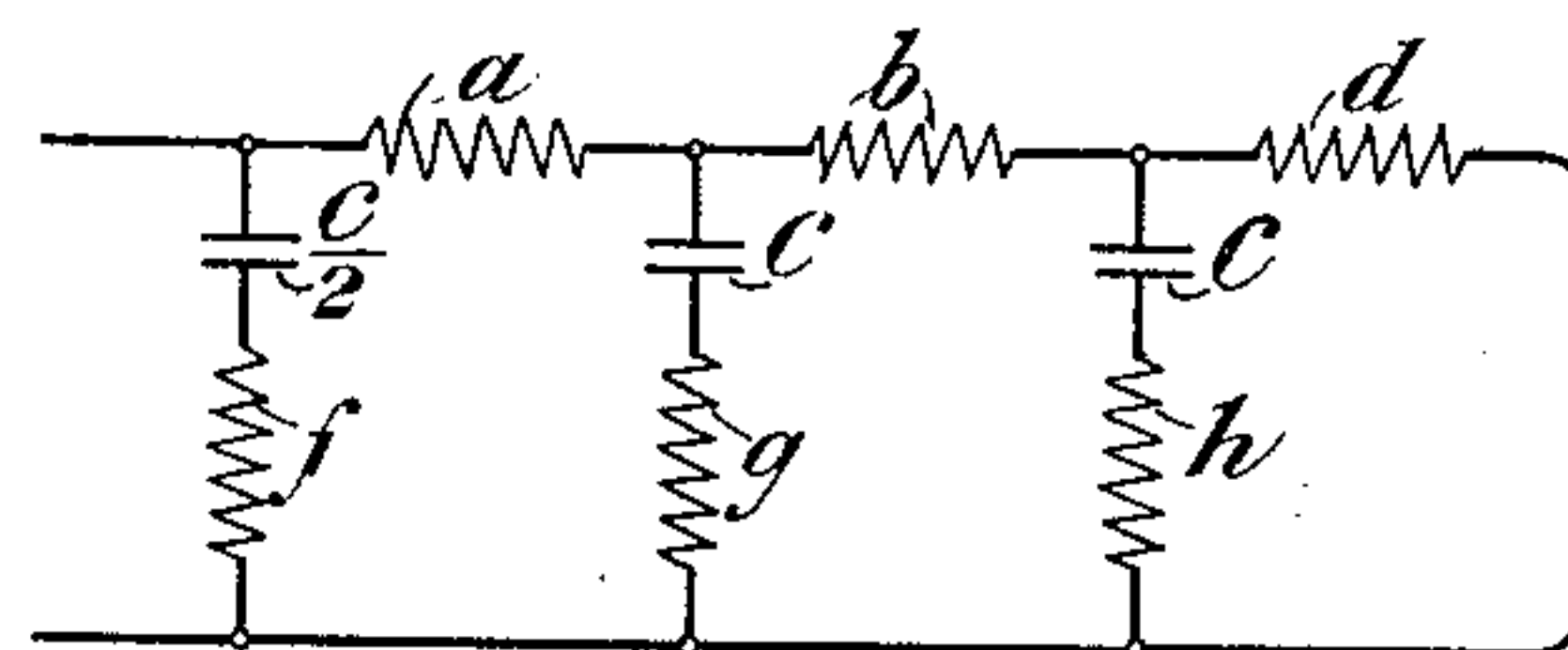


Fig. 3

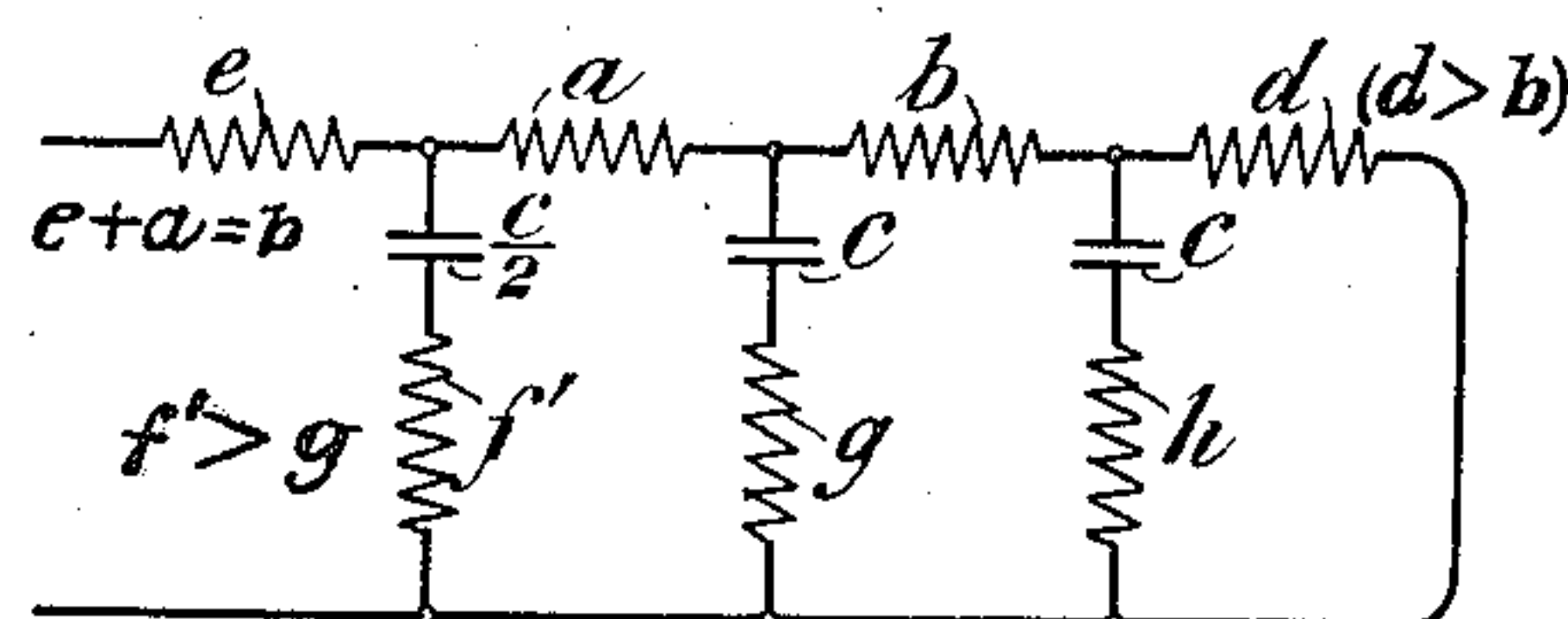


Fig. 4

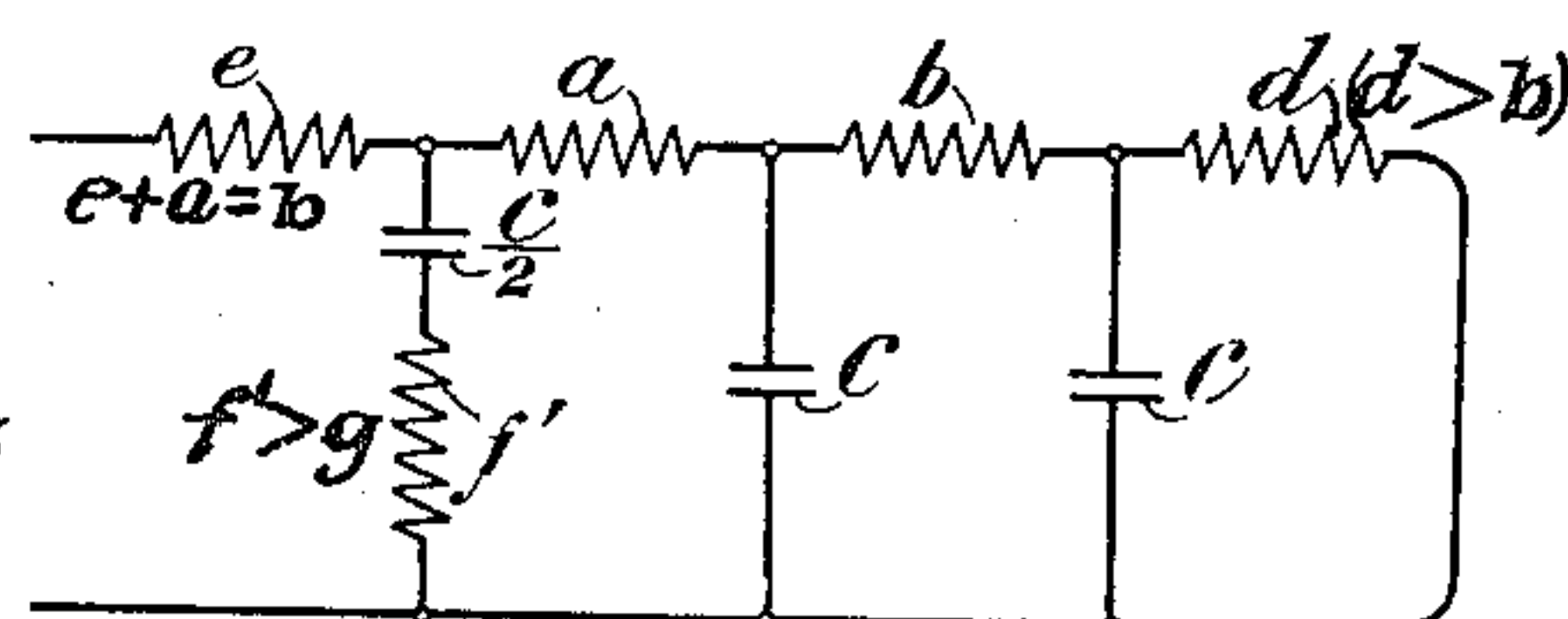


Fig. 5

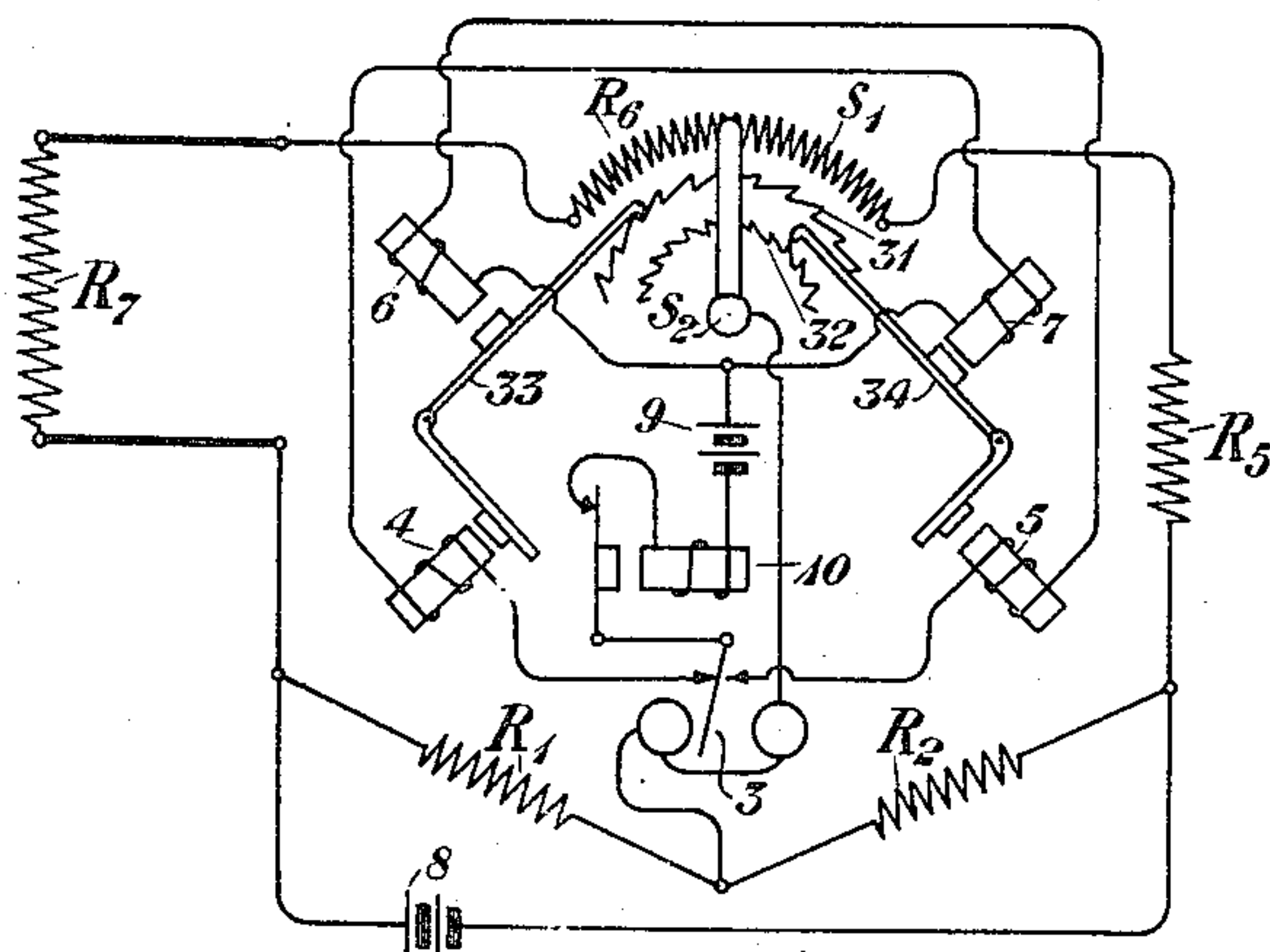


Fig. 7

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UNITED STATES PATENT OFFICE.

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ARTIFICIAL LINE.

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This invention relates to an artificial line for duplex telegraphy and has for one of its objects that of producing an artificial line which consists principally of fixed elements having preassigned values so that a balance may be obtained by the adjustment of a minimum number of elements. A second object is to produce an artificial line which will make possible the maintenance of the balance for the system, although the line itself may undergo various physical changes, such as temperature changes. Still another purpose is to make such an artificial line which can be readily adjusted for temperature or other changes either by a simple and convenient hand adjustment, or by automatic adjustment brought into operation by the changes to be compensated.

Artificial lines for duplex telegraph lines have been used heretofore and arrangements provided to permit adjustments for temperature or other changes taking place over a long length of line, but it has been necessary to include in the artificial line variable capacities and resistances, practically all of which had in general to be adjusted in order to bring about suitable balance. In my invention it is the purpose to obtain this adjustment or compensation by varying resistances only and preferably by varying a minimum number of the resistances involved.

In the case of telegraphy over a pair of wires included in a cable, the only climatic elements which need be considered as affecting the line are temperature changes. These in general produce no substantial effect upon the shunt capacity and leakage of the pair, but do have an important and appreciable effect on the resistances of the pair of conductors themselves, this change being sufficient to vitiate the balance at a given temperature afforded by the artificial line, and it is this change which makes it necessary to adjust from time to time the constants of the artificial line. Since in such a pair of wires the only change which need be considered is that due to the change of resistance of the conductors, it seems that it should be possible with an artificial cable of the proper characteristics to make the necessary corrections on compensations by changes in the series resistance of the artificial line only,

and in accordance with my invention it is proposed to use such an artificial line.

The invention will be better understood by reference to the following specification and the accompanying drawing, in which Figure 1 represents a transmission line made up of an infinitely large number of sections containing resistance R and inductance L in series in the line, and capacity C and conductance G in shunt across the line. In case the line is non-loaded the inductance L becomes substantially equal to zero, and in case the line is loaded the line may be considered as made up of sections of appreciable size, in which R , L , C and G are the constants for a length of line corresponding to each loading section.

Fig. 2 represents a form of artificial line, the characteristics of which will be developed later, and consisting of a large number of sections of the form shown.

Figs. 3 to 5 represent general forms of artificial lines which embody the characteristics of my invention. Fig. 6 represents a telegraph transmission line with which is associated my artificial line and also the telegraph apparatus which is intended for duplex operation on the line, and Fig. 7 shows in detail the mechanical arrangements for automatically compensating for temperature or other physical changes in the line.

The invention will be made more clear by an analytical consideration of the properties of the lines of Figs. 1 and 2. The characteristic impedance of the line of Fig. 1 is

$$Z_0 = \sqrt{\frac{R + ipL}{G + ipC}}$$

and its propagation constant is

$$P = \sqrt{(R + ipL)(G + ipC)}$$

where p equals 2π times the wave frequency and $i = \sqrt{-1}$.

Similarly the impedance over the line of Fig. 2 would be

$$Z = \sqrt{\frac{R_1}{G + ipC + 1 + r(G + ipC)}}$$

in which the quantity under the numerator

R_1 represents the conductance per section across the line.

It can readily be shown that this impedance will be equal to the impedance of the line of Fig. 1 if

$$r = \frac{L}{CR - GL}$$

and

$$R_1 = \left(R - \frac{GL}{C} \right)$$

The propagation constant however will be different and will be given by

$$P' = \frac{RC - GL}{C\sqrt{R^2 + P^2L^2}}P$$

The equations given above are for lines of infinite length, and the problem now before us is that of duplicating the impedance of a finite line of the kind shown in Fig. 1 by means of a finite network of the type shown in Fig. 2. As a first simplification we may take cognizance of the fact that in a pair of wires included in a cable, the leakage G is negligible over the telegraph range of frequencies, in which case

$$Z_0 = \sqrt{\frac{R + ipL}{ipC}}$$

The artificial line then would take on the form shown in Fig. 3, in which $a = b = d = R$, and in which

$$h = g = \frac{f}{2} = r = \frac{L}{CR},$$

it being understood that for an infinitely long telegraph line there should be an infinite number of sections in the artificial line.

It is seen from this that C is a condenser which has a capacity equal to the shunt capacity of any desired section of the transmission line and a has the resistance of the same section of line, while g ($=r$) is proportional to the inductance of the same section of line. In case the line is non-loaded, the inductance is substantially equal to zero and therefore r equals zero.

However, the expression for the impedance given above was obtained on the assumption of a line of infinite length and infinitely small sections. If the sections are not very short, the above expression is approximate only and the exact formula is:

$$Z = Z_0 \left(1 + \frac{(R + ipL)ipC}{4} \right)^{-\frac{1}{2}}$$

If each section of the network is made to

correspond to n sections of the line, the impedance of the network then becomes:

$$Z = Z_0 \left(1 + \frac{n^2(R + ipL)ipC}{4} \right)^{-\frac{1}{2}}$$

and to a first approximation this becomes:

$$Z = Z_0 \left(1 - \frac{ipn^2C(R + ipL)}{8} \right)$$

The expression in the brackets may be considered as a correction factor due to the fact that the sections are not infinitely short, and the correction varies as the square of n . For close simulation, therefore, it is desirable to make n small but in order to simplify the apparatus it is desirable to keep the number of sections of the artificial network small, which means a corresponding increase in n . In practice I find that if the line does not exceed one or two hundred miles a sufficiently close simulation of the actual line may be obtained with a network of three sections, as shown in Fig. 3.

I have discovered, and it is a part of my invention, that the departure of the circuit of Fig. 3 from correct simulation, as given in equation 1, can be almost completely taken care of by inserting a resistance e of the proper size ahead of the first section of the network and this can in general be done by bringing a part of the resistance of the element a in front of the first condenser so that the artificial network takes on the form of Fig. 4. The simulations may be further improved by changing the value of f to f' this change being, in general, an increase. The relation $e + a = b$ would naturally hold, in general, but I find that this is not essential. It still remains true, however, that the sum of the series resistance e , a , b and d , should equal the series resistance of the line, which it is to balance. The particular value to be given to e and f' can be determined by experiment for any given circuit, various values being introduced until the amount of the unbalance is reduced to a minimum. Having once obtained this for a given circuit however, there is no need for further change.

Fig. 5 shows an artificial line similar to that of Fig. 4 but designed to balance a cable or line having no inductance. Accordingly the resistance elements such as g and h are omitted from the shunt connections of the network. A resistance f' will, however, be retained in the shunt connection including the capacity $\frac{C}{2}$. Although its value will

be different from that of the element f' in Fig. 4, it is necessary to provide the resistance f' because said resistance is not intended to balance the inductance of a section of the line. As stated in connection with Fig. 4, the resistances e and f' are adjusted

pirically after the remainder of the network has been computed, the empirical adjustment being necessary to compensate for factors disregarded in the computations, which

5 assume practically perfect conditions.

Thus far no consideration has been given to the terminal apparatus at the far end of the telegraph line. Such apparatus, however, will have an influence, which should

10 be accounted for in the balancing network, and I find that this can be done by an alteration in the resistance d of the last section of the network, (see Figs. 3, 4 and 5), that being the proper place for such correction since

15 the last section and the terminal apparatus are both furthest removed from the point of connection of the line and the network. For this reason d will in general be made somewhat larger than b .

20 In view of the above it is seen that the characteristic equations for my new network are as follows:

$$\begin{aligned} C &= nc \\ b &= R \\ g &= h = \frac{L}{CR} \\ e + a &= b \\ f' &= g + r_1 \\ d &= b + r_2 \end{aligned}$$

30 where c is the capacity per section of the line to be balanced, L and R are the inductance and resistance for n sections of the line and e , r_1 and r_2 are determined experimentally for any given line and terminal ap-

35 paratus.

As mentioned earlier in the specification, telegraph lines of the type under consideration, are subject to climatic variations and,

40 in particular, to change in temperature. In the case of a pair of wires, included in a cable, the only change which is of any importance is the change in the resistance of the line. This change is of sufficient magni-

45 tude to seriously upset the balance for duplex work and as a part of my invention I provide an arrangement of elements which will permit of a ready alteration of the necessary elements in order that the temperature changes may be compensated. I find that

50 suitable compensation can be secured by changes in the series resistance of my balancing network making it unnecessary to supply condensers of variable capacity. To

55 this end I make each of the resistances a , b and d , adjustable, this being better illustrated in Fig. 6, which at the same time shows the circuit connection for duplex telegraph operation. In said figure L represents a telegraph line, with which there is

60 associated the relay 11, comprising in this case four windings, two in each line. Across the mid-points of the windings of each line is connected the sending apparatus which

65 consists of a battery 12 and contacts 13 and

14. These contacts are controlled by relay 16, the winding of which includes the grounded battery 17 and the grounded key 18. As shown in the circuit, when the key 18 is depressed, the relay 16 is operated to

70 connect positive of battery 12 on one side of the line and negative to the other side. Upon opening the key 18 the contacts are released and reverse the connection of the battery 12 to line. A filter to eliminate high

75 frequency impulses may be inserted between the transmitter and the line, this filter comprising inductances 20 and 21 in series with the battery and condenser 22 in shunt. On

80 the side of the relay coils remote from the line is connected my balancing network N and when the line is properly balanced the current from the battery 12 divides equally, half of the current flowing to the line and

85 half to the network. Under these conditions the vibrating member of the relay 11 shown at 14 will not be affected by such transmitted impulses, but impulses coming from the remote station will be effective to operate the

90 vibrating member, which, in turn, may be used to control a sounder 24 associated with a battery 26 in a manner well known in the art.

While the resistance a , b and d may be made variable in any desired way, the figure

95 6 shows the variable portions a_1 , b_1 , and d_1 connected on the other side of the line from fixed portions a , b and d . Also the variations a_1 , b_1 and d_1 may be made separately, although for the sake of simplicity in opera-

100 tion I find it desirable to vary these simultaneously and in the same direction. These variable resistances may, for example, be dial resistances, the dials being mounted one

105 above the other and having a common shaft carrying contacts over each of the variable resistances. Under these circumstances the operator may adjust the network from time

110 to time as it is found necessary in order to maintain suitable balance of the line.

The networks illustrated in Figs. 3, 4 and 5 will be seen to possess a number of important advantages, whereas, with networks of the prior art, made up of combinations

115 of series of resistances and shunt connections including capacities and resistances, all of the elements were made adjustable, and each element was adjusted separately by an empirical method until a balance was attained. The adjustment of the various elements of

120 such a network is purely a matter of cut and try and has no necessary relation to the theoretical requirements for balance. In accordance with the present invention, the series elements a , b and d are computed in

125 advance, and the same holds true for the elements including the capacities C and $\frac{C}{2}$ and the resistances g and h . The network built up with these elements fixed is then

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connected in a balancing circuit for balancing a line of the type for which it is designed, and the elements e and f' (which are adjustable) are then adjusted empirically until the best balance is obtained. Each time the element e is increased, the element a will be decreased, or vice versa. When the proper balance has been obtained, the elements e and f' may be fixed, and the artificial line may be sent out to the field for use in the plant. The automatic adjustment of the elements a , b and d is a simultaneous adjustment merely intended to take care of variations in the resistance of the line to be balanced and has nothing to do with the design of these elements at the factory, the latter design being made with reference to a line which is assumed to have fixed characteristics.

The variation of the series resistances may be controlled automatically and in Fig. 7 I show one type of mechanism adapted for such automatic control, although it is apparent that a large variety of expedients might be used for this purpose. In this Fig. 7 is shown a Wheatstone bridge containing two fixed arms R_1 and R_2 . A third arm consists of a fixed resistance R_5 in series with a variable portion of a resistance R_6 . The fourth arm of the bridge consists of the remainder of the resistance R_6 and a resistance R_7 , which latter may be a resistance subject to substantially the same temperature as the cable conductor to be balanced or it may be a pair of wires included in the same cable as the line to be balanced. In general, I find that for telegraph lines which do not exceed one or two hundred miles in length, the temperature change is sufficiently uniform throughout this whole line so that the changes are sufficiently proximated by a concentrated resistance at the transmitting station, this resistance being preferably exposed to the external temperature changes. The bridge is supplied with battery 8 and an indicator relay 3 which relay is connected to the resistance R_6 at an adjustable point by the contact arm S_1 . The contact arm S_1 is mounted on a shaft S_2 which shaft also carries the contact arms for the variable resistances a_1 , b_1 and d_1 . The arm S_1 may be operated in one direction or another by the two ratchets 31 and 32, these ratchets, in turn, being operated by levers 33 and 34. In proximity to these levers are arranged the magnet coils 4, 5, 6 and 7. The relay 3 controls a circuit including battery 9, relay 10 and the magnet coils 4 to 7.

The operation of the bridge is as follows: In case the resistance R_7 increases the balance of the bridge will be destroyed. Current will then flow through the relay 3 in such a direction as to operate its contact to close circuit 9, 10, 4 and 7. The operation

of the magnet 7 will lift the lever 34 away from the ratchet 32 and at the same time the operation of the magnet 4 will cause the lever 33 to advance the ratchet 31. The relay 10 will intermittently open this circuit, causing a continuous step by step operation of the ratchet 31 and a corresponding advancement of the contact S_1 until balance of the bridge is restored. Corresponding changes will thus be made in the resistances a_1 , b_1 , and d_1 . In case the resistance R_7 falls, the contact of the relay 3 will then close circuit through battery 9, relay 10 and magnet coils 5 and 6, which will cause a corresponding operation of the arm S_1 in the reverse direction, and a corresponding change in the resistances a_1 , b_1 and d_1 .

Although I have described an automatic arrangement of one form, it is apparent that numerous changes may be made in this mechanism as well as in other parts of the disclosure, without departing from my invention.

What is claimed is:—

1. A balancing network for a telegraph circuit comprising a plurality of sections, each having a resistance in series and a series combination of resistance and capacity in shunt, a portion of the series resistance of the first section being placed in front of the capacity of said section to correct for limited number of sections.

2. A balancing network for a telegraph circuit comprising a plurality of sections each having a resistance in series and a series combination of resistance and capacity in shunt, a portion of the series resistance of the first section being placed in front of the capacity of said section to correct for a limited number of sections, the shunt resistance of the first section differing from the shunt resistances of other sections by an amount determined by the series resistance of that section.

3. A balancing network for a telegraph circuit comprising a plurality of sections each having a resistance in series and a series combination of resistance and capacity in shunt, a portion of the series resistance of the first section being placed in front of the capacity of said section to correct for a limited number of sections, the shunt resistance of the first section differing from the shunt resistances of other sections by an amount determined by the series resistance of that section, and the values of the series resistance in front of the capacity of the first section and the shunt resistance of the first section being determined by the constants of the circuit to be balanced.

4. A balancing network for a telegraph circuit comprising a plurality of sections, each having a resistance in series and a series combination of a fixed resistance and fixed capacity in shunt, the series resistance of the

last section being in part determined by the resistance of the remote terminal apparatus, the total series resistance of the sections exclusive of the part of the last section determined by the terminal equipment being equal to the series resistance of the line.

5. A transmission line, a balancing network therefor containing capacity and resistance impedances forming series and shunt elements, all of said elements except series resistances being fixed, said series resistances being adjustable in proportion to temperature variations of the line to effect a balance.

6. A transmission line, a balancing network therefor containing shunt capacity and series resistance elements and adapted to be adjusted in accordance with climatic variations of the line, said adjustment being effected by variations of the series resistance elements only in proportion to said climatic variations, the shunt capacity elements being fixed.

7. A balancing network for a telegraph line comprising a plurality of sections, each having a resistance in series and a capacity in shunt, and means operating in response to physical variations in the line to vary said network in accordance with said physical variations.

8. In combination, a balancing network for a transmission line, and means operating in response to physical variations in the line to vary said network automatically in accordance with said physical variations.

9. A balancing network for a telegraph circuit comprising a plurality of sections, each having a resistance in series and a series resistance and capacity in shunt, and temperature controlled means for varying said network automatically in accordance with temperature variations.

10. A balancing network for a telegraph circuit comprising a plurality of sections, each having a resistance in series and a series combination of resistance and capacity in shunt, and temperature controlled means for varying the resistance of the elements in said network in accordance with temperature variations in the line.

11. A balancing network for a telegraph line comprising a plurality of sections, each having a resistance in series and a series combination of a fixed resistance and fixed capacity in shunt, and means for varying the series resistance of said network in proportion to temperature variations in the line.

12. A balancing network for a telegraph line comprising a plurality of sections, each having a resistance in series and a series combination of a fixed resistance and fixed capacity in shunt, and means automatically responsive to temperature variations in the line for adjusting the series resistance of said network in proportion to said temperature variation.

13. A balancing network for a variable transmission line comprising a plurality of sections, each having a resistance in series and a series combination of resistance and capacity in shunt, certain of said elements being variable and a Wheatstone bridge, one arm containing an element subject to line variations and means controlled by said bridge to vary the variable elements of said network in accordance with the line variations.

14. A balancing network for a telegraph line comprising capacities and resistances, and means for simultaneously adjusting a plurality of said resistances in proportion to and in response to climatic variations in the line.

15. A balancing network for a telegraph line comprising capacities and resistances, and means for simultaneously and automatically adjusting a plurality of said resistances in accordance with and in response to climatic variations in the line.

16. A balancing network for a telegraph circuit comprising series resistance and fixed shunt capacity and fixed shunt resistance, and mean for simultaneously adjusting a plurality of said series resistances in proportion to and in response to climatic variations in the line.

In testimony whereof, I have signed my name to this specification this 29th day of August 1921.

HARRY NYQUIST.