Aug. 28, 1923. 1,465,972

G. CRISSON

TRANSMISSION REGULATING CIRCUITS

Filed March 7, 1921 2 Sheets-Sheet 1

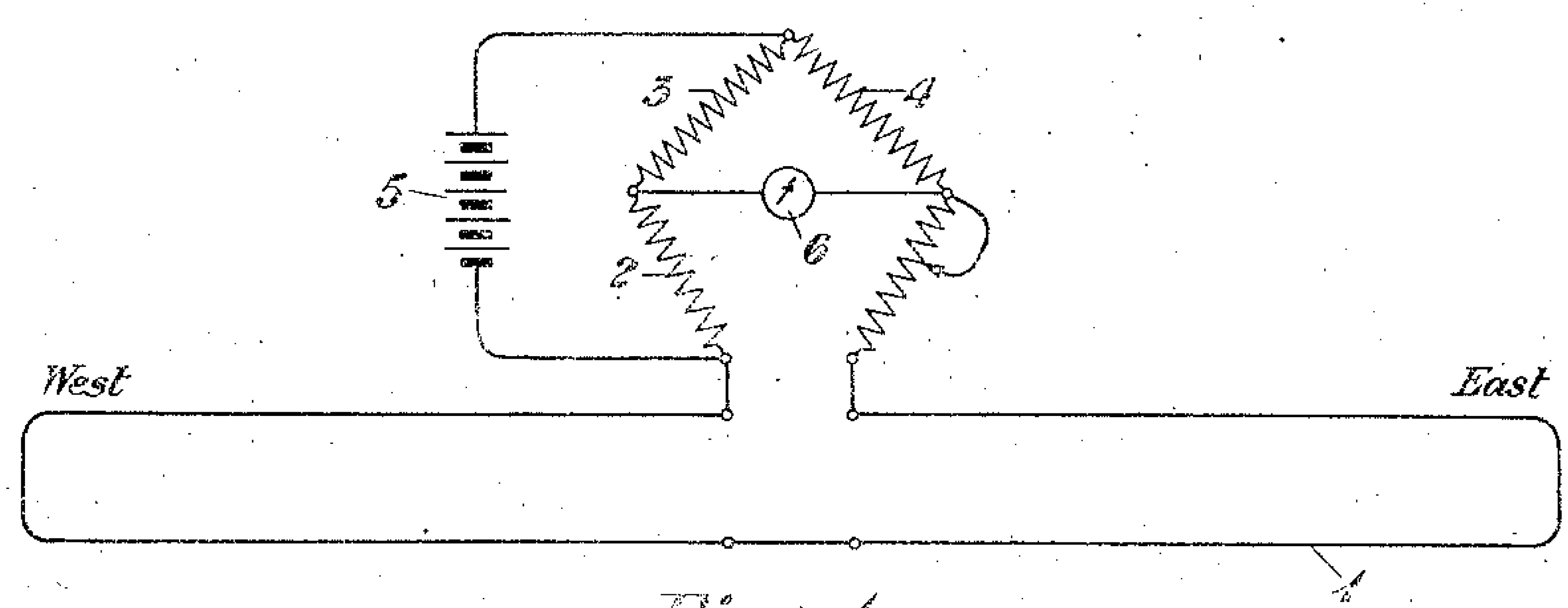

Fig. 1

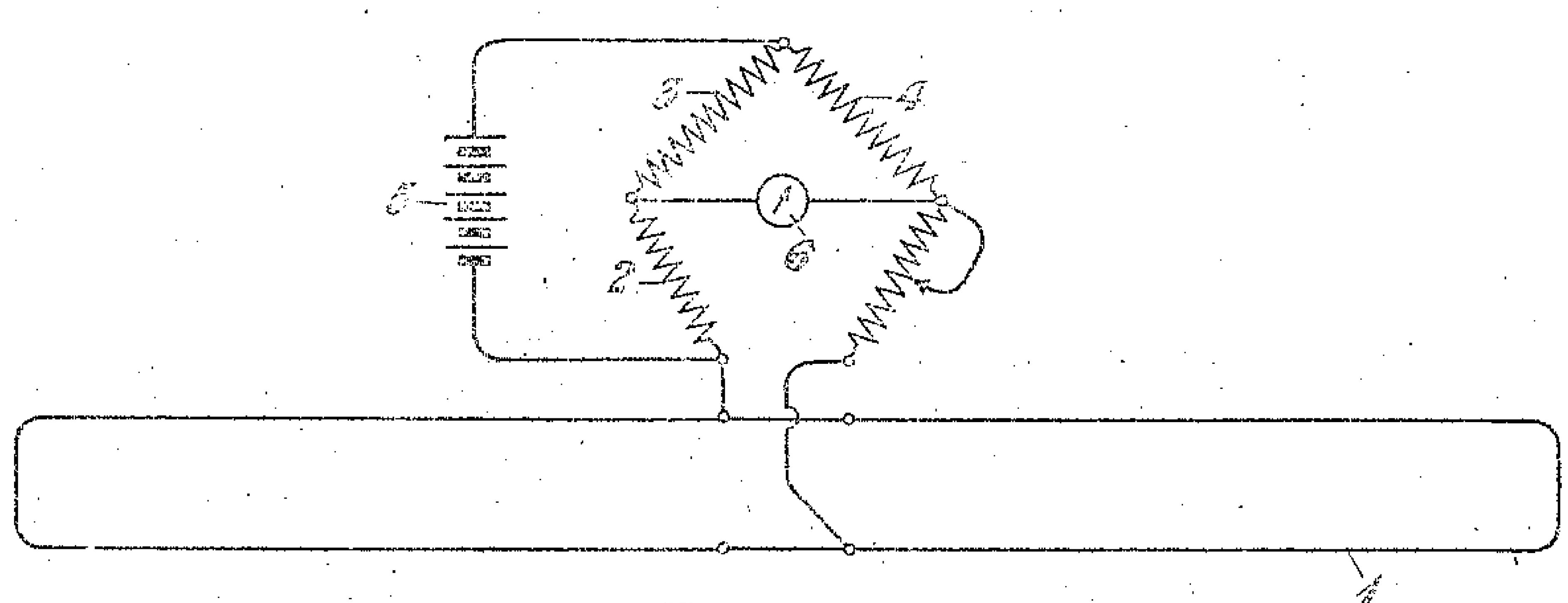

Fig. 2

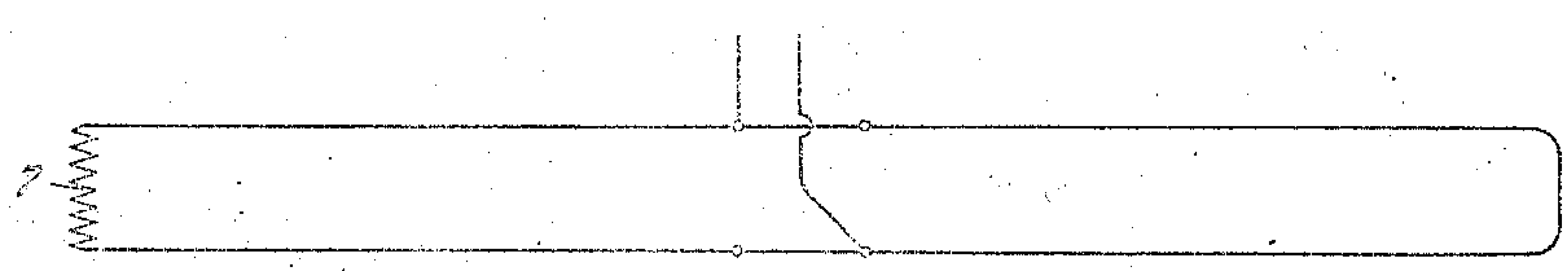

Fig. 3

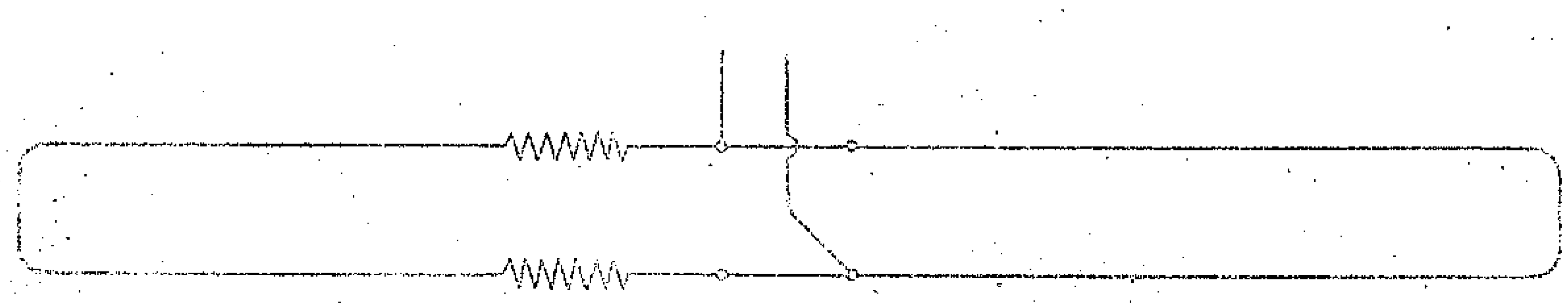

Fig. 4

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TRANSMISSION REGULATING CIRCUITS

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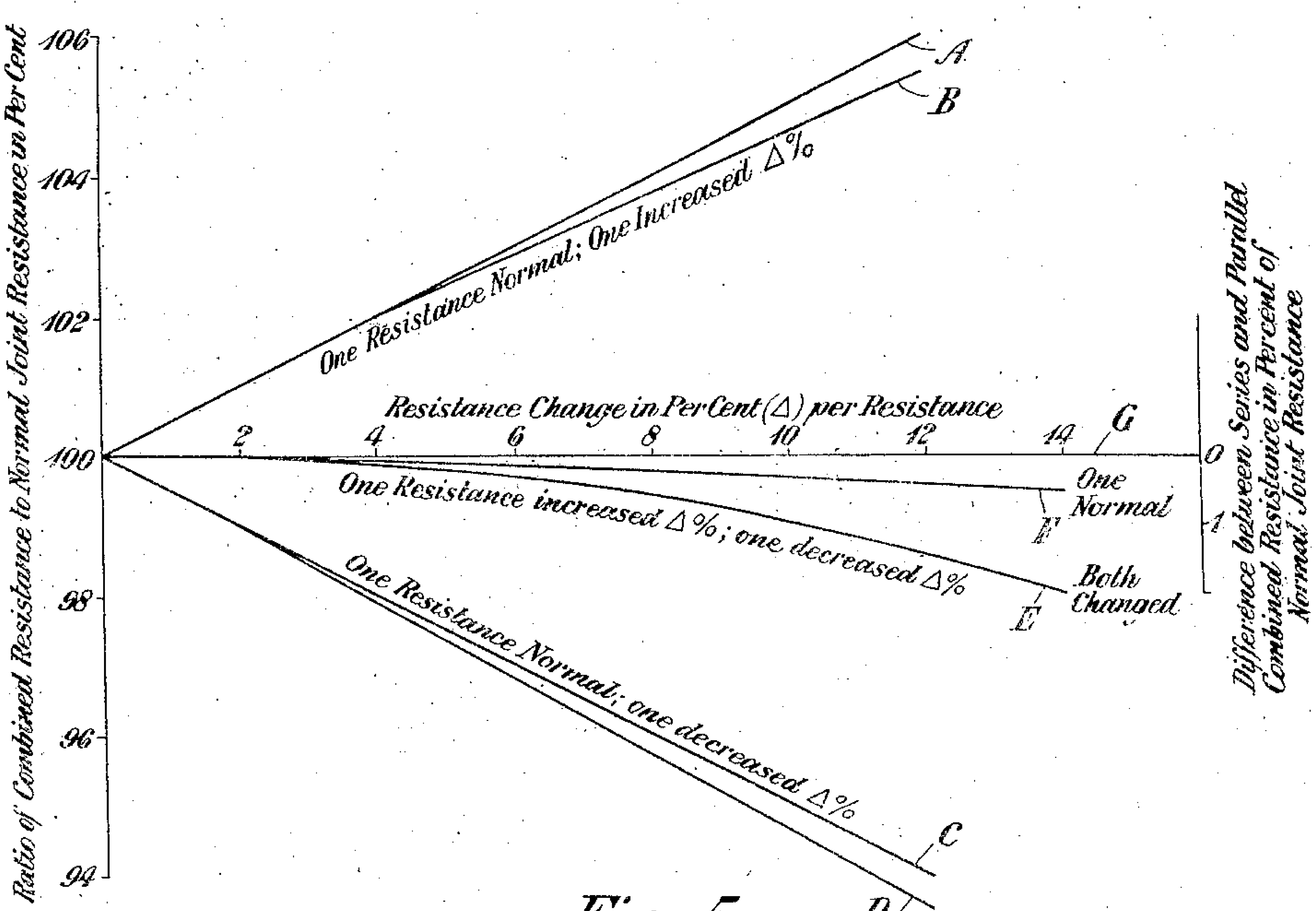

Fig. 5

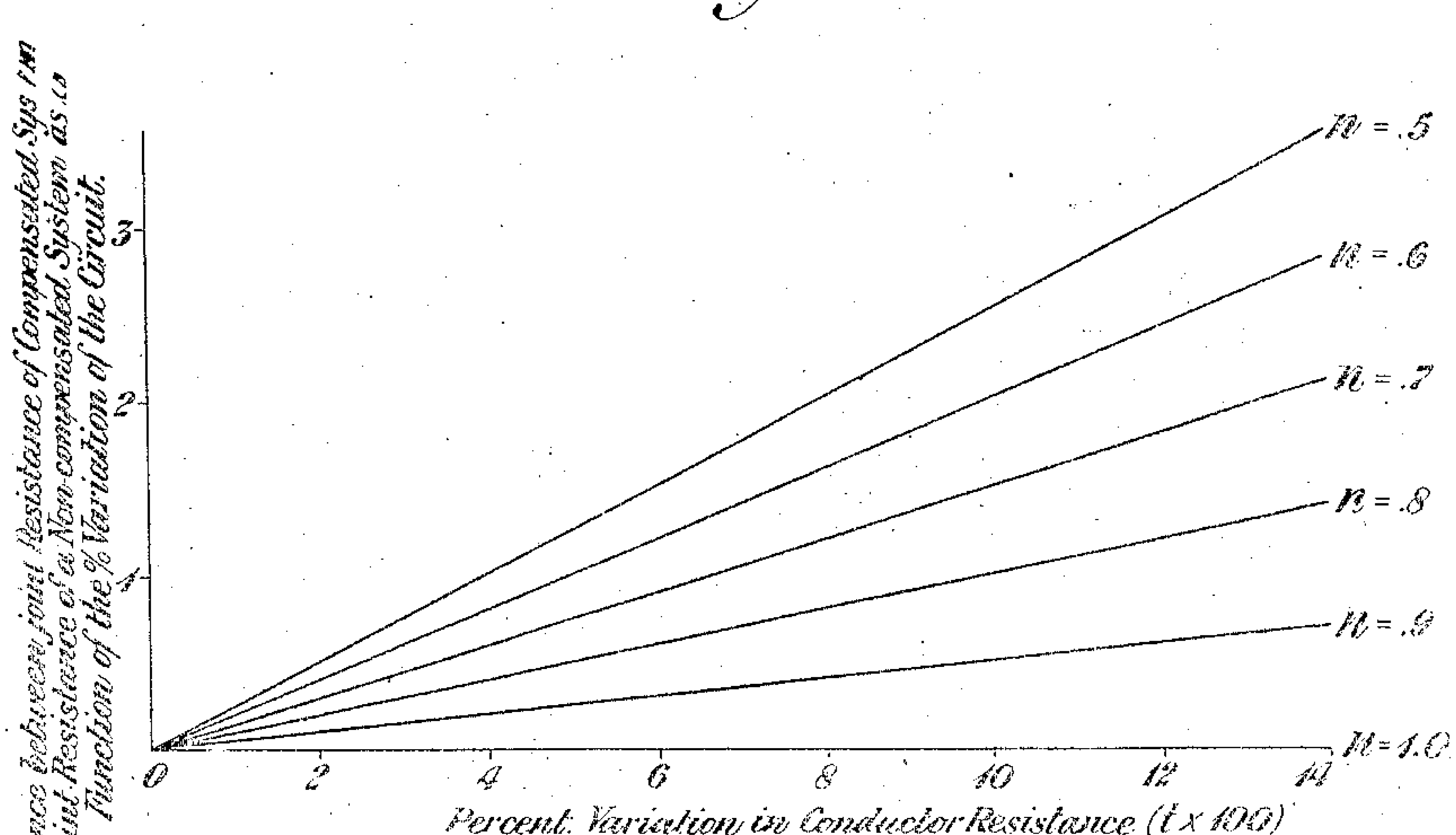

Fig. 6

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By his Attorney G. E. Folk

Patented Aug. 28, 1923. **1,465,972**

UNITED STATES PATENT OFFICE.

GEORGE CRISSON, OF HACKENSACK, NEW JERSEY, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

TRANSMISSION REGULATING CIRCUITS.

Application filed March 7, 1921. Serial No. 450,352.

To all whom it may concern:

Be it known that I, George Crisson, residing at Hackensack, in the county of Bergen and State of New Jersey, have invented certain Improvements in Transmission Regulating Circuits, of which the following is a specification.

This invention relates to signaling circuits and more particularly to arrangements for controlling the transmission equivalent of such circuits.

It has been found that the transmission equivalent of signaling circuits such, for example, as telephone circuits, varies from time to time, due to a number of causes, the principal of which is a change in resistance produced by temperature variations. As it is common practice to carry the wires of a number of telephone circuits along the same pole line or through the same cable, it is apparent that all of the lines thus treated will be subject to substantially the same change in temperature conditions. It has, therefore, been proposed to overcome the difficulties due to these variations by observing the changes produced in one circuit of a cable, for example, and then varying in accordance with such changes similar transmission elements of all of the circuits which are affected in like manner. By varying the transmission elements in proper proportion to the change in resistance of the pilot circuit, the transmission equivalent of all of the circuits may be maintained constant so far as resistance changes with temperature are concerned. This method may, of course, be carried out by measuring the current in the pilot circuit in any well known manner, and then making the changes in the transmission elements of the other circuits manually, or it may be carried out by providing apparatus which automatically responds to changes in the current flowing in the pilot circuit to perform the necessary adjustments in the other circuits, by means of suitable switching arrangements. Apparatus for carrying out the method automatically is disclosed in the U. S. application of A. B. Clark, Serial No. 253,486, filed September 10, 1918, patented Dec. 12, 1922, No. 1,438,219.

In the practice of the method above outlined, it was contemplated that the measuring instrument in the case where the adjustment is made manually, or the current responsive device in the case in which the adjustment is made automatically, be included serially in the pilot circuit at one end thereof. Under practical conditions, however, it is frequently undesirable to arrange this apparatus at the terminal of the pilot circuit, and it should preferably be located at some intermediate point. While the measuring instrument or current responsive device will function to record changes in resistance due to temperature variations in exactly the same way when serially included in the pilot circuit at an intermediate point, a difficulty has been encountered in connection with such an arrangement of the apparatus, due to disturbing currents induced from neighboring circuits and flowing over the two sides of the pilot circuit in parallel.

One of the principal objects of this invention is to provide arrangements for overcoming this difficulty, although other objects of the invention will be clear from the following description of the invention, when read in connection with the accompanying drawing, in which Figure 1 is a schematic diagram of a pilot wire with the measuring instrument or current responsive device serially included therein at an intermediate point; Fig. 2 illustrates the apparatus bridged across the pilot wire at an intermediate point in accordance with the present invention; Figs. 3 and 4 illustrate the same arrangement provided with means for compensating for the difference in the two loops of the pilot circuit on each side of the current responsive device; while Figs. 5 and 6 are curves illustrating the characteristics of the apparatus of the present invention.

Referring to the drawings, Fig. 1 shows a pilot wire 1, forming part of one arm of a Wheatstone bridge, of which resistances 2, 3 and 4 form the other arms. The bridge is supplied with a battery 5 connected across the two opposite terminals thereof and a measuring instrument 6 is connected across the other two points of the bridge. This arrangement is schematic and is illustrative of means which would be employed for observing the changes in resistance in the pilot wire circuit where the adjustment of the transmission elements of the telephone circuits is to be performed manually. Obviously the device 6 may be instead of a measuring instrument a current responsive device for automatically controlling the transmission elements of the various telephone circuits as disclosed in the Clark application previously referred to. It will be noted that in Fig. 1, the measuring instrument and associated apparatus is serially included in the pilot circuit 1 at an intermediate point 5. This arrangement has been found to be satisfactory as long as the pilot wire conductors are not exposed to induction, but if one of the loops as, for example, the west loop, is paralleled by a conductor carrying Morse or other currents, a charge will be induced upon the two wires of the west loop which causes momentary currents to flow over the two wires of the west loop in parallel. The flow of these currents in the wire which is cut directly through from west to east, does no harm, but the current in the other wire passes through the regulating apparatus and causes the current measuring instrument 6 to give a false reading, or in the case of the automatic apparatus of the Clark application previously referred to, causes the galvanometer relay corresponding to the device 6 to chatter and produce false operation of the automatic gain controlling mechanism. In order to overcome this difficulty it is proposed in accordance with the present invention to connect the east and west loops in parallel with the terminals of the Wheatstone bridge arrangement bridged across the loops as illustrated in Fig. 2. This will permit the current responsive device 6 to measure the joint resistance of the two loops so that the trouble from induction can be eliminated. The two wires extending to the east are accurately balanced with respect to their surroundings, as are the two wires extending to the west. Consequently, when one pair is exposed to induction from a neighboring conductor, equal currents flow over the two wires into the other pair and no difference in potential is produced between the points connected with the bridge. The balance of the bridge is therefore undisturbed, provided it is insulated from the earth.

In the series arrangement of Fig. 1 the joint resistance of the two pilot wire loops is the sum of the resistances of the separate loops, that is

$$R_s = R_1 + R_2 \quad (1)$$

in which R_s is in the joint resistance and R_1 R_2 are the resistances of the two separate loops. In this case a change in the resistance of any part of the circuit causes an equal change in the joint resistance and consequently, the response of the device 6 will be proportional to the change in the resistance of the whole circuit.

In the parallel arrangement of Fig. 2, the joint resistance R_p is given by the formula

$$R_p = \frac{R_1R_2}{R_1 + R_2} \quad (2)$$

Assume that one of the loops, for example, R_1, changes its resistance by an amount r_1 and that the resulting change in the joint resistance is r_p, then the new condition is given by the formula

$$R_p + r_p = \frac{(R_1+r_1)R_2}{r_1+R_1+R_2} \quad (3)$$

Substituting the value of R_p from (2) and transposing

$$r_p = \frac{(R_1+r_1)R_2}{r_1+R_1+R_2} - \frac{R_1R_2}{R_1+R_2}$$

Simplifying:

$$r_p = \frac{r_1R_2^2}{(R_1+R_2)(r_1+R_1+R_2)} = \frac{r_1}{\left(1+\frac{R_1}{R_2}\right)\left(1+\frac{r_1}{R_2}+\frac{R_1}{R_2}\right)} \quad (4)$$

From this equation it is readily seen that if the initial value R_1 of the varied resistance is greater than R_2 the change r_p in the joint resistance R_p is small and if R_1 is smaller than R_2, r_p is large, that is, if one loop has less resistance than the other, the loop of lower resistance has the greater effect upon the joint resistance. This is undesirable as the longer portion of the transmission circuit associated with the pilot circuit has the greater effect upon the transmission equivalent. Where it is impossible to locate the controlling apparatus exactly at the middle of the pilot wire so that the two loops will be equal, the influence of the shorter loop will be greater than the longer loop, unless some means be provided to compensate for this effect. In accordance with the present invention, it is, therefore, proposed to include in the shorter loop a constant compensating resistance such as the resistance 7 of Fig. 3, which illustrates the compensating resistance as being inserted at the distant end of the shorter loop. Where it is desired to include the compensating resistance at the same point as the controlling apparatus, the resistance may be divided into two equal parts, and one part put in series with each conductor of the short loop, as illustrated in Fig. 4. A single resistance cannot be used in the latter case as it would unbalance the system with respect to disturbing induced currents, and therefore defeat the object of the parallel arrangement.

When the loops are given equal resistance by providing a compensating resistance for the shorter loop, the effect of a given change in temperature upon the resistance of either loop is proportional to the length of the pilot wire in that loop, and is therefore proportional to the change in transmission equivalent produced in the corresponding portion of the transmission circuit, assuming of course, that the pilot wire is of uniform diameter throughout its length. However, with the parallel arrangement, changes in joint resistance are not exactly proportional to the changes in the resistances of the individual loops as in the series arrangement although for the range of variations encountered in pilot wires in practice, the approximation is sufficiently close so that no difficulty is encountered from these sources.

The effect of this factor will be clear from a consideration of the curves illustrated in Fig. 5. In these curves the behavior of the series and parallel arrangements of the two loops is compared and it is assumed that the two loops are initially of equal resistance, and that one or both varies from the initial value by a certain percentage $\triangle$. Curves A, B, C and D are plotted with the values of the resistance change in percentage as the abscissæ and the ratio of joint resistance to normal joint resistance in percentage as ordinates. The curve A represents the variation in the ratio of combined resistance to the normal joint resistance for the series arrangement of Fig. 1, where the resistance of one loop remains normal and the resistance of the other loop increases. The curve B is a plot under the same conditions of the combined resistance of a parallel arrangement such as that illustrated in Fig. 2. The curve C is a plot for the series case, where the resistance of one loop remains normal and the resistance of the other loop decreases. Curve D is a similar curve for the parallel arrangement. Curves A and C show that when one loop varies, the percentage change of the joint series resistance is one-half $\triangle$. A comparison of these curves with curves B and D shows that the per cent increase of the joint parallel resistance is slightly less and the per cent decrease slightly greater than the per cent change in the joint series resistance. Curve F near the horizontal axis is plotted with the differences between the series and parallel combined resistances as ordinates and shows the difference between the series and parallel arrangements in per cent of the normal value. As will be seen, this difference is relatively small and need not be considered.

If one loop should increase and one decrease in resistance by equal percentage, there would be no change in the joint series resistance, this being indicated by the curve G, which coincides with the horizontal axis. The joint parallel resistance would decrease, however, as indicated by the curve E. While this curve shows a considerable deviation from the ideal condition represented by the curve G, this particular situation would probably never occur in practice, as the line sections to which the invention applies are usually limited to between 200 and 300 miles. Consequently, the two loops will not be subjected simultaneously to opposite extremes of temperature.

Another factor to be considered is the effect of the compensating resistance, such as the resistance 7, on the accuracy of the arrangement, it being noted that while the resistance of the line will vary with uniform temperature changes, the compensating resistance will not vary, and consequently, where both loops are subjected to the same change in temperature conditions, this fact will not be reflected accurately by the current-responsive device.

The effect of this factor may be understood from the following theoretical considerations:

If we assume that the two loops are of equal resistance, equation (2) becomes

$$R_p = \frac{1}{2}R_1 = \frac{1}{2}R_2$$

and R_p is proportional to R_1 and R_2 as in the series arrangement, but if one of the loops is compensated and the temperature of both varies, an error is introduced. This error can be found as follows:

Let R=initial resistance of each loop.

t=fractional change in resistance of the loop wires due to change in temperature.

n=the fraction of the resistance of the compensated loop which is in the loop conductors.

$1-n$=fraction in the compensating resistance.

r_p^1=change in joint resistance of compensated system.

Then the changed resistance of the uncompensated loop is $R(1+t)$ and in the compensated loop

$$(1-n)R + nR(1+t) = (1+nt)R.$$

The joint varied resistance is

$$R_p + r_p^1 = \frac{R^2(1+t)(1+nt)}{R(1+t)+R(1+nt)} = \frac{(1+t)(1+nt)}{2+t+nt}R \quad (5)$$

With no compensating resistance $n=1$ and

$$R_p + r_p = \frac{1}{2}(1+t)R \quad (6)$$

The difference between the compensated and noncompensated systems from (5) and (6) is

$$r_p - r_p^1 = \frac{1}{2}(1+t)R - \frac{(1+t)\,(1+nt)}{2+t+nt}R \quad (7)$$

Multiplying each side by $\frac{2}{R}$ and remembering that

$$R_p = \frac{R}{2}$$

when both loops are equal, the difference is expressed as a fraction of the initial joint resistance

$$\frac{r_p - r_p^1}{R_p} = \frac{2(r_p - r_p^1)}{R} = 1 + t - 2\frac{(1+t)\,(1+nt)}{2+t+nt} = \frac{t(1+t)\,(1-n)}{2+t+nt} \quad (8)$$

When the fractional difference is plotted for various values of n and t as in Fig. 6, it is found that the difference in joint resistance between the compensated and noncompensated systems is closely proportional to the change in resistance of the pilot wire conductors and the compensated system acts in very nearly the same way as a noncompensated system of conductors having a somewhat smaller temperature coefficient over the ranges likely to be encountered in practice. For example, from the curve drawn for the case where $n=.9$, the difference between the joint resistance of a compensated system and that of a noncompensated system is only about .7 of 1%, when the variation in conductor resistance is as high as 14%. Even in the case where $n=.5$, the difference between the resistance of the compensated system and that of the noncompensated system is only 3.6% for a variation in conductor resistance of 14%. The error cause by a given amount of compensating resistance can, therefore, be corrected by using slightly smaller steps in the adjustable transmission elements of the telephone circuits. Of course, when there is no compensating resistance and uniform temperature changes occur throughout the system, no error is produced by the parallel arrangement, for the whole system changes uniformly.

While the parallel pilot wire arrangement does not give precisely the changes in resistance theoretically required to produce an exact equalization of transmission for all possible temperature conditions, the degree of approximation obtained when correction is made by the insertion of compensating resistances in the low resistance loop (where required), is so close for any probable temperature condition that no serious difficulty will be encountered in its use, and it does have the advantage of preventing disturbances of the controlling apparatus by induced charges flowing from one loop to the other.

While in the foregoing discussion an automatically operated Wheatstone bridge has been assumed as the device which responds to the pilot wire variations, nevertheless the discussion applies equally well to any equivalent arrangement. Furthermore, it will be obvious that the general principles herein disclosed may be embodied in many other organizations widely different from those illustrated, without departing from the spirit of the invention as defined in the following claims.

What is claimed is:

1. In a signaling system, a group of signaling conductors similarly subjected to conditions producing variations in their transmission efficiency, a pilot circuit subjected to the same conditions as the signaling conductors, and an apparatus for determining the adjustments to be made in the signaling circuits to compensate for the change in transmission, said apparatus being bridged across the conductors of the pilot circuit at a point intermediate the ends of said circuit and being balanced with respect to the two sides of the pilot circuit.

2. In a signaling system, a group of signaling conductors similarly subjected to conditions producing variations in their transmission efficiency, a pilot circuit subjected to the same conditions as the signaling conductors, and an apparatus for determining the adjustments to be made in the signaling circuits to compensate for the change in transmission, said apparatus being bridged across the conductors of the pilot circuit at a point intermediate the ends of said circuit so that the loop of the pilot circuit on one side of the point of connection is longer than the loop on the other side, said apparatus also being balanced with respect to the two sides of the pilot circuit.

3. In a signaling system a group of signaling conductors similarly subjected to conditions producing variations in their transmission efficiency, a pilot circuit subjected to the same conditions as the signaling conductors, an apparatus for determining the adjustment to be made in the signaling circuits to compensate for the change in transmission, said apparatus being bridged across the conductors of the pilot circuit at a point intermediate the ends of said circuit so that the loop of the pilot circuit on one side of the point of connection is longer than the loop on the other side, and

means included in the shorter loop to compensate for the difference in the length of the two loops.

4. In a signaling system, a group of signaling conductors similarly subjected to conditions producing variations in their transmission efficiency, a pilot circuit subjected to the same conditions as the signaling conductors, an apparatus for determining the adjustments to be made in the signaling circuits to compensate for the change in transmission, said apparatus being bridged across the conductors of the pilot circuit at a point intermediate the ends of said circuit so that the loop of the pilot circuit on one side of the point of connection is longer than the loop on the other side, and a fixed resistance included in the shorter of the two loops to compensate for the difference in the lengths of the two loops.

5. In a signaling system, a group of signaling conductors similarly subjected to conditions producing variations in their transmission efficiency, a pilot circuit subjected to the same conditions as the signaling conductors, an apparatus for determining the adjustments to be made in the signaling circuits to compensate for the change in transmission, said apparatus being bridged across the conductors of the pilot circuit at a point intermediate the ends of said circuit so that the loop on one side of the point of connection has a greater resistance than that of the loop on the other side, and means included in the loop having the smaller resistance to compensate for the difference between the resistances of the two loops.

6. In a signaling system, a group of signaling conductors similarly subjected to conditions producing variations in their transmission efficiency, a pilot circuit subjected to the same conditions as the signaling conductors, an apparatus for determining the adjustment to be made in the signaling circuits to compensate for the change in transmission, said apparatus being bridged across the conductors of the pilot circuit at a point intermediate the ends of said circuit so that the loop on one side of the point of connection has a greater resistance than that of the loop on the other side, and a fixed resistance in the loop having the smaller resistance to compensate for the difference between the resistances of the two loops.

7. In a signaling system, a group of signaling conductors similarly subjected to conditions producing variations in their transmission efficiency, a pilot circuit subjected to the same conditions as the signaling conductors, and a Wheatstone bridge circuit including a current responsive device, the terminals of one of the arms of the bridge being connected across the conductors of said pilot circuit at a point intermediate the ends thereof, said bridge being balanced with respect to the two sides of the pilot circuit.

8. In a signaling system, a group of signaling conductors similarly subjected to conditions producing variations in their transmission efficiency, a pilot circuit subjected to the same conditions as the signaling conductors, and a Wheatstone bridge circuit including a current responsive device, the terminals of one of the arms of the bridge being connected across the conductors of said pilot circuit at a point intermediate the ends thereof, so that the loop of the pilot circuit on one side of the point of connection is longer than the loop on the other side, said bridge being balanced with respect to the two sides of the pilot circuit.

9. In a signaling system, a group of signaling conductors similarly subjected to conditions producing variations in their transmission efficiency, a pilot circuit subjected to the same conditions as the signaling conductors, and a Wheatstone bridge circuit including a current responsive device, the terminals of one of the arms of the bridge being connected across the conductors of said pilot circuit at a point intermediate the ends thereof, so that the loop of the pilot circuit on one side of the point of connection is longer than the loop on the other side, and means included in the shorter loop to compensate for the difference in the length of the two loops.

10. In a signaling system, a group of signaling conductors similarly subjected to conditions producing variations in their transmission efficiency, a pilot circuit subjected to the same conditions as the signaling conductors, and a Wheatstone bridge circuit including a current responsive device, the terminals of one of the arms of the bridge being connected across the conductors of said pilot circuit at a point intermediate the ends thereof, so that the loop of the pilot circuit on one side of the point of connection is longer than the loop on the other side, and a fixed resistance included in the shorter of the two loops to compensate for the difference in the length of the two loops.

11. In a signaling system, a group of signaling conductors similarly subjected to conditions producing variations in their transmission efficiency, a pilot circuit subjected to the same conditions as the signaling conductors, and a Wheatstone bridge circuit including a current responsive device, the terminals of one of the arms of the bridge being connected across the conductors of said pilot circuit at a point intermediate the ends thereof, so that the loop on one side of the point of connection has a greater resistance than the loop on the other side, and means included in the loop having the

smaller resistance to compensate for the difference between the resistance of the two loops.

12. In a signaling system, a group of signaling conductors similarly subjected to conditions producing variations in their transmission efficiency, a pilot circuit subjected to the same conditions as the signaling conductors, and a Wheatstone bridge circuit including a current responsive device, the terminals of one of the arms of the bridge being connected across the conductors of said pilot circuit at a point intermediate the ends thereof, so that the loop on one side of the point of connection has a greater resistance than the loop on the other side, and a fixed resistance in the loop having the smaller resistance to compensate for the difference between the resistances of the two loops.

In testimony whereof I have signed my name to this specification this 3rd day of March, 1921.

GEORGE CRISSON.