Dec. 8, 1931. K. W. PFLEGER 1,835,080

TRANSMISSION REGULATION IN CABLE CIRCUITS

Filed Aug. 16, 1929 3 Sheets-Sheet 1

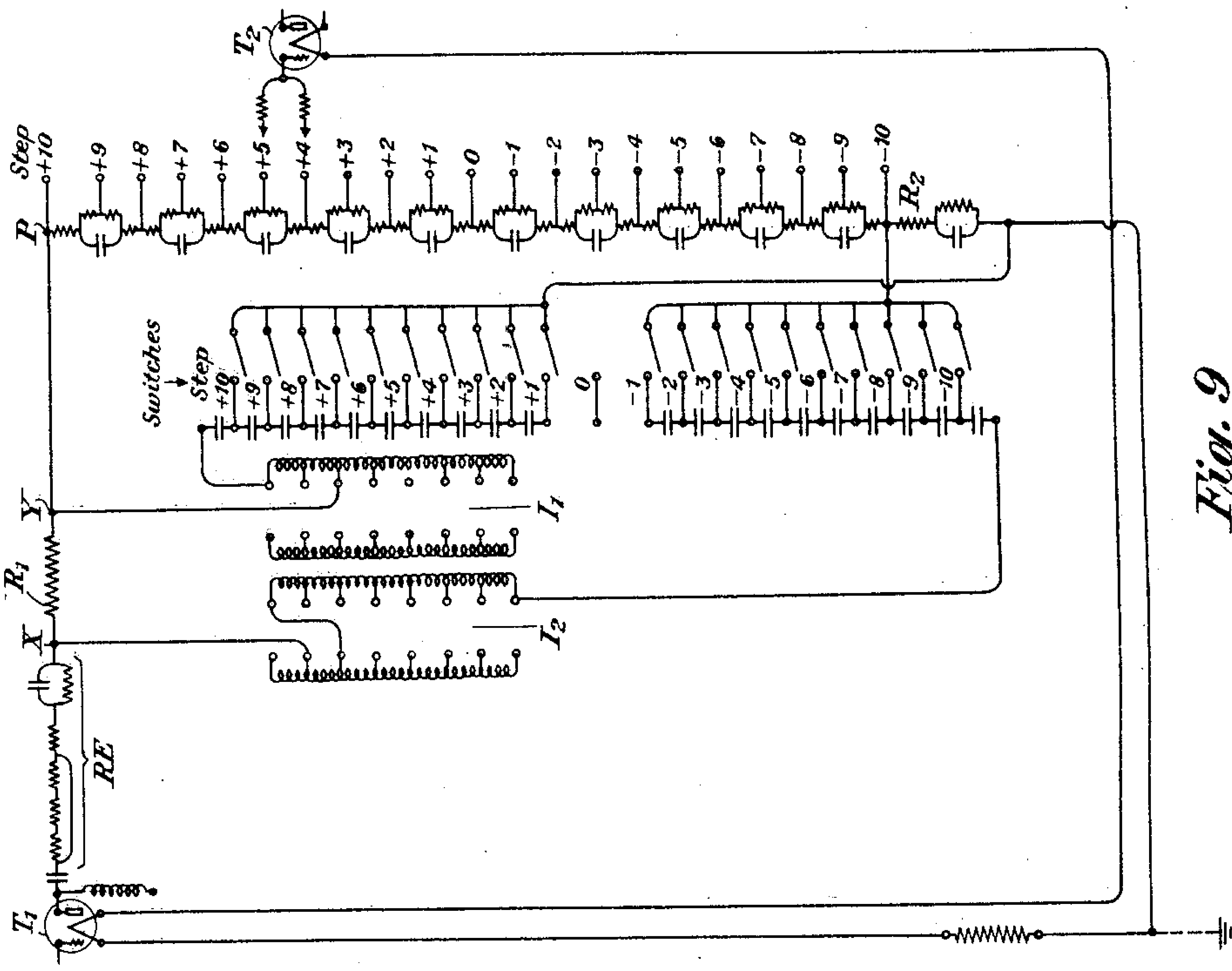

Fig. 9

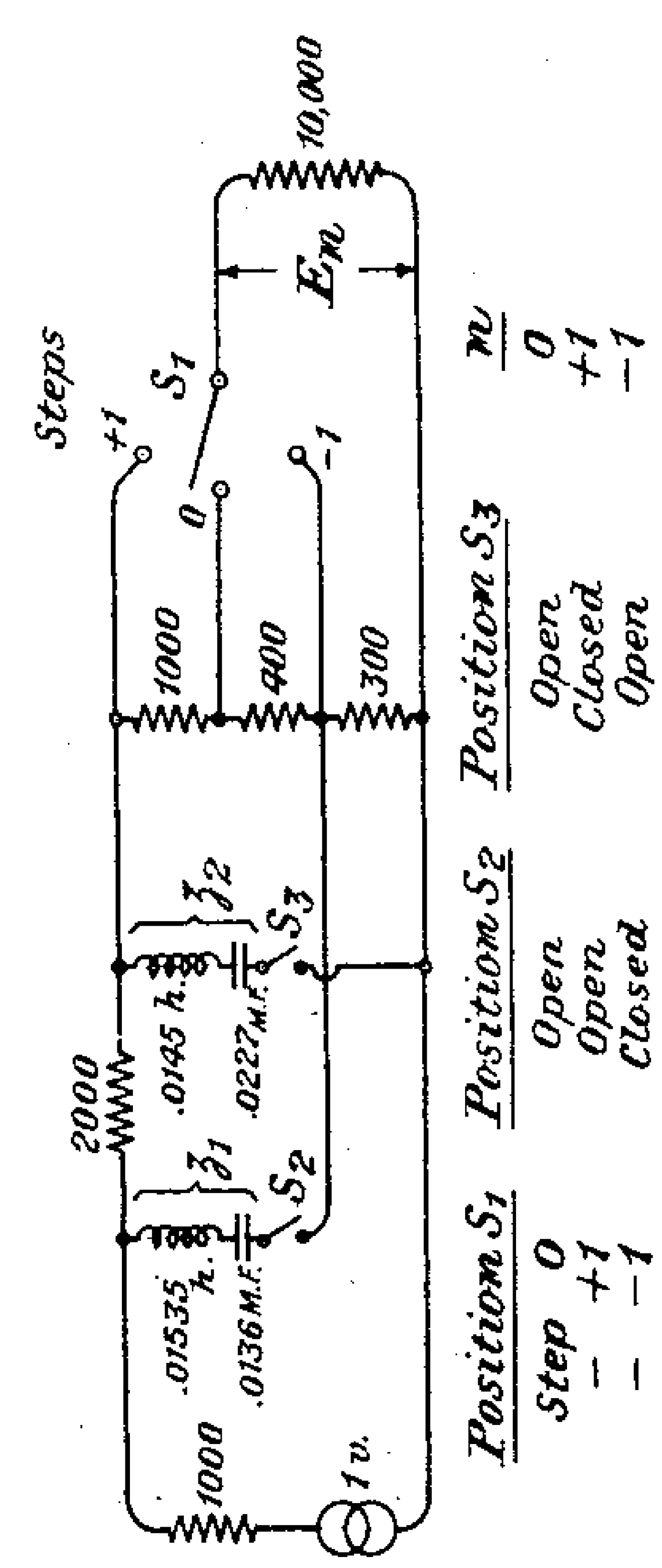

Fig. 1

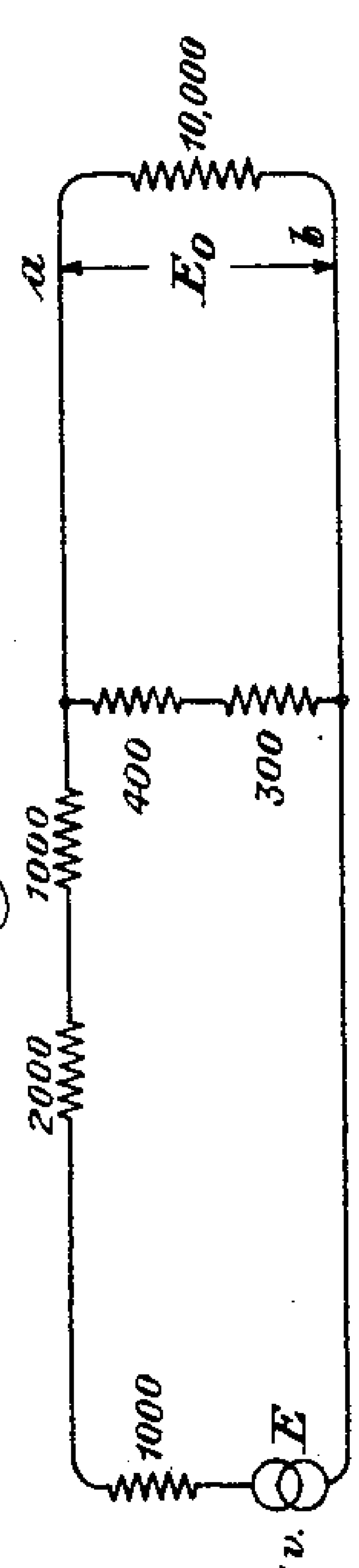

Fig. 2

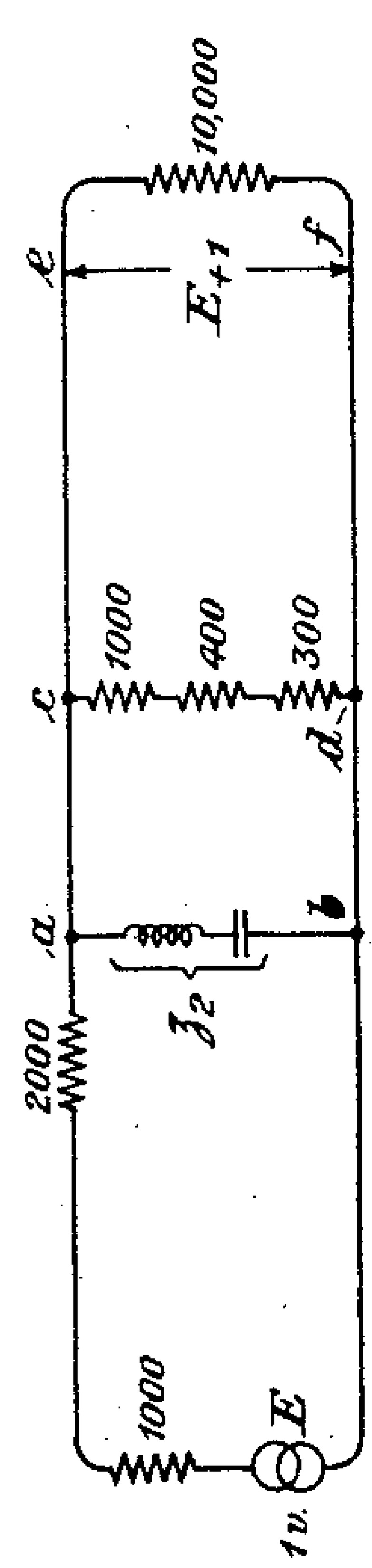

Fig. 3

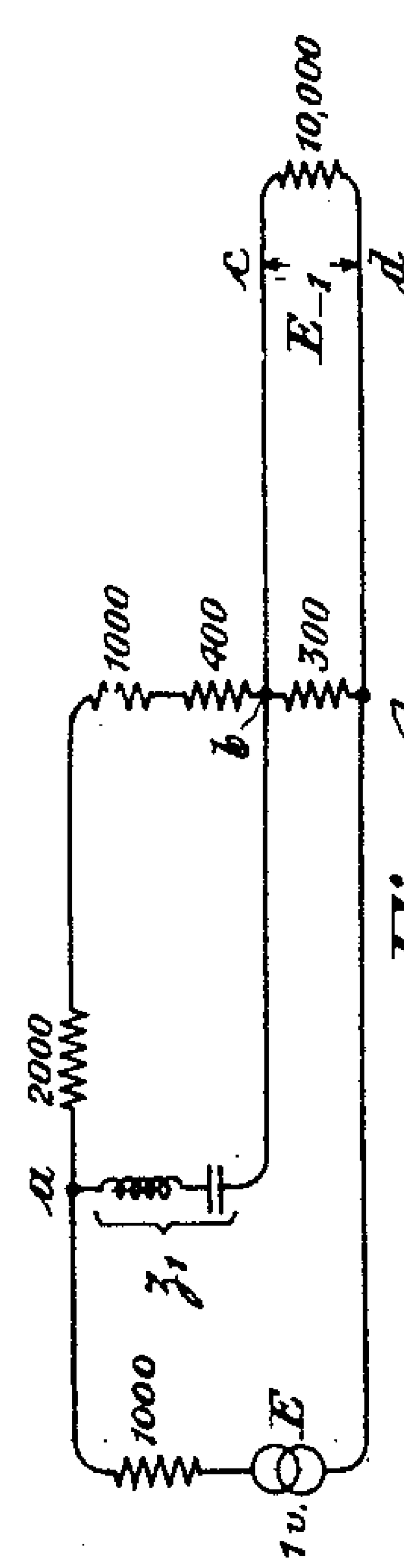

Fig. 4

INVENTOR
K. W. Pfleger
BY
[signature]
ATTORNEY

TRANSMISSION REGULATION IN CABLE CIRCUITS

Filed Aug. 16, 1929 3 Sheets-Sheet 2

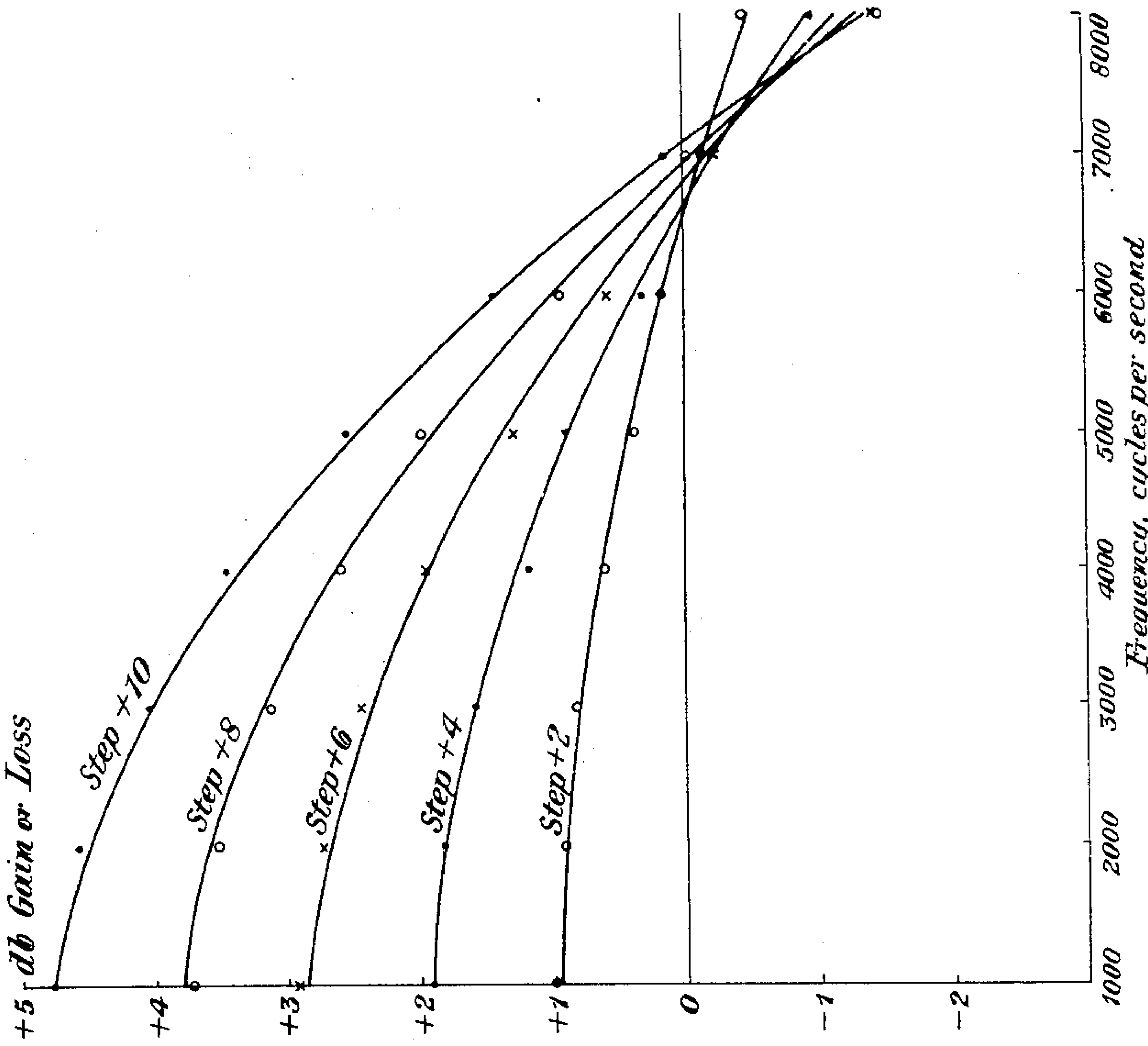

Fig. 6

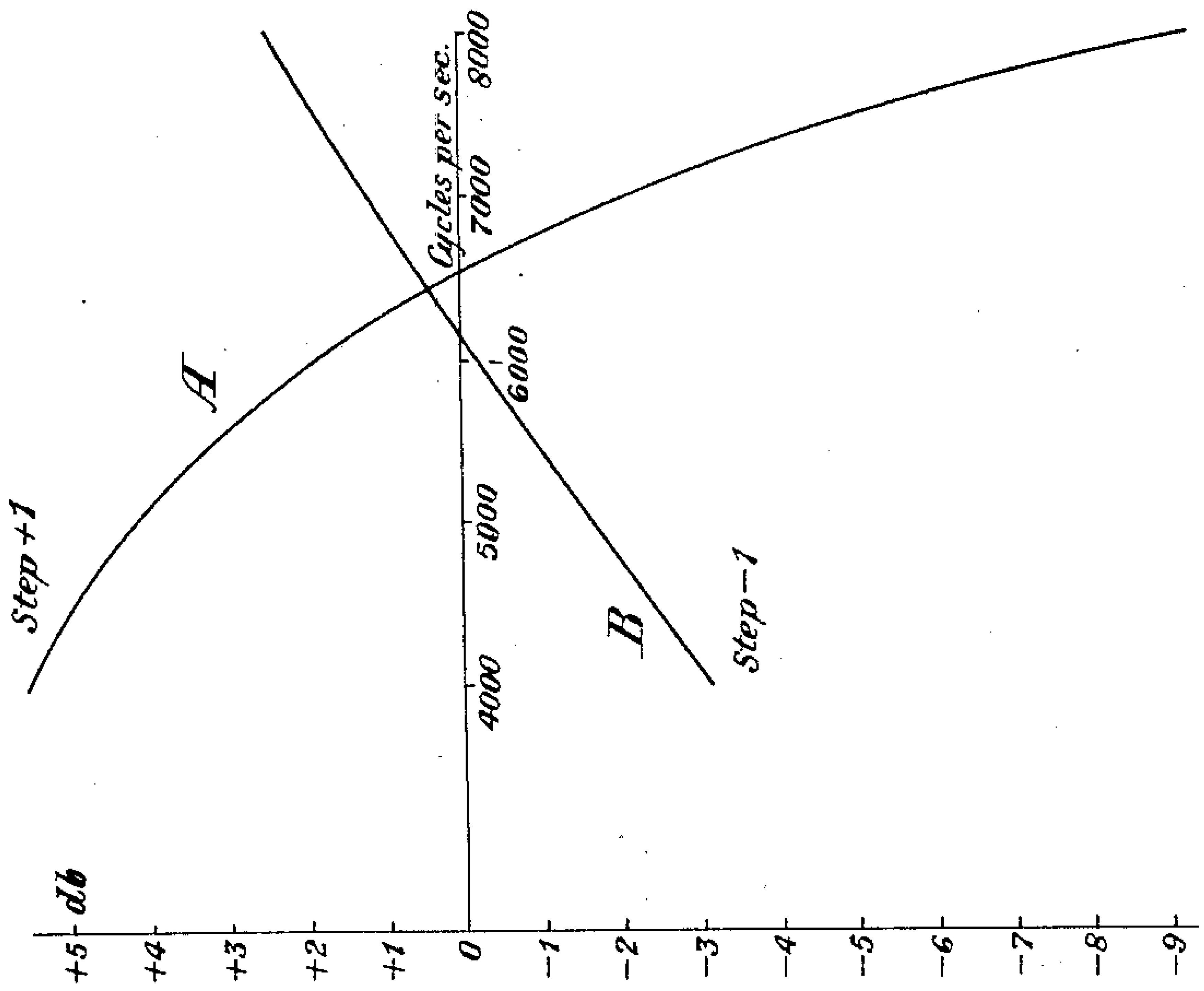

Fig. 5

INVENTOR
K. W. Pfleger
BY
ATTORNEY

Dec. 8, 1931. K. W. PFLEGER 1,835,080

TRANSMISSION REGULATION IN CABLE CIRCUITS

Filed Aug. 16, 1929 3 Sheets-Sheet 3

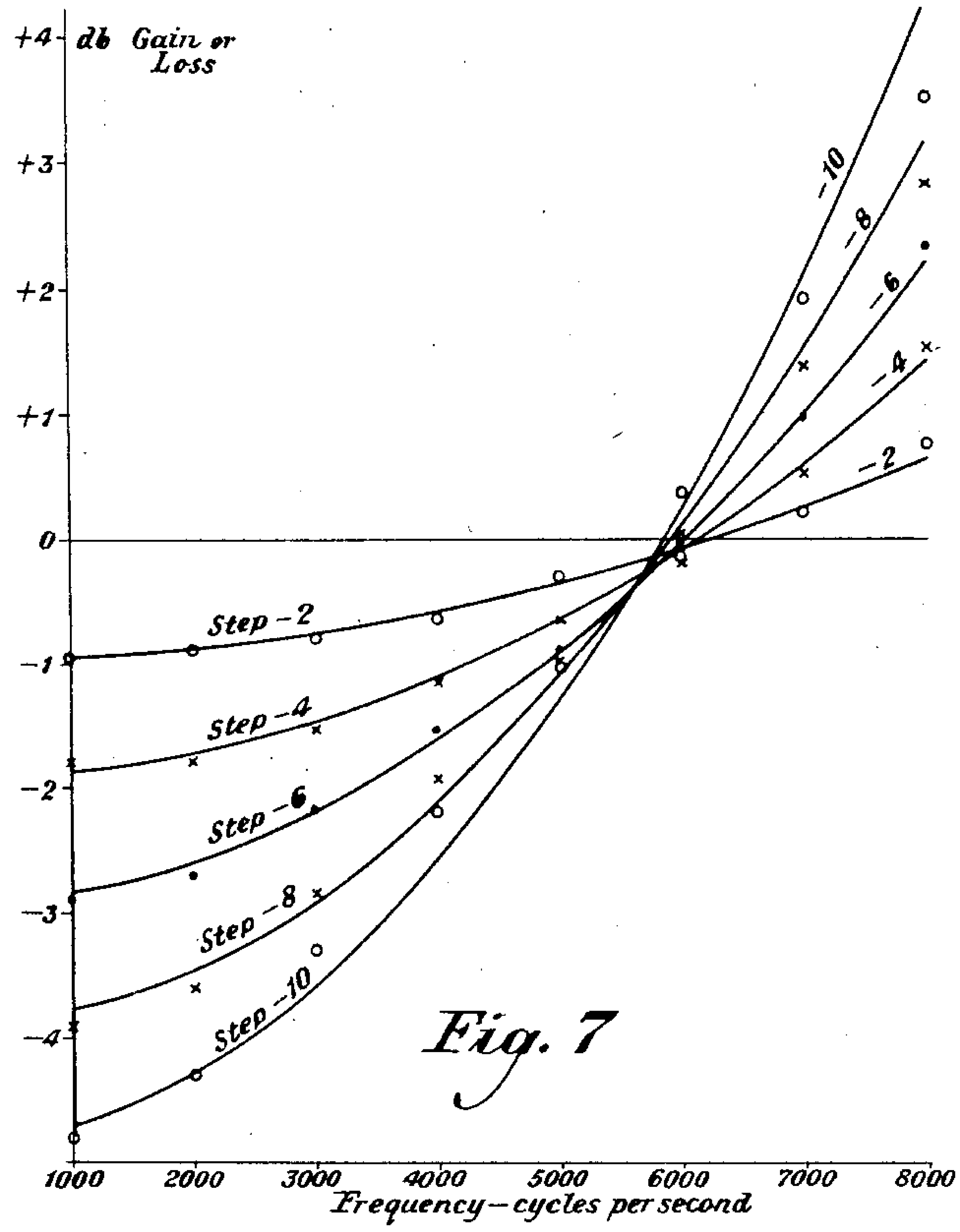

Fig. 7

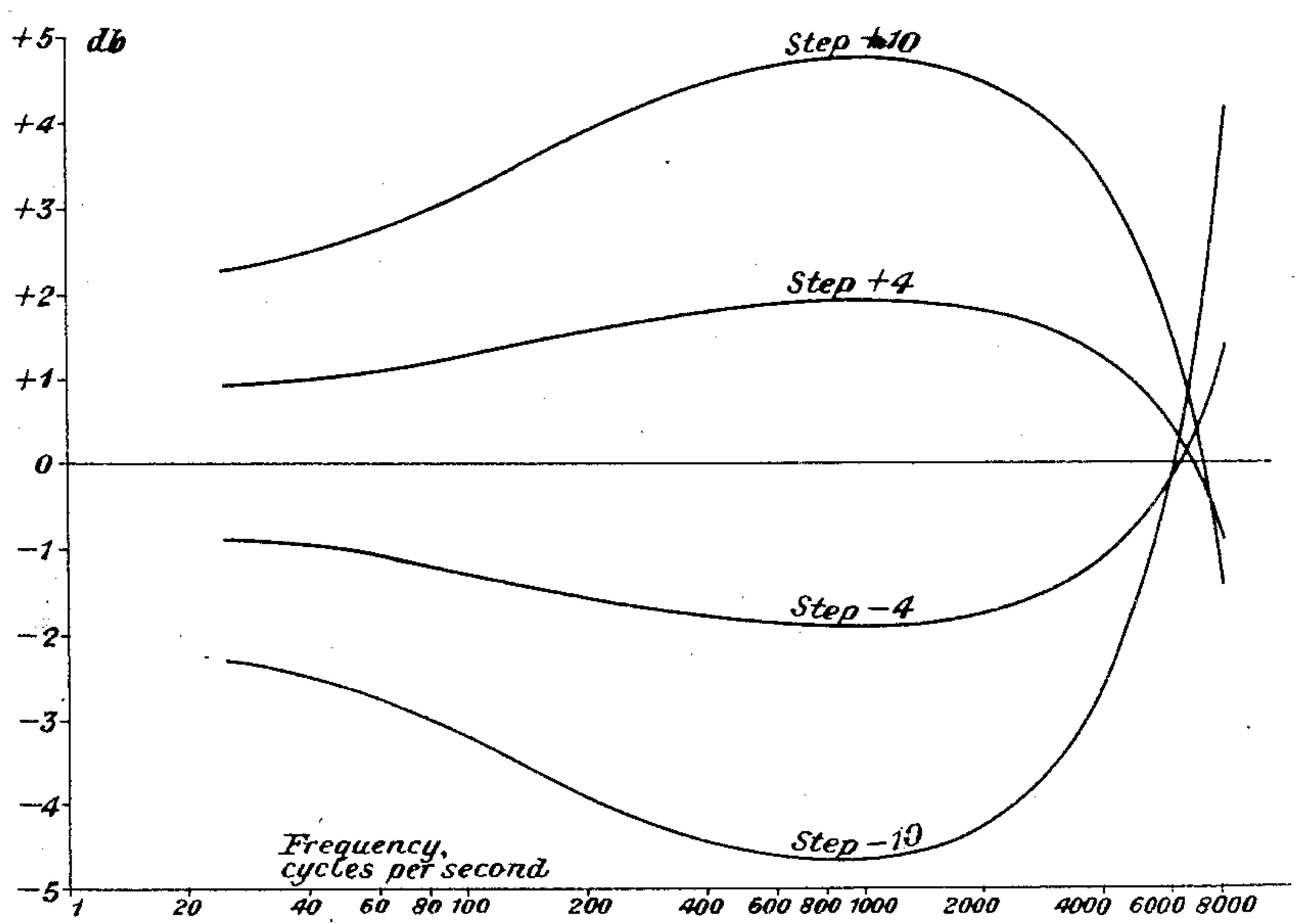

Fig. 8

INVENTOR
K. W. Pfleger
BY
G. E. Folk
ATTORNEY

Patented Dec. 8, 1931

1,835,080

UNITED STATES PATENT OFFICE

KENNETH W. PFLEGER, OF ARLINGTON, NEW JERSEY, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK

TRANSMISSION REGULATION IN CABLE CIRCUITS

Application filed August 16, 1929. Serial No. 386,436.

This invention relates to methods of and means for regulating the transmission over telephone or carrier telegraph circuits, and more particularly to regulation suitable to program transmission over telephone cable circuits.

Cable circuits are affected as to transmission characteristics by changes of temperature, the transmission characteristics being a function of the frequency of the transmitted current. In certain types of cables, at least, field measurements show that an increase of temperature, for instance, produces an increase of transmission loss at low and intermediate frequencies and that this change of transmission varies with frequency change, passing through zero at a certain high frequency and becoming a negative increment in loss at the higher frequencies.

The principal object of the invention is to provide for transmission regulation which will offset the variations mentioned above and produce a substantially flat transmission characteristic over the normal range of temperatures and a wide range of frequencies.

In general I accomplish the above-stated object by associating resonant shunt circuits with a potentiometer in the transmission line, and providing for impedance adjustments in accordance with the regulation required.

The invention will be clearly understood when the following description is read with reference to the accompanying drawings, of which—

Figure 1 shows diagrammatically a simple circuit illustrating the principles of the invention;

Figs. 2, 3 and 4 show diagrammatically the effective circuits produced by adjustment of the arrangement of Fig. 1 to meet various transmission conditions;

Fig. 5 shows curves illustrating the effect of the circuit adjustments of Fig. 1;

Figs. 6, 7 and 8 show the effect on the transmission of temperature and frequency changes and indicate the correction to be introduced; and

Fig. 9 shows diagrammatically a desirable form of apparatus embodying the invention as applied to a vacuum tube repeater.

With reference, first, to Fig. 1 of the drawings, there is shown a circuit including a potentiometer controlled by a switch S_1, which has three positions, step 0, step +1 and step −1. These steps have relation to changes in temperature of a certain number of degrees, measurements being made on a certain cable circuit of fixed length. Step 0 may correspond to the average temperature affecting the circuit. While certain impedance elements are shown as pure resistances, and the resonant shunts are shown as composed of an inductance and a capacity in series, it will be understood that this specific disclosure is merely for the purpose of illustration of the methods and means of the invention. Furthermore, the values assigned to the various elements are merely for the purpose of exposition through equations.

The potential impressed on the circuit is assumed to be 1 volt, and the values of the resistances in ohms are indicated. For the purpose of simplification, the impedances of the shunts are designated as z_1 and z_2. With switch S_1 on step 0, switch S_2 open and switch S_3 open, the received voltage (E_n) will be designated E_0; with S_1 on step +1, S_2 open and S_3 closed, the received voltage is E_{+1}; and with S_1 on step −1, S_2 closed and S_3 open, the received voltage is E_{-1}. The discussion will be clarified by reference to Figs. 2, 3 and 4 which show these three circuit conditions, respectively.

With particular reference, now, to Fig. 2, let R represent the total resistance of the circuit and R_0 the resistance from a to b. Then,

$$\frac{E_0}{E}=\frac{R_0}{R}.$$

Since E=1,

$$E_0=\frac{R_0}{R}$$

$$=\frac{\dfrac{(400+300)\times 10{,}000}{400+300+10{,}000}}{1000+2000+1000+\dfrac{(400+300)\times 10{,}000}{400+300+10{,}000}}$$

$$=\frac{\dfrac{700\times 10{,}000}{10{,}700}}{4000+\dfrac{700\times 10{,}000}{10{,}700}}$$

$$=\frac{\dfrac{7{,}000{,}000}{10{,}700}}{\dfrac{42{,}800{,}000+7{,}000{,}000}{10{,}700}}=\frac{7{,}000{,}000}{49{,}800{,}000}=\frac{1}{7.114}$$

which is the voltage across the circuit from a to b.

With reference, next, to Fig. 3, let

Z represent the total impedance of the circuit,

z_2 represent the impedance from a to b,

r_2 represent the resistance from c to d,

r_3 represent the 10,000 ohm resistance, and

$$Z_{+1}\text{ represent }\frac{1}{\dfrac{1}{z_2}+\dfrac{1}{r_2}+\dfrac{1}{r_3}}.$$

$$\frac{E_{+1}}{E}=\frac{Z_{+1}}{Z}.$$

Since $E=1$ and since

$$Z_{+1}=\frac{1}{\dfrac{1}{z_2}+\dfrac{1}{r_2}+\dfrac{1}{r_3}},$$

$$E_{+1}=\frac{\left(\dfrac{1}{z_2}+\dfrac{1}{r_2}+\dfrac{1}{r_3}\right)^{-1}}{Z}$$

$$=\frac{\left(\dfrac{1}{z_2}+\dfrac{1}{1000+400+300}+\dfrac{1}{10{,}000}\right)^{-1}}{1000+2000+\left(\dfrac{1}{z_2}+\dfrac{1}{1000+400+300}+\dfrac{1}{10{,}000}\right)^{-1}}$$

$$=\frac{1}{1+3000\left(\dfrac{1}{z_2}+\dfrac{1}{1700}+\dfrac{1}{10{,}000}\right)}$$

$$=\frac{1}{1+\dfrac{3000}{z_2}+\dfrac{3000}{1700}+\dfrac{3000}{10{,}000}}$$

$$=\frac{1}{3.0647+\dfrac{3000}{z_2}},$$

which is the voltage across the circuit from e to f.

With reference to Fig. 4, let Z' represent the total impedance of the circuit and R_{-1} the resistance from c to d. Then,

$$\frac{E_{-1}}{E}=\frac{R_{-1}}{Z'}$$

Since E=1,

$$E_{-1}=\frac{R_{-1}}{Z'}$$

$$=\frac{\dfrac{300\times 10{,}000}{300+10{,}000}}{1000+\dfrac{z_1(2000+1000+400)}{z_1+2000+1000+400}+\dfrac{300\times 10{,}000}{300+10{,}000}}$$

$$=\frac{\dfrac{3{,}000{,}000}{10{,}300}}{1000+\dfrac{3400z_1}{3400+z_1}+\dfrac{3{,}000{,}000}{10{,}300}}$$

$$=\frac{1}{.003433\left(1000+\dfrac{3400z_1}{3400+z_1}\right)+1}$$

$$=\frac{1}{4.433+\dfrac{11.673z_1}{3400+z_1}}$$

$$=\frac{1}{4.433+\dfrac{11.673}{1+\dfrac{3400}{z_1}}}$$

which is the voltage across the circuit from c to d.

On the change from step 0 to step +1, the gain in db is:

$$20\log_{10}\left|\frac{E_{+1}}{E_0}\right|=20\log_{10}\left|\frac{7.114}{3.0647+\dfrac{3000}{z_2}}\right|. \qquad \text{(A)}$$

On the change from step 0 to step −1, the gain in db is:

$$20\log_{10}\left|\frac{E_{-1}}{E_0}\right|=20\log_{10}\left|\frac{7.114}{4.433+\dfrac{11.673}{1+\dfrac{3400}{z_1}}}\right|. \qquad \text{(B)}$$

When $z_1=j\omega .01535+\dfrac{10^6}{j\omega .0136}$,

$z_2=j\omega .0145+\dfrac{10^6}{j\omega .0227}$, and

$\omega=2\pi$ times the frequency in cycles per second, it is found that Equations (A) and (B) give the curves A and B, respectively, of Fig. 5 of the drawings, transmission being plotted as ordinates and frequency as abscissæ.

It will be understood in general, and it will appear specifically hereinafter, that a greater number of steps may be—and usually will be—used, and that z_1 and z_2 may be varied for each step.

It appears from the above discussion, with reference to the drawings, that the receiving impedance may be nearly infinite (as in the case of a vacuum tube grid), but that this feature is not essential.

Figs. 6 and 7 of the drawings show some of the transmission variations brought about in a cable circuit by change of temperature and change of frequency, and indicate the correction which approximates the ideal result of constant transmission. The field measurements are expressed in terms of a cable circuit having a length of 173 miles; an average or step-zero temperature of 55 degrees Fahrenheit is taken; and each step corresponds to a change in temperature of about 5.4 degrees Fahrenheit. Only the results for the even steps are shown, and the figures are concerned with the variation with frequency in the range over one thousand cycles per second.

In Fig. 6, a curve is shown corresponding to each of the even plus steps, transmission losses in *db* being plotted as ordinates and frequencies in cycles per second as abscissæ. These curves show the variations of gain or loss with respect to frequency which it is desired that the regulating system should give, the curves being determined by measurements made on existing cable systems. The dots, crosses and circles indicate the variation in gain which, it has been found from measurements made on a particular regulator, may be introduced to give an approximate compensation for the transmission variation. It is seen that these variations give a very close approximation to the ideal variations indicated by the curves. It will be noted that at the higher frequencies, the transmission loss becomes negative, and accordingly losses must be introduced at those frequencies to give constant transmission.

Fig. 7 shows the transmission loss variation with frequency for the even minus steps and, like Fig. 6, which covers the positive steps, indicates the variation of gain which must be introduced for correction.

In Fig. 8 four curves are shown, two for the plus steps and two for the minus steps. These curves show on a scale different from that of Figs. 6 and 7 the gain which is to be introduced to give a substantially flat transmission characteristic. It will be noted that in this figure, the lower as well as the higher frequencies are covered.

It remains to show by way of illustration a regulator for producing a compensating variation such as that indicated in Figs. 6, 7 and 8. The specific case chosen for illustration is an arrangement including a potentiometer designed to operate between the stages of a vacuum tube repeater. This arrangement is shown in Fig. 9 of the drawings.

The vacuum tubes T_1 and T_2 are two tubes of a repeater. At the right of Fig. 9, in association with the grid of the tube T_2, a potentiometer P has a plurality of steps—0, +1 to +10 and −1 to −10—corresponding to temperature changes. The potentiometer P is made up of resistances and a plurality of condensers as shown. With the condensers included the potentiometer can provide the compensation necessary for the low-frequency variation of the transmitted currents. The problem of correcting for the high-frequency variation as indicated in Figs. 6, 7 and 8, however, calls for a more complicated arrangement. Such an arrangement may take the form of variable resonant shunts connected as shown at points X and Y, one on each side of the series resistance R_1.

It will be understood, of course, that the potentiometer contacts are adjusted, in any suitable manner, between step +10 and step −10 in accordance with the temperature affecting the transmission circuit. Likewise, the resonant shunts are varied by switches shown on the drawings and designated step 0, steps +1 to +10 and steps −1 to −10.

On the positive steps a resonant shunt, including in series one or more of the upper bank of condensers, shown to the left of the switches, and the inductance indicated at I_1, is connected from step +10 of the potentiometer over point Y to ground. The tuning of the shunt is provided for as indicated above, the shunt impedance being made suitable to the given positive step of the potentiometer. Thus, the current in the potentiometer is reduced at high frequencies, and the voltage acting on the grid of tube T_2 is diminished, giving the desired characteristics on the positive steps.

On the negative steps a different shunt, including in series one or more of the lower bank of condensers shown to the left of the switches and the inductance I_2, is connected from step −10 of the potentiometer to the point X. This shunt, like that discussed above, is varied by operation of the switches to give a suitable impedance shunted across both the upper portion of the potentiometer and the resistance R_1. This results in the reduction of the load impedance of tube T_1, and the current delivered by this tube increases at high frequencies. Accordingly, the voltage across the resistance R_2 is increased, and as a result, when the regulator is on the negative steps, the voltage acting on the grid of tube T_2 is increased.

It will, of course, be understood from an examination of Fig. 9 and from the more general discussion appearing hereinabove that on step 0 both the shunts described above are open. In order that the transmission frequency characteristics of the regulating stage of the repeater may be flat when the potentiometer is on step 0, a "regulator equalizer" network RE should be located in the interstage circuit of the regulating repeater between the regulating potentiometer and the apparatus from which it receives its current, the impedance of the elements of the "equalizer" being chosen to produce the desired result.

While the invention has been described specifically for the purpose of illustration, it is to be understood that many changes may be made from the specific form described within the scope of the appended claims.

What is claimed is:

1. In a transmission circuit including a potentiometer, the method of transmission regulation which consists in associating a variable impedance in shunt with the potentiometer and adjusting the potentiometer and the shunt impedance by corresponding steps in accordance with temperature changes affecting the circuit, to give a flat transmission characteristic over the range of temperatures and a wide range of frequencies.

2. In a transmission circuit including a potentiometer, the method of transmission regulation which consists in adjusting the potentiometer by steps corresponding to variations of the temperature affecting the circuit and introducing in corresponding steps auxiliary transmission variations which are positive at certain frequencies and negative at certain other frequencies for the same potentiometer setting.

3. In a circuit including a potentiometer, the method of regulating the transmission of alternating currents over the circuit which consists in determining the transmission variations with changes of temperature and with changes of frequency, including the range from 3,000 to 8,000 cycles per second, introducing an auxiliary impedance in shunt with the potentiometer, and adjusting the potentiometer and the shunt impedance by definite steps corresponding to temperature changes to produce transmission variations compensating for those caused by the temperature and frequency changes.

4. In a transmission circuit, a potentiometer adjustable in definite steps, and a variable impedance in shunt with said potentiometer and adjustable in definite steps corresponding to the potentiometer steps, whereby there may be produced in the circuit a flat transmission characteristic over a wide range of temperatures and frequencies.

5. In a transmission circuit, a potentiometer, a variable impedance in shunt with said potentiometer, and means for adjusting said potentiometer and said shunt impedance by definite and corresponding steps to give a flat transmission characteristic over a wide range of temperatures and frequencies.

In testimony whereof, I have signed my name to this specification this 15th day of August, 1929.

KENNETH W. PFLEGER.