Sept. 29, 1931. L. L. BOUTON 1,824,801

ELECTRICAL POTENTIOMETER

Filed July 8, 1926

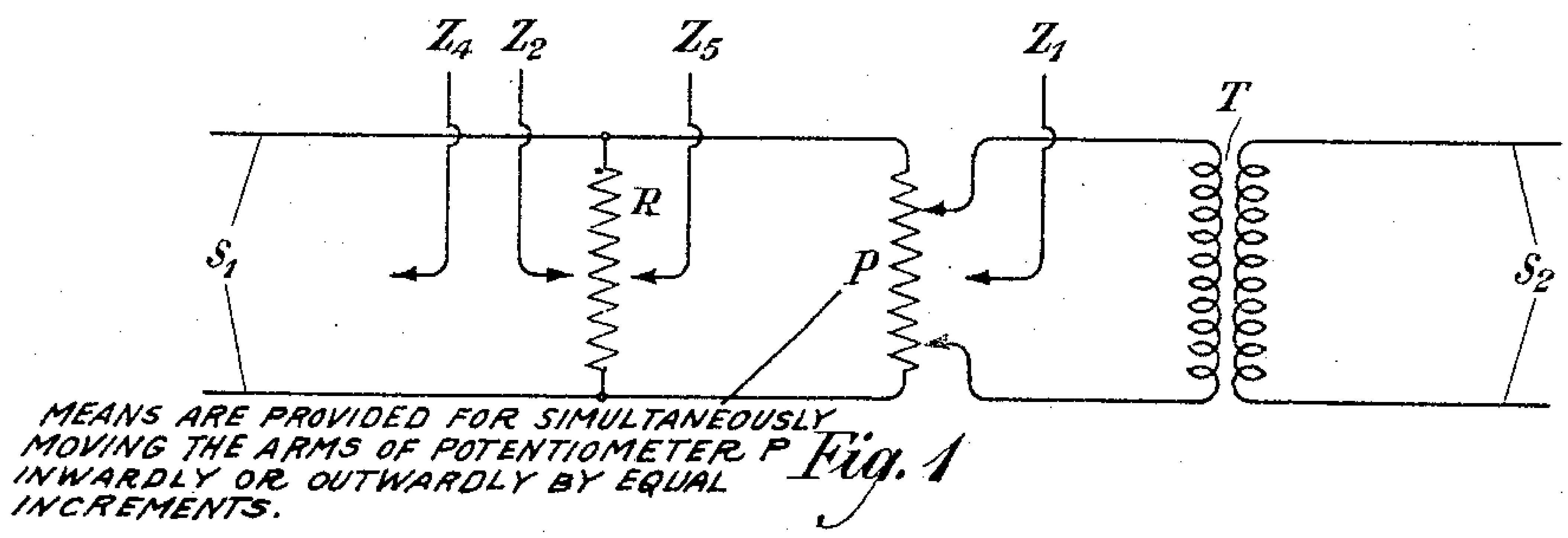

Fig. 1

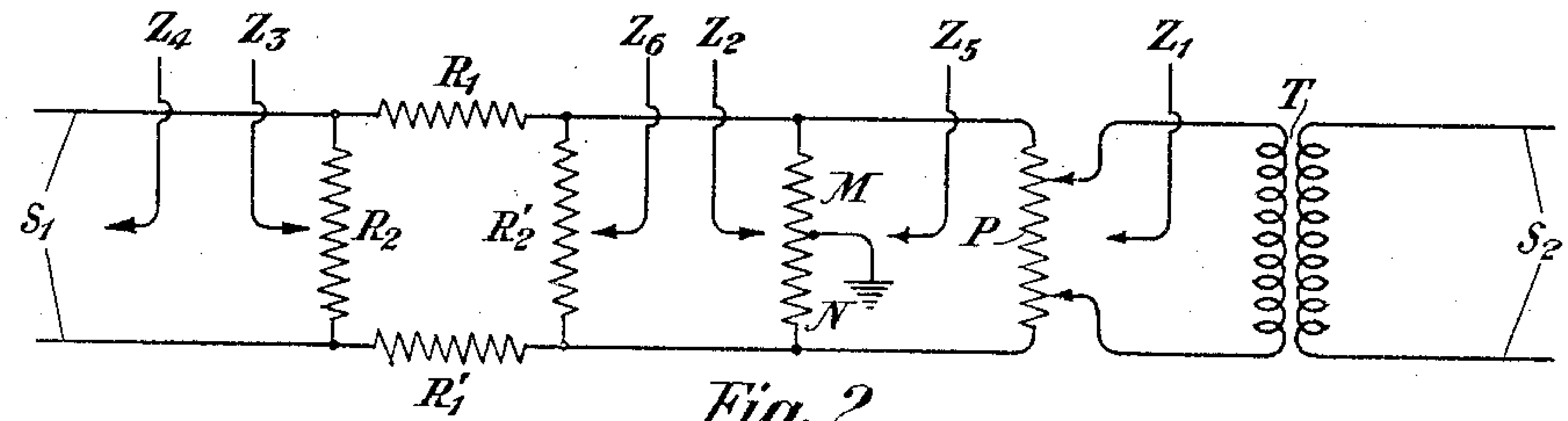

Fig. 2

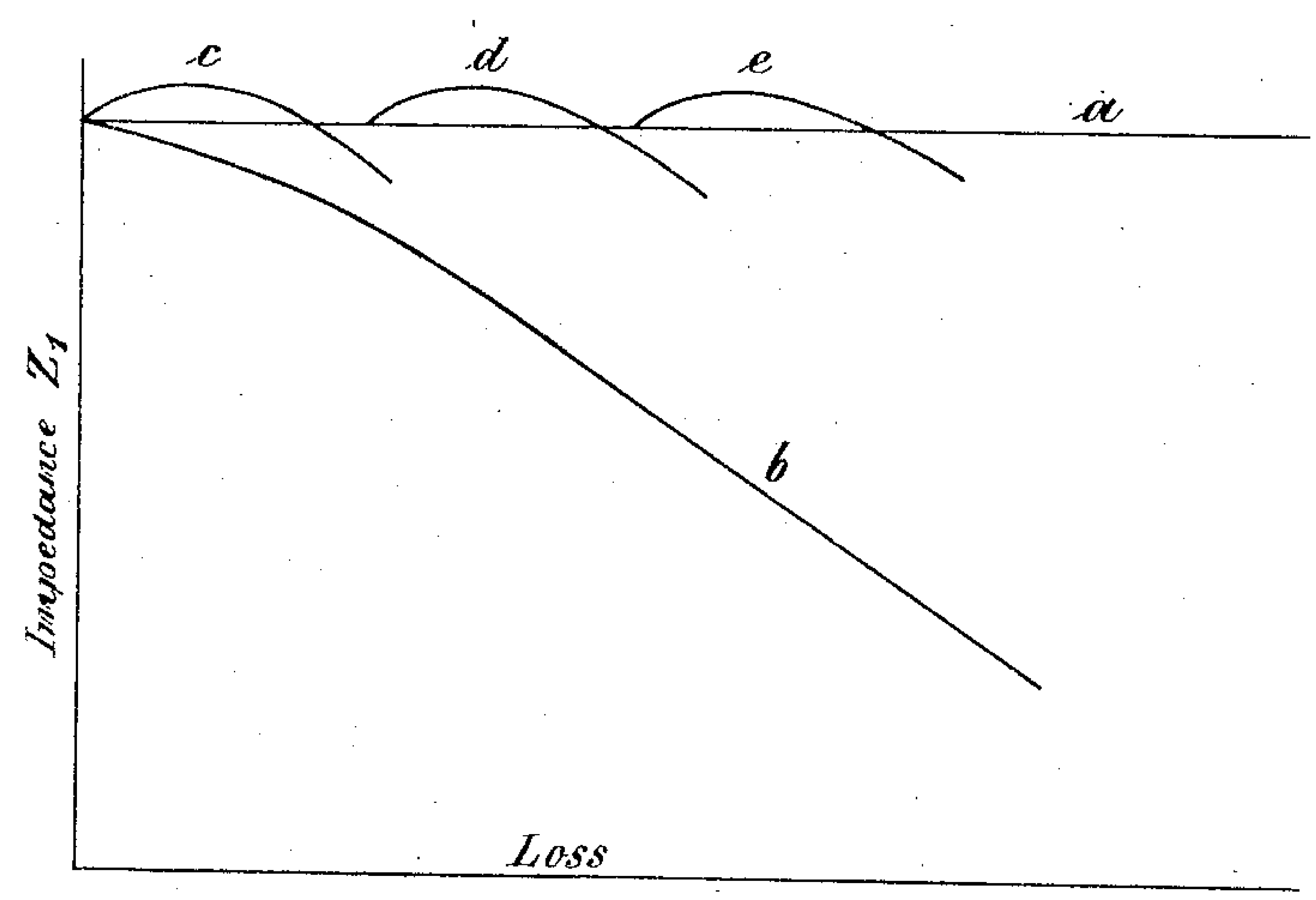

Fig. 3

INVENTOR
L. L. Bouton
BY
ATTORNEY

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UNITED STATES PATENT OFFICE

LEWIS L. BOUTON, OF LEONIA, NEW JERSEY, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK

ELECTRICAL POTENTIOMETER

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This invention relates to electrical circuits, and particularly to arrangements interconnecting an input circuit and an output circuit for controlling the potential applied to said output circuit by said input circuit.

Heretofore, whenever it was necessary to vary the potential of an input circuit applied to an output circuit, a potentiometer was interposed between the input circuit and the output circuit which had a movable contact arm associated therewith for adjusting the potential applied to the output circuit within predetermined limits. This potentiometer usually consisted of a number of resistances connected in series, the end terminals of which were connected to the input circuit. A movable arm moved over contacts connected to the various junction points in this potentiometer. The movable arm and one of the end terminals of the potentiometer were connected to the output circuit. By manipulating the movable arm the proportion of the potential of the input circuit applied to the ouput circuit was easily under control.

It was discovered that when such a potentiometer was connected between the input circuit and the output circuit, preferably through a transformer, an unbalanced condition was obtained by virtue of the fact that there was a greater drop in potential in the branch of the potentiometer including the movable arm than in the other branch, which therefore introduced stray currents and consequently "noise".

It was also discovered that all frequencies were not transmitted equally; that is to say, different frequencies were differently transmitted, the transmission loss existing at any one frequency being different from that existing at other frequencies. Generally, the higher frequencies were more easily transmitted than the lower frequencies. Furthermore, this distortion in the transmission-frequency characteristic was found to vary when the potentiometer adjustment was changed.

It is an object of this invention to provide a comparatively inexpensive potentiometer which when used to adjust the transmission efficiency of a circuit, will not provide a different adjustment at some frequencies than at other frequencies. This may be accomplished, in accordance with this invention, by employing suitable impedance relationships in the potentiometer itself as compared to the impedances of the input and output circuits, as will be described more fully in the description hereinafter following.

However, the arrangement of this invention is so set up as to provide a potentiometer which is balanced, and which does not, of itself, introduce stray currents and "noise". This is accomplished by interposing between the input circuit and the output circuit a potentiometer comprising resistance over which pass two movable arms, both arms changing the resistance by equal increments. Equal potential differences are therefore established in the circuits to which the arms of the potentiometer are connected.

It is a further object of this invention to provide a transmission circuit whose transmission efficiency may be adjusted within any predetermined range without changing the relative transmission efficiencies at the different frequencies within the frequency band transmitted.

And it is a further object of this invention to provide means for conveniently changing the efficiency range through which adjustments can be made, as conditions may necessitate. This object of the invention may be accomplished by providing a special network which interposes a transmission loss of predetermined magnitude between the input circuit and the transmission circuit itself.

While the nature of the invention will be pointed out with particularity in the appended claims, the invention itself, both as to its further objects and features, will be better understood from the detailed description hereinafter following when read in connection with the accompanying drawings, in which Figures 1 and 2 represent two transmission circuits, in each of which a potentiometer is employed embodying the principles of this invention, and in which Fig. 3 represents curves characteristic of the invention.

Referring to Fig. 1, S_1 represents an input circuit and S_2 an output circuit. A potentiometer comprising two resistances arranged in parallel relationship with each other is connected to the input circuit S_1, one of these resistances being designated by the reference character R and the other by the reference character P. Two movable arms are associated with the resistance P. These arms move simultaneously, inwardly or outwardly, depending upon whether the potential applied to the output circuit is to be decreased or increased, respectively. Moreover, these arms change the proportion of the resistance P, across which the output circuit S_2 is connected, by equal increments. These arms are also connected to the primary winding of the transformer T, the secondary winding of which is connected to the output circuit S_2.

In Fig. 2 similar reference characters are employed to designate parts similar to those of Fig. 1. Accordingly, the reference characters S_1 and S_2 designate the input and output circuits respectively, and the reference character T designates the transformer. The potentiometer of Fig. 2 comprises two resistances which are also in parallel relationship with each other, the midpoint of one of these resistances being grounded. This latter resistance is divided into two parts and these parts are identified by the reference characters M and N. The other resistance is identified by the reference character P. An artificial network is interposed between the input circuit S_1 and the potentiometer. This network comprises equal series resistance elements R_1 and R'_1 and equal shunt resistance elements R_2 and R'_2. This artificial network is substantially free from inductive or capacitative reactance.

The resistance P is connected to the primary winding of the transformer T. Owing to practical limitations in transformer design, the inductive reactance of the primary winding of the transformer T cannot be made as high as may be desired. Now, if a constant potential be applied at the source S_1 and if its frequency be varied, a varying current will flow through the primary winding of the transformer T, and this current will increase as the frequency is decreased. As a result of this, the potential across the potentiometer and, accordingly, across the transformer windings, will vary, being lower if the frequency is reduced. This is manifested in the operation of the system by reduced efficiency at low frequencies. Moreover, if when the adjustment of the potentiometer is changed, the impedance across which the primary winding of the transformer is connected also changes appreciably, this will result in a corresponding change in the transmission-frequency characteristic of the system, the relative efficiency at the lower frequencies being improved if the impedance Z_1 is lowered. More specifically, when the adjustment of the potentiometer is increased or decreased there will be a tendency for a change to take place in the transmission-frequency characteristic curve because the impedance across which the primary winding is connected is correspondingly increased or decreased. Yet in the present invention the transmission-frequency characteristic curve remains practically the same throughout because the impedance Z_1, across which the primary winding of the transformer T is connected, is maintained substantially constant.

The potentiometer of this invention is designed to provide negligible variations in impedance, or rather a substantially constant impedance, Z_1, which is the impedance viewing the potentiometer from the primary winding of the transformer T, for a limited or predetermined range of potentiometer adjustment. That is to say, in accordance with this invention the impedance Z_1 is to remain substantially constant at all times throughout a limited and predetermined range of loss introduced by the potentiometer. Furthermore, the impedance Z_2 which is the impedance viewing the potentiometer from the direction of the input circuit S_1 is substantially constant at a predetermined magnitude whenever the potentiometer is employed, as is usual, to adjust the gain of, for example, a repeater.

Fig. 3 shows a number of curves indicating the relationship between the impedance Z_1 of the potentiometer and the transmission loss introduced by the potentiometer for various combinations of the elements of this invention. The straight line curve "*a*" shows an ideal condition in which the impedance Z_1 is constant. If a potentiometer were designed having the ideal characteristic curve represented by the reference character "*a*", the transmission at all frequencies would be modified by the same magnitude when the position of the potentiometer arms was changed.

Curve "*b*" shows the impedance-loss characteristic curve for an old and well known potentiometer. This curve shows that the impedance looking back toward the potentiometer varies with the potentiometer adjustment. Obviously, the results obtained with the old type of potentiometer differed considerably from the ideal values represented by curve "*a*".

Curve "*c*" represents a curve of a potentiometer embodying the principles of this invention. This curve indicates variations in the impedance presented to the transformer T which differ by negligible amounts from those presented by the potentiometer of which curve "*a*" is characteristic. By suitable adjustments of the constants of the potentiometer the curvature of curve "*c*" may be controlled within suitable limits.

Letting Z_4 = the impedance of the circuit S_1
R_S = the resistance of the shunt R
R_P = the total resistance of the potentiometer
nR_P = the portion of the potentiometer resistance included between the terminals of the receiving circuit
m = the ratio $\frac{R_P}{Z_4}$, and
Z_1 = the impedance presented by the combination of the circuit S_1, the shunt R, and the potentiometer P toward the transformer T,

then the following relationship will exist:

$$Z_1 = \frac{nR_P\left\{(1-n)R_P + \frac{Z_4 R_S}{Z_4 + R_S}\right\}}{R_P + \frac{Z_4 R_S}{Z_4 + R_S}} \quad (1)$$

In order that the combination of the potentiometer and the shunt may receive waves from the circuit S_1 without reflection losses, the following relationship must exist:

$$\frac{R_S R_P}{R_S + R_P} = Z_4 \quad (2)$$

From these relationships it may be readily shown that:

$$\frac{Z_1}{Z_4} = \frac{n}{2}\{2m(1-n) + n\} \quad (3)$$

In the potentiometers used heretofore, as already explained, the ratio m was equal to unity and no shunt resistance such as R was used. Under these conditions the impedance Z_1 fell off as n decreased in magnitude from unity. The loss introduced between the circuit S_1 and the transformer T increased as n was reduced. Curve b of Fig. 3 shows the relationship between the impedance Z_1 and the loss caused by turning down the potentiometer. In the practice of this invention, however, the resistance of the potentiometer P, as explained heretofore, is made greater than the impedance of the circuit S_1. In other words, m is made greater than unity. It will readily be seen that when the resistance of the potentiometer P is made very great, the impedance Z_1 will first increase and then decrease as the value of n is decreased. This follows also from Equation 3, given hereinabove, and is illustrated by curve c of Fig. 3. By choosing a suitable value for m, the maximum value reached by the impedance Z_1, as illustrated by curve c, will be within certain tolerable limits which are fixed by the requirement that the effect of changing the potentiometer setting must be substantially the same at all frequencies of the transmitted current. By adopting a suitable limit for the variation of the potentiometer P, the variation of the impedance Z_1 below the desired value can be kept within tolerable limits.

The potentiometer, of which "c" is the characteristic impedance-loss curve, introduces a transmission loss within predetermined magnitudes. When gain variations are desired in some other predetermined range, for example, in some lower range it becomes necessary to supplement the potentiometer with the artificial network (shown in Fig. 2) comprising series and shunt resistances. As is very readily understood, such a network introduces a transmission loss of a definite magnitude. By employing resistance in such a network to the exclusion of capacitative or inductive reactance the artificial network becomes distortionless, and thus does not affect the transmission-frequency characteristic of the system. By employing different artificial networks to supplement the potentiometer, gain adjustments may be made over a considerable range, as may be required, and the impedance-loss curves may, at the same time, be made to assume the shapes of, for example, the curves "d" or "e".

The variations in the impedance Z_1 presented to the transformer T by the potentiometer depend on the relative magnitudes of resistance P and impedance Z_5. By varying the comparative magnitudes of the resistance P and the impedance Z_5, the impedance-loss characteristic curve may be made to vary in shape. In the old and well known type of potentiometer the resistance P was made equal to the impedance Z_5 so that the characteristic curve assumed the shape of the curve "b" of Fig. 3. Moreover, by changing the ratio of the resistance P to the impedance Z_5, the impedance Z_1 presented to the transformer T can be controlled to a considerable degree. The resistance R of Fig. 1 is bridged across the resistance P so that the impedance Z_2 may be made as nearly equal to the impedance Z_4 as may be found desirable.

Whenever it becomes necessary to have impedances Z_4 and Z_2 equal, the values of resistances R and P may be determined from the following equations:

$$R = Z_2\frac{Q+1}{Q-1}$$

and

$$P = Z_2\frac{Q+1}{2} \quad (4)$$

in which Q is the ratio

$$\frac{P}{Z_5}.$$

While the invention has been disclosed in certain particular arrangements for the purpose of illustration, it is to be understood that the general principles of this invention may be embodied in other and widely varied organizations without departing from the spirit of the invention and the scope of the appended claims.

What is claimed is:

1. The combination of a potentiometer, a circuit supplying currents to said potentiometer, said potentiometer comprising two resistances of predetermined magnitudes connected parallel relationship with each other, each of said resistances having a greater impedance than the circuit supplying currents thereto and so related to each other that their joint impedance substantially equals the impedance of said circuit, and means for adjusting the gain of the potentiometer, said means comprising two arms and an arrangement whereby said arms may determine and change the proportion of the potential drop across one of said resistances to be delivered by said potentiometer.

2. A potentiometer free from frequency discrimination interconnecting an input circuit and an output circuit, comprising two resistances in parallel relationship with each other, and two movable arms associated with one of the resistances for simultaneously varying the effect of the latter resistance by equal increments, one of said resistances being greater than the impedance of said input circuit, said resistances exhibiting a magnitude substantially equal to the impedance of said input circuit.

3. A potentiometer interconnecting an input circuit and an output circuit, comprising two resistances in parallel relationship with each other, and two movable arms associated with one of the resistances for simultaneously varying the potential therebetween by equal increments, the resistance with which the movable arms are associated having greater magnitude than the impedance of said input circuit, said input and output circuits having at all times substantially constant impedances when viewed from opposite sides of the potentiometer.

4. A potentiometer free from frequency discrimination connected across the terminals of an input circuit for varying the voltage of said input circuit applied to an output circuit, comprising two resistances each of greater magnitude than the impedance of said input circuit, and means for maintaining said potentiometer balanced while varying the voltage of the input circuit applied to the output circuit, said means including arrangements for varying the proportion of the potential drop across one of said resistances which shall be delivered to said output circuit.

5. A potentiometer interconnecting an input circuit and an output circuit, comprising two resistances in parallel relationship with each other, one of said resistances being grounded at its midpoint, and two movable arms associated with the other of said resistances for simultaneously varying the voltage between said arms by equal increments, the latter resistance being greater than the impedance of said input circuit.

6. A potentiometer interconnecting an input circuit and an output circuit, comprising two resistances in parallel relationship with each other each being greater than the impedance of said output circuit, two arms associated with one of said resistances, and means to simultaneously move said arms in order to vary the voltage set up by said latter resistance equally and in opposite directions, said resistances being so related that the impedance looking from the input circuit to the output circuit equals the impedance looking from the output circuit to the input circuit.

7. A system for controlling the proportion of the voltage of an input circuit applied to an output circuit within a predetermined range, comprising an adjustable resistance of greater impedance than that of said input circuit and an artificial line including equal series resistances and equal shunt resistances, said adjustable resistance and said artificial line being connected between said input and output circuits, said predetermined range of voltage variation depending upon the loss introduced by the artificial line.

8. A potentiometer interconnecting an input circuit and an output circuit, comprising two resistances in parallel relationship with each other, one of said resistances being greater than the impedance looking into said input circuit, means for adjusting the potential impressed on the output circuit by the input circuit, and an artificial line interposed between the parallel resistances and the input circuit, said artificial line including two equal series resistances and two equal shunt resistances and being employed for shifting the limits of voltage variation of said parallel resistances to other limits in the voltage spectrum.

9. A potentiometer interconnecting an input circuit and an output circuit, comprising two resistances in parallel relationship with each other, each of said resistances being greater than the impedance of said input circuit and each being so proportioned with respect to the other that their impedance substantially equals the impedance looking into said input circuit, means for adjusting the potential impressed on the output circuit by the input circuit, and an artificial line interposed between said input circuit and said two resistances in parallel relationship, said artificial line comprising equal series resistance elements and equal shunt resistance elements, said artificial line introducing a loss of predetermined magnitude between the input circuit and the output circuit.

10. A potentiometer interconnecting an in-

put circuit and an output circuit, comprising two resistances in parallel relationship with each other, the joint impedance of said resistances being equal to the impedance of said input circuit said resistances individually exhibiting greater magnitudes than the impedance of said input circuit and their combined impedance terminating said input circuit without introducing reflection, means for adjusting within predetermined limits in the voltage spectrum the potential impressed on the output circuit by the input circuit, and means comprising equal series impedances and equal shunt impedances for shifting said predetermined limits in the voltage spectrum to other limits therein.

11. A system comprising two parallel resistances, one resistance being grounded at its midpoint, two movable arms associated with the other resistance, the latter resistance being greater in magnitude than the impedance of the circuit containing the source of energy and being so proportioned with respect to the first resistance that their combination terminates said circuit containing said source of energy without the introduction of reflection, each varying its effective potential magnitude equally with respect to the terminals of said resistance, and an artificial line comprising equal series resistance elements and equal shunt resistance elements, said system being substantially free from unbalanced currents.

12. A system for adjusting voltage within predetermined limits of variation without frequency discrimination, comprising two parallel resistances one of which is adjustable and has a greater impedance than the circuit transmitting energy thereto, and an artificial line including equal series resistances and equal shunt resistances, the loss characteristic of the artificial line determining the limits of variation of the voltage.

13. A system for interconnecting an input circuit and an output circuit suitable for adjusting the voltage of the input circuit to be applied to the output circuit, comprising two parallel resistances and a resistance artificial line, said parallel resistances being individually greater than the impedance of said input circuit, the parallel resistances being so related that the impedance of the system viewed from the input circuit substantially equals the impedance of the system viewed from the output circuit.

14. A system for interconnecting an input circuit and an output circuit suitable for adjusting the voltage of the input circuit to be applied to the output circuit without the introduction of noise, comprising two parallel resistances each of greater magnitude than the impedance of said input circuit and jointly terminating said input circuit without reflection, and an artificial line including equal series resistances and equal shunt resistances and introducing a loss of predetermined magnitude.

15. A system interconnecting an input circuit and an output circuit, comprising two parallel resistances, one resistance being grounded at its midpoint, means for simultaneously varying the effective magnitude of the other resistance by equal increments with respect to its terminals, the latter resistance being of a predetermined magnitude which is greater than the impedance of said input circuit, a balanced artificial line, means whereby said system is rendered substantially free from eddy currents.

16. A system interconnecting an input circuit and an output circuit, comprising two parallel resistances, one resistance being grounded at its midpoint, means for changing the effective magnitude of the other resistance by equal increments with respect to its terminals, the total magnitude of the latter resistance being greater than the impedance looking into said input circuit, an artificial line having equal series elements and equal shunt elements, and means whereby said system is rendered substantially free from eddy currents.

17. A balanced potentiometer interconnecting an input circuit and an output circuit for varying the gain of the output circuit, said potentiometer having two parallel elements of resistance each having an impedance greater than that of the input circuit and being so proportioned that the impedance presented to the output circuit substantially equals the impedance of the input circuit, said potentiometer presenting to the output circuit an impedance which increases to a small extent above a definite value and decreases below that value as the loss increases, the maximum departure from said definite value being within predetermined limits.

18. A potentiometer substantially free from frequency discrimination, comprising a plurality of parallel resistance elements bridged across a telephone line, one of which is greater than the impedance of the telephone line, said resistances conjointly exhibiting an impedance equal to that of the telephone line, and means for adjusting the gain of the potentiometer, said means comprising two arms and arrangements to move said arms simultaneously over one of said resistances to vary the portion of the resistance included therebetween in such a way that the portions of the resistance not included between said arms remain equal.

In testimony whereof, I have signed my name to this specification this 2nd day of July, 1926.

LEWIS L. BOUTON.