

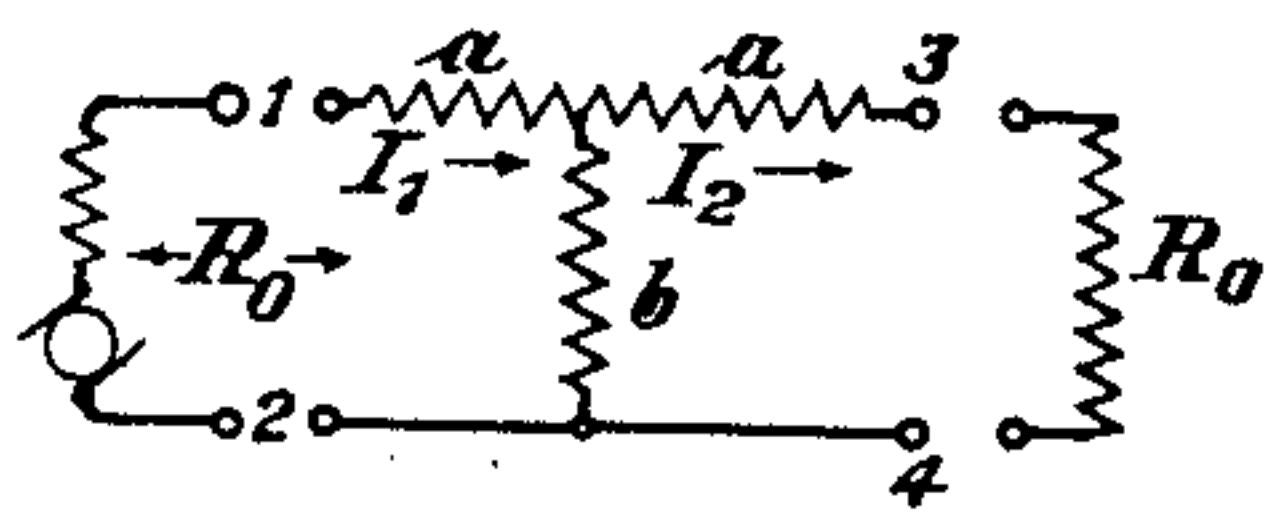
Feb. 27, 1934.

H. A. RHODES

1,948,675

ARTIFICIAL LINE AND ATTENUATOR OF CONSTANT RESISTANCE

Filed Aug. 25, 1931



$$a = \frac{1-k}{1+k} R_0 \quad (1)$$

$$b = \frac{2k}{1-k^2} R_0 \quad (2)$$

$$k = \frac{I_2}{I_1} \quad (3)$$

Fig. 1

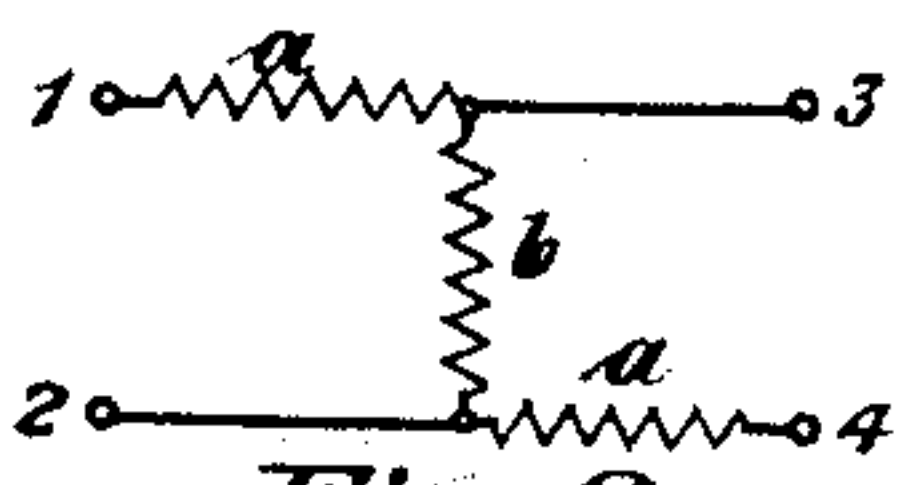


Fig. 2

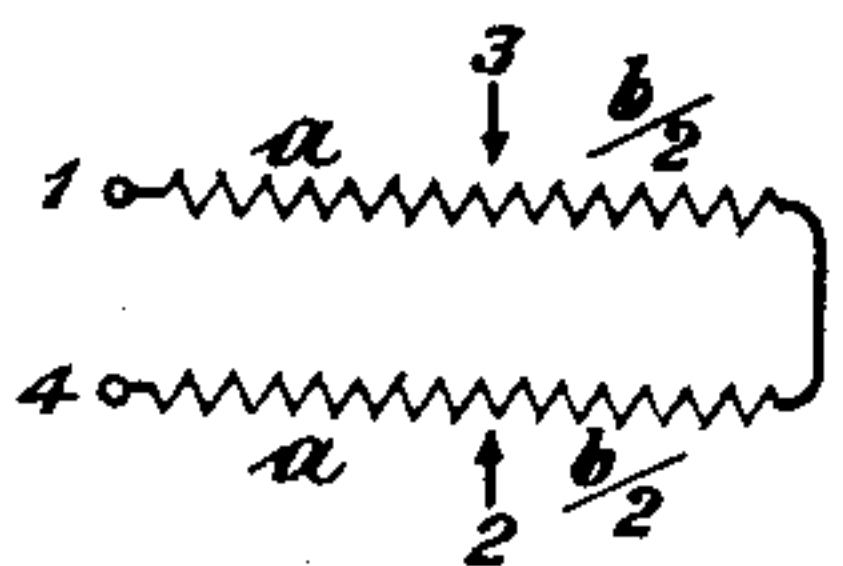


Fig. 4

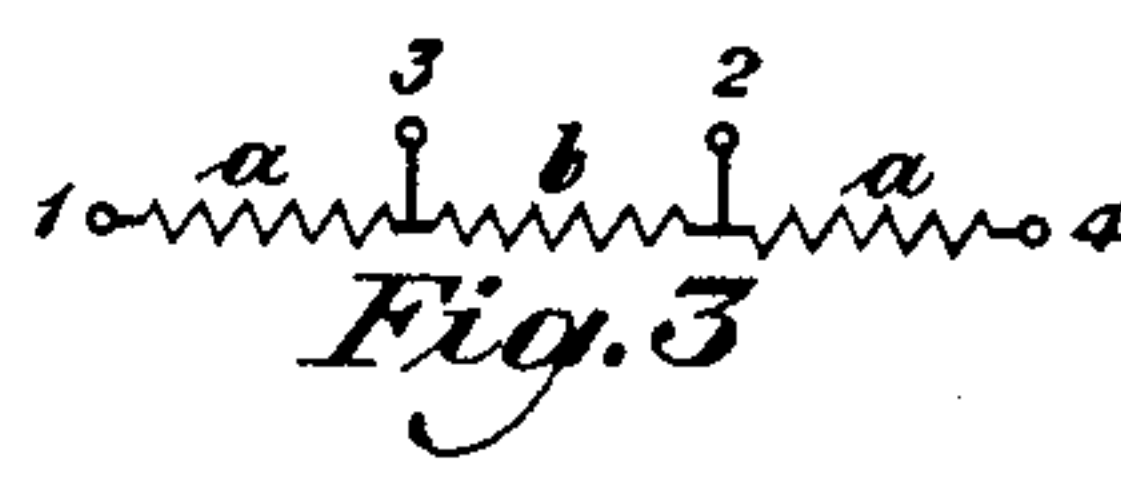


Fig. 3

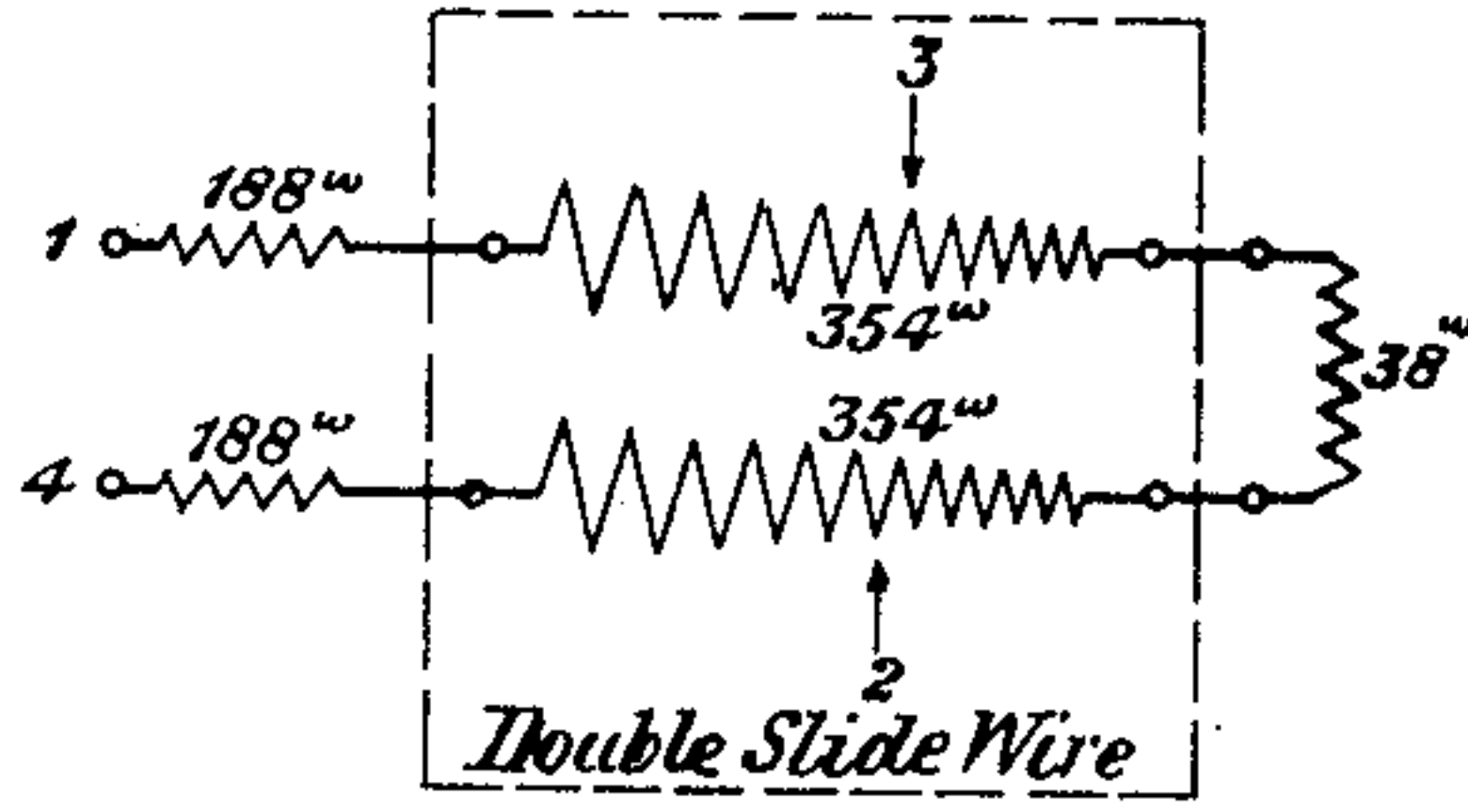


Fig. 5

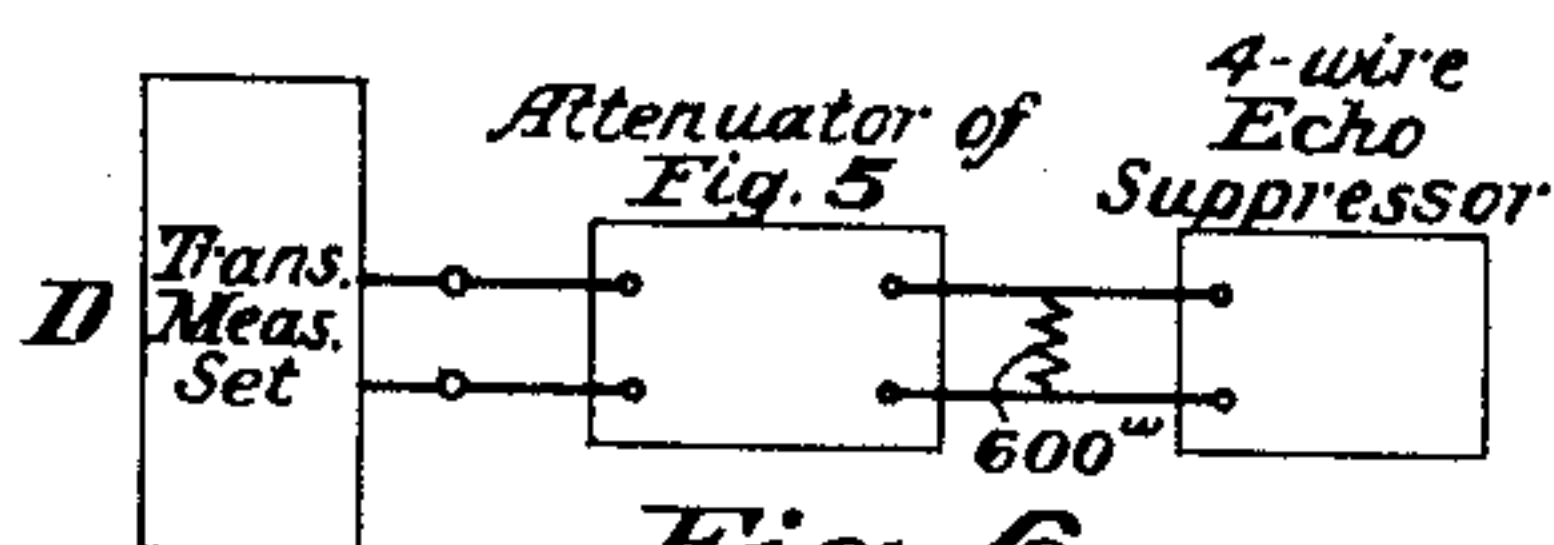


Fig. 6

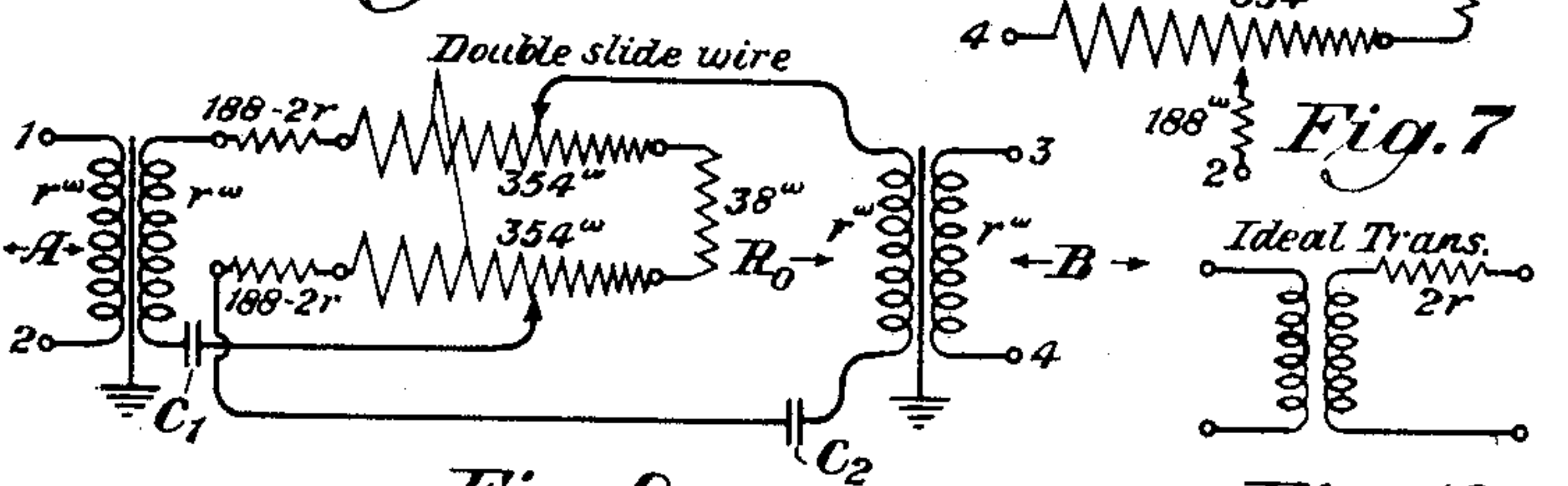


Fig. 9

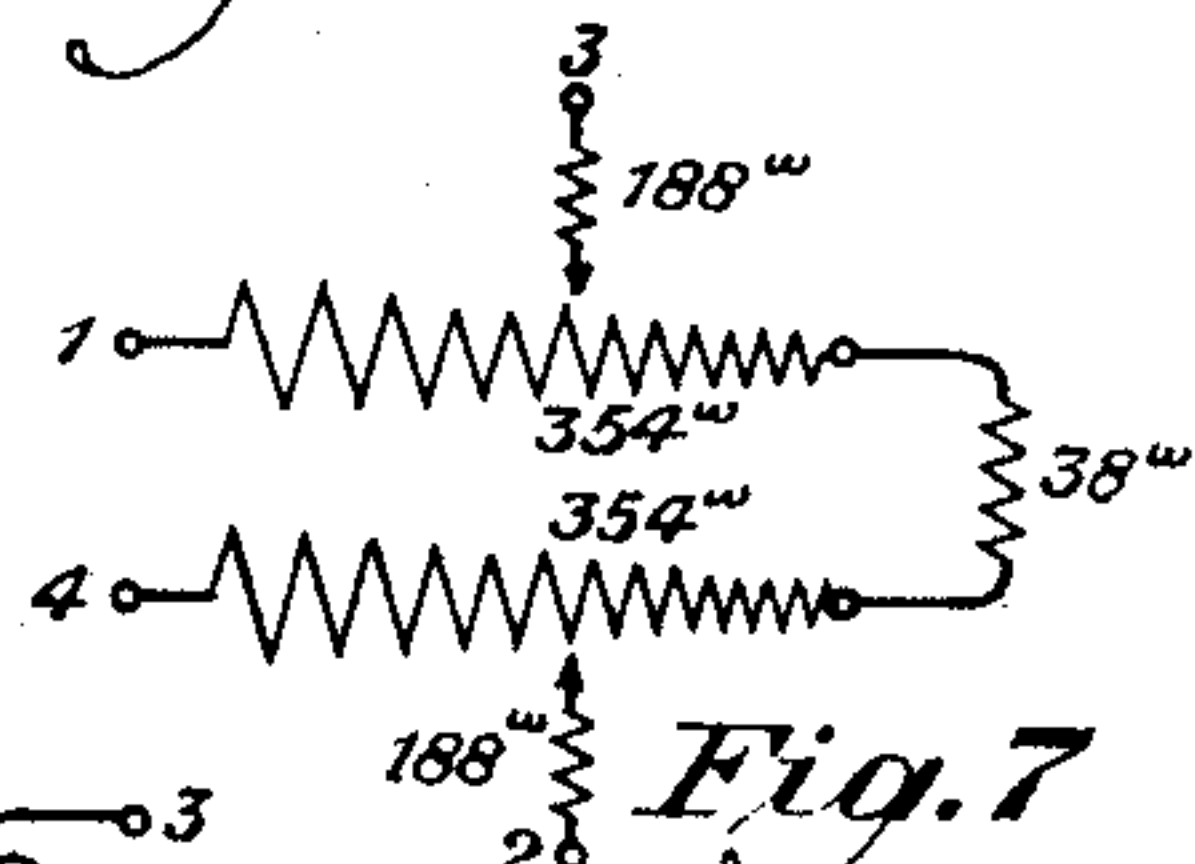


Fig. 7

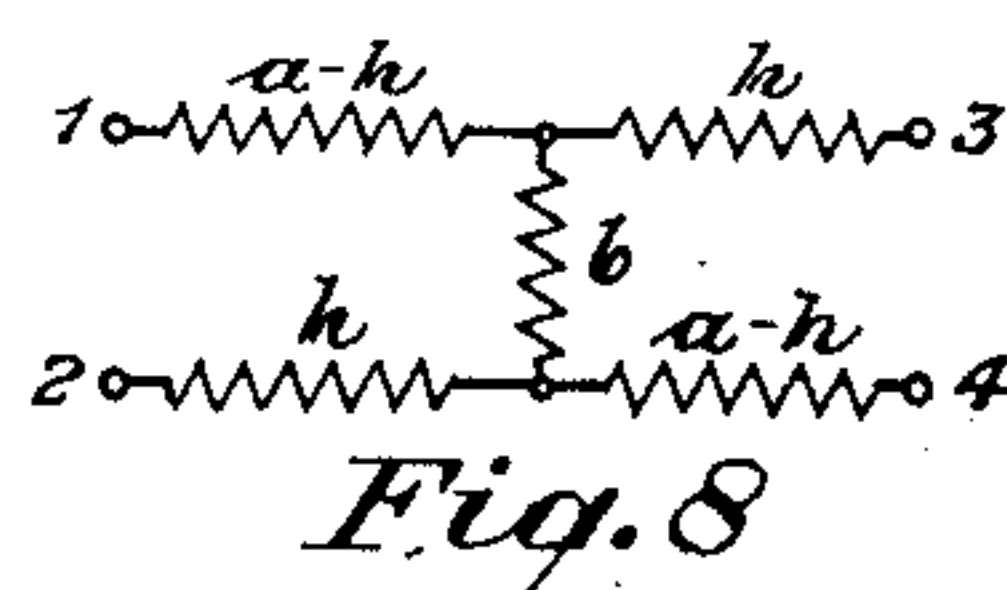


Fig. 8

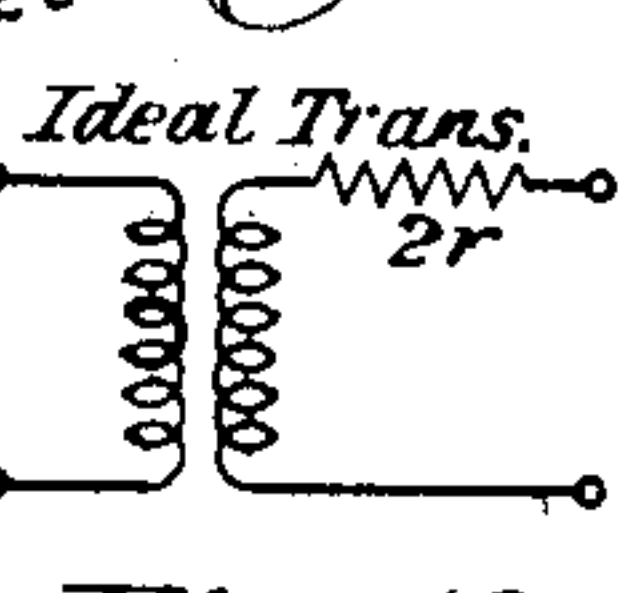


Fig. 10

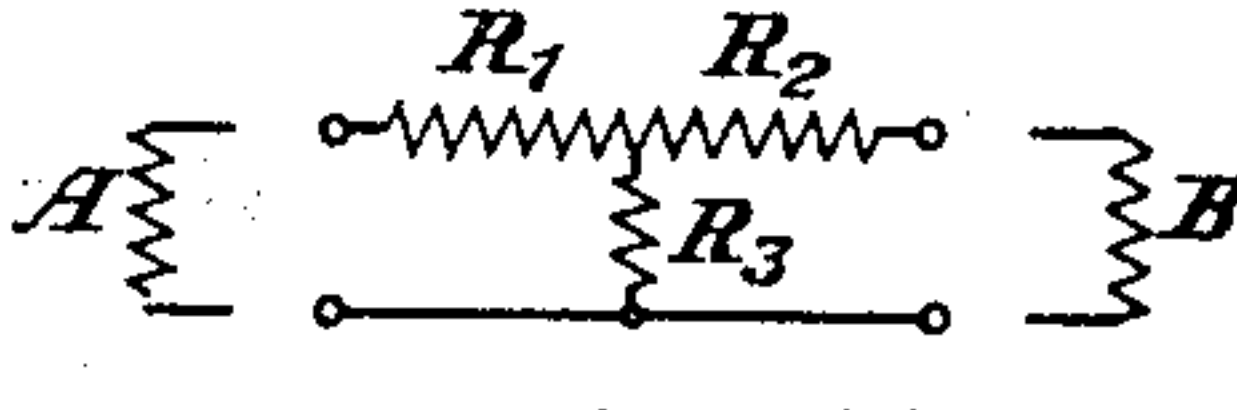


Fig. 11

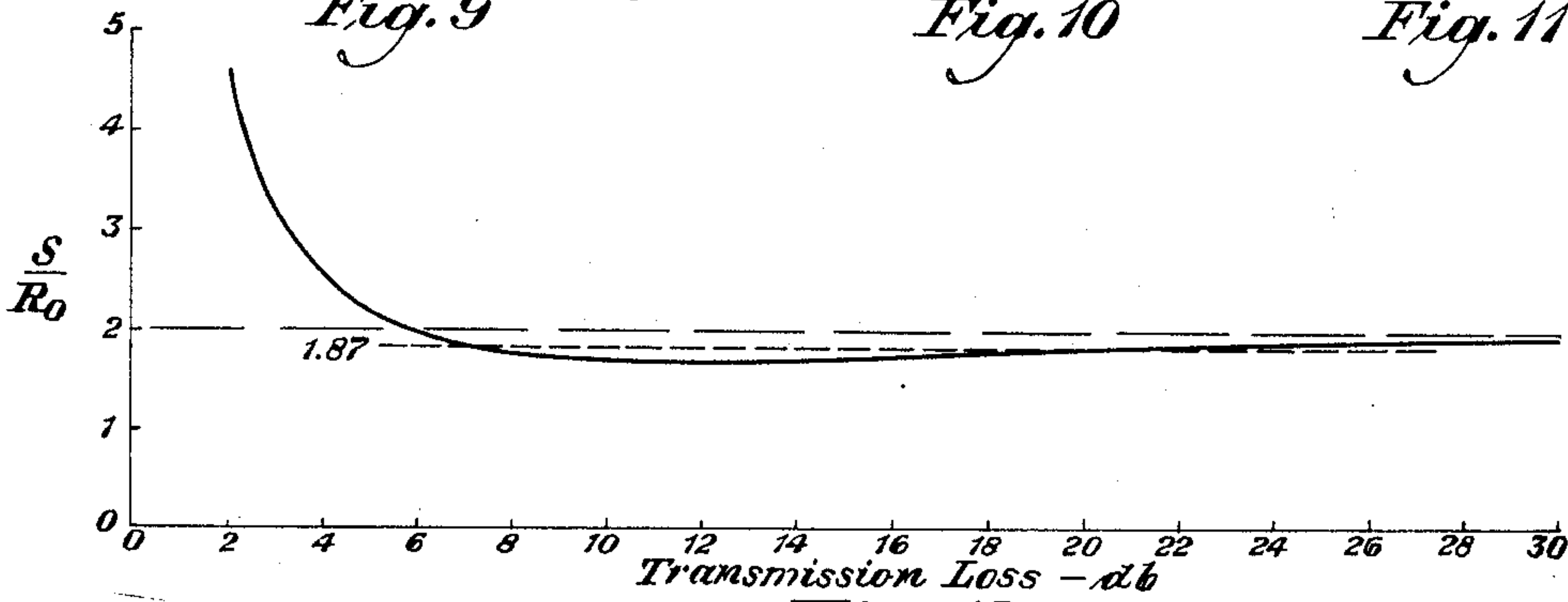


Fig. 12

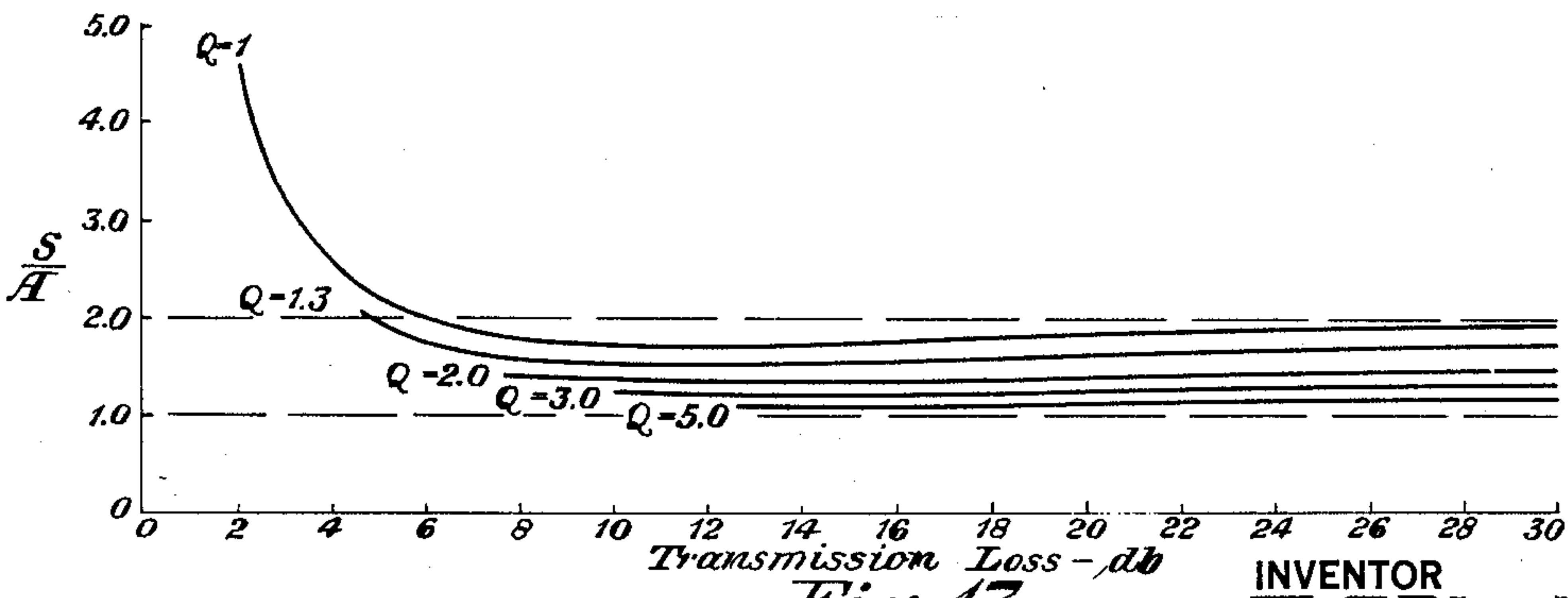


Fig. 13

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1,948,675

ARTIFICIAL LINE AND ATTENUATOR OF CONSTANT RESISTANCE

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Application August 25, 1931. Serial No. 559,323

7 Claims. (Cl. 178—44)

This invention relates to artificial lines of constant resistance and more particularly to lines or networks of this nature by which to introduce transmission loss in a given part of a circuit.

Its purpose is to provide a network of the above characteristics which will enable one to vary the current through a load, or the E.M.F. available for the load, without destroying the impedance matching between the source and the load. Another purpose is to design a circuit of the above characteristics which may be adjustable and continuously adjustable without appreciable change in the resistance of the whole network. Still another purpose is to afford means by which such continuous adjustment for all intermediate values may be made readily and quickly to any desired value of transmission loss between certain limits.

The invention will be better understood by reference to the following specification and accompanying drawing in which Figures 1 to 4 show certain fundamental circuit relations. Figs. 5 and 6 show specific embodiments of these circuits to my invention. Figs. 7, 8 and 9 show modifications of the circuit of Fig. 6. Fig. 10 is a diagrammatic of transformer properties. Fig. 11 shows the fundamental circuit relationships in case the source and the load have different impedances and Figs. 12 and 13 give the characteristics of some of the circuits.

In designing various kinds of equipment for communication purposes, numerous occasions arise where the use of a T-connected network of constant resistance and definite loss is desirable. Such a T-network is shown in Fig. 1 in which the network with its load of impedance R_0 smoothly terminates the incoming line whose impedance is also R_0 . As is already known in the art, the condition necessary is that the impedance as seen looking into the network from the source shall also be R_0 and that the impedance as seen looking into the T-network from the load shall be R_0 . It can readily be shown that the series and shunt arms must have values given by the relations

$$a = \frac{1-k}{1+k} R_0 \quad (1)$$

$$b = \frac{2k}{1-k^2} R_0 \quad (2)$$

where k is the ratio of I_2 to I_1 or more specifically the square root of P_2/P_1 , where P_1 is the power delivered by the source into the circuit at the terminals 1 and 2 and P_2 is the power delivered into the load at terminals 3 and 4. It is evident that

P_1 is equal to $I_1^2 R_0$ and P_2 is equal to $I_2^2 R_0$. The transmission loss associated therewith, and expressed in decibels, is given by

$$L = 20 \log_{10} \frac{I_1}{I_2} = 20 \log_{10} \frac{1}{k} \quad (3)$$

By adjusting the values of a and b , any desired transmission loss may be obtained, still retaining the impedance R_0 , as seen from the line or as seen from the load.

Figs. 2 to 4 show various modifications of the circuit of Fig. 1 and they are all the electrical equivalents thereof in that the impedance as seen looking into the terminals 1 and 2 is R_0 and the values of a and b , are those given above, with k having the same significance.

It will be noted that by making the contacts 2 and 3 of Figs. 2 to 4 adjustable and mechanically movable together, the value of a can be reduced while b is increased an equal amount so that the resistance $2a+b$ remains constant. This is particularly apparent in the circuit as rearranged in Fig. 4. The question now arises as to whether, and to what extent, one can change the value of k and keep the relationship of Equations (1) and (2) in order to maintain proper impedance matching and still keep $2a+b$ constant, thus permitting a change in position of contacts 2 and 3 but no physical changes in the total resistance. Another way to express this is to inquire how the quantity $2a+b$ changes for different values of k on the condition that impedance matching is retained. I have shown in Fig. 12 a plot of the relation between transmission loss as abscissæ and

$$\frac{2a+b}{R_0}$$

as ordinates and it will be observed that for transmission losses above about six decibels, the quantity $S=2a+b$ remains practically constant. For large attenuation this quantity is equal to $2R_0$ but if one desires to use low attenuation or loss, it will be noted that $1.87 R_0$ is a good average value to take for the sum of the resistance $2a+b$.

In this Fig. 12, as well as in Fig. 13, the transmission loss is plotted in decibels; where the decibel is defined by the Equation (3). Thus, for six decibels

$$\frac{I_1}{I_2}$$

is approximately 2; while for thirty decibels, it is approximately 32.

The circuit equivalence, which I have described above, is, so far as I am aware, novel and its application to a specific structure representing one embodiment of my invention is shown in Fig. 5 in which the resistances are arranged in the form of a double slide wire with two fixed contacts 1 and 4 and two sliding contacts 2 and 3 corresponding to the similarly numbered terminals in Figs. 1 to 4. In this circuit of Fig. 5, R_0 has been given the value of 600 ohms for illustrative purposes, whence $S=2a+b=1.87 R_0=1122$. From the curve of Fig. 12, it is seen that the minimum loss for which the circuit is adapted is about six decibels corresponding to $k=\frac{1}{2}$, approximately, whence, from Equations (1) and (2) it is found that $a=200$ and $b=300$. These values would give a total resistance of 1200 ohms but on reference to Fig. 12 it will be seen that a better value for

$$\frac{S}{R_0}$$

would be about 1.87, giving a slight error in one direction below 20 decibels, and a slight error in the other direction above 20 decibels. This, however, yields a value of $S=1122$ ohms. With this slight adjustment, it is found that with six decibels loss $a=188$ ohms. Furthermore, at an extreme loss of 30 decibels, a similar calculation shows that $a=188+354$. If, in any particular work, one limits the transmission loss to the range of six decibels to thirty decibels, it will not be necessary to make a less than 188 ohms or more than 542 ohms. It is to be understood that the above numbers I have taken for illustration purposes and in Fig. 5 it will be noted the sliding contact takes place only over the portion whose resistance has the value 354 ohms.

It is evident that if the slide wire or rheostat comprising the variable portion is uniformly wound then a scale indicating transmission loss will not be uniform but will be much condensed at one end. To overcome this inconvenience I find it desirable in practice to have a tapered rheostat, as indicated in the drawing, thus opening the scale to practically uniform spacing.

As an illustration of the application of this attenuating device, reference may be made to Fig. 6 which shows circuits for taking measurements of the sensitivity of a four-wire echo suppressor. Here D represents a source of alternating currents of any desired frequency which is impressed upon the four-wire echo suppressor, through the apparatus of Fig. 5 and a 600 ohm resistance. Inasmuch as the impedance of an echo suppressor is very high, it is seen that the shunt of 600 ohms gives a load of the desired magnitude. One may now steadily introduce transmission loss in the attenuator until the echo suppressor fails to operate. This same maybe repeated at other frequencies and thus a curve plotted showing the sensitivity of the echo suppressor as a function of frequency.

It will be observed that the circuit of Fig. 5 which is equivalent to that of Fig. 2 is not symmetrical on the two sides of the line. In some cases, it would not be desirable to connect such an unsymmetrical T-network in the line. Fig. 7 shows a modification of Fig. 5 in which its dissymmetry is reduced in part. This is accomplished by transferring the fixed portion of a from its position adjacent to the terminal 1 to a position adjacent to terminal 3 and the portion adjacent the terminal 4 to a position adjacent terminal 2. That this yields the desired results

is made more evident by rearranging the circuit of Fig. 7 to its equivalent of Fig. 8 in which h represents the portion transferred.

Still another method to overcome the objections mentioned above is to connect the circuit of Fig. 5 by means of transformers as shown in Fig. 9, thus removing all conductive connection between the parts. In case the line and the load impedance are equal, then 1 to 1 transformers should be used. A slight correction, however, is necessary in view of the fact that even a good transformer is not ideal but may be represented by an ideal transformer with a lumped external resistance $2r$ as shown in Fig. 10, where $2r$ is the resistance of the two windings of the transformer. In that event, the fixed resistance of Fig. 5 should be reduced correspondingly as indicated in Fig. 9. Also, if there is transformer leakage there is an equivalence of series inductance in the circuit and this may be compensated for by the introduction of suitable condensers c_1 and c_2 .

Still another extension of my invention can be made to the case where the source and load do not have the same value of impedance. Thus the source may have the impedance A and the load impedance B. In that event, the transformers of Fig. 9 should be step-up or step-down transformers of the proper ratio to establish matching throughout the circuit in the manner well understood in the art.

Instead of using step-up or step-down transformers for the case of unequal image impedances, as just mentioned, it is possible to use an adjustable T-network also having unequal image impedances, as indicated in Fig. 11. In order to obtain matching throughout, the necessary relationship of resistances is given by

$$R_1 = \frac{1+k^2-2k\sqrt{Q}}{1-k^2} A \quad (4) \quad 115$$

$$R_2 = \frac{Q(1+k^2)-2k\sqrt{Q}}{1-k^2} A \quad (5)$$

$$R_3 = \frac{2k\sqrt{Q}}{1-k^2} A \quad (6) \quad 120$$

$$\frac{B}{A} = Q \text{ and } \frac{P_2}{P_1} = \frac{I_2^2 B}{I_1^2 A} = k^2 \quad (7)$$

If, in accordance with the suggestions given above, the sum of these resistances is to remain constant, we have the relation

$$\frac{S}{A} = \frac{R_1+R_2+R_3}{A} = \frac{(1+k^2)(1+Q)-2k\sqrt{Q}}{1-k^2} \quad (8)$$

Plotting the relationship between

$$\frac{S}{A}$$

and transmission loss in the same manner as for Fig. 12, there is obtained the family of curves of Fig. 13 in which different values for Q have been assumed. It will be noted, as in Fig. 12, that the quantity

$$\frac{S}{A}$$

remains substantially constant over a wide range of losses. It will be evident, therefore, that a double slide wire arrangement could be developed to provide networks of the same characteristics as described in connection with Fig. 5.

While in the invention thus described it has been implied that the elements a and b are pure ohmic resistances, it is to be understood that such a restriction is not necessary for in some cases

it would be very convenient to introduce a definite amount of inductive reactance along with the resistance by having the resistance wound in a cylindrical or conical form. The relative amount of inductance can, of course, be controlled by suitable choice of diameter of the cylinder or cone and by choice of a resistance material with suitable resistivity, or by other changes which will be obvious to those skilled in the art. It is also understood that while in tapering the resistance it would be simplest from a mechanical point of view to make the taper uniform, such restriction is not necessary, for at times it would be advisable to vary the taper in accordance with the particular form of indicator scale desired.

Also, while I have given one specific application for this attenuator, describing it in connection with the measurement of sensitivity of echo suppressors, it must be understood that this is for illustrative purposes only and that it may find application in any place where attenuation is desired, especially if that attenuation is to be accompanied by substantially no change in impedance matching throughout the circuit. It could, for instance, be used to advantage as "pads" or attenuating devices in front of repeaters in long transmission lines where such attenuation is frequently introduced specifically for the purpose of reducing excessive echo effects in the transmission line.

What is claimed is:

1. In a transmission line including an artificial network of adjustable loss, a resistance with two terminals at the ends and two intermediate adjustable contacts, an input circuit across one fixed and one adjustable contact, and an output circuit across the other two contacts the resistance of the network as seen from its terminals remaining invariant.

2. In a transmission line including an artificial network of adjustable loss, an impedance with two terminals at the ends and two intermediate

adjustable contacts, an input circuit across one fixed and one adjustable contact, and an output circuit across the other two contacts the impedance of the network as seen from its terminals remaining invariant.

3. In an electric circuit, a transducer of adjustable loss comprising a double slide resistance, an input and an output circuit symmetrically connected thereto to give adjustable loss and constant impedance, the input circuit being connected from one end of one-half of the resistance to a sliding contact on the other half.

4. The combination of claim 3 characterized by the fact that the two halves of the resistance are tapered from the free ends toward the point of junction.

5. A transducer of adjustable loss and constant impedance comprising a double slide rheostat which consists of two tapered resistances connected at the tapered ends, input terminals one at the free end of one resistance and the other a sliding contact on the second resistance, and output terminals symmetrically but oppositely located.

6. A transducer with input and output terminals and of adjustable loss and constant impedance as viewed from either the input or the output terminals, said transducer comprising a double slide rheostat which consists of two tapered resistances connected at the tapered ends, the input terminals consisting of one of the free ends of one resistance and a sliding contact on the second resistance, and the output terminals consisting of the free end of the second resistance and a sliding contact on the first.

7. The combination of claim 6 characterized by the presence of transformers connected to the input terminals and the output terminals, the transformer ratios being adjusted to match the impedance of the incoming line and the impedance of the load circuit to the impedance of the transducer.

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