April 12, 1927. M. E. STRIEBY ET AL 1,624,023

EQUALIZATION OF TRANSMISSION

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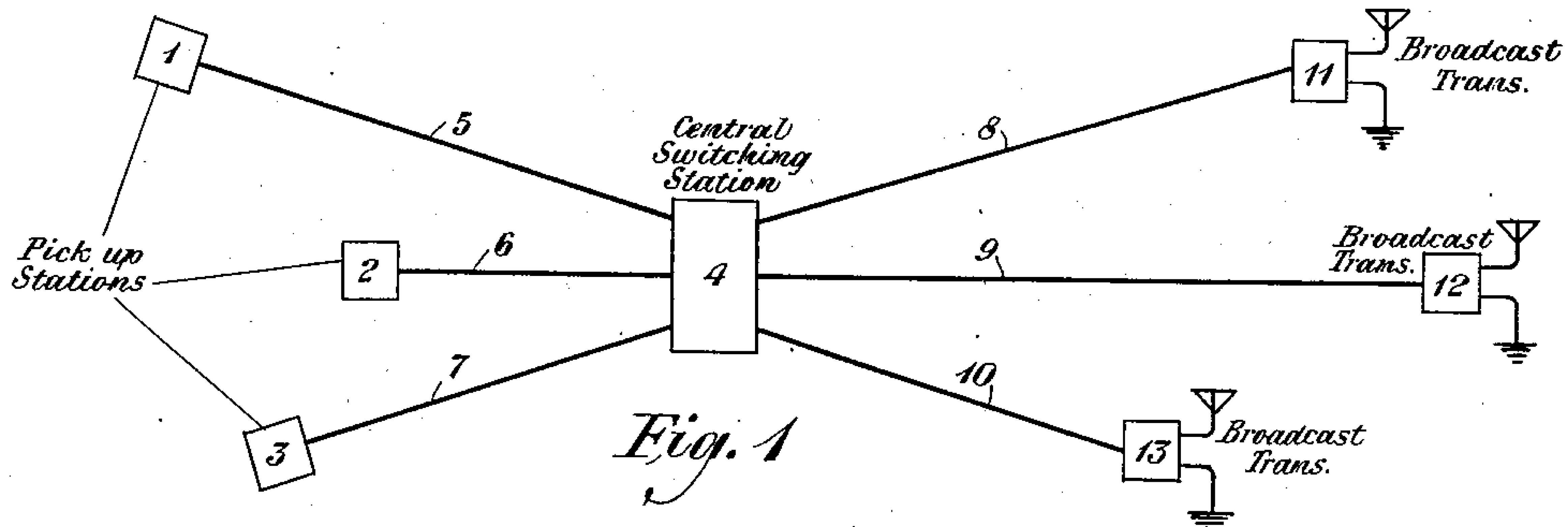

Fig. 1

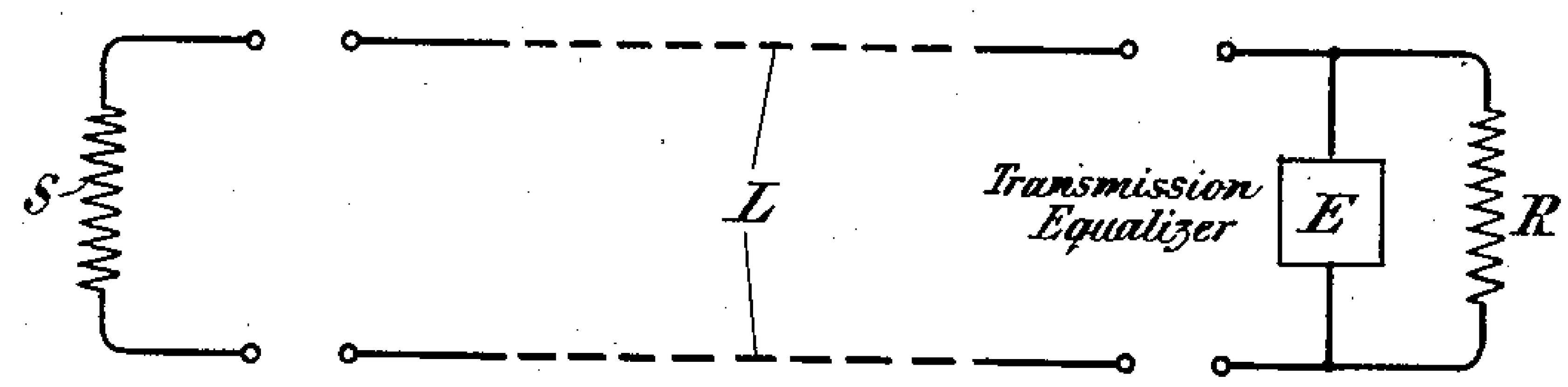

Fig. 2

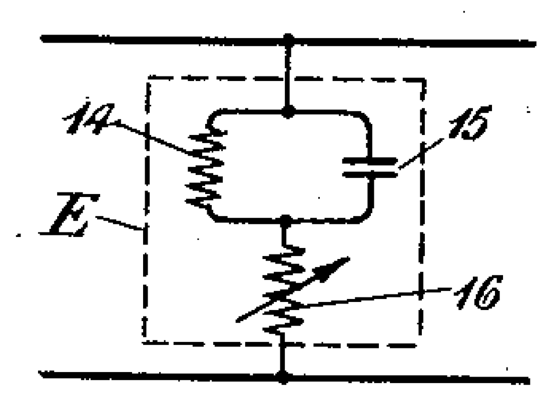

Fig. 3

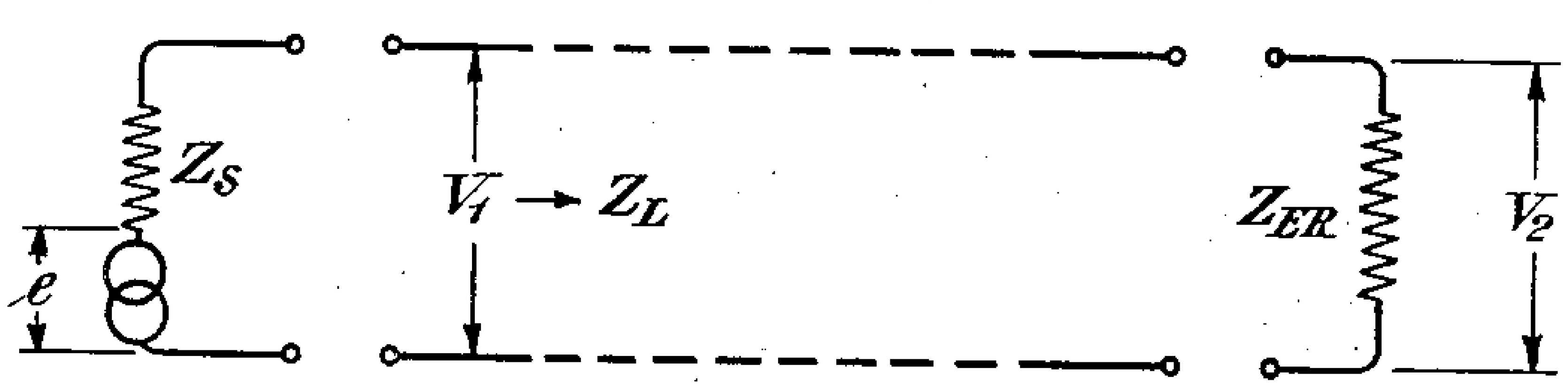

Fig. 4

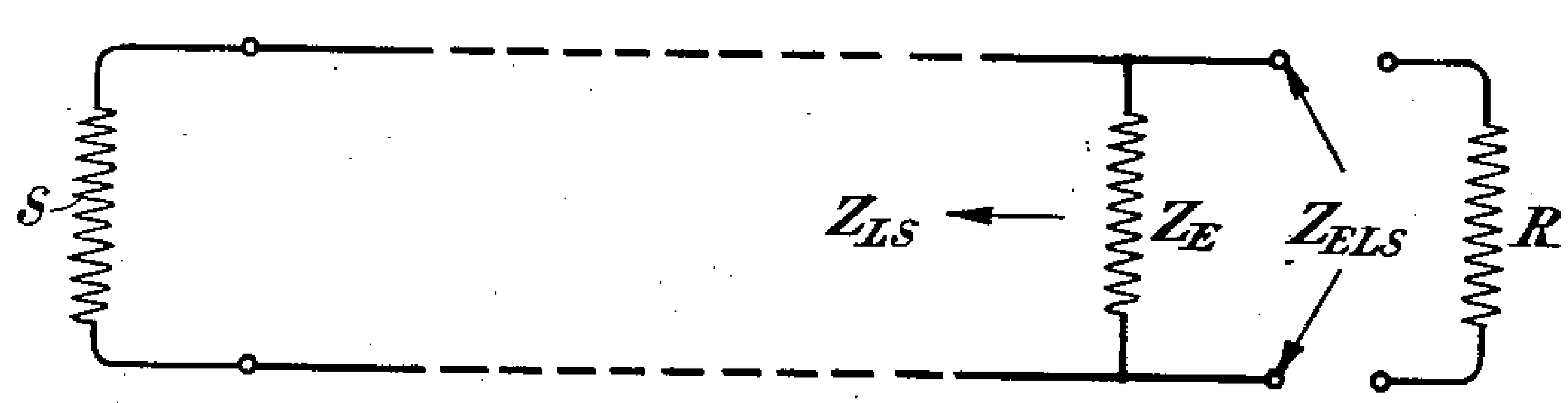

Fig. 5

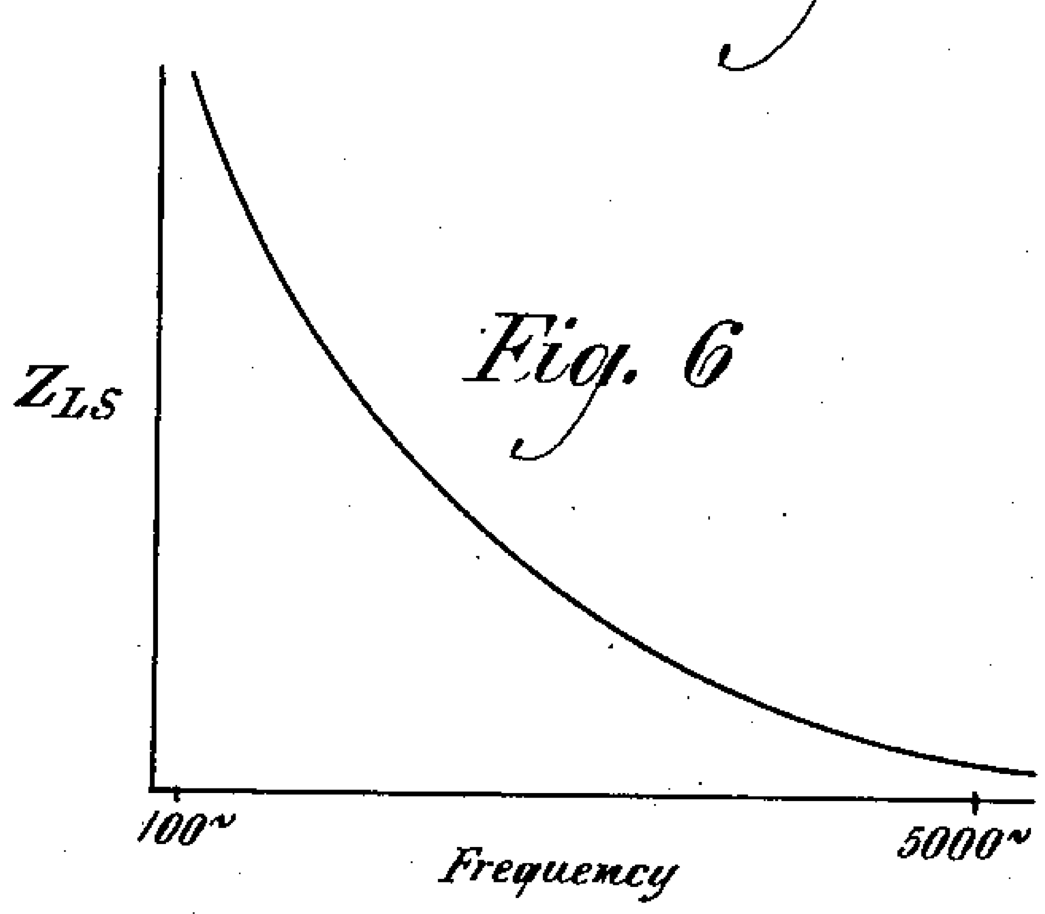

Fig. 6

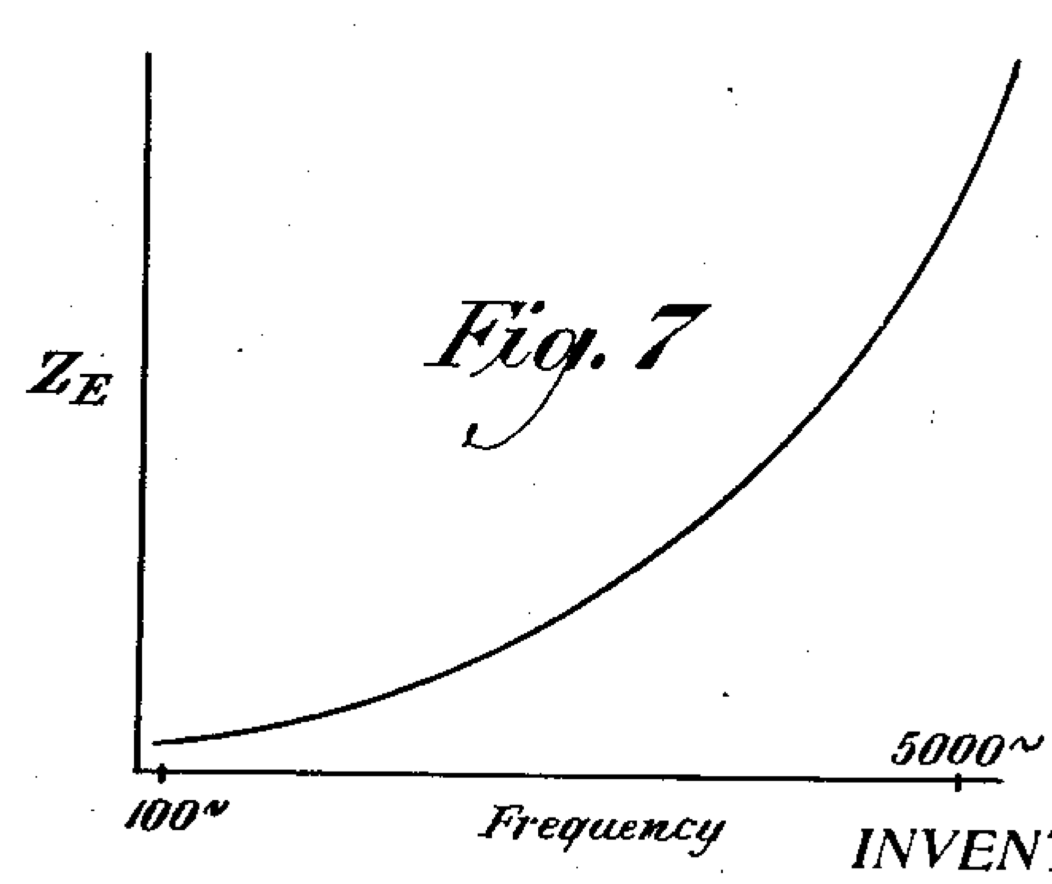

Fig. 7

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EQUALIZATION OF TRANSMISSION

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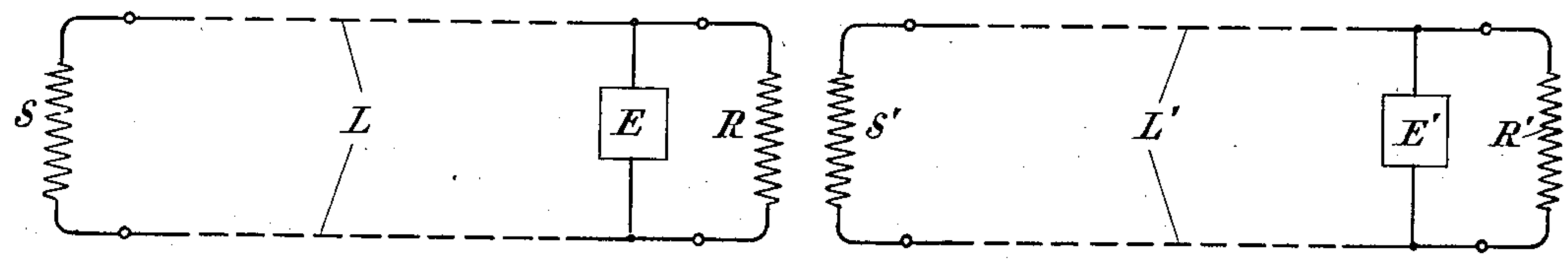

Fig. 8

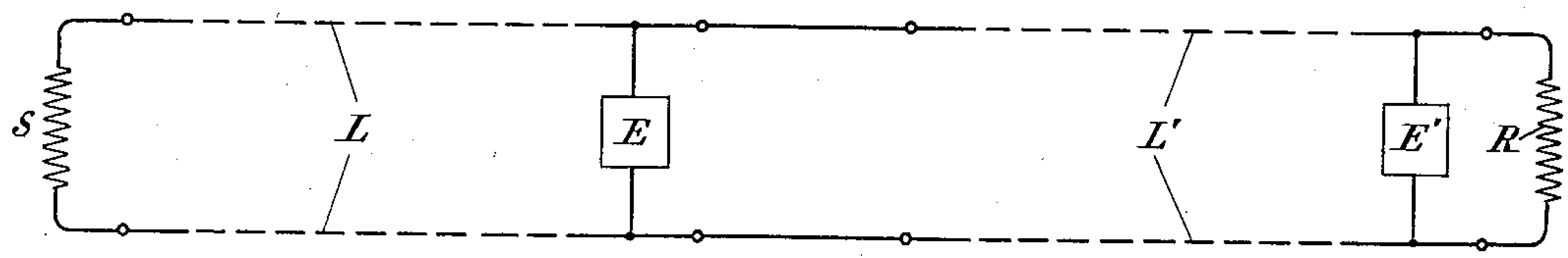

Fig. 9

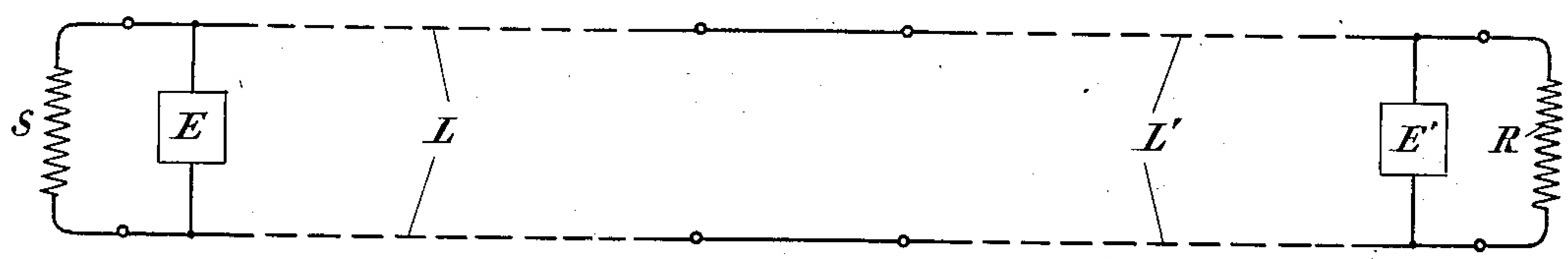

Fig. 10

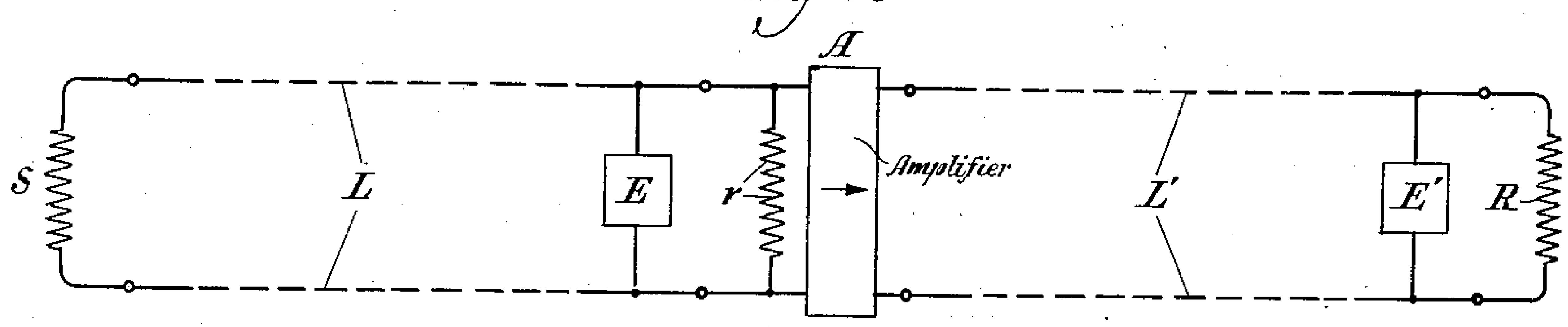

Fig. 11

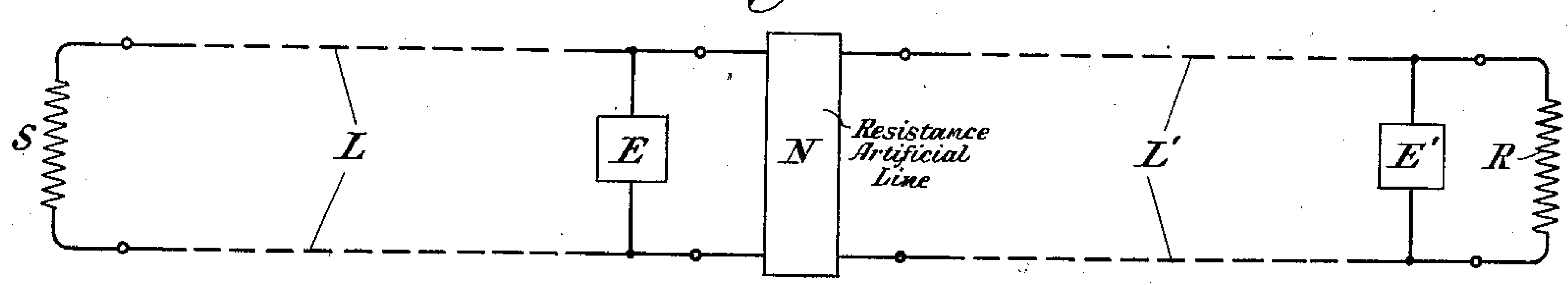

Fig. 12

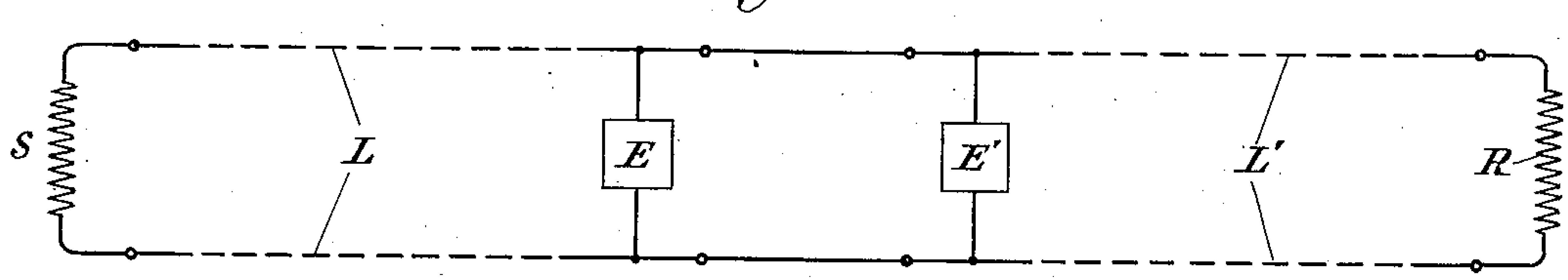

Fig. 13

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UNITED STATES PATENT OFFICE.

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EQUALIZATION OF TRANSMISSION.

Application filed March 27, 1926. Serial No. 98,000.

This invention relates to equalization of transmission, and more particularly to the connection of equalized transmission circuits in tandem.

In a telephone plant where high quality transmission is desirable, it is the practice to compensate for the variation of attenuation of a transmission circuit with frequency by associating with the circuit a network so designed as to have a variation of attenuation with frequency which is complementary to that of the circuit. As the equalizing network is not susceptible of any considerable degree of adjustment it is in general designed and set to equalize a particular line or at least a line of a particular type, and cannot be used to equalize a line of a considerably different type.

Circumstances frequently arise which render it necessary to connect independently equalized lines in tandem. Equalizers are designed to work under certain conditions and will not properly equalize a circuit unless the conditions are maintained. For example, the so-called "shunt" type of equalizer is arranged to properly equalize a given non-loaded cable circuit under conditions such that the cable circuit is terminated at one end in a resistance of 500 ohms and the equalizer is connected between the other end of the non-loaded cable circuit and a pure resistance. In attempting to directly connect the terminals of two independently equalized lines with the equalizers located in the usual manner, one of the equalizers would be connected directly between two non-loaded cable circuits instead of being connected between a non-loaded cable circuit and a pure resistance. It has therefore been considered necessary heretofore to separate the two circuits either by a section of resistance artificial line or by means of an amplifier in order to maintain the impedance condition for proper equalization.

Under certain conditions this would be uneconomical, and in any event would require additional apparatus. While it would be physically possible to provide a single equalizer properly designed to equalize two circuits connected in tandem, this would be impractical because it is desirable to have the circuits connected in tandem in different combinations. Therefore, in accordance with the present invention the equalizers are so located with respect to the circuits that when the circuits are directly connected together at their terminals each of the equalizers will be in such relation to the circuits as to operate properly. This result may be accomplished by connecting the equalizers at the ends of the lines and then connecting together those ends of the lines at which the equalizers are located. It has been found that by connecting the circuits in this manner the conditions for proper equalization are substantially fulfilled for each line so that the transmission characteristic of the over-all circuit is substantially as flat as the sum of the two equalized circuits taken separately. Measurements also show that the transmission equivalent of the over-all circuit is somewhat less than the sum of the equivalents of the two equalized circuits taken separately.

The invention may now be more fully understood from the following description when read in connection with the accompanying drawing in which Figure 1 shows schematically the type of system to which the invention is applicable; Fig. 2 illustrates symbolically the elements of a single equalized circuit; Fig. 3 shows the form of network used for equalization of transmission; Figs. 4 and 5 are simplified diagrams showing the electrical relations involved in an equalized circuit; Figs. 6 and 7 are curves showing the impedance frequency characteristics of a properly terminated line and an equalizer for equalizing transmission over the line; Fig. 8 is a diagram showing the elements of two independently equalized lines which are to be connected in tandem; Figs. 9 and 10 illustrate methods of connecting such lines in tandem which will not give proper equalization; Figs. 11 and 12 show how independently equalized lines may be indirectly connected through an amplifier and an artificial line, respectively; and Fig. 13 illustrates an arrangement of equalizers whereby two independently equalized lines may be directly connected together.

While the present invention is applicable to many different situations, a typical situation involving the necessity of connecting separately equalized lines in tandem is indicated in Fig. 1. In this figure 1, 2 and 3 designate different pick-up stations located at various distances from a central switching station to which they are connected by means of lines 5, 6 and 7. Lines such as 8, 9 and 10 also extend from the switching station 4 to distant broadcast transmitters 11, 12 and 13. The several lines may be of different lengths and characteristics, and in practice may be connected in tandem in various combinations; for example, at certain times pick-up station 2 may be connected to broadcast transmitter 11; at other times it may be connected to broadcast transmitter 12, etc. The complete tandem circuit could be equalized (that is, it could be made to transmit all frequencies within a given range with substantially uniform attenuation) by the use of a single equalizer designed for use with the complete over-all line. This would mean, however, that every time a different combination of circuits were connected in tandem a different equalizer would have to be used. It is therefore desirable that each line be independently equalized and so arranged that it may be connected in tandem to any other line without disturbing the equalization of the circuit as a whole.

As has already been stated it does not follow that because two lines are properly equalized as independent units they will function as a single equalized line when connected together in tandem. In fact, the matter of connecting together such lines in tandem has been a matter of considerable difficulty.

In order to understand how this difficulty arises it is desirable to consider briefly the fundamental nature of an equalized line and certain of the practical requirements which must be met before proper equalization is possible. Referring to Fig. 2, let us consider a line L on non-loaded cable and of a given length. Assuming that this line is to be used for transmission in a direction from west to east, the line will necessarily be terminated in a terminal impedance at the sending end S. In the practical case where the line is being used for the transmission of music and the like to broadcasting stations the sending end will include pick-up apparatus connected to the line terminal through an amplifier. The output impedance of the amplifier will constitute the termination of the line and in practice the line is terminated at the sending end in an impedance which is equivalent to a resistance of 500 ohms, as indicated at S. At the receiving end of the line it must also be terminated in an impedance of some kind depending on the nature of the receiving apparatus. This impedance is represented at R. The transmission equalizer E is then so designed as to equalize the transmission over the line when the equalizer is connected between the line and the receiving end termination R, with the line L terminated at the sending end in an equivalent resistance of 500 ohms. The equalizer E may be of any well known type, such, for example, as the "shunt" type of equalizer illustrated in Fig. 3, and comprising a resistance 14 in parallel with the condenser 15, this combination being connected in series with an adjustable resistance 17. When such an equalizer as illustrated in Fig. 3 is designed to equalize transmission over the line L under the conditions above stated, it will not function properly to equalize the line if the value of the terminal impedance S is materially changed, and it will only function properly if the terminating impedance R is a pure resistance.

In order to understand why this is so let us assume that the line of Fig. 2 has been equalized under the conditions above stated. The complete circuit is equivalent to the circuit shown in Fig. 4 in which Z_S represents the sending end impedance, Z_L represents the impedance at the line terminals looking toward the receiving end and Z_{ER} represents the combined impedance of the transmission equalizer E and the receiving termination R. Let us assume that a voltage e is applied in series with the sending end impedance Z_S. If the line has been properly equalized the voltage drop V_2 across the receiving terminals will bear a ratio to the applied voltage e which is constant with frequency.

It may be shown that in a circuit organization such as that of Fig. 4 the following relation holds:

$$V_2=\frac{V_1 Z_{ER}}{Z_L \sinh l\alpha+Z_{ER}\cosh l\alpha} \quad (1)$$

where V_1 is the voltage drop across the sending end impedence, l is the length of the line and α the attenuation constant of the circuit. Now it is quite evident from Ohm's law that if the line is electrically long so that the impedance Z_L is independent of the receiving termination, the drop V_1 is related to the applied voltage e as follows:

$$V_1=\frac{Z_L}{Z_L+Z_S}e \quad (2)$$

Combining equations 1 and 2 we have:

$$V_2=\frac{\frac{Z_L}{Z_L+Z_S}\cdot Z_{ER}}{Z_L \sinh l\alpha+Z_{ER}\cosh l\alpha}\cdot e \quad (3)$$

The condition for equalization is that the term which is the coefficient of e in the above expression must be constant with frequency. This coefficient may be represented in the form of two factors as follows:

$$\left(\frac{Z_L}{Z_L+Z_S}\right)\left(\frac{Z_{ER}}{Z_L \sinh l\alpha+Z_{ER}\cosh l\alpha}\right) \quad (4)$$

For a given circuit l and α are constant, and for a given sending termination Z_S is constant. Z_{ER}, however, includes the impedance of the equalizer and is therefore variable with frequency, and similarly the impedance Z_L, looking into the electrically long line, is variable with frequency. Consequently both terms of expression 4 are variable. Therefore, if the expression is to be constant with frequency the two terms of the expression must vary in a complementary manner. It is evident from the form of the right-hand factor of expression 4 that for an equalizer of a given design the factor will vary with frequency in accordance with a fixed law. From the form of the left-hand factor it is equally evident that any change in the value of the terminal impedance Z_S will change the law of variation of the factor with respect to frequency. It therefore follows that for a given design of equalizer, which of course determines the value of Z_{ER} for any given frequency, the sending end impedance Z_S must be fixed. Otherwise the two factors would not vary with frequency in accordance with complementary laws.

It has now been shown why an equalizer will only properly equalize the line when it is terminated at the opposite end by an invariable impedance. It remains to be shown why the equalizer must be connected between the line to be equalized and a receiving termination which is a pure resistance.

Referring to the equivalent circuit of Fig. 5, the impedance looking into the line towards the sending end at the left of the equalizer will be Z_{LS}. (In the case already assumed where the line is electrically long the terminal impedance S does not affect the impedance Z_{LS} so that it will be the same as the impedance looking from the sending end which is Z_L.) Z_E is the impedance of the equalizer E. This impedance as seen from the receiving terminals is in parallel to the impedance Z_{LS} looking into the line. Now the impedance looking into the line varies with frequency in the general relation indicated by the curve of Fig. 6. The impedance of the equalizer, on the other hand, varies in a somewhat complementary manner, as shown by the curve of Fig. 7. If the impedance of the parallel combination be determined for each frequency in accordance with the formula for two impedances connected in parallel, the resultant impedance will be found to be substantially constant for all frequencies within a range from say 100 cycles to 5,000 cycles. In other words, the impedance Z_{ELS}, looking into the combination of the line and equalizer from the receiving end will be substantially constant within the range of frequencies with which we are concerned. Obviously, in Fig. 5 we may connect a pure resistance R across the terminals of the circuit without materially affecting the equalization. On the other hand, if a terminal impedance which varies with frequency be connected across the circuit at the receiving end the equalization will be disturbed, for varying reflection losses will occur. The second requirement for proper equalization then is that the equalizer must be connected between the line and a terminal impedance which is a pure resistance. The actual value of the terminal impedance is of less importance since the only effect of a change in the value of the resistance is to change the ratio of the drop V_2 to the applied voltage e without producing any variation of this ratio with frequency.

From the above considerations it will be evident that if we have two equalized circuits L and L′, as shown in Fig. 8, the two lines cannot be connected in tandem by directly connecting the receiving terminal of the one to the sending terminal of the other, as shown in Fig. 9. This would result in having one equalizer near the middle of the over-all circuit and the other equalizer near one terminal. From the standpoint of the equalizer E′ equalization may be disturbed since the line L′ is not terminated at the distant end in an impedance of 500 ohms. As has already been explained the impedance looking into the equalizer E and line L may be substantially constant, but it is not necessarily substantially constant at 500 ohms. On the other hand, from the standpoint of the equalizer E, instead of being connected between the line L to be equalized and a pure resistance, it is connected between the line L and the impedance looking into the line L′, which is certainly not a pure resistance and which, as a matter of fact, varies with frequency. It will be evident from similar considerations that the two parts of the circuit will not be properly equalized if the situation in Fig. 9 is reversed by placing equalizer E′ at the center and equalizer E at the sending end.

An alternative arrangement that suggests itself would be to connect the equalizers across the sending terminal of the one line and the receiving terminal of the other line as shown in Fig. 10. Assuming, as would be the case in practice, that the receiving termination is equivalent to a pure resistance of 500 ohms and is therefore the same as the sending impedance (these being the conditions met with in practice), it will be clear that proper equalization will not be obtained in Fig. 10. From the standpoint of the line L the conditions for equalization are not present, for although the equalizer E is connected between the line and a terminal impedance equivalent to a resistance, the line L is terminated at the opposite end in the variable impedance looking into the line L′ and has already been shown, one of the conditions for equalization is that the terminal impedance at the end of the line opposite to the equalizer must be fixed. The same argument holds true for the equalizer E′ and the line L′.

Heretofore it has been proposed to obtain the conditions for proper equalization in the case of such a circuit as that of Fig. 9 by interposing a one-way amplifier, such as A in Fig. 11, between the lines L and L′, bridging if necessary a pure resistance r across the input side of the amplifier so that the input circuit of the amplifier will be equivalent to a pure resistance. It will be seen at once that the conditions for equalization are met so far as the line L is concerned and as the amplifier A has an output impedance of say 500 ohms (the amplifier being similar to the amplifier of the pick-up arrangement which constituted the sending termination S of Fig. 2), the conditions for equalization of the line L′ are also met. Such an arrangement has the obvious disadvantage that the amplifier A constitutes an additional piece of equipment for each connection, which might make the circuit uneconomical.

An alternative proposal has been to interpose between the two lines a resistance artificial line or network N as shown in Fig. 12. This network may, for example, be the so-called H type of network familiar in telephone practice and comprising series resistances in each line conductor and a shunt resistance bridged across the conductor. Obviously the artificial line may be made to have an impedance looking from the equalizer E equivalent to a pure resistance, and it may likewise be made to have an impedance looking from the left-hand end of the line L′ equivalent to 500 ohms. Under these conditions the two lines of the over-all circuit will be independently equalized, but the transmission loss is greatly increased due to the loss of the artificial line N. Not only does the artificial line N involve the provision of additional equipment but in some cases it may introduce so much additional transmission loss that another amplifier may have to be provided at some point in the circuit.

In accordance with the present invention it is proposed to overcome all of these objections by directly connecting the two lines L and L′ at their terminals, as shown in Fig. 13, and bridging both equalizers E and E′ across the terminals of the lines in parallel with each other at the junction point. Here the conditions for equalization of both lines are substantially met. From the standpoint of the equalizer E it is clear that the equalizer is connected between the line L with its distant termination S and the equivalent impedance of the equalizer E′ bridged across the impedance looking into the line L′, which, as already stated, is substantially constant and therefore substantially equivalent to a pure resistance. Likewise, the impedance looking into the equalizer E bridged across the impedance of the line L is substantially constant with frequency, so that the equalizer E′ is connected between the line L′ and an impedance which is substantially equivalent to a pure resistance. The conditions for equalization of both lines L and L′ are therefore substantially satisfied.

Measurements upon lines connected in tandem and equalized in the manner illustrated in Fig. 13 show that the transmission characteristic of the over-all circuit is substantially as flat (that is, as constant with frequency) as the sum of the transmission characteristics of the two equalized circuits taken separately. The measurements also show that the transmission equivalent of the over-all circuit is actually somewhat less than the sum of the equivalents of the two equalized circuits taken separately, this this being due to the fact that a better impedance match exists when the circuits are connected together at the equalizer point than exists when the circuits are equalized separately and terminated in pure resistance.

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. A transmission system comprising a pair of transmission lines, each terminated at one end in a terminal impedance, an attenuation equalizer for each line connected thereto at the opposite end, and means to directly connect the ends of said lines at which the attenuation equalizers are located.

2. In a transmission system, a pair of transmission lines each terminated at one end in a terminal impedance, the electrical characteristics of each line being such that the attenuation varies with frequency, an attenuation equalizer at the opposite end of each line having such electrical characteristics that its attenuation varies with frequency in a manner substantially complementary to that of the line with which it is associated, and means to directly connect the ends of the lines at which the attenuation equalizers are located.

3. In a transmission system, a pair of transmission lines each terminated at one end in a terminal impedance, an attenuation equalizer for each line connected thereto at its opposite end, the attenuation equalizer being so proportioned with respect to the line with which it is associated that the impedance looking into the combination of the

attenuation equalizer and line from the end of the line at which the attenuation equalizer is located will be substantially constant with frequency, and means to directly connect the ends of the lines at which the attenuation equalizers are located so that each attenuation equalizer is in effect connected between the substantial equivalent of the pure resistance and one end of a line terminated at its opposite end in a terminal impedance.

4. In a transmission system, a pair of lines each terminated at one end in a terminal impedance, the electrical characteristics of each line being such that its attenuation varies with frequency, an attenuation equalizer for each line associated therewith at its opposite end, each attenuation equalizer having electrical characteristics such that its attenuation varies with frequency in a manner substantially complementary to that of the line with which it is associated, and that the impedance looking into the combination of attenuation equalizer and line from the end of the line at which the attenuation equalizer is located is substantially constant, and means to directly connect the ends of the said lines at which the attenuation equalizers are located whereby each attenuation equalizer is in effect connected between the substantial equivalent of a pure resistance and one end of a line which is terminated at its opposite end in a terminal impedance.

5. A signaling system comprising a central switching station, transmission lines extending from said switching station to distant points, terminal impedances for the lines at the distant points, an attenuation equalizer associated with each line at the central switching station and so related to the line that when it is connected between the end of the line and a substantially pure resistance the combination of the line and attenuation equalizer will have substantially uniform attenuation over a range of frequencies to be transmitted, the electrical characteristics of each line and its associated attenuation equalizer being such that the impedance of the combination consisting of attenuation equalizer and line will be substantially constant with frequency over the range to be transmitted, and means at the central switching station for directly connecting the terminals of said lines in pairs so that the attenuation equalizer for each line of a pair is in effect connected between the line and an impedance which is substantially constant with frequency.

In testimony whereof we have signed our names to this specification this 26th day of March, 1926.

MAURICE E. STRIEBY.
CHARLES H. FETTER.