June 17, 1941. N. MONK 2,246,058

COMPENSATION FOR VARIATIONS IN PHASE CHANGE

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FIG. 1

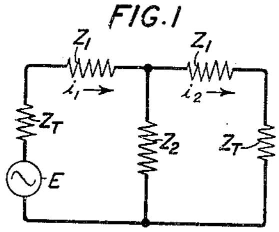


FIG. 2

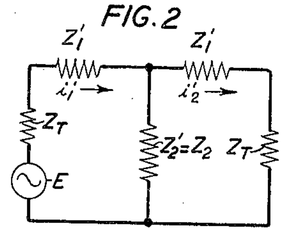


FIG. 3

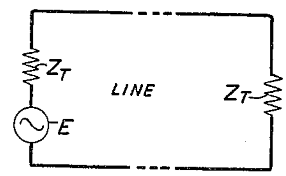
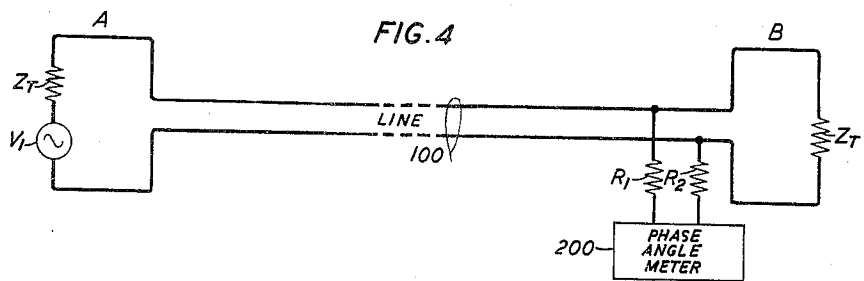



FIG. 4



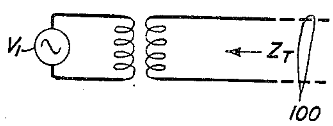




FIG. 4A

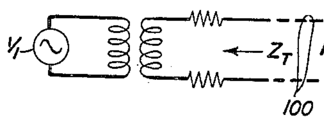



FIG. 4B

FIG. 5

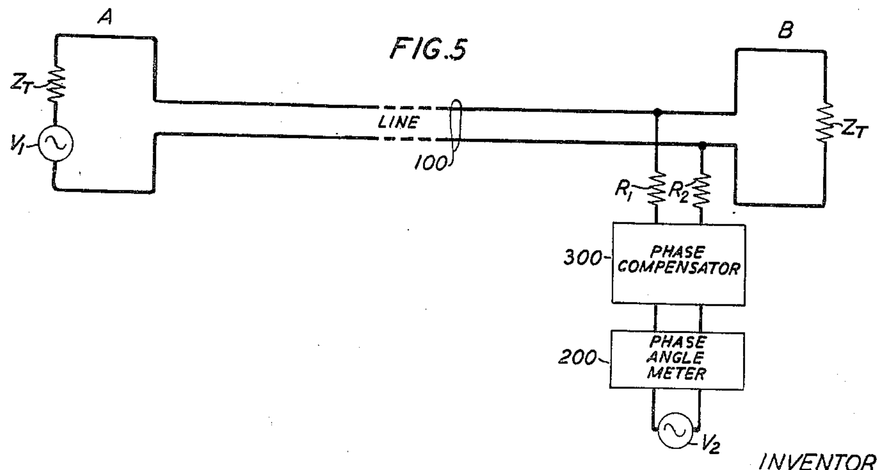



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FIG. 6

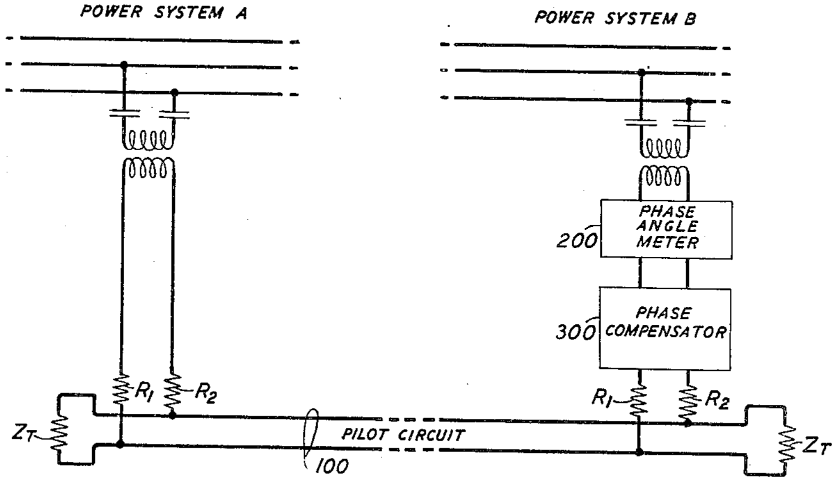
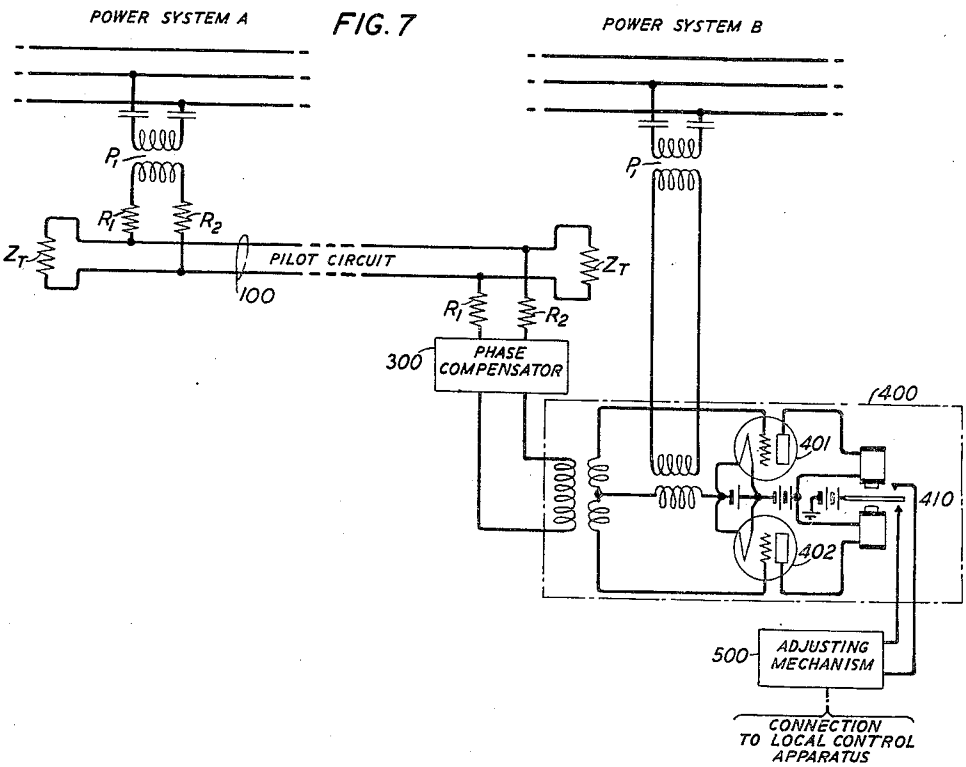



FIG. 7

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2,246,058

# UNITED STATES PATENT OFFICE

2,246,058

## COMPENSATION FOR VARIATIONS IN PHASE CHANGE

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Application February 21, 1939, Serial No. 257,674

9 Claims. (Cl. 178—44)

This invention relates to a method and means for substantially reducing variations in the phase characteristic of a transmission circuit particularly at any one frequency and is applicable more especially to a cable circuit.

An object of this invention is to provide a new and improved method and means for substantially reducing variations in the phase characteristics of a cable circuit particularly at any one frequency due to varying weather conditions or other causes.

Another object is to provide a method and means for improving transmission characteristics of cable circuits.

A further object is to provide a pilot circuit, in which variations in phase change are substantially eliminated, for use in measuring the phase relationship of the current at different points in an electrical system.

This is accomplished primarily by terminating each end of the circuit in a specific impedance as described below. The method is applicable to those circuits for which the shunt impedance of the equivalent T-network remains very nearly a pure reactance for various conditions to which a cable may be subjected, such for example as temperature changes; in other words for cases in which the effect of leakage is very small or negligible. This is true for transmission of currents of frequencies up to the order of several thousand cycles over cable circuits of some length.

A description of an embodiment chosen for illustrating this invention in which reference is made to the accompanying drawings, follows:

Fig. 1 is an equivalent T-network of a cable circuit;

Fig. 2 is an equivalent T-network of the cable circuit of Fig. 1 showing the impedance changed due to varying weather conditions or the like;

Fig. 3 shows an application of terminating impedances according to the principles of this invention for compensating for variation in phase characteristic of a circuit when an alternating current is transmitted thereover;

Fig. 4 shows an application of this invention for measuring by means of a pilot line the phase differences between voltages at two points;

Figs. 4A and 4B show different arrangements for connecting an alternating voltage source to the pilot line arrangement of Fig. 4;

Fig. 5 shows an application of this invention for measuring by means of a pilot line the phase differences between voltages at two points in which compensation is introduced for the change in phase introduced by the pilot line itself;

Fig. 6 shows an application of this invention for measuring by means of a pilot circuit the phase angle differences between different points of a power system or systems; and

Fig. 7 shows an application of this invention to power transmission for automatically maintaining the current at different points of the system or systems in phase.

The underlying principles of this invention are first described by referring to the equivalent T-network included in Figs. 1 and 2; while certain applications are described in connection with subsequent figures.

Fig. 1 shows a cable circuit reduced to its equivalent T-network for a given weather condition. The network is assumed to be connected to a generator E of any impedance $Z_T$ and terminated in an impedance also of value $Z_T$. The impedance $Z_1$ which is one-half of the series impedance of the network is equal to

$$\frac{R_1+jL_1\omega}{2}$$

where $R_1$ is the total resistance of the circuit, $L_1$ its total inductance, and $\omega=2\pi$ times the frequency. $Z_2$ represents the shunt impedance of the equivalent T-network and is equal to

$$\frac{1}{G_1+jC_1\omega}$$

in which $G_1$ is the leakage conductance of the circuit, and $C_1$ its capacitance.

Fig. 2 represents the equivalent T-network of the same circuit under a different weather condition in which the series and shunt impedances may be considered to have new values $Z'_1$ and $Z'_2$, resulting from changes in the fundamental constants of the circuit. It is a well-known fact that the leakage conductance G of a well insulated cable circuit enclosed in a protective sheath is very small. The term G can, therefore, be neglected in comparison to the term $C\omega$. Consequently, the values of the shunt impedances $Z_2$ and $Z'_2$ of the networks reduce to

$$\frac{1}{jC_1\omega} \text{ and } \frac{1}{jC'_1\omega}$$

respectively. Furthermore, for changes in weather, including temperature changes, the capacitance C of a cable circuit will not change materially. Thus the shunt impedance $Z'_2$ of the network of Fig. 2 will be substantially equal to that of the original network of Fig. 1 and $Z'_2$ will be substantially equal to $Z_2$.

The ratio between the currents $i_2$ and $i'_2$ determine the variation in phase change. These currents may be expressed as follows:

$$i_2=\frac{EZ_2}{2(Z_1+Z_T)Z_2+(Z_1+Z_T)^2} \quad (1)$$

$$i'_2=\frac{EZ'_2}{2(Z'_1+Z_T)Z'_2+(Z'_1+Z_T)^2} \quad (2)$$

and their ratio is

$$i_2/i'_2=\frac{2(Z'_1+Z_T)Z'_2+(Z'_1+Z_T)^2}{2(Z_1+Z_T)Z_2+(Z_1+Z_T)^2}\times\frac{Z_2}{Z'_2} \quad (3)$$

or if $Z'_2=Z_2$

$$i_2/i'_2=\frac{2(Z'_1+Z_T)Z_2+(Z'_1+Z_T)^2}{2(Z_1+Z_T)Z_2+(Z_1+Z_T)^2} \quad (4)$$

If the value of $Z_T$ is now made very large the impedances $Z_1$ and $Z'_1$ (which will be only slightly different from $Z_1$), which represent one-half of the total series impedance of the equivalent T-networks of Fig. 1 or Fig. 2, may be neglected and the right-hand side of Equation 4 reduces to unity indicating that the phase change between the two currents is zero.

It is obvious from Equation 4 that the value of $Z_T$ may be any value large in comparison with $Z_1$ and may be either a resistance or a reactance. However, it must not be so great that the attenuation becomes excessive. In order to determine the best value for the impedance $Z_T$ the expression for the attenuation, that is, the relation between the currents $i_1$ and $i_2$ may be written:

$$\frac{i_2}{i_1}=\frac{Z_2}{Z_1+Z_2+Z_T} \quad (5)$$

which neglecting $Z_1$ reduces to

$$\frac{i_2}{i_1}=\frac{Z_2}{Z_2+Z_T} \quad (6)$$

From this expression and the maximum value of attenuation, which may be allowed, the value for $Z_T$ may be determined.

The results which may be obtained with this method for reducing the variations in phase change of the circuit will, of course, depend upon the relative values of $Z_1$, one-half the series impedance of the equivalent T-network, and the terminating impedances $Z_T$. If the attenuation is permitted to be large the value of $Z_T$ can be made very large and the variation in the phase change can be eliminated for all practical purposes.

This method is applied in the following example to an actual cable circuit at 60 cycles taking a non-loaded 19-gauge cable circuit 10 miles in length. The fundamental constants for such a circuit at 68° F. are as follows:

R=85 ohms per mile
L=.00106 henry per mile
C=.066 mfd. per mile
G=.1 micromho per mile

Considering a temperature change from 68° F. to 32° F., which is roughly the yearly temperature variation for underground cable, the values for the fundamental constants at 32° F. are as follows:

R=78.2 ohms per mile
L=.00106 henry per mile
C=.0654 mfd. per mile
G=.05 micromho per mile

It is assumed that the leakage G is equal to 0.1 micromho per mile and that it changes 50 per cent over the temperature range from 68° F. to 32° F.

Employing these fundamental constants the equivalent T-networks for a 10-mile circuit work out to have the following impedance values:

| 68° F. | 32° F. |
|---|---|
| $Z_1=426-j3.6$<br>$Z_2=4020\sqrt{91°.28}$ | $Z_1'=390-j2.7$<br>$Z_2'=4059\sqrt{91°.22}$ |

If an attenuation of 20 db is permitted the maximum value of resistance or reactance which may be employed for $Z_T$ is from Equation 5 about 40,000 ohms.

Substituting the above values for $Z_1$, $Z_1'$, $Z_2$, $Z_2'$ and $Z_T$ into Equation 3 we find that the variation in phase change will be as follows:

| $Z_T$ | Variation in phase change |
|---|---|
| | *Degrees* |
| 40,000 ohms | 0.18 |
| +j40,000 ohms | .20 |
| −j40,000 ohms | .14 |

This compares with a total variation in phase change of about 1.0 degree which would obtain if the circuit were terminated in characteristic impedance.

The leakage in such a circuit may, however, be considerably different from 0.1 micromho per mile at 68° F. Furthermore, the change in leakage over the temperature range assumed may be considerably less than 50 per cent. If either the leakage is less than that assumed or the change in leakage is less than 50 per cent the variation in the phase change will be less than the computed values given above.

The figures given are merely for illustrative purposes. By increasing the value of $Z_T$ the variation in phase change can be still further reduced. This will, however, increase the over-all attenuation of the circuit.

Fig. 3 shows an application of terminating impedances to a transmission line according to the principles of this invention for compensating for variations in the phase characteristics of a circuit when an alternating current is transmitted. The values of the impedances $Z_T$ at each end of the line are so determined that when the voltage of an alternating current of a given frequency generated by source E is impressed upon the line, the variation in phase change caused by the transmission line is neutralized or reduced. Such a compensated line may be used by itself or as a pilot circuit in conjunction with other circuits or systems, examples of which are subsequently described herein.

The method and means described above of providing a circuit of substantially constant phase characteristic may be utilized in various ways, a number of illustrative applications of this invention being described below.

Fig. 4 shows an application of this invention for comparing by means of a pilot circuit, such as a telephone line, the phase angle between two voltages $V_1$ and $V_2$ originating at different sources or stations A and B. The voltage $V_1$ is transmitted from station A over the pilot line **100** to station B at the distant end of the pilot line where another voltage $V_2$ is to be compared with the voltage $V_1$ by means of a phase angle meter **200**, to determine the difference in phase between the two voltages $V_1$ and $V_2$. The voltage $V_1$ generated at station A is impressed upon the pilot line **100** and transmitted to the distant end at station B where the voltage is taken off from the pilot line through series resistances $R_1$ and $R_2$ which must have a high resistance in comparison with the impedance of the line and of the terminating impedances $Z_T$. In order that the phase angle between the voltages $V_1$ and $V_2$ may be obtained from the readings of the phase angle meter **200**, it is of course necessary to correct for any change in phase of voltage $V_1$ which may be introduced by the line **100**. This may be accomplished by measuring the phase change caused by the line itself between proper impedances $Z_T$ at each end of the line. This phase change caused by the line must then be subtracted from the indication given by the phase angle meter in order to obtain the true phase difference between the voltages $V_1$ and $V_2$. The phase change caused by the line itself may be measured by any of the well-known methods, for example, that shown in W. P. Mason Patent 1,684,403, issued September 28, 1928. The phase change caused by the line itself will change with weather variations and the like and this may be minimized in accordance with this invention by terminating the ends of the line with similar impedances $Z_T$, the value of which may be calculated as explained above, particularly in describing Figs. 1 and 2.

Figs. 4A and 4B show alternative arrangements for connecting the source of alternating voltage to the line circuit **100**. In Fig. 4A the coupling is a transformer so designed that the impedance $Z_T$ looking into the line side of the transformer is of the proper value for terminating this end of the line for effecting the desired reduction of phase variations therein. In Fig. 4B the coupling is also a transformer and in addition separate impedances are inserted in the line to build up the impedance $Z_T$ looking into the line side thereof to afford the proper impedance.

Fig. 5 also shows an application of this invention for comparing by means of a pilot line, the phase angle between two voltages $V_1$ and $V_2$, at stations A and B, respectively, in a manner similar to that described in Fig. 4 but without the necessity of separately measuring the phase change caused by the line itself, since in this arrangement a phase compensator **300** is employed to compensate for phase changes in the line. The action of the phase compensator **300** is such that the phase angle meter **200** is held at zero indication when the voltages $V_1$ and $V_2$ are in phase. The phase compensator may consist of a network composed of one or more of the following elements, resistances, inductances, and capacitances. The design of such networks is well known in the art. See, for example, H. Nyquist Patent 1,770,422, July 15, 1930. With this arrangement wherein the phase change introduced by the line is corrected the phase angle meter always directly indicates the phase angle between voltages $V_1$ and $V_2$. The general description of Fig. 4 is obviously applicable to this figure.

Fig. 6 shows another application of this invention wherein it is employed for measuring the phase angle difference between two different power systems or two different points on the same power system. The two different power systems A and B or the two different points on the same power system are connected through suitable coupling means by a pilot circuit for comparing the phase relationship of the two systems or points on the same system. The power systems, or system, are shown as three-phase systems and the pilot circuit **100** is connected at two selected points A and B by means of suitable coupling elements across one phase of the power line. Measuring the phase difference between the two points in one phase of a polyphase system may be sufficient when the several phases are substantially balanced, but if phase angle measurements for the other phases of a polyphase system are desired, they may be made for the other phases of the power system either by employing a pilot circuit for each phase or by having switching devices for synchronously switching the pilot circuit connections from one phase to another of the power system. The arrangement here shown is similar to that of Fig. 5 for measuring the phase angle between two sources of voltage and is here applied to measure the phase angle between the two points on one phase of the power system or systems A and B, irrespective of the location of the source or sources of power. The series resistances $R_1$ and $R_2$ must be high in comparison with the terminating impedance $Z_T$ at each end of the pilot circuit. The phase compensator **300** compensates for any phase displacement caused by the pilot circuit and consequently the readings of the phase angle meter **200** show directly the phase difference between the voltages of the different power systems.

Fig. 7 shows a further application of this invention as applied to power transmission for automatically maintaining two different power systems or two different points in the same power system in phase. The arrangement here shown is similar to that of Fig. 6 but employs in addition automatic means for adjusting the phase relationship of one system to that of another system so that they may be automatically maintained substantially in phase with one another. A differential relay arrangement **400** is here substituted for the phase angle meter measuring arrangement shown in Fig. 6 which automatically operates when there is a difference in phase between the two systems A and B. When a relative phase change occurs in one direction, the relay closes a circuit which operates an adjusting mechanism **500** connected with local control apparatus to cause a shift in the proper direction of the phase in the local system and when the relative phase change is in the opposite direction, the relay closes another circuit which causes a shift in the opposite direction of the phase of the local system, thereby automatically causing a phase change in the local system to substantially eliminate the phase difference between the systems. The differential relay arrangement **400**, as here shown, consists of two vacuum tubes **401** and **402** in push-pull arrangement and so connected that the output circuit of each tube controls the energization of one side of a differential relay **410** which in turn operates the phase adjusting mechanism **500**, and thus maintains a balance in the phase relationship of the systems. The input circuits of this differential relay arrangement are connected by suitable coupling transformers with the pilot circuit **100** interconnecting the power systems A and B and with a local circuit associated with the power system B. The adjusting mechanism **500** which may be mechanically connected to the local control apparatus for adjusting the phase relationship of the local system to that of the other system may be of any suitable type such as is now used and mechanically operated for changing the phase relationship of a power system with that of another such system. Fig. 7, as above stated, relates primarily to the automatic control of the relationship rather than to the mechanism operating the local control apparatus. The adjusting mechanism may be of any suitable type such, for example, as that shown in Patent 1,703,142 to E. I. Green, especially Fig. 2a in which relay 32 may correspond to relay 410 of the present application.

All of these applications are made practicable by providing a circuit of substantially constant phase relation.

This invention may be applied to any line, within the limits outlined above, for which the phase characteristic is required to be substantially constant.

A division of this application has been filed as Serial No. 310,129, filed December 20, 1939, for Compensation for variations in phase change.

While this invention has been disclosed as embodied in certain particular forms, it is to be understood that it is not limited to such forms but is capable of embodiment in other forms without departing from the spirit and scope of the appended claims.

What is claimed is:

1. A method of minimizing variations in the phase change in alternating current being transmitted between points in a circuit, which consists in terminating both ends of said circuit with substantially equal impedances ($Z_T$) having values large in comparison with one-half the series impedance of the equivalent T-network of said circuit ($Z_1$ and $Z'_1$).

2. A method of minimizing variations in the phase change in alternating current being transmitted between points in a circuit, which consists in terminating both ends of said circuit with equal resistances having values large in comparison with one-half the series impedance of the equivalent T-network of said circuit ($Z_1$ and $Z'_1$).

3. A method of minimizing variations in the phase change in alternating current being transmitted between points in a circuit, which consists in terminating both ends of said circuit with equal reactances having values large in comparison with one-half the series impedance of the equivalent T-network of said circuit ($Z_1$ and $Z'_1$).

4. A method of minimizing variations in the phase change in alternating current being transmitted between points in a circuit, which consists in terminating both ends of said circuit with equal positive reactances having values large in comparison with one-half the series impedance of the equivalent T-network of said circuit ($Z_1$ and $Z'_1$).

5. A method of minimizing variations in the phase change in alternating current being transmitted between points in a circuit, which consists in terminating both ends of said circuit with equal negative reactances having values large in comparison with one-half the series impedance of the equivalent T-network of said circuit ($Z_1$ and $Z'_1$).

6. Means for compensating for variations in phase change in an electrical circuit which includes terminating each end of the circuit with substantially equal impedances large in comparison with one-half the series impedance of the equivalent T-network for said circuit.

7. Means for compensating for variations in phase change in an electrical circuit which includes terminating each end of the circuit with substantially equal resistances large in comparison with one-half the series impedance of the equivalent T-network for said circuit.

8. Means for compensating for variations in phase change in an electrical circuit which includes terminating each end of the circuit with substantially equal reactances large in comparison with one-half the series impedance of the equivalent T-network for said circuit.

9. A transmission line over which alternating current is transmitted, the current undergoing a change in phase between separated points in said line, said phase change normally varying with variation in the atmospheric conditions surrounding said line, and means to maintain said phase change substantially constant regardless of variation in said atmospheric conditions, said means comprising substantially equal impedances at each end of the line, each impedance being large in comparison with one-half the series impedance of the equivalent T-network of the line.

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