Nov. 26, 1935. A. C. NORWINE 2,021,920

CONTROL CIRCUITS

Filed Jan. 15, 1935

FIG. 1

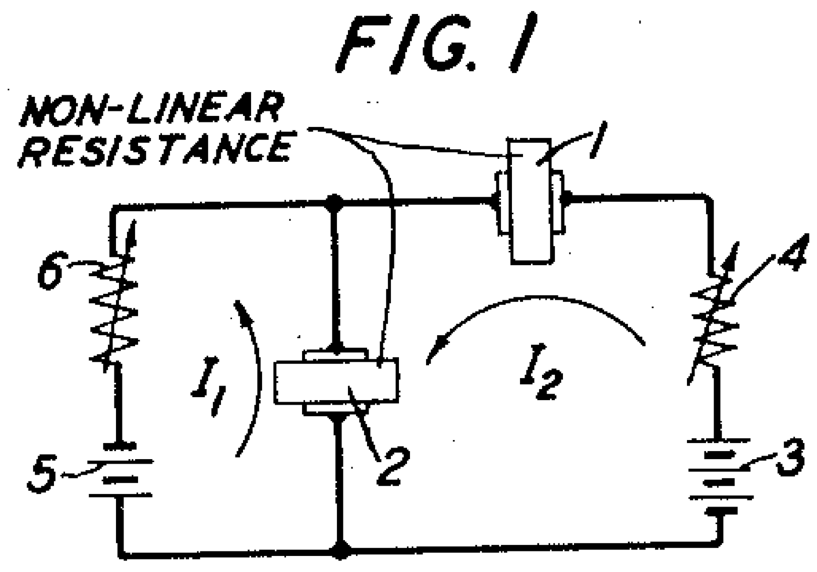


FIG. 2

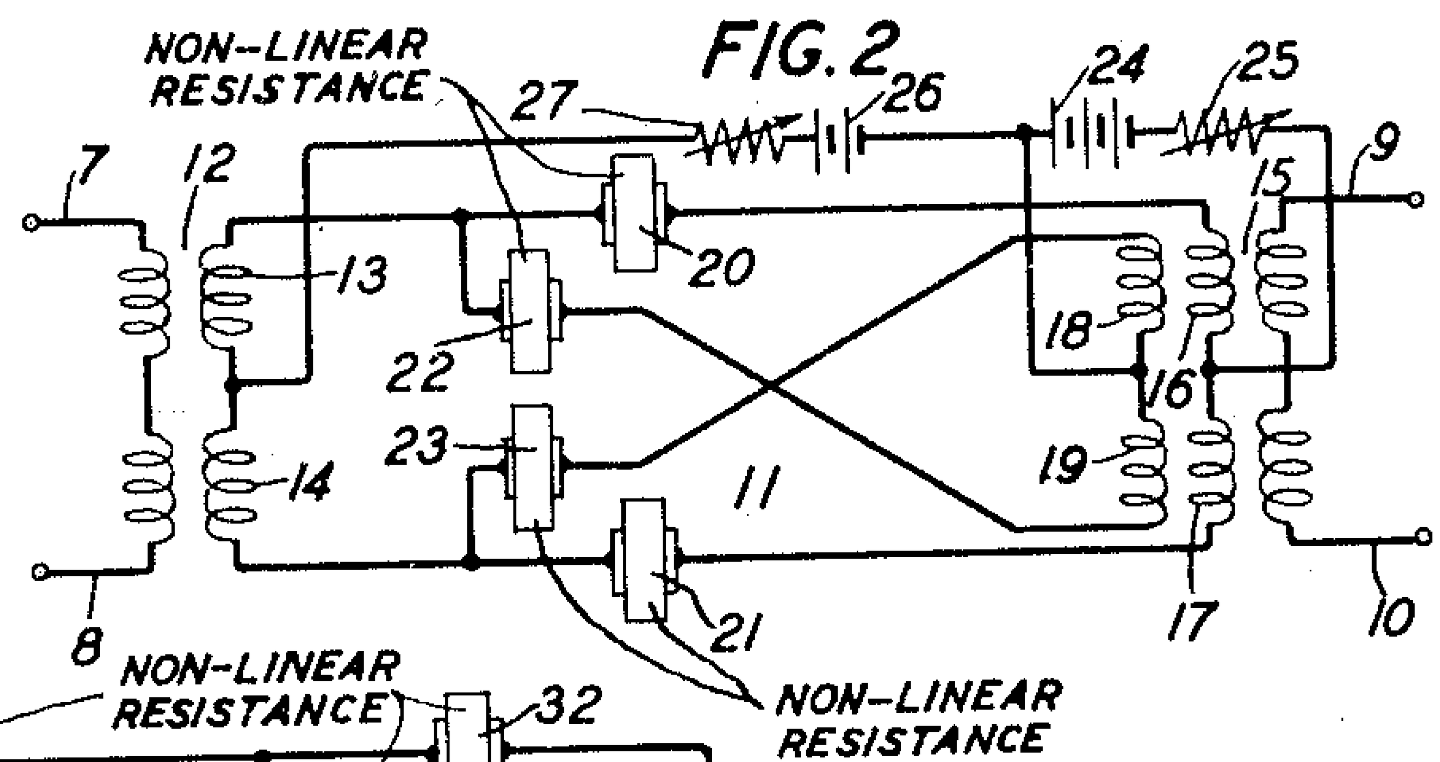


FIG. 3

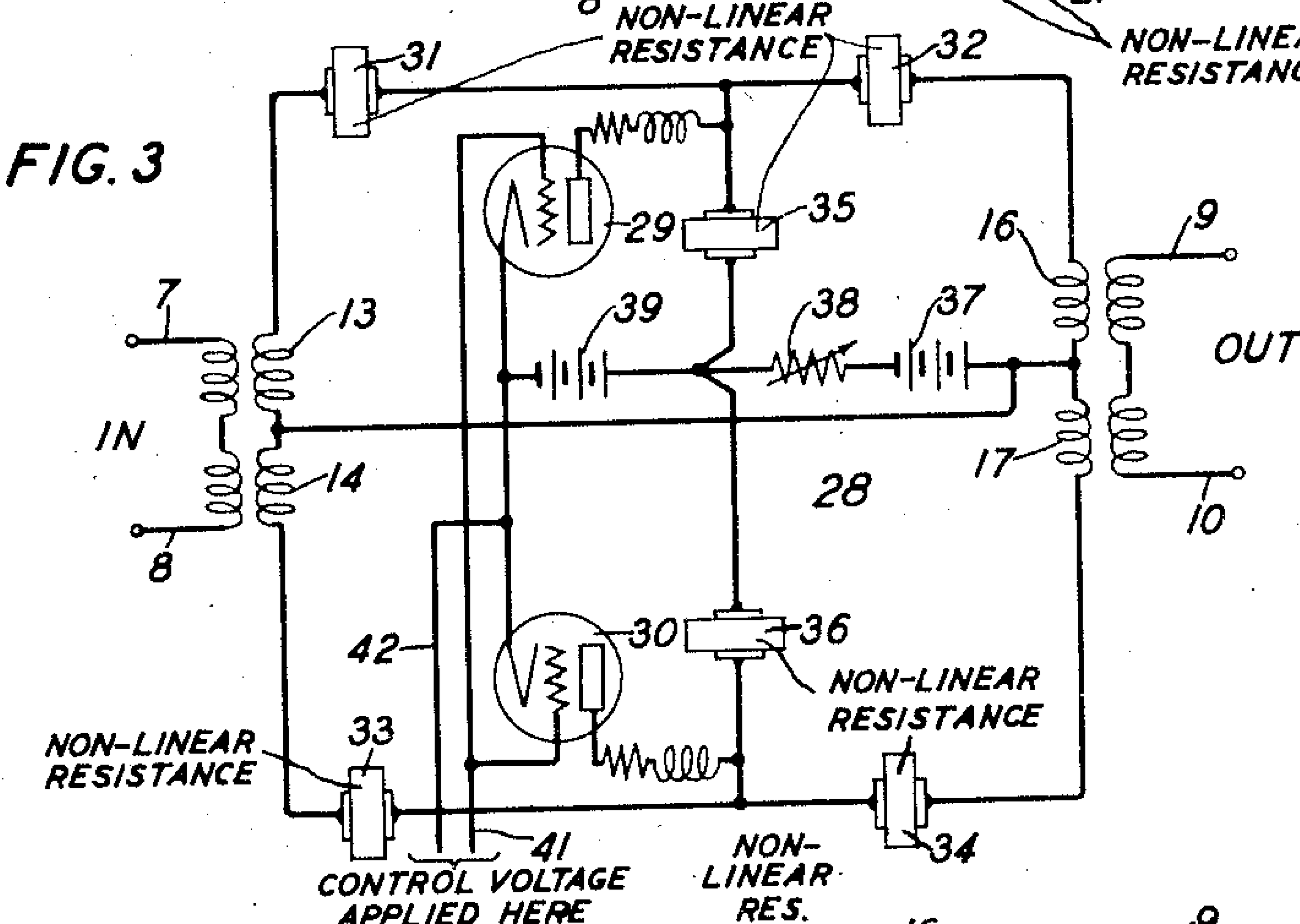


FIG. 4

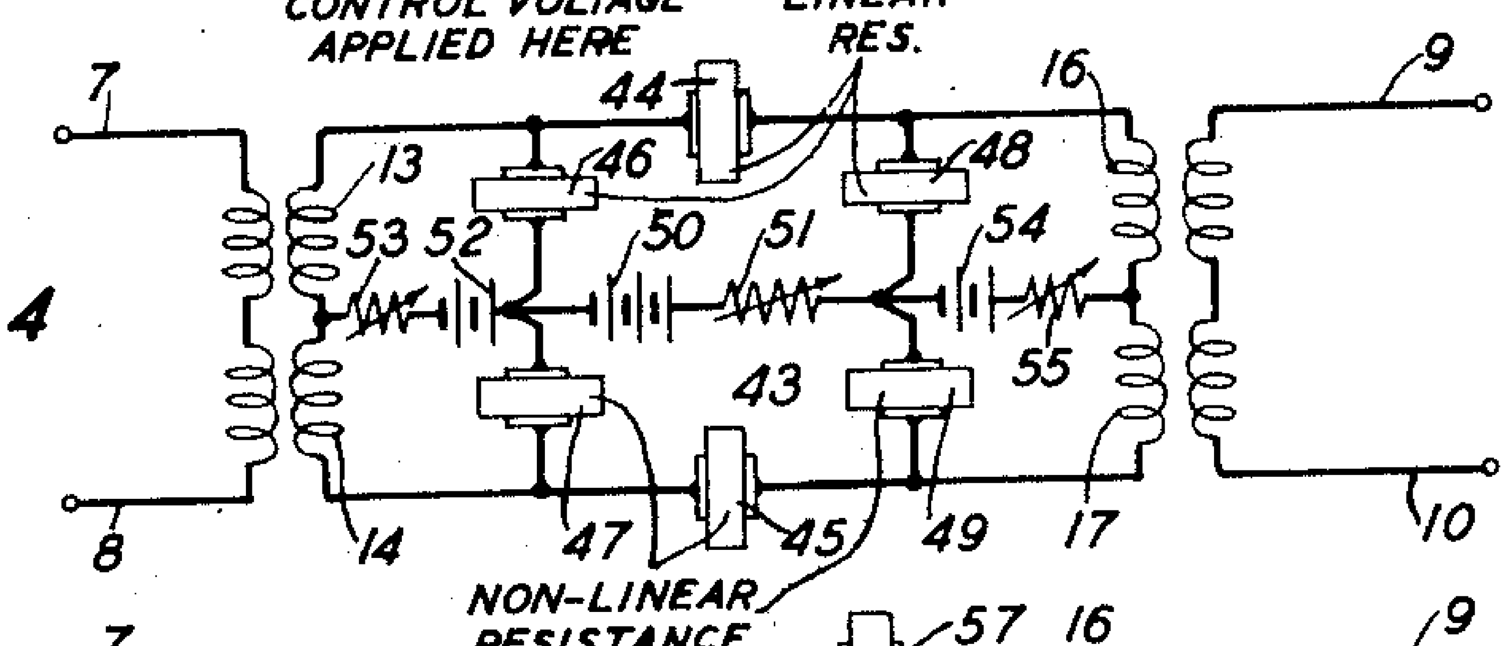


FIG. 5

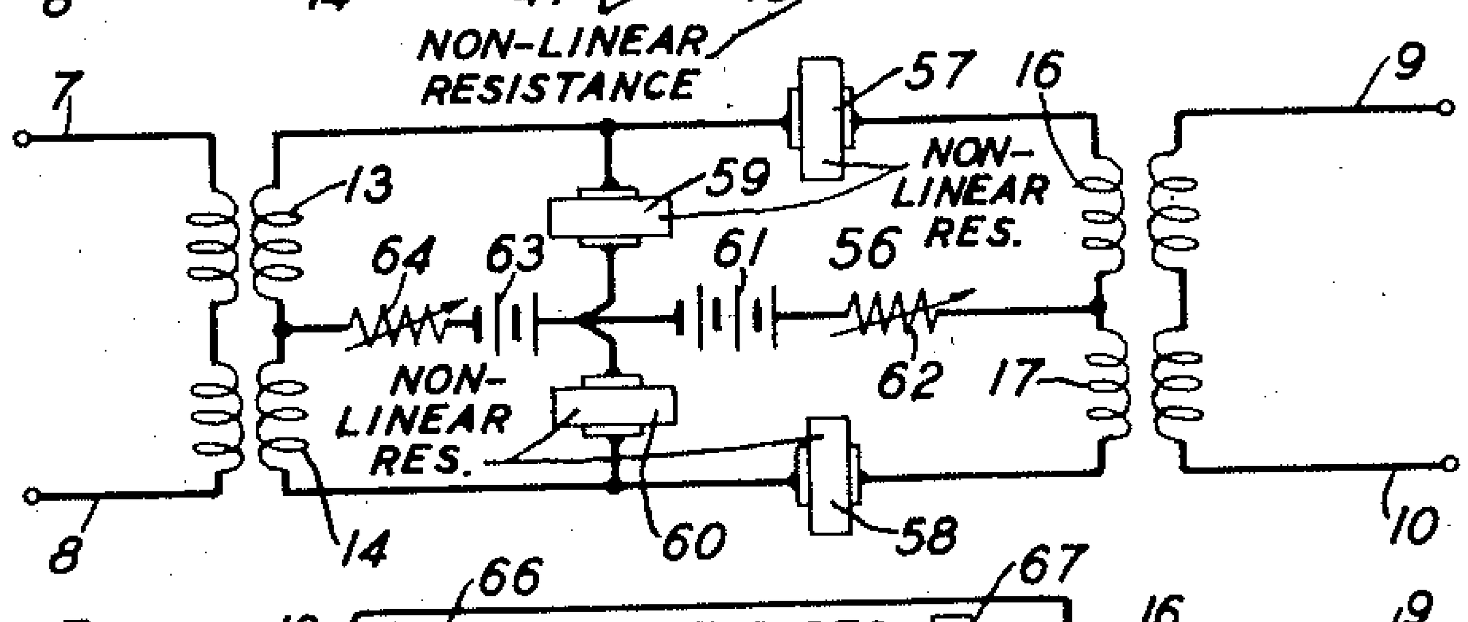
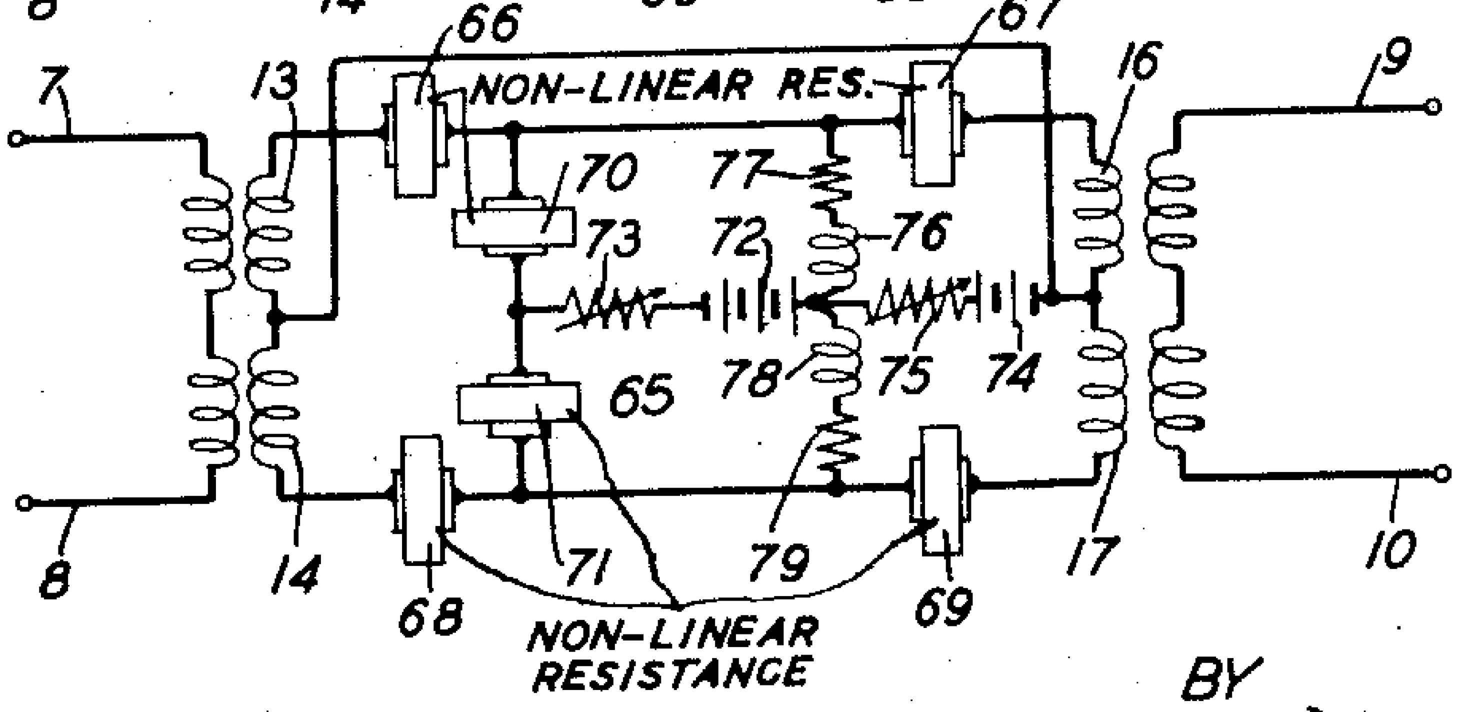


FIG. 6



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UNITED STATES PATENT OFFICE

2,021,920

CONTROL CIRCUITS

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12 Claims. (Cl. 178—44)

This invention relates to control circuits and particularly to control circuits for attenuation networks on signal transmission lines.

One object of the invention is to provide an attenuation network comprising impedance elements having non-linear resistance characteristics that shall have a low minimum loss and a substantially constant input impedance.

Another object of the invention is to provide a transmission line with an attenuation network comprising impedance elements having non-linear resistance characteristics connected in series with and in shunt to the transmission line that shall have a single controllable impedance for varying the resistances of the shunt connected impedances and the series connected impedances inversely.

A further object of the invention is to provide a transmission line with an attenuation network comprising impedance elements having non-linear resistance characteristics connected in series with and in shunt across the transmission line and sources of current connected to the impedance elements that shall vary the effective voltage of one of said sources to vary the resistances of said shunt connected impedances and the series connected impedances inversely.

Attenuation networks or attenuation pads are employed for transmission regulation on signal transmission lines or telephone lines. The networks comprise impedances which are connected in series with and in parallel across the transmission line. Generally relays or cam operated switches are provided for inserting the impedances in circuit with or withdrawing the impedances from the transmission line. The control of the impedances of a network by means of relays or cam operated switches is generally complex and requires considerable apparatus.

According to the present invention the impedances in the network or pad have non-linear resistance characteristics and are preferably composed of silicon carbide crystals and a binder mixed with conducting material. The impedances may be composed of the material disclosed in the patent to K. B. McEachron No. 1,822,742, dated September 8, 1931. The material disclosed in the K. B. McEachron patent is known as thyrite. This material has a non-linear voltage current characteristic at constant temperature and therefore a non-linear resistance characteristic at constant temperature.

The resistance values of the impedance elements in a network constructed in accordance with the present invention are controlled by governing the current flow through the elements. The non-linear resistance characteristic of silicon carbide crystals combined with a binder mixed with conducting material is disclosed in the above-mentioned patent to K. B. McEachron.

The invention is illustrated by networks which may be of the L, T, Π or lattice type. In each of the networks impedance elements are connected in series with and in parallel to the line or circuit to be controlled. Two sources of current are provided in circuit with each attenuation network to vary the resistance characteristics of the impedance elements. Preferably one of the sources of current is connected in series with one or a number of impedance elements connected across the circuit being controlled. The second source of current is connected in series not only with the impedance element connected in series to the line, but also in series with the impedance elements connected in shunt across the line. A resistance or impedance element is connected in series with each of the sources of current. The resistance elements may be the space path of a vacuum tube or may be resistance elements controlled in any suitable manner.

The networks should have a low minimum loss, a constant input impedance and the impedance elements in series with and in parallel to the controlled circuit should have their resistance values varied inversely. A network constructed as above set forth and having impedance elements composed of silicon carbide crystals and a binder mixed with conducting material will answer the above requirements if the resistance element in series with either source of current is varied. If the resistance in circuit with the source in series with all the impedance elements is varied to supply maximum voltage to the network then the impedance elements in series with the line will have minimum resistance and the impedance elements across the line will have maximum resistance. A reverse operation takes place if the effective voltage of the source connected in series with all the impedance elements is reduced to a small value. In this case the series connected impedance elements will have maximum resistance and the parallel connected impedance elements will have minimum resistance. If the resistance element in series with the source connected only in series with the parallel connected impedance elements is controlled, then variation of the resistance to supply a maximum voltage to the shunt connected impedance elements will lower the resistance value of the shunt connected impedance element to a minimum and raise the resistance values of the series connected impedance elements to a maximum resistance value. If the effective voltage of the source connected in series with the shunt connected impedance elements is reduced to a very low value, then the resistance value of the shunt connected impedance elements is raised and the resistance value of the series connected impedance elements is lowered.

In networks provided with impedance elements having non-linear resistance characteristics as above set forth, the lattice network has the greatest range whereas the Π network has the smallest range. The impedance variations are the greatest for a T network and are of the order of 3:1 for a 30 decibel range. A lattice network has a fairly constant impedance in one direction and this fact, coupled with the feature that it can have a high maximum loss makes it a very advantageous network.

In the accompanying drawing,

Fig. 1 is a diagrammatic view of a basic control circuit constructed in accordance with the invention;

Fig. 2 is a diagrammatic view of a lattice network constructed in accordance with the invention;

Fig. 3 is a diagrammatic view of a network constructed in accordance with the invention and controlled by space discharge devices;

Fig. 4 is a diagrammatic view of a Π network constructed in accordance with the invention;

Fig. 5 is a diagrammatic view of an L network constructed in accordance with the invention; and

Fig. 6 is a diagrammatic view of a T network constructed in accordance with the invention.

Referring to Fig. 1 of the drawing, a control circuit is shown comprising elements 1 and 2 having a non-linear resistance characteristic such as the material disclosed in the above-mentioned patent to K. B. McEachron 1,822,742. A battery 3 and a variable resistance 4 are connected in series with each of the resistance elements 1 and 2. The direction of the current flow from the battery 3 is indicated by the arrow I_2. A battery 5 and a variable resistance 6 are connected in series with the resistance element 2. The current flow from battery 5 is indicated by the arrow I_1. The voltage supplied by the battery 3 is controlled by varying the resistance 4 and the voltage from battery 5 is controlled by varying the resistance 6. The non-linear resistance characteristics of the elements 1 and 2 are described and shown in the above mentioned patent to K. B. McEachron. The two resistance elements 1 and 2 may be simultaneously varied by varying either of the resistance elements 4 and 6.

If the resistance element 4 is varied to supply a maximum voltage from the battery 3 to the non-linear resistance elements 1 and 2, the resistance value of the resistance element 1 will be reduced to a minimum, whereas the resistance value of resistance element 2 will be raised to a maximum. This is apparent because the current flow through the element 1 will be maximum whereas the current flow through the element 2 will be reduced to a minimum. The voltage from battery 3 opposes the voltage from the battery 5 so that the current flow through element 2 is reduced to a minimum. If the resistance element 4 is varied so as to reduce the effective voltage of battery 3 to a minimum, then the current flow through element 1 will be reduced to a minimum and the resistance value of this element will be raised to a maximum value. On the other hand, the current flow through element 2 will be raised to a maximum value and the resistance value of element 2 will be a minimum. In a circuit so constructed it is apparent that elements 1 and 2, if so positioned in a transmission line, will have a constant input impedance and will also have a low minimum loss. Although Fig. 1 has been described by referring to the variation of resistance 4, it is apparent that the same results may be accomplished by varying the resistance 6. Lowering the effective voltage of the battery 5 has the same effect as raising the effective voltage of battery 3.

Referring to Fig. 2 of the drawing, a lattice network is illustrated employing the control circuits shown in Fig. 1 of the drawing. A transmission line comprising input conductors 7 and 8 and output conductors 9 and 10 is connected to a network 11 having non-linear resistance elements. The input conductors 7 and 8 are connected to the network 11 by means of a transformer 12 having secondary windings 13 and 14. The network 11 is connected to the output conductors 9 and 10 by means of a transformer 15 having primary windings 16 and 17. Auxiliary windings 18 and 19 are associated with primary windings 16 and 17.

Non-linear resistance elements 20 and 21 in the network 11 are effectively connected in series with the transmission line and non-linear resistance elements 22 and 23 are effectively connected across the transmission line. A battery 24 and a variable resistance 25 are effectively connected in series with all the resistance elements 20 to 23, inclusive. A battery 26 and a variable resistance 27 are connected in series with resistance elements 22 and 23. The circuit from battery 24 through resistance elements 20 and 22 may be traced from one terminal of battery 24 through resistance element 25, primary winding 16, resistance elements 20 and 22, auxiliary coil 19 to the other terminal of battery 24. A circuit from battery 24 through resistance elements 21 and 23 may be traced from one terminal of battery 24 through resistance element 25, primary winding 17, resistance elements 21 and 23 and auxiliary coil 18 to the other terminal of battery 24. The circuit from battery 26 through resistance element 23 may be traced from one terminal of battery 26, through the auxiliary coil 18, resistance element 23, secondary winding 14 and resistance element 27 to the other terminal of battery 26. The circuit from battery 26 through resistance element 22 may be traced from one terminal of battery 26 through the auxiliary winding 19, resistance element 22, secondary winding 13, and the variable resistance 27 to the other terminal of battery 26.

The non-linear resistance elements 20 and 21 and 22 and 23 may be varied inversely by varying either the resistance element 27 or the resistance element 25. If the resistance element 25 is varied to supply a maximum voltage from the battery 24 then a maximum current will flow through the non-linear resistance elements 20 and 21, whereas a minimum current will flow through the resistance elements 22 and 23. Therefore, the non-linear resistance elements 20 and 21 will have a minimum resistance value whereas the non-linear resistance elements 22 and 23 will have a maximum resistance value. If the resistance 25 is varied to supply a minimum voltage from battery 24 then the current flow through the non-linear resistance elements

20 and 21 will be reduced to a minimum whereas current flow through the non-linear resistance elements 22 and 23 will be raised to a maximum. Therefore, the non-linear resistance elements 20 and 21 will have a maximum resistance value whereas the non-linear resistance elements 22 and 23 will have a minimum resistance value. In each of the cases above set forth, it should be noted that battery 26 opposes battery 24 in the same manner as battery 5 opposes battery 3 in the circuit shown in Fig. 1 of the drawing. The network 11, shown in Fig. 2 of the drawing, may be controlled by varying the resistance 27 in the same manner as the control circuits shown in Fig. 1 may be controlled by varying resistance 6.

Referring to Fig. 3 of the drawing, an attenuation network 28 is shown controlled by space discharge devices 29 and 30. Similar reference characters to those employed in Fig. 2 in referring to the transmission line and the connection of the transmission line to the network will be employed in Figs. 3, 4, 5 and 6. The attenuation network 28 comprises non-linear resistance elements 31, 32, 33 and 34 effectively connected in series with the transmission line and non-linear resistance elements 35 and 36 effectively connected across the transmission line. The non-linear resistance elements 31 to 36, inclusive, are preferably constructed of the material disclosed in the above-mentioned patent to K. B. McEachron. A battery 37 and a variable resistance element 38 are shown effectively connected in circuit with all the non-linear resistance elements 31 to 36, inclusive. A space discharge device 29 is provided with a plate battery 39 connected in circuit with the non-linear resistance element 35 and a space discharge device 30 is connected in circuit with the battery 39 and the non-linear resistance element 36. The potential from the battery 39 under control of the devices 29 and 30 oppose the potential from the battery 37. The two space discharge devices 29 and 30 are controlled by impressing a variable potential on the conductors 41 and 42.

The network 28 shown in Fig. 3 of the drawing may be controlled by varying the resistance element 38 or by varying the potential impressed on conductors 41 and 42. Moreover, if so desired, the resistance element 38 may be replaced by a space discharge device similar to the devices 29 and 30. A like substitution may be made with respect to the variable resistance elements 25 and 27, shown in Fig. 2 of the drawing, if so desired. One circuit from battery 37 may be traced from one battery terminal, through the primary winding 16, non-linear resistance elements 32 and 35 and the variable resistance element 38 to the other terminal of battery 37. Another circuit from battery 37 may be traced from one battery terminal, through the secondary winding 13, resistance elements 31 and 35 and variable resistance 38 to the other battery terminal. Another circuit from battery 37 may be traced from one battery terminal, through the primary winding 17, non-linear resistance elements 34 and 36 and the variable resistance 38 to the other battery terminal. A further circuit from battery 37 may be traced from one battery terminal, through the secondary winding 14, non-linear resistance elements 33 and 36 and variable resistance 38 to the other battery terminal. If the effective voltage of the battery 37 is raised to a maximum value by means of the variable resistance 38, a maximum current flows through the non-linear resistance elements 31, 32, 33 and 34 and a minimum current flows through the non-linear resistance elements 35 and 36. Therefore, non-linear resistance elements 31, 32, 33 and 34 will have a minimum resistance value whereas non-linear resistance elements 35 and 36 will have a maximum resistance value. If the effective voltage of battery 37 is reduced to a minimum, the resistance values of non-linear resistance elements 31, 32, 33 and 34 will have their resistance values raised to a maximum and non-linear resistance elements 35 and 36 will have their resistance values lowered to a minimum.

The attenuation network 28 shown in Fig. 3 of the drawing may also be controlled by varying the potential impressed upon the conductors 41 and 42 in the input circuits of the space discharge devices 29 and 30. The varying of the impedances of devices 29 and 30 varies the effective voltages of battery 39 and has the same effect on the network 28 as the varying of resistance 38 to vary the effective voltage of battery 37.

Referring to Fig. 4 of the drawing, a Π network 43 is shown connected to the transmission line. The network 43 comprises non-linear resistance elements 44 and 45 effectively connected in series with the transmission line and non-linear resistance elements 46, 47, 48 and 49 effectively connected across the transmission line. The non-linear resistance elements 44 to 49, inclusive, are preferably constructed of the material disclosed in the above-mentioned patent to K. B. McEachron. A battery 50 and a variable resistance element 51 are provided in circuit with all the non-linear resistance elements 44 to 49, inclusive. A battery 52 and a variable resistance element 53 are provided in circuit with the non-linear resistance elements 46 and 47. A battery 54 and a variable resistance element 55 are provided in circuit with the non-linear resistance elements 48 and 49. The attenuation network 43 may be controlled by varying the resistance element 51 or by simultaneously varying the resistance elements 53 and 55. The battery 54 opposes the current flow from battery 50 through the non-linear resistance elements 48 and 49 and the battery 52 opposes the current flow from battery 50 through the non-linear resistance elements 46 and 47.

When the resistance element 51 is varied to reduce the effective voltage of battery 50 to a minimum, a minimum current flows through the non-linear resistance elements 44 and 45 and a maximum current flows through the non-linear resistance elements 46, 47, 48 and 49. Accordingly, the non-linear resistance elements 44 and 45 have a maximum resistance value and the non-linear resistance elements 46 to 49, inclusive, have a minimum resistance value. If the resistance element 51 is varied to produce a maximum voltage from the battery 50, a maximum current flows through the non-linear resistance elements 44 and 45 and a minimum current flows through the non-linear resistance elements 46 to 49, inclusive, therefore, the non-linear resistance elements 44 and 45 have a minimum resistance value and the non-linear resistance elements 46 to 49, inclusive, have a maximum resistance value. If so desired, the resistance 51 may be replaced by a spare discharge device, or the two resistance elements 53 and 55 may be replaced by space discharge devices as shown in Fig. 3 of the drawing.

Referring to Fig. 5 of the drawing, an L impedance network 56 is shown connected to the transmission line. The impedance network 56 comprises two non-linear resistance elements 57 and 58 effectively connected in series with the transmission line and two non-linear resistance elements 59 and 60 effectively connected across the transmission line. The non-linear resistance elements 57 to 60, inclusive, may be constructed of the material disclosed in the above-mentioned patent to K. B. McEachron. A battery 61 and a variable resistance element 62 are connected in circuit with all the non-linear resistance elements 57 to 60, inclusive, in two circuit meshes and a battery 63 and a variable resistance element 64 are connected in circuit with the non-linear resistance elements 59 and 60 in two other circuit meshes. The potential of battery 63 opposes the potential of battery 61 across resistance elements 59 and 60.

The resistance values of the non-linear resistance elements 57 to 60, inclusive, in the L network 56 may be controlled by varying the resistance element 62 or by varying the resistance element 64. If the resistance element 62 is varied to supply a maximum voltage from battery 61, a maximum current flows through the non-linear resistance elements 57 and 58 and a minimum current flows through the non-linear resistance elements 59 and 60. Therefore, the non-linear resistance elements 57 and 58 will have a minimum resistance value, and the non-linear resistance elements 59 and 60 will have a maximum resistance value. If the resistance element 62 is varied to supply a minimum potential from battery 61, then a minimum current flows through the non-linear resistance elements 57 and 58 and a maximum current flows through the non-linear resistance elements 59 and 60. Therefore, the non-linear resistance elements 57 and 58 have a maximum resistance value and the non-linear resistance elements 59 and 60 have a minimum resistance value. The variable resistance elements 62 and 64 may be replaced by space discharge devices if so desired.

Referring to Fig. 6 of the drawing, the T attenuation network 65 is shown connected to the transmission line. The network 65 comprises non-linear resistance elements 66, 67, 68 and 69 effectively connected in series with the transmission line and non-linear resistance elements 70 and 71 effectively connected across the transmission line. The non-linear resistance elements 66 to 71, inclusive, are preferably constructed of the material disclosed in the above-mentioned patent to K. B. McEachron. A battery 72 and a variable resistance element 73 are connected in circuit with the non-linear resistance elements 70 and 71 and a battery 74 and a variable resistance 75 are connected in circuit with all the non-linear resistance elements 66 to 71, inclusive. The non-linear resistance elements 66 to 69, inclusive, may be varied inversely with respect to the non-linear resistance elements 70 and 71 by varying the variable resistance element 75 or by varying the resistance element 73. The resistance elements 73 and 75 may be replaced by space discharge devices as shown in Fig. 3 of the drawing, if so desired.

One circuit from battery 74 may be traced from one battery terminal through secondary winding 13, non-linear resistance element 66, resistance element 77, inductance 76 and resistance element 75 to the other terminal of the battery 74. Another circuit from battery 74 may be traced from one battery terminal, through secondary winding 14, non-linear resistance element 68, resistance element 79, inductance 78 and resistance element 75 to the other terminal of battery 74. Another circuit from battery 74 may be traced from one battery terminal, through primary winding 16, non-linear resistance element 67, resistance element 77, inductance 76 and resistance element 75 to the other terminal of battery 74. Another circuit from battery 74 may be traced from one terminal of the battery through primary winding 17, non-linear resistance element 69, resistance element 79 and resistance element 75 to the other terminal of battery 74. The circuit from battery 72 through non-linear resistance element 70 is completed through the inductance 76 and the resistance element 77. The circuit through non-linear resistance element 71 is completed through the inductance 78 and the resistance 79. The two batteries 72 and 74 oppose each other in their action on the non-linear resistance element by means of the coupling effected by elements 76, 77, 78 and 79.

Modifications in the circuits and in the arrangement and location of parts may be made within the spirit and scope of the invention and such modifications are intended to be covered by the appended claims.

What is claimed is:

1. In combination, a transmission line, an attenuation network in said line, resistance elements in said network each having a non-linear resistance characteristic at constant temperature and varying in resistance according to the current flow therethrough, said elements being connected in series with and in shunt across said line, a source of potential connected to said network for effecting current flow through said elements, and means for varying the impedance of said shunt and series resistance elements inversely upon varying the effective voltage of said source.

2. In combination, a circuit having series and shunt resistance elements therein, each of said elements having a non-linear resistance characteristic at constant temperature and varying in resistance according to the current flow therethrough, a source of potential connected to said circuit, and means for varying the voltage of said source with respect to said elements to effect maximum impedance of the series elements when the shunt elements have a minimum impedance and vice versa.

3. In combination, an attenuation network having series and shunt impedance elements therein, said elements having non-linear resistance characteristics at constant temperature and varying in resistance according to the direct current flow therethrough, a direct current source of potential in said network, a resistance means in circuit with said source, and means for varying the resistances of said shunt and series impedance elements inversely upon varying said resistance means.

4. In combination, an attenuation network having series and shunt resistance elements therein, each of said elements having a non-linear resistance characteristic and varying in resistance according to the current flow therethrough, two sources of direct current respectively connected to said series and shunt resistance elements, and means for effecting maximum impedance of said series elements when the shunt elements have a minimum impedance and vice versa by varying the relative effective values of said sources.

5. In combination, an attenuation network hav-

ing a series and a shunt resistance element therein, each of said elements having a non-linear resistance characteristic and varying in resistance according to the current flow therethrough, two sources of direct current, one of said sources being connected in series with one of said resistance elements and the other source being connected in series with both of said resistance elements, and means for varying the effective voltage of one of said sources to vary the impedances of said resistance elements inversely.

6. In combination, a transmission line, an attenuation network connected in said line, a set of impedance elements in said network connected in series with said line, a set of impedance elements in said network connected in shunt to said line, two sources of current in said network, one of said sources being connected in series with one set of said impedance elements and the other source being connected in series with both sets of said impedance elements, and means comprising an impedance means in series with one of said sources for varying said sets of impedance elements inversely upon variation thereof.

7. In combination, a transmission line, an attenuation network in said line, two impedance elements in said network respectively in series with and in shunt to said transmission line, two sources of current in said network, one of said sources being connected in series with one of said impedance elements and the other source being connected to supply potential to both of said impedance elements, and two impedance means respectively connected in series with said sources so that variation of one of said impedance means varies the resistances of the shunt and series impedance elements inversely.

8. In combination, a transmission line, an attenuation network in said line, two impedance elements in said network respectively in series with and in shunt across said transmission line, two sources of current in said network, one of said sources being connected in series with the impedance element connected across the transmission line and the other source being connected in series with both of said impedance elements, and an impedance means connected in series with one of said sources for varying the resistances of said impedance elements inversely upon variation thereof.

9. In combination, an attenuation network having series and shunt impedance elements therein, said elements having non-linear resistance characteristics and varying in resistance according to the direct current flow therethrough, two sources of direct current respectively connected to said series and shunt impedance elements, two resistance elements respectively in circuit with said sources, and means for varying the impedances of said shunt and series impedance elements inversely upon varying one of said resistance elements.

10. In combination, a signal transmission line, an input transformer and an output transformer in said line, an attenuation network connected to the secondary winding of the input transformer and to the primary winding of the output transformer, series and shunt impedance elements in said network, said elements having non-linear resistance characteristics and varying in resistance according to the current flow therethrough, two sources of direct current respectively connected to said series and shunt impedance elements, a resistance element in series with one of said sources, and means for varying the resistances of said series and shunt impedance elements inversely upon varying said resistance element.

11. In combination, a transmission line, an attenuation network in said line, two impedance elements in said network respectively in series with and in shunt across said transmission line, two sources of current in said network, one of said sources being connected in series with the impedance element in shunt across the transmission line and the other source being connected in series with both of said impedance elements, and impedance means in series with the source connected to the shunt impedance means for varying the resistances of said impedance elements inversely upon variation thereof.

12. In combination, a circuit, a network in said circuit, impedance elements in said network each having a non-linear impedance characteristic at constant temperature and varying in impedance according to the current flow therethrough, said elements being connected in series with and in shunt across said circuit, a source of potential connected to said network for effecting current flow through said elements, and means for varying the impedance of said shunt and series elements inversely upon varying the effective voltage of said source.

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