

May 24, 1949.

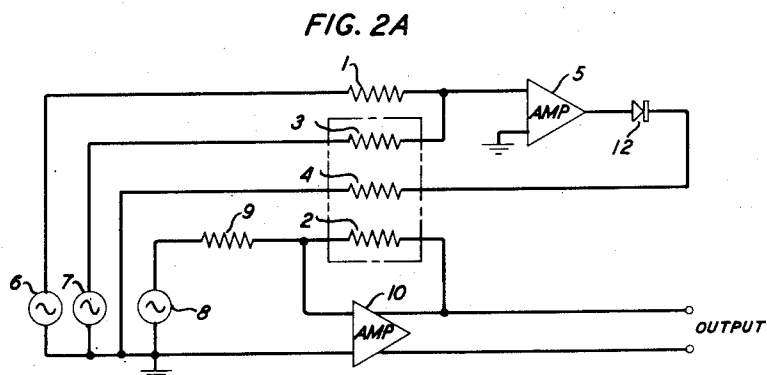
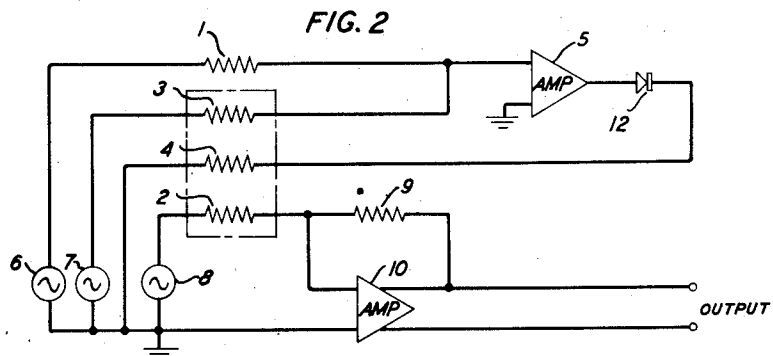
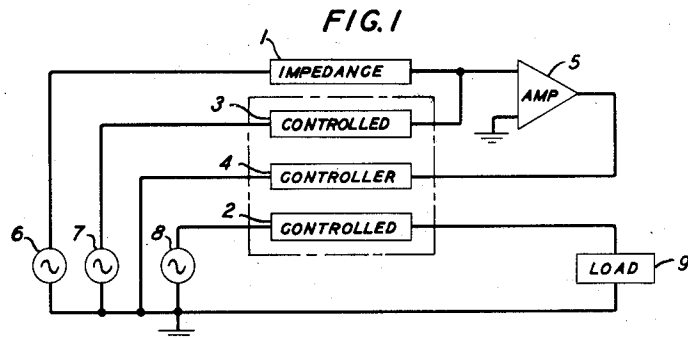
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2,471,262

MEANS FOR MULTIPLYING VOLTAGES

Filed Oct. 24, 1946

2 Sheets-Sheet 1



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FIG. 3

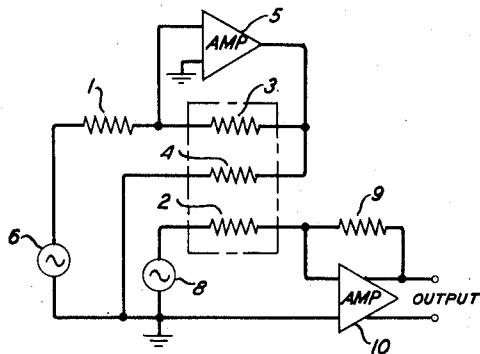


FIG. 3A

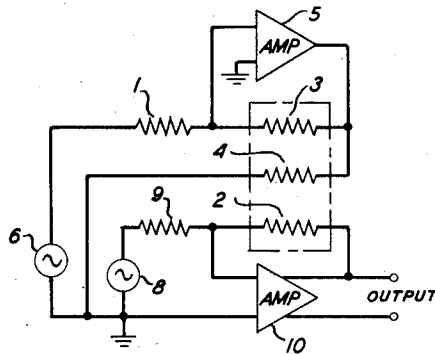


FIG. 4

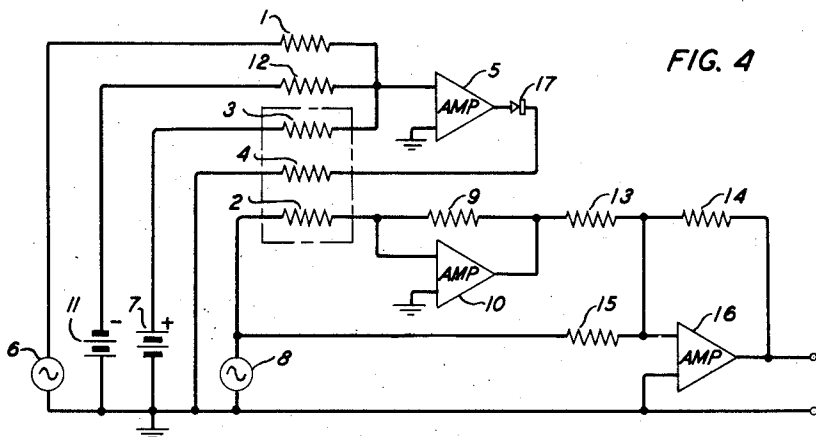
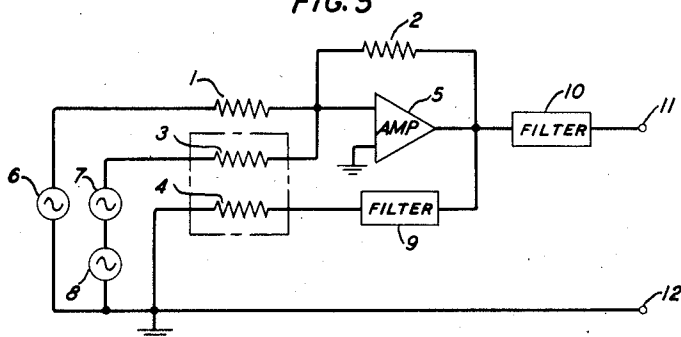


FIG. 5



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MEANS FOR MULTIPLYING VOLTAGES

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8 Claims. (Cl. 250-27)

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This invention relates to voltage multipliers, voltage dividers, modulators and demodulators.

The object of the invention is an electrical circuit producing a voltage proportional in amplitude to the product or quotient of the amplitudes of two given voltages.

A feature of the invention is the combination of an amplifier, a controlling element and a first controlled element connected in a loop circuit, and a second element controlled by said controlling element and connected in a second circuit.

Another feature of the invention is the design and disposition of the controlling element and the controlled elements so that the controlled elements will have similar variations with a variation of the current in the controlling element.

In many devices, the current in a controlling element varies the electrical properties of two or more controlled elements. For example, in the article *Thermistors, Their Characteristics and Uses*, by G. L. Pearson, published in the *Bell Laboratories Record*, vol. XIX, number IV, December, 1940, page 106, directly heated thermistors are described in which a heating element controls the resistances of one or more thermistor beads, and many other devices, thermal, optical, magnetic, mechanical or other, are known in which the current in a controlling element controls some electrical characteristics of two or more controlled elements.

In a typical embodiment of the invention, a source of a first signal voltage is connected to the input circuit of an amplifier, and the output circuit of the amplifier is connected to the controlling element. The first controlled element is so connected to the amplifier as to control the output voltage of the amplifier by supplying a voltage which opposes the first signal voltage. The system will stabilize itself when some electrical property of the controlled element has been changed by the current in the controlling element proportionally to the amplitude of the first signal voltage. A similar change is produced in a characteristic of the second controlled element. A source of a second signal voltage is connected to a circuit so arranged that the transmission equivalent of this circuit for the current from the second signal source is controlled by the second controlled element. The output voltage of this second circuit will then be proportional in amplitude to the product or quotient of the amplitudes of the two signal voltages.

In the drawings:

Fig. 1 is a simplified schematic of the circuit;

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Figs. 2, 2-A, 3, 3-A, 4 show voltage multipliers and dividers embodying the invention;

Fig. 5 shows a modulator or demodulator embodying the invention.

In Fig. 1, a source 6 of a first signal voltage e_1 is connected through an element 1 having an admittance A_1 to the input circuit of a high gain amplifier 5, having a common grounded input and output terminal. The output circuit of the amplifier 5 is connected to ground through a controlling element 4, which may be the heater of a thermistor, or similar device. The controlling element 4 controls the admittances A_2 , A_3 of the two controlled elements 2, 3. A source 7 of a voltage $-e_3$, of opposite polarity to the voltage from the source 6, is connected through the element 3 to the input circuit of the amplifier 5. A source 8 of a second signal voltage e_2 is connected through the element 2 to a load circuit 9. The source 6 is connected through the impedance 1 and the element 3 in series with the source 7. The voltage from the source 6 supplied to the input circuit of the amplifier 5 will cause a current to flow from the output circuit of amplifier 5 through the controlling element 4 to ground, changing the admittances of the elements 2, 3, until the voltage from the source 7, supplied to the input circuit of the amplifier 5 is substantially but not quite equal to the voltage supplied by the source 6, and the voltage across the input circuit of the amplifier 5 is reduced to a negligible value. Let the current flowing in the series circuit including the sources 6 and 7 at this time be i .

Then

$$i = e_1 A_1 = e_3 A_3$$

$$A_3 = e_1 \frac{A_1}{e_3} \quad (1)$$

The admittance A_2 of the element 2 has changed in the same manner as the admittance A_3 of the element 3, so that the ratio

$$K = \frac{A_2}{A_3}$$

is constant. Let the current in the load 9 be i_2 , then, if the impedance of the load 9 is small, compared to that of element 2,

$$i_2 = e_2 A_2 = e_2 K A_3 = e_1 e_2 \frac{K A_1}{e_3} \quad (2)$$

The current in the load 9, and the voltage across the load, are proportional to the product of the amplitudes of the voltages $e_1 e_2$, divided by the amplitude of the voltage e_3 .

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The voltages from the sources 6 and 7 should be of the same kind, but opposite polarity; that is, the voltages may both be unidirectional but of opposite polarity, or both alternating, of the same frequency but opposite phase. The voltage from the source 8 may be of any kind or polarity.

In Fig. 1, since the controlling element 4 is equally affected by currents of either polarity, if the voltage supplied to the input circuit of the amplifier by the source 7 exceeds the voltage supplied by the source 6, the source 7 will take control, causing the element 4 to increase the admittance of element 3 until the output current is limited only by the overload current of the amplifier, or the failure of some element in the circuit. This effect may be avoided by the circuit shown in Figs. 2 and 2-A, in which elements which correspond to the elements of Fig. 1, have the same reference characters.

In Fig. 2, a source of voltage is connected through a resistor 1 to the input circuit of an amplifier 5. The source 6 is symbolic of any voltage source which is arbitrarily varied, and may be replaced by any such source of variable voltage.

A source of biasing voltage 7, of the same kind but opposite polarity to the voltage from the source 6, is connected through the bead 3 of an indirectly heated thermistor to the input circuit of amplifier 5.

The output circuit of amplifier 5 is connected to ground through a unilaterally conductive device 12 and the heater 4 of the thermistor.

A source of voltage 8 is connected through a second bead 2 of the thermistor to the input circuit of a second amplifier 10 having a feedback resistor 9.

The amplifier 10 may be of the type shown in United States Patent 2,401,779, June 11, 1946, K. D. Swartzel, Jr., though other high-gain stable amplifiers, having suitable response-frequency characteristics, may be used.

The source 7, elements 3, 1 and the voltage applied by the source 6 are in series. Let the voltages supplied by the source 6 and source 7 be e_1 , e_3 and the admittances of elements 1, 3 be A_1 , A_3 . Assume that initially

$$e_1 A_1 > e_3 A_3, \text{ or, if } A_1 \geq A_3, \text{ that } e_1 > e_3$$

so that a net excess voltage from source 6 will be applied to the input circuit of amplifier 5 which will cause a current to flow in the heater 4 which will increase the admittance A_3 of the bead 3, and this action will continue until the net voltage applied to the input circuit of the amplifier is just sufficient to maintain the required current in the heater 4.

If the output voltage required to maintain this current is say 50 volts, and the voltage amplification of the amplifier is say 50,000, the net voltage applied to the input circuit of amplifier 5 need only be .001 volt, and may be ignored. Let the current flowing in elements 1, 3 be i , then if the voltage across the input circuit is ignored, as before

$$i = e_1 A_1 = e_3 A_3$$

$$A_3 = e_1 \frac{A_1}{e_3}$$

The beads 2, 3 of the thermistor are symmetrically disposed with respect to the heater 4, so that the ratio

$$K = \frac{A_2}{A_3}$$

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of the admittances of the beads is a constant over the operating range, thus

$$A_2 = e_1 \frac{K A_1}{e_3}$$

Let the voltage of the source 8 be $\pm e_2$, the admittances of elements 2, 9 be A_2 , A_9 and the output voltage of amplifier 10 be e_0 .

Then,

$$e_0 = - \frac{(\pm e_2 A_2)}{A_9} = - \left[\frac{e_1 (\pm e_2) K A_1}{e_3 A_9} \right] \quad (3)$$

The output voltage of amplifier 10 has an amplitude proportional to the product of the amplitudes of the voltages applied by the sources 6 and 8.

Fig. 2—A is identical with Fig. 1, except that the elements 2 and 9 have been interchanged.

Then

$$e_0 = - \frac{(\pm e_2 A_9)}{A_2} = - \left[\frac{(\pm e_2) e_3 A_9}{e_1 K A_1} \right] \quad (4)$$

In this case the output voltage is proportional to the quotient of the amplitudes of the applied voltages.

To prevent the runaway action found in the simple circuit of Fig. 1, a unilaterally conductive element 12, such as a diode, copper-copper oxide couple, grid controlled or other rectifier, may be connected in the circuit to the heater 4, so that current is only supplied to the heater 4 when the voltage at the input of amplifier 5 from the source 6 exceeds the voltage from the source 7.

If the voltage from the source 6 is alternating, the element 12 should be a device, such as a grid controlled rectifier in which the conduction period is controlled by the phase of the voltage from the source 6. A similar effect may be secured by arranging the output circuit of amplifier 5 so that only voltage of the proper polarity is supplied by the output circuit.

Fig. 3 is similar to Fig. 2 except that the device 12 and source 7 have been removed, and the bead 3 connected as a feedback resistor from the output to the input of amplifier 5.

Let

- e_1 be the voltage of the source 6
- $\pm e_2$ the voltage of the source 8
- e_3 the output voltage of amplifier 5
- e_0 the output voltage of amplifier 10

Then

$$e_1 A_1 = e_3 A_3$$

$$A_3 = \frac{e_1}{e_3} A_1$$

$$e_0 = - \frac{(\pm e_2) A_2}{A_9} = - \frac{(\pm e_2) K A_3}{A_9} = - \left[\frac{(\pm e_2) e_1 K A_1}{e_3 A_9} \right] \quad (5)$$

Fig. 3—A is similar to Fig. 3, except that the connections of the bead 2 and resistor 9 have been interchanged. In this case

$$e_0 = - \frac{(\pm e_2) A_9}{A_2} = - \frac{(\pm e_2) A_9}{K A_3} = - \left[\frac{(\pm e_2) e_3 A_9}{e_1 K A_1} \right] \quad (6)$$

The circuits of Figs. 2, 2-A, 3, 3-A give output voltages proportional in magnitude to the product or quotient of e_1 and e_2 , but the polarity or sign of the product or quotient is determined only by the polarity or sign of the voltage e_2 , the amplitude of the voltage e_1 being a mere multiplier or divisor.

Fig. 4 is generally similar to Fig. 2, and elements having similar functions are designated

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by the same reference characteristics, but a source 11 of voltage e_{12} , of opposite polarity to the source 7 is connected through resistor 12, having an admittance A_{12} , to the input circuit of amplifier 5 to bias the thermistor to the center of the operating range.

The output voltage e_{10} of amplifier 10 will be

$$-\frac{(\pm e_2)A_2}{A_9}$$

where A_2 and A_9 are the admittances of the elements 2 and 9.

The current i_1 from the source 6 is $\pm e_1 A_1$; the current i_{12} from the source 11 is $-e_{12} A_{12}$; and the current i_3 from the source 7 is $e_3 A_3$, where A_1 , A_{12} , A_3 are respectively the admittances of elements 1, 12, 3.

$$i_1 + i_{12} = i_3; \pm e_1 A_1 - e_{12} A_{12} = e_3 A_3$$

Let

$$A_{12} = A_1; (\pm e_1 - e_{12}) A_1 = e_3 A_3$$

or

$$A_3 = \frac{((\pm e_1) - e_{12}) A_1}{e_3}$$

let

$$A_2 = K A_1$$

then

$$e_{10} = -\frac{(\pm e_2) A_2}{A_9} = -\left[\frac{(\pm e_2)(\pm e_1) K A_1}{e_3 A_9} - \frac{(\pm e_2) e_{12} K A_1}{e_3 A_9} \right]$$

Let the voltage of the source 11 be initially so selected that, when the voltage $\pm e_1$ from source 6 is zero, the zero signal admittance A_{20} of the bead 2 equals $K A_1$, then,

$$e_{10} = -\left[\frac{(\pm e_2)(\pm e_1) K A_1}{e_3 A_9} - \frac{(\pm e_2)(e_{12}) A_{20}}{e_3 A_9} \right]$$

The output circuit of amplifier 10 is connected through resistor 13, to the input circuit of a unity gain amplifier 16, having a feedback resistor 14. The source 8 is connected through resistor 15 having the same resistance as resistors 13, 14, to the input circuit of amplifier 16. Let the resistor 9 be selected so that its admittance

$$A_9 = A_{20} \frac{e_{12}}{e_3}$$

Then, the output voltage e_0 of the amplifier 16 will be,

$$e_0 = \left[\frac{(\pm e_1)(\pm e_2) K A_1}{e_{12} A_{20}} - \frac{(\pm e_2)(e_{12}) A_{20} e_3}{e_3 A_{20} e_{12}} + (\pm e_2) \right] \\ = \frac{(\pm e_1)(\pm e_2) K A_1}{e_{12} A_{20}} \quad (7)$$

The amplitude of the output voltage e_0 is proportional to the product of the amplitudes of the voltages $e_1 e_2$ and the polarity or phase of the output voltage e_0 is that of the algebraic product $(\pm e_1)(\pm e_2)$.

The voltage e_{12} from the source 11 may also be varied in amplitude so that the output voltage e_0 is proportional to the product of the amplitudes of the voltages e_1 , e_2 , divided by the amplitude of the voltage e_{12} . In this case, as in Figs. 2, 2-A, a unilaterally conductive device 17 is connected in series with the heater 4.

A plurality of beads, such as the bead 2, may be associated with the heater 4. Independent sources of voltages, similar to the source 8, may be connected to these beads, or to input resistors corresponding to resistor 9, producing an output voltage of the form $\pm e_1 (\pm e_2, \pm e_3, \text{etc.})$ or the corresponding quotient.

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Fixed resistors may be associated with the elements of the thermistor to modify the characteristics of these elements, to improve the performance of the circuit, or to produce desired functional variations in the amplitudes of the voltages.

In Fig. 5 a source 6 of a voltage $-e_1$ is connected through a resistor 1, having an admittance A_1 , to the input circuit of a high gain amplifier 5. A feedback resistor 2, having an admittance A_2 is connected from the output to the input of amplifier 5. A second source 7 of a voltage $+e_3$ is connected through the bead 3 of a thermistor, having an admittance A_3 to the input circuit of the amplifier 5. A filter 9 in series with the heater 4 of the thermistor is connected across the output circuit of the amplifier 5. The output circuit of the amplifier 5 is connected through a filter 10 to the output terminal 11; the common grounded connection of the input and output circuits being connected to the output terminal 12.

The filter 9 has a transmission characteristic which will pass the current from the source 6 and source 7.

Let a source 8 of a voltage e_2 be connected in series with the source 7, and the filter 10 have a transmission characteristic which will pass the current from the source 8 and reject the current from the sources 6 and 7.

The current i_1 from the source 6 equals $e_1 A_1$ and the current i_3 from the source 7 equals $e_3 A_3$, and as only currents of this type are passed by the filter 9 to the heater, when the system is balanced,

$$A_3 = e_1 \frac{A_1}{e_3}$$

The filter 10 passes only currents from the source 8, thus, the output voltage

$$e_0 = e_2 \frac{A_3}{A_2} = e_1 e_2 \frac{A_1}{A_2 e_3}$$

The voltages $e_1 e_3$ from the sources 6 and 7 are of the same kind, but of opposite polarity or phase, are passed by the filter 9 and rejected by the filter 10. The voltage e_2 from the source 8 is of different kind, is passed by the filter 10 and rejected by the filter 9.

If e_1 is a varying unidirectional voltage, e_3 a constant unidirectional voltage of opposite polarity, and e_2 an alternating voltage of constant amplitude, the output voltage e_0 will be an alternating voltage, of the frequency of e_2 , but varying in amplitude with the variations of e_1 . If e_2 is an alternating voltage of varying amplitude, then e_0 will be an alternating voltage, of the frequency of e_2 , but varying in amplitude with the product of the amplitudes of e_1 and e_2 . The circuit thus operates as a modulator. Similarly, e_1 and e_3 may be alternating voltages of one frequency but opposite phases and e_2 may be an alternating voltage of different frequency.

On the other hand, the voltages $e_1 e_3$ from the sources 6 and 7 may be alternating voltages of the same frequency but opposite phases, and the voltage e_2 from the source 8 may be a unidirectional voltage. The circuit will then operate as a demodulator.

What is claimed is:

1. An amplifier having an input and an output circuit, a device having a controlling element connected across said output circuit and at least one controlled element, two sources of voltages of opposite polarity, an impedance connected in

serial relationship with said controlled element to the free poles of said sources, and a connection from the junction of said impedance and said controlled element to the input circuit of said amplifier, whereby the characteristics of said controlled element are varied proportionally with the voltages from said sources.

2. The combination in claim 1 with a source of a third voltage, a load, and a second element controlled by said controlling element so that the ratio of the admittances of said controlled elements is substantially constant connected from the source of said third voltage to said load.

3. A high gain amplifier having an input and an output circuit, a thermistor having a heating element connected across said output circuit and at least one bead, two sources of voltages of opposite polarity, a resistor connected in serial relationship with said bead to the free poles of said sources, and a connection from the junction of said resistor and said bead to said input circuit.

4. The combination in claim 3 with a source of a third voltage, a load, and a second bead of said thermistor controlled by said heating element so that the ratio of the admittances of said two beads is substantially constant connected from the source of said third voltage to said load.

5. The combination in claim 3 with a unilaterally conductive device in series with said heating element, a second amplifier having a second input and a second output circuit, a source of a third voltage, a second resistor, a second bead of said thermistor, said source of a third voltage, second resistor and second bead being connected in serial relationship across said second output circuit, and a connection from the junction of said second resistor and second bead to said second input circuit.

6. A first amplifier having an input and an output circuit, a unilaterally conductive device, a thermistor having a heater connected in serial relationship with said device across said output circuit and two beads, two sources of unidirectional voltages of opposite polarity, a first resistor connected in serial relationship with one of said beads to the free poles of said sources, a connec-

tion from the junction of said resistor and bead to said input circuit, a second amplifier having a second input and second output circuit, a third source of voltage, a second resistor, said third source, second resistor and second bead being connected in serial relationship across said second output circuit, and a connection from the junction of said second resistor and bead to said second input circuit.

7. The combination in claim 6 in which said second resistor is connected from said second output circuit to said second input circuit.

8. A first amplifier having an input and an output circuit, a thermistor having a heater connected across said output circuit and two beads, two sources of unidirectional voltages of opposite polarity, a resistor connected in serial relationship with one of said beads to the free poles of said sources, a connection from the junction of said resistor and bead to said input circuit, a first source of signal voltage, a second resistor connected from said first source of signal voltage to said input circuit, a second amplifier having an input and an output circuit, a second source of signal voltage, a third resistor connected in serial relationship with the second bead of said thermistor and said second source of signal voltage across said second output circuit, the junction of said third resistor and bead being connected to said second input circuit, a third amplifier having an input and an output circuit, a fourth resistor connected from the output to the input circuit of said third amplifier, a fifth resistor connected from the output circuit of said second amplifier to the input circuit of said third amplifier, and a sixth resistor connected from said second source of signal voltage to the input circuit of said third amplifier.

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