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2,764,731

THERMISTOR NETWORK

Filed May 6, 1953

FIG. 1

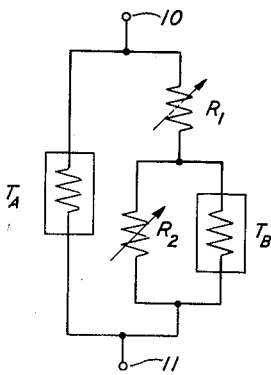


FIG. 2

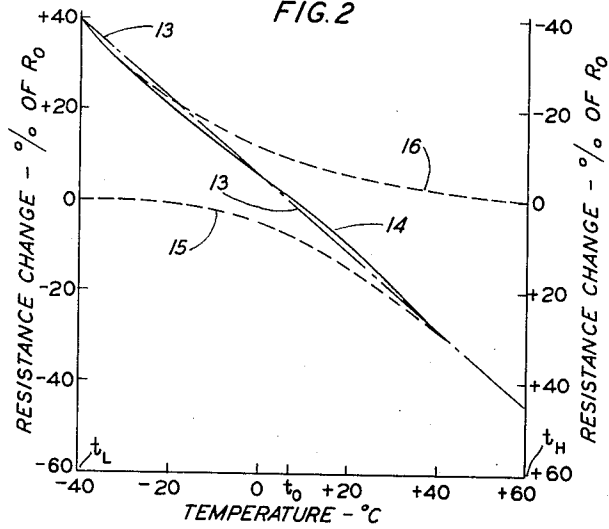


FIG. 5

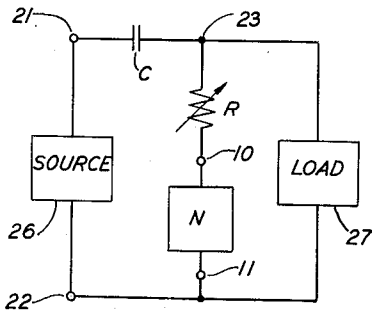


FIG. 4

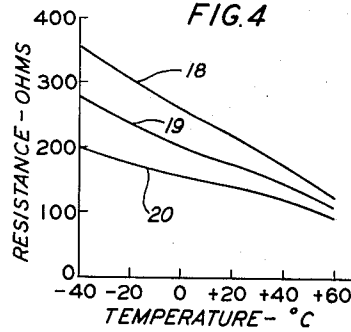


FIG. 3

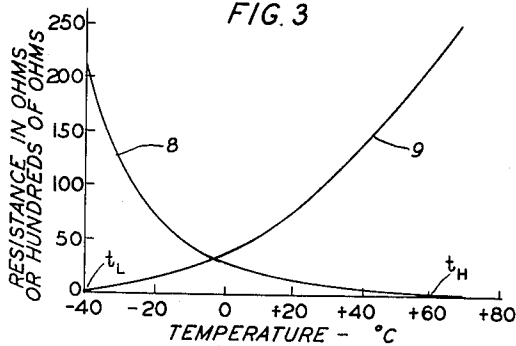
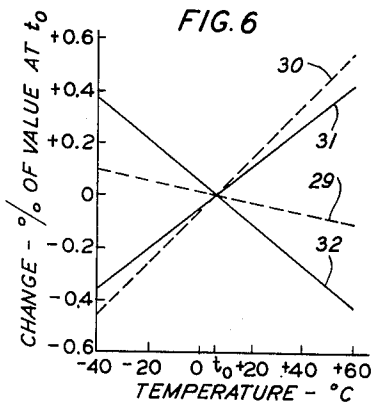


FIG. 6



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THERMISTOR NETWORK

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5 Claims. (Cl. 323—69)

This invention relates to wave transmission networks and more particularly to means for compensating for impedance variation with temperature in such networks.

An object of the invention is to provide an impedance branch the resistance of which has a prescribed temperature characteristic.

Another object is to provide an impedance branch the resistance of which has a uniform negative or positive slope with increasing temperature.

A further object is to compensate for the variation of impedance with temperature in electrical networks.

Another object is to extend the temperature range over which impedance compensation may be provided in a network.

Still another object of the invention is to compensate the time constant of a resistance-capacitance network over a range of temperatures.

In electrical networks such, for example, as wave transmission networks, the impedance of a component branch often exhibits such a large variation over the range of operating temperatures that compensation is required. In accordance with the present invention, such compensation is provided over an extended temperature range by a two-terminal network comprising a plurality of thermistors, which may have either positive or negative temperature coefficients, and a plurality of resistors, either fixed or adjustable.

In the embodiment of the network shown, a first thermistor is connected in parallel with a branch comprising a first resistor in series with an impedance consisting of a second resistor and a second thermistor in parallel. The first thermistor is principally effective at one end of the temperature range and the second thermistor has its greatest effect at the other end of the range. The resistance of the network may be designed to have any of a large variety of preselected temperature characteristics. If, for example, the resistance of the network is to have a generally negative slope with increasing temperature, thermistors with negative temperature coefficients are used, the first thermistor has a resistance which is high compared to the sum of the resistance of the resistors at the lower end of the temperature range, and the second thermistor has a resistance which is low compared to the resistance of its shunting resistor at the upper end of the range. For a network with a generally positive slope, on the other hand, the thermistors have positive coefficients, the resistance of the first thermistor is high compared to the sum of the two resistances at the upper end of the range, and the resistance of the second thermistor is low compared to the shunting resistance at the lower end of the range. If desired, the slope, either negative or positive, may be made substantially constant over the operating temperature range.

As an example, there is disclosed the application of the invention to a network in order to compensate the time constant thereof over an extended range of temperatures. The network is of the ladder type comprising the series combination of a resistor of value R and a

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capacitor of value C , in which the time constant RC varies with temperature. A two-terminal impedance of the type described above is added in series with the resistor, and the resistance of the added impedance is designed to make the time constant of the entire combination substantially constant throughout a preselected temperature range.

The nature of the invention and its various objects, features, and advantages will appear more fully in the following detailed description of preferred embodiments illustrated in the accompanying drawing, of which

Fig. 1 is a schematic circuit of a two-terminal thermistor network in accordance with the invention;

Fig. 2 presents typical curves showing the percentage change in resistance versus temperature for the network of Fig. 1 and for portions thereof;

Fig. 3 shows typical resistance versus temperature characteristics of thermistors suitable for use in the network of Fig. 1;

Fig. 4 shows how the resistance versus temperature characteristic of a network of the type shown in Fig. 1 having a negative slope varies with changes in the values of the resistances R_1 and R_2 ;

Fig. 5 is a schematic circuit of a ladder-type resistance-capacitance network to which a thermistor network has been added in accordance with the invention to compensate its time constant over a range of temperatures; and

Fig. 6 presents typical curves showing the percentage change versus temperature for the resistance R and the capacitance C used in the network of Fig. 5.

Taking up the figures in greater detail, the thermistor network in accordance with the invention shown in Fig. 1 comprises two thermistors T_A and T_B and two resistors R_1 and R_2 , designated by their resistances, connected between a pair of terminals 10 and 11. The thermistor T_A is paralleled by a branch comprising R_1 in series with an impedance consisting of R_2 and T_B in parallel. The resistors may be made adjustable, as indicated by the arrows, to permit an adjustment of the network characteristic.

The network may be designed to have a variety of useful resistance versus temperature characteristics which depend upon the choice of the component elements. It is especially adapted to provide a resistance characteristic having a substantially constant slope, either positive or negative, over an extended range of temperatures. The dot-and-dash curve 13 of Fig. 2 shows, for example, a typical desired characteristic having a negative slope. Using the left ordinate scale, the percentage change in the resistance of the network from its nominal value R_0 at a selected reference temperature t_0 is plotted against the ambient temperature in degrees centigrade. The curve is a straight line extending from +37.9 per cent at -40 degrees to -44.6 per cent at +60 degrees for a total change of 82.5 per cent, with t_0 at +6 degrees.

There will now be presented an example of how to design the network of Fig. 1 to simulate the curve 13 of Fig. 2 when the left ordinate scale is read. It will be assumed that R_0 is 200 ohms. The desired resistance R_L of the network at -40 degrees will, therefore, be 275.8 ohms and the desired resistance R_H at +60 degrees will be 110.8 ohms, giving a difference of 165 ohms at the two temperatures. It will also be assumed that the changes in the resistances R_1 and R_2 over the temperature range of interest are small enough to be neglected.

First, thermistors T_A and T_B having negative temperature coefficients are selected. In order to obtain the desired characteristics, the resistance R_{AL} of the thermistor T_A at a temperature t_L , near the low end of the range should be high compared to the sum of R_1 and R_2 , and the resistance R_{BH} of the thermistor T_B at a temperature

t_H near the high end of the range should be low compared to R_2 . With these relationships, the elements T_A and R_1 chiefly determine the characteristic of the network over the high portion of the temperature range, whereas T_B , R_1 , and R_2 have their greatest effect over the low portion. The curve 8 of Fig. 3 shows resistance versus temperature characteristics of thermistors suitable for use as the elements T_A and T_B . The ordinate scale represents ohms for T_B and hundreds of ohms for T_A . Only one curve is shown because, for this particular example, it was found satisfactory for the resistance of T_A to be a hundred times that of T_B throughout the temperature range of interest. It is to be understood, of course, that other ratios of thermistor resistance may be required if other conditions are to be satisfied.

The resistances of the elements T_A and T_B at any temperature are thus known. This leaves only the elements R_1 and R_2 to be determined. Their values may be so chosen that the characteristic of the network matches the desired curve 13 at any two selected temperatures such, for example, as t_L and t_H . The resistances R_1 and R_2 may be adjusted alternately until the required values are found by trial. Alternatively, their values may be found by setting up two independent equations and solving them simultaneously. For a match at the temperatures t_L and t_H , these expressions are

$$R_L = \frac{R_{AL} \left[R_1 + \frac{R_2 R_{BL}}{R_2 + R_{BL}} \right]}{R_{AL} + R_1 + \frac{R_2 R_{BL}}{R_2 + R_{BL}}} \quad (1)$$

and

$$R_H = \frac{R_{AH} \left[R_1 + \frac{R_2 R_{BH}}{R_2 + R_{BH}} \right]}{R_{AH} + R_1 + \frac{R_2 R_{BH}}{R_2 + R_{BH}}} \quad (2)$$

where R_L is the resistance of the network, R_{AL} is the resistance of T_A , and R_{BL} is the resistance of T_B , all at the first selected temperature t_L and R_H is the resistance of the network, R_{AH} is the resistance of T_A , and R_{BH} is the resistance of T_B , all at the second selected temperature t_H . If, for example, t_L is chosen at -40 degrees and t_H as $+60$ degrees, the corresponding values of R_L and R_H have already been given as 275.8 ohms and 110.8 ohms, respectively. From the curve 8 of Fig. 3 the values of R_{AL} , R_{BL} , R_{AH} , and R_{BH} in ohms are found to be, respectively, 21,500, 215, 300, and 3. By substituting these values in Equations 1 and 2 and solving, the required values of R_1 and R_2 are found to be 173 ohms and 185 ohms, respectively.

The solid-line curve 14 of Fig. 2, reading the left ordinate scale, shows the characteristic obtainable with a network designed as explained above. It is seen that the curves 13 and 14 coincide at -40 degrees and at $+60$ degrees and that the one follows the other quite closely over the entire temperature range. The match might, in some cases, be improved by choosing the matching-point temperatures t_L and t_H farther within the range instead of at the ends thereof. For example, t_L might be taken as -20 degrees and t_H as $+40$ degrees. This would improve the match over the central portion of the range at the expense of a slight impairment at the ends.

The broken-line curves 15 and 16 of Fig. 2, using the left ordinate scale, are included to show the type of match obtainable if only a single thermistor is employed. If the network consisted only of T_A and R_1 , the characteristic 15 would result. This gives a good match in the upper portion of the range but a poor one at lower temperatures. The curve 16 shows the resulting characteristic if the network is constituted by only R_1 , R_2 , and T_B . In this case, the match is good in the lower part of the range but bad in the upper part. From a comparison of these characteristics with curve 14, it is apparent that the two-thermistor network of Fig. 1 greatly extends the

temperature range over which a good match may be obtained.

The resistance versus temperature characteristics of Fig. 4 show how, in the example just presented, the magnitude of the slope may be changed, while remaining substantially constant over the range, by changing the values of R_1 and R_2 while retaining the same thermistors T_A and T_B . For the curve 18, the values of R_1 and R_2 in ohms are 250 and 155, respectively, for the curve 19 they are 176 and 187, and for the curve 20 they are 150 and 72.

As mentioned above, the network of Fig. 1 may, if desired, be designed to have a substantially constant positive slope over the temperature range from t_L to t_H . In this case, the thermistors T_A and T_B will have positive temperature coefficients, the resistance of T_A will be high compared to the sum of R_1 and R_2 at t_H , and the resistance of T_B will be low compared to R_2 at t_L . For a second illustrative example it will be assumed that the desired resistance characteristic of the network has the constant positive slope shown by the curve 13 of Fig. 2 when the right ordinate scale is used. It will be noted that this scale is the same as the one shown on the left except that it is inverted. The desired value of R_L at -40 degrees is 110.8 ohms, and that of R_H at $+60$ degrees is 275.8 ohms. Thermistors having the temperature characteristics shown by the curve 9 of Fig. 3 are found to be suitable. For T_A , the ordinate scale represents ohms, and for T_B it represents hundreds of ohms. From curve 9 the values of R_{AL} , R_{BL} , R_{AH} , and R_{BH} in ohms are, respectively, 215, 21,500, 3, and 300. When these values are substituted in Equations 1 and 2 and the equations are solved, the required values of the resistances R_1 and R_2 are found to be 226 ohms and 65 ohms, respectively. The match obtained with the network thus designed is of the same order as that between the curves 13 and 14 of Fig. 2.

Fig. 5 shows schematically how the invention may be applied to a ladder-type, resistance-capacitance network to compensate the time constant over a range of temperatures. The network comprises a pair of input terminals 21 and 22 between which is connected the series combination of a capacitor designated by its capacitance C , a resistor designated by its resistance R , and a compensating network N which may be of the type shown in Fig. 1. The resistor R may conveniently be made adjustable, as indicated by the arrow. If R is adjusted, it may also be necessary to adjust the resistances R_1 and R_2 in N . A source of voltage 26 is shown connected to the input terminals. The load 27 may be connected between the terminal 22 and the common terminal 23 of C and R , as shown. In this case, C constitutes a series impedance branch of the network, and R and N form a shunt impedance branch thereof. Alternatively, the load 27 may be connected between the terminals 21 and 23, so that R and N are in the series branch and C in the shunt branch.

It will be assumed that it is desired to keep the time constant, which is the product RC , constant over the temperature range from -40 degrees to $+60$ degrees centigrade. The valid assumption is also made that the value of C decreases linearly and the value of R increases linearly over this range, as shown by the broken-line curves 29 and 30, respectively, of Fig. 6. As compared with its value at the reference temperature t_0 , which is $+6$ degrees, the capacitance C is 0.10 per cent higher at -40 degrees and 0.117 per cent lower at $+60$ degrees. On a like basis, the resistance R is 0.47 per cent lower at -40 degrees and 0.57 per cent higher at $+60$ degrees. The solid-line curve 31 gives the percentage change in the product RC . It is found by adding algebraically the ordinates of the curves 29 and 30 at each temperature, giving a straight line extending from -0.379 per cent at -40 degrees to $+0.446$ per cent at $+60$ degrees.

The function of the network N is to compensate the deviation curve 31. Its required characteristic is given by the curve 32, which passes through the point t_0 and

has the same slope as the curve 31 except that it is negative instead of positive. The curve 32, therefore, is a straight line extending from +0.379 per cent at -40 degrees to -0.446 per cent at +60 degrees. Now, for example, if the resistance R has a value of 20,000 ohms at +6 degrees, its value at -40 degrees will be 75.8 ohms higher, and 89.2 ohms lower at +60 degrees, giving a difference of 165 ohms. The first example of the thermistor network of Fig. 1 worked out above, having the characteristic shown by the negative slope curve 14 of Fig. 2, is adapted to compensate for this variation in resistance, as it was designed to have a difference of 165 ohms at the temperature of -40 degrees and +60 degrees. The addition of the network N will increase the resistance of the branch comprising R and N by 200 ohms at +6 degrees, but this may readily be taken into account in choosing or adjusting the value of R. There is thus provided a network with a time constant which is constant within very close limits over the considerable temperature range from -40 degrees to +60 degrees.

The resistance-capacitance network with compensated time constant shown in Fig. 5 may, for example, be used in a plate-coupled, single-cycle multivibrator of the type shown in Fig. 9-1b on page 320 of the book by Von Tersch and Swago entitled "Recurrent Electrical Transients," published by Prentice-Hall, Inc., New York. In that figure, the elements corresponding to the capacitor C and the resistor R are designated, respectively C_c and R_{g2}, the voltage source is the plate circuit of the tube T₁, and the load is the grid circuit of the tube T₂. The length of the operating cycle depends upon the effective time constant of the elements C_c and R_{g2}. In order to keep the period of the cycle constant over a range of temperatures, a compensating impedance of the type shown between the terminals 10 and 11 in Fig. 1 of the present application may be connected in series with the resistance R_{g2}. In this way, the stability of the multivibrator with temperature changes is greatly improved.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A network comprising a first thermistor in parallel with a branch comprising a first resistor in series with an impedance consisting of a second resistor and a second thermistor in parallel, the resistance of said first thermistor being high compared to the sum of the resistances of said resistors at a first selected temperature and the resistance of said second thermistor being low compared to the resistance of said second resistor at a second selected temperature.

2. In combination, a network in accordance with claim 1, a resistor of resistance R, and a capacitor of capacitance C all connected in series, the product of R and C

varying with temperature, and the component thermistors and resistors in said network being so selected and proportioned that the time constant of said combination is approximately constant throughout the range between said temperatures.

3. A network having a selected resistance R_L at a first selected temperature and a different selected resistance R_H at a second selected temperature, said network comprising a first thermistor in parallel with a branch comprising a first resistor of resistance R₁ in series with an impedance consisting of a second resistor of resistance R₂ and a second thermistor in parallel, said resistances having values which approximately satisfy the expressions

$$R_L = \frac{R_{AL} \left[R_1 + \frac{R_2 R_{BL}}{R_2 + R_{BL}} \right]}{R_{AL} + R_1 + \frac{R_2 R_{BL}}{R_2 + R_{BL}}}$$

and

$$R_H = \frac{R_{AH} \left[R_1 + \frac{R_2 R_{BH}}{R_2 + R_{BH}} \right]}{R_{AH} + R_1 + \frac{R_2 R_{BH}}{R_2 + R_{BH}}}$$

where R_{AL} is the resistance of said first thermistor and R_{BL} the resistance of said second thermistor at said first temperature, and R_{AH} is the resistance of said first thermistor and R_{BH} the resistance of said second thermistor at said second temperature.

4. In combination, a network in accordance with claim 3, a resistor of resistance R, and a capacitor of capacitance C all connected in series, the product of R and C varying with temperature, and said resistances R_L and R_H being so chosen that the time constant of said combination is approximately constant throughout the range between said temperatures.

5. A network comprising a first thermistor in parallel with a branch comprising a first resistor in series with an impedance consisting of a second resistor and a second thermistor in parallel, the resistance of said first thermistor being high compared to the sum of the resistances of said resistors at a first selected temperature, the resistance of said second thermistor being low compared to the resistance of said second resistor at a second selected temperature, and the resistances of said resistors being so chosen that said network has a preselected resistance at said first temperature and a different preselected resistance at said second temperature.

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