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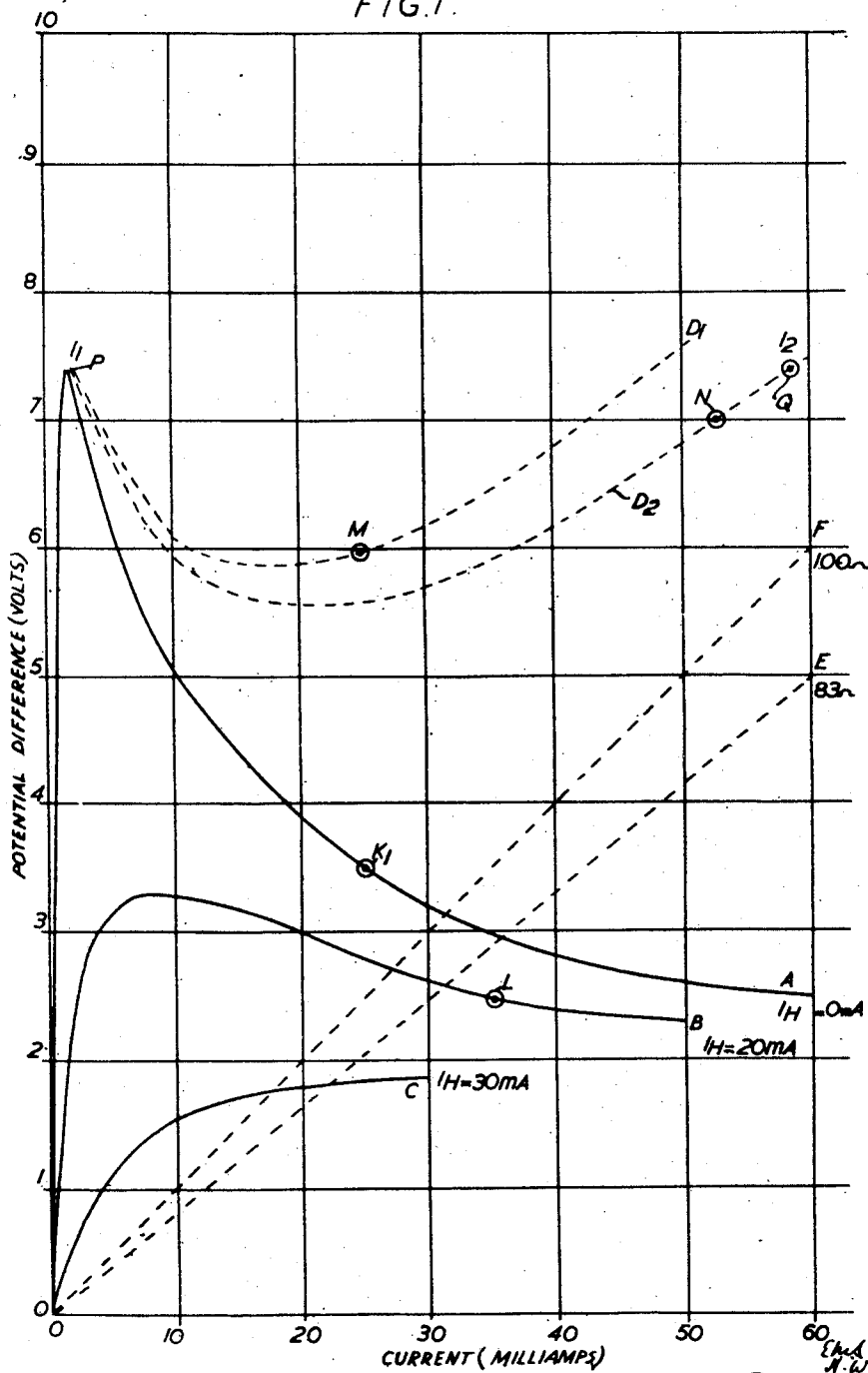
2,423,107

THERMISTOR CONTROLLED RELAY CIRCUITS

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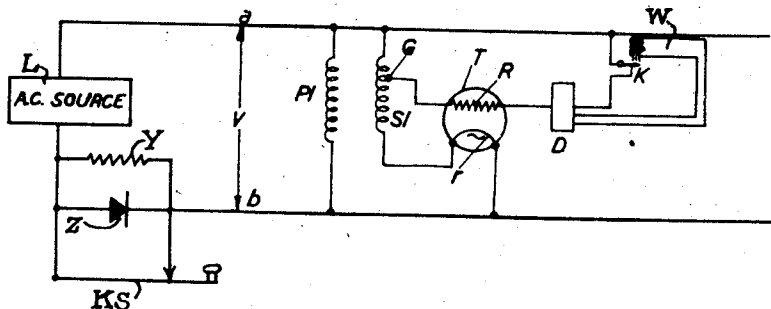
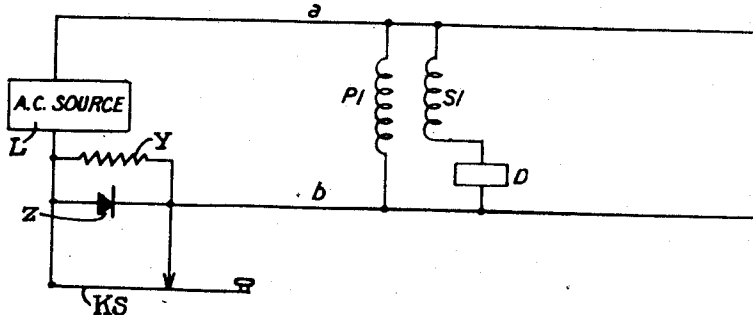
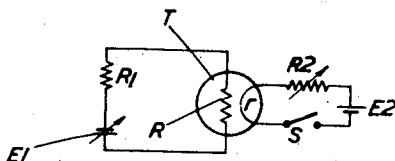
FIG. 1.



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THERMISTOR CONTROLLED RELAY
CIRCUITS

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The present invention relates to electrical relay circuits for receiving signals, and makes use of the special properties of thermally sensitive resistance devices known as thermistors, and in particular, those having a negative temperature coefficient of resistance.

Thermistors have been in use for some years and are characterised by a temperature coefficient of resistance which may be either positive or negative and which is moreover many times the corresponding coefficient for a pure metal such as copper. This property renders thermistors particularly suitable for a variety of special applications in electric circuits.

Various different materials are available for the resistance element of a thermistor, these various materials having different properties in other respects; as one example, a resistance material having a high negative temperature coefficient of resistance comprises a mixture of manganese oxide and nickel oxide, with or without the addition of certain other metallic oxides, the mixture being suitably heat treated.

Thermistors have been employed in two different forms: (a) known as a directly heated thermistor and comprising a resistance element of the thermally sensitive resistance material provided with suitable lead-out conductors or terminals, and (b) known as an indirectly heated thermistor comprising the element (a) provided in addition with a heating coil electrically insulated from the element. A directly heated thermistor is primarily intended to be controlled by the current which flows through it and which varies the temperature and also the resistance accordingly. Such a thermistor will also be affected by the temperature of its surroundings and may therefore be used for thermostatic control and like purposes with or without direct heating by the current flowing through it. An indirectly heated thermistor is chiefly designed to be heated by a controlling current which flows through the heating coil and which will usually, but not necessarily, be different from the current which flows through the resistance element, but this type of thermistor may also be subjected to either or both of the types of control applicable to a directly heated thermistor.

More detailed information on the properties of thermistors will be found in an article by G. L. Pearson in the Bell Laboratories' Record, Dec. 1940, page 106.

In signal receiving arrangements, it is usually desired that a signal shall operate apparatus requiring considerably more power than is con-

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tained in the signal itself. One very well known way of achieving this result is to cause the signal to operate a sensitive relay which in turn controls the power necessary for the apparatus.

In certain cases it is found that a suitably sensitive relay which meets other conditions such as reliability and robustness is difficult to provide or maintain in adjustment in practice. The present invention makes use of a thermistor having a negative temperature coefficient of resistance to which is applied the low power signal, and may be made to control a much larger power than is contained in the signals; the thermistor takes the place of the sensitive relay, but there are no mechanical moving parts and nothing to maintain or adjust, and there are no cumbersome high tension supplies such as are needed for thermionic valve amplifiers.

According to the invention, there is provided a receiving circuit for electrical signals comprising a thermistor having a negative temperature coefficient of resistance, the resistance element of which is connected in series with a constant resistance and a local source of electromotive force, the current through the resistance element being adjusted so that the operating point is on that part of the current-voltage characteristic curve having a positive slope, and means for applying the incoming signal power to raise the temperature of the thermistor, whereby the operating point is transferred over the critical point on to that part of the curve having a negative slope.

According to another aspect, the invention comprises a receiving circuit for electrical signals comprising a thermistor resistance element connected in series with a constant resistance and a source of electromotive force, and means for applying a signal of low power to the thermistor in such manner that it produces an increase in the electric power absorbed by the constant resistance, which increase is much greater than the signal power, the thermistor having a negative temperature coefficient of resistance.

The invention will be more clearly understood from the following detailed description and by reference to the accompanying drawings in which:

Fig. 1 shows characteristic curves of a thermistor;

Fig. 2 shows a schematic circuit diagram of one arrangement according to the invention;

Fig. 3 shows a schematic circuit diagram of a receiving arrangement suitable for application of the invention, and

Fig. 4 shows the application of the invention to Fig. 3.

Fig. 1 shows a typical family of curves for a certain indirectly heated thermistor having a negative temperature coefficient of resistance, the resistance cold being about 13,000 ohms. The abscissae represent the currents which flow through the resistance element of the thermistor, and the ordinates represent the potential differences across it. The curve A is the characteristic obtained with no current in the heating coil, and curves B and C are the characteristics obtained with currents of 20 and 30 milliamperes flowing through the heating coil, respectively.

It will be noted from curve A that as the current through the element is increased, the voltage across it rises very steeply to a maximum value of about 7.4 volts for a current I_1 of about 2 milliamperes at the point P, and then falls quite rapidly at first and then less rapidly as the current is increased.

The part of the characteristic beyond the point P where the curve has a negative slope, represents an unstable condition and the element behaves in some respects like a negative resistance, because an increase in current produces a decrease in the potential difference. There are two possible values of current corresponding to any given voltage drop, the lower of which is stable and the other unstable. If, therefore, the voltage applied to a thermistor be gradually increased, as soon as the maximum value corresponding to the point P has been passed the current will proceed to increase indefinitely until the thermistor is destroyed, or some other factor operates to limit the current increase.

Curve B shows that by providing a current in the heating coil, the steepness of the unstable part of the characteristic may be reduced; while in curve C, the negative slope has disappeared. It will be evident that as the power capacity of the thermistor is limited, curves B and C cannot be safely taken so far as curve A.

The unstable part of the characteristic can be brought under control and employed to advantage, according to the invention. Fig. 2 shows an indirectly heated thermistor T with its resistance element having a resistance R connected in series with an ordinary constant resistance R_1 and an adjustable source of electromotive force E_1 . The heating coil of T has an approximately constant resistance r which is connected in series with another source of electromotive force E_2 and an adjustable constant resistance R_2 , a switch S being included in the circuit.

To simplify the explanation it will be assumed that the adjustable source E_1 presents a constant resistance to the circuit, this resistance being included with R_1 . Such a condition is easily met with the help of a constant resistance attenuator, for example. The switch S will first be assumed to be open as shown.

The dotted curve D_2 shows the characteristic for the circuit of Fig. 2, the constant resistance R_1 being taken as 83 ohms. The characteristic for this resistance alone will be the dotted straight line E shown in Fig. 1. By adding the ordinates of the curves A and E, the characteristic D_2 is obtained, giving the relation between the voltage and the current for the circuit of Fig. 2. The curve D_2 is scarcely distinguishable from A up to the point P, but thereafter it falls less steeply and after reaching a minimum at about 5.5 volts it rises again. It will be noted that 7.4 volts is

again reached on the curve D_2 for a current I_2 of about 58 milliamperes. If therefore the electromotive force E_1 be increased from zero up to 7.4 volts, the current will increase steadily up to 2 milliamps after which it will quickly rise to 58 milliamps corresponding to the point Q where the voltage is again 7.4. The point Q is, of course, stable because the right hand slope of the curve D_2 is positive. It will be noted that the power absorbed by the thermistor at the critical point P is nearly 15 milliwatts.

This property of the circuit of Fig. 2 will be recognized as very similar to that of the well known gas-discharge triode valve in which a discharge is initiated by a certain critical voltage, producing a relatively large plate current. The circuit therefore is applicable to the same kind of uses where a trigger action is desired, but is simpler since it does not require a high tension source or filament heating means.

The heating coil circuit shown in Fig. 2 is optional and is provided as a means of controlling the characteristic of the thermistor. If the switch S be closed, the resistance R_2 may be adjusted so that a curve such as B in Fig. 1 may be employed instead of A. This enables the value of the critical voltage to be varied, and the arrangement is obviously adaptable to remote control of the thermistor.

One class of application for the circuit of Fig. 2 is that in which a small incoming signal is required to control a large current, for example to operate a relatively heavy switch. Thus if the curve D_2 is employed, the electromotive force E_1 could be adjusted to, say, 7 volts and a signal of $\frac{1}{2}$ volt applied in series with E_1 would be sufficient to raise the voltage above the critical value, after which a current of about 52 milliamps (point N on curve D_2) would be obtained, assuming that the signal does not persist.

The heating coil circuit shown in Fig. 2 could be conveniently used to adjust the operation of the arrangement in accordance with the incoming signals, and to stop its operation when desired. Thus, for example, by adjusting R_2 with the switch S closed so that some curve intermediate between A and B is used, the circuit could be made just to operate satisfactorily with the incoming signals. If the switch S were then opened, the critical voltage would be raised to 7.4 volts and the signals would be unable to operate the circuit. On closing S again, the circuit would work as before.

It will be evident, of course, that if repeated operation by a train of signals is required, it will be necessary to provide means for periodically interrupting the current through the thermistor to allow it to cool, for restoring the circuit to the unoperated condition. This is, of course, a usual requirement with circuits of this type and any of the well known arrangements which are suitable may be used.

Referring again to Figs. 1 and 2, the choice of the resistance R_1 will be guided by the current required when the circuit has operated. By choosing a larger value of R_1 , the curve E will be rotated anticlockwise about the origin and the right hand slope of the curve D_2 will be steepened. Accordingly the higher current I_2 corresponding to 7.4 volts will be reduced. The value 83 ohms chosen for the curve E is nearly the lowest allowable on the assumption that the current through the thermistor should not exceed 60 milliamps. Thus suppose I_2 is to be 25 milliamps for 6 volts, as indicated by the point M, the

line E must be rotated so that a new curve D₁ passing through M is obtained; in other words to increase the ordinate at 25 milliamperes by about 0.4 volt. Thus the dotted line F is obtained, corresponding to a new value of about 100 ohms for R₁.

The circuit of Fig. 2 may be operated in a different way; the incoming signal may be introduced into the heating coil circuit instead of into the circuit containing the resistance element R. Thus suppose that the voltage E₁ is 7 volts and resistance R₁ is 83 ohms, the operating point will be on the stable side of the curve A, Fig. 1, the switch S, Fig. 2 being open. The power heating the thermistor will be a little less than 10 milliwatts. Thus by closing switch S and supplying say 6 milliwatts to the heating coil from the source E₂ the temperature of the thermistor will be raised sufficiently to take it over the critical point P and the current will rise to about 52.5 milliamperes at the point N, assuming that the signal does not persist. If the resistance R₁ is a relay, for example, the power operating it will be about 230 milliwatts, and this has been made available by an incoming signal power of only 6 milliwatts, corresponding to a gain of nearly 16 decibels.

It will, of course, be necessary to provide means for opening the circuit of R to reset the arrangement after the relay or other apparatus has been operated.

It will be understood that although the curves of Fig. 1 and their applications have been discussed in numerical terms in order that the invention may be clearly understood, it is not confined to the particular values which have been used. All thermistors having negative temperature coefficients have characteristic curves which have the same general form as those shown in Fig. 1, but their actual resistance values and the critical voltage and other details can be given almost unlimited choice.

It will be clear that if in the case of Fig. 2 it is not desired to employ the heating coil circuit, the thermistor T may be replaced by a directly heated thermistor and the curves A and D will still apply in principle if not with the same numerical values.

A specific application of the invention lies in an improvement to the invention described in U. S. patent specification No. 2,287,164. This specification describes a method of signalling with direct current over an alternating power supply system for carrying out switching operations and the like. By operating a key KS, at a transmitting point, a small continuous potential is superposed on the supply wires and operates a direct current relay at one or more receiving points. The relay is bridged across the line by means of a circuit which prevents any appreciable alternating current from flowing through the relay. The key KS acts upon depression to insert between an alternating current source L and the line, a rectifier Z, shunted by a resistance Y.

It has, however, been found that in some older power systems the resistance of the supply circuit may be abnormally high and accordingly it has been found difficult to obtain sufficiently sensitive relays which are at the same time reliable and robust. By using a thermistor in the manner explained above, a relatively insensitive relay may be used, its operation being controlled by the direct current through the thermistor heating coil.

Fig. 3 is copied from Fig. 3 of the above

quoted specification and shows a preferred form of the arrangement at a receiving point. The primary winding P₁ of a transformer is bridged across the supply circuit wires a and b and the secondary winding S₁ is connected across the wires in series with the winding of a relay D. The transformer windings and the resistance of the relay are so proportioned and arranged as explained in the quoted specification that substantially no alternating current flows through the relay. This may be done by making the resistance of the primary winding low and the inductance of the primary winding substantially equal to the mutual inductance of the primary and secondary windings.

Fig. 4 shows the modification of Fig. 3 according to the present invention. In order to explain clearly the operation of the invention specific numerical values will again be used, but it is to be understood that these will be only typical, and the circuit can be adapted for any desired conditions.

When the key at the transmitting point on the power system is operated, a continuous voltage V (Fig. 4) of about 4 volts or more will normally be expected at the receiving point. As already explained, however, in some cases the normal minimum voltage may not be actually obtained. The secondary winding S₁ may have a resistance of 100 ohms and is connected in series with the heating coil r of a thermistor T, the resistance r being also conveniently 100 ohms. The relay D, also assumed to have a resistance of 100 ohms, is connected in series with the resistance element R of the thermistor to a tapping point G on S₁ and through a normally closed pair of contacts K to the wire a. The voltage obtained from G will be taken as 6 volts, the relay being, of course, designed for operation on alternating current.

Before the voltage V is applied, the thermistor is cold and the value of R will be very high. It is found that with the conditions assumed above a thermistor having the characteristic curve A of Fig. 1 is suitable. With 6 volts applied it will be seen that the current flowing will be about 1 milliamp, and the resistance R will be about 6000 ohms. The resistance of D will accordingly be negligible compared with this, and the relay will be assumed to be unaffected by such a small current.

On applying 4 volts continuous potential to the wires a and b, 2 volts will appear across the heating coil r, and since its resistance is 100 ohms, the current flowing through it will be 20 milliamperes, and the curve B (Fig. 1) will then apply. The maximum of this curve is well below 6 volts, and the current through the relay will thus increase to about 35 milliamperes (point L) where the voltage across the thermistor is 2.5, its resistance being about 70 ohms; the remaining 3.5 volts being taken up in the resistance of the relay D (100 ohms). The relay can be designed to operate on this current. When the applied voltage is removed, the curve A will again hold, and the current will fall to about 25 milliamperes (point K₁ on curve A), the resistance of the thermistor rising to about 140 ohms.

The curve D₁ will apply for the complete circuit, the current for 6 volts being given by the point M, namely 25 milliamperes as already explained.

According to well known practice, the relay D may be designed to release or to remain operated as may be desired after the current is reduced in this way. It is assumed that the relay

has contacts (not shown) which perform some series of operations. The contacts K shown in Fig. 4 are supposed to be attached to some relay which operates during the desired switching process, or after it is completed. This relay is intended to open contacts K to disconnect the thermistor so that it may be allowed to cool, for restoring the circuit to normal. Various arrangements for doing this are possible and will be readily contrived by those skilled in the art when the nature of the switching operation is specified. For example electromagnet W may be connected to relay D and be energized so as to open key K.

It is again emphasized that the numerical values which have been used in this specification as illustrations are not intended to limit the invention, which makes use of the special properties of thermistors having a negative temperature coefficient of resistance as typified by the curves shown in Fig. 1. Other values suitable to any other circumstances may be chosen, within a wide range.

It will be evident also, that although the embodiment described in Fig. 4 is concerned with signalling over a power supply circuit for performing switching operations at a distant point, the invention would be applicable also to a receiving arrangement for direct or alternating current signals transmitted over a system of much more general type. The essential characteristic is that the arrangement described operates by a trigger action, so that an incoming signal of low power is able to control a much larger power for operating apparatus which the signal by itself would be unable to operate.

What is claimed is:

1. A receiving circuit for receiving direct current signals transmitted over an alternating current supply system including a transformer having a primary winding connected across the supply wires of said system and a secondary winding, an indirectly heated thermistor including a heating coil, means connecting said secondary winding and said heating coil in series across said supply wires, said primary, said secondary and said heating coil having such electrical constants as to draw little alternating current energy from said supply wires, a relay and means connecting said relay and the resistance element of said thermistor in series between one supply wire and a tap on said secondary, whereby said heating coil is heated by said direct current signals to cause changes in the degree of heating of said resistance element, thereby causing said relay to function.

2. Circuit according to claim 1, also including a key connected in series between said relay and one supply wire, and means for opening said key and thereby disconnecting said thermistor for restoring the circuit to normal after operation of said relay.

3. A receiving circuit for receiving direct current signals transmitted over an alternating current supply system including, a transformer having a primary winding connected across the supply wires of said system and a secondary winding, an indirectly heated thermistor having a variable resistance element and a heating element, said resistance element having the characteristic that the voltage drop across it varies

as the current flowing therethrough varies with said voltage drop reaching a relatively high peak at a relatively low current value when the temperature of the resistance element is low and said relatively high peak being relatively lower as the temperature of the resistance element is raised, whereby a predetermined voltage below the value of said relatively high peak will result in a relatively low current flow, means connecting said secondary winding and said heating element in series across said supply wires, said primary and secondary windings and their associated parts having such characteristics as to draw substantially no alternating current from said supply wires, a relay, and means connecting said relay and said resistance element in series between one of said supply wires and a tap on said secondary winding, whereby said resistance element remains substantially unheated prior to the receipt of a direct current signal and whereby a direct current signal flows through said heating element and heats said resistance element with the result that the voltage drop across said resistance element is reduced and an alternating current flows through said resistance element and said relay of sufficient value to operate said relay.

4. In a circuit for receiving direct current signals transmitted over an alternating current supply system in which a transformer has a primary winding and a tapped secondary winding connected in parallel across the supply lines of the system with the transformer and the circuits of the two windings having such electrical constants as to draw a relatively small amount of alternating current from said supply lines, an indirectly heated thermistor including a resistance element having a negative temperature-resistance coefficient and a heating element with the heating element connected in series with the secondary winding of the transformer, and a relay circuit including a relay and circuit means connecting the resistance element of said thermistor and the relay in series between one of said supply lines and a tap on said secondary winding, whereby said heating element is heated by the direct current signals to increase the temperature of said resistance element sufficiently to cause an increase in the current flow through said relay of such magnitude to operate said relay.

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