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Thermistor Applicator

By the Engineering Department, Aerovox Corporation

AS its name implies, the thermistor is a thermally-sensitive resistor. It is also a non-linear resistor. Although it is a 2-terminal semiconductor device, the thermistor is not a rectifier. It accordingly may be employed in either a-c or d-c circuits. Thermistors are manufactured in a number of shapes, principally beads, discs, and rods, and in various sizes including subminiature.

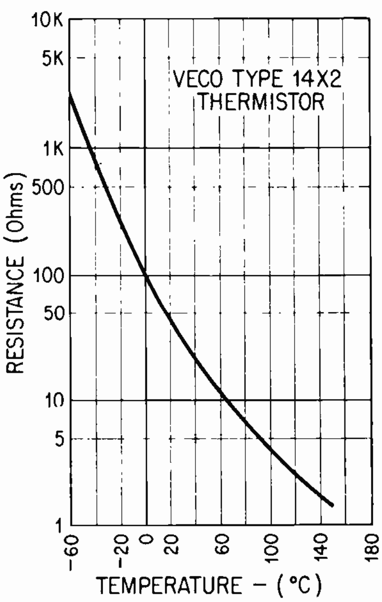
The basic property of the thermistor is its change of resistance with temperature. The temperature change affecting it may arise externally or it may result from current flowing through the thermistor. This property gives rise to the nonlinearity of the thermistor resistance characteristic.

Thermistor action may be employed in several ways to modify the behavior of electrical circuits. Many applications are rendered especially attractive by the simplicity of the thermistor and its compactness. A number of typical applications are described in this article.

Typical Characteristics

Figures 1, 2, and 3 illustrate typical thermistor characteristics.

Figure 1 displays the non-ohmic variation of resistance with temperature. From this curve, the resistance of this particular unit is seen to decrease over a range of approximately 2000 to 1 for a temperature increase from —60 to +150 degrees C.



THERMISTOR TEMPERATURE-RESISTANCE CHARACTERISTIC

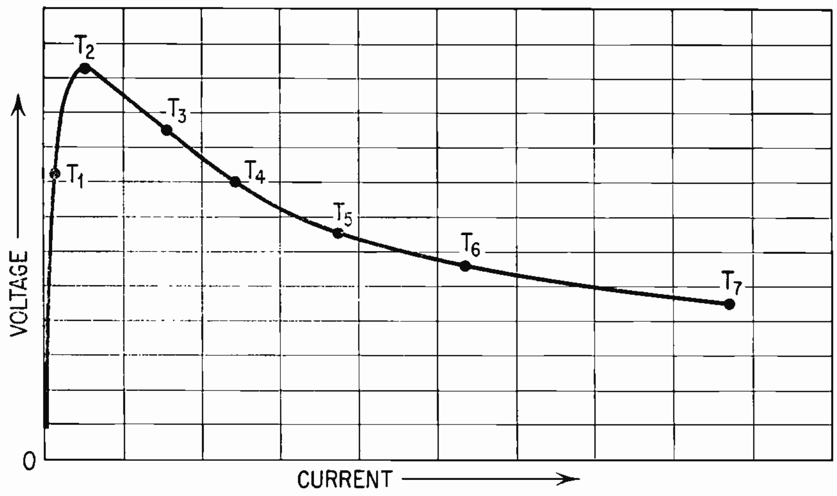
FIG. 1

Figure 2 shows the static EI characteristic of the thermistor. This plot reveals that as the current through the thermistor is increased, the voltage drop across this component first increases rapidly from zero to a peak (T_3) and then decreases with further increase in current, finally falling to point T_7. Thus, the thermistor shows positive resistance from zero to T_3, but negative resistance from T_3 to T_7. Points T_1 to T_7 on the curve represent temperature levels at those points resulting from internal heating in the thermistor due to current flow.

Thermal lag prevents the thermistor temperature from increasing instantaneously with initiation of current. A significant time interval thus elapses after application of voltage before the current through the thermistor reaches the magnitude expected from an examination of the voltage-vs-resistance characteristic. Figure 3 illustrates this time delay characteristic.

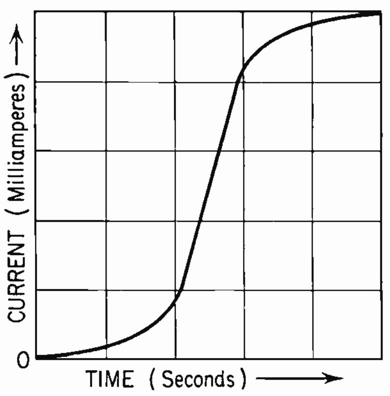
The slopes of the curves shown in Figures 1, 2, and 3 and the values of their coordinates will vary with thermistors of different types. However, the over-all configurations will remain substantially the same.

Each of the wide range of thermistor applications is based upon one of the characteristics illustrated by Figures 1, 2, and 3. These applica-



THERMISTOR VOLTAGE-CURRENT CHARACTERISTIC

FIG. 2



THERMISTOR CURRENT-TIME CHARACTERISTIC

FIG. 3

tions may be grouped further according to whether the thermistor is internally or externally heated (that is, whether by current flow or ambient temperature). The temperature dependence of the thermistor resistance has been utilized for the stabilization of circuit resistances in an environment of fluctuating temperature. Thus, thermistors have been employed to compensate indicating meters, fixed resistors, and balancing circuits; and, in the d-c bias net-works of transistor circuits, to stabilize operating points.

Illustrative Circuits

Figures 4 to 15 show representative thermistor circuits. These have been selected to illustrate the wide range of applications possible with thermally-sensitive resistors of this class.

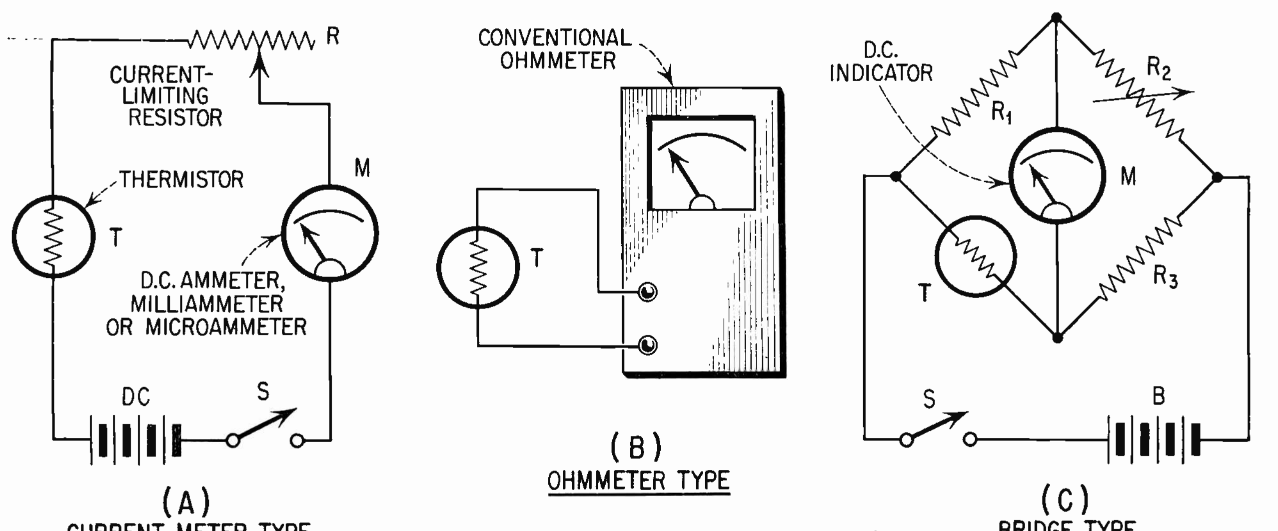
Temperature Measurement. The thermistor is applicable as a temperature sensing element of good sensitivity. In this connection, a small thermistor may be mounted in the nose of an exploring probe. Figure 4 shows several circuits for temperature measurement.

In Figure 4(A), the thermistor (T) is connected in series with a d-c source, adjustable current-limiting resistor (R), and a direct current meter (M). Reference to Figure 1 shows that, since the thermistor undergoes a large resistance change with temperature, meter M probably will be required to indicate amperes as well as milliamperes.

The meter may be set to zero, or to some other desired initial reading, by adjustment of R. As the temperature to which the thermistor is exposed rises, the meter deflection will increase. The deflection may be referred to a current-vs-temperature chart, or the meter scale may be graduated directly in degrees.

In Figure 4(B), a conventional d-c ohmmeter is employed to indicate the thermistor resistance as it changes with temperature. The meter deflection may be referred to a resistance-vs-temperature calibration or the instrument scale may be graduated directly in degrees on the basis of such a calibration.

Figure 4(C) shows one type of bridge circuit for checking temperature by measuring thermistor resistance. In this arrangement, the ther-



TEMPERATURE MEASUREMENT CIRCUITS

FIG. 4

When the switch is closed, load device R_{L1} can operate almost instantaneously. The other load devices will be operated at later intervals, the time of each depending upon its resistance, since each is in series with a thermistor which introduces a time delay. By choice of appropriate values of load resistances (or of individual external series resistances when each load device has the same resistance) the devices may be caused to operate in a desired sequence after the switch has been closed.

Lockout Switching System. Figure 11 shows another switching system employing series thermistors.

In this circuit, when any switch is closed, that leg of the circuit draws current through a thermistor. By properly proportioning the series resistor (R_1 to R_n), the thermistor can be caused to "fire". analogous to Thyratron action, and to conduct as long as its switch is closed. When one leg is conducting, the current draw through the common series resistor, R_s, sets up a voltage drop across R_s sufficient to reduce the line voltage too low for any other thermistor to fire.

The result of this action is that when one leg of the circuit is in operation, all other legs are locked out. The latter will not operate when their switches are closed. Only when the switch in the conducting leg is opened will the circuit be restored to the initial condition in which any other leg may conduct.

Amplifier Feedback. The thermistor in Figure 12 is of the heater type (also called "directly-heated"). This thermistor has an internal heater element which is connected across the output terminals of the amplifier. The thermally-sensitive resistance element of the thermistor is connected across the amplifier input terminals where it forms a potentiometer with resistor R_s.

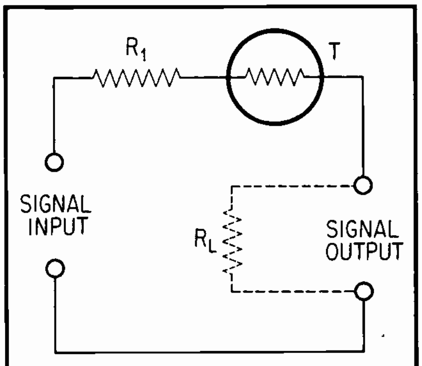
When te signal output rises, the thermistor is heated by this increased voltage across its heater, and its resistance decreases. By potentiometer action with R_s, the thermistor resistance then lowers the signal input voltage, and in turn the amplifier output. The amplifier output thus is stabilized at a predetermined level governed largely by the ratio of R_s to the thermistor resistance and is adjustable by means of R_s.

Limiter. The simple limiter or compressor circuit in Figure 13 utilizes thermistor non-linearity in very much the same manner as the voltage regulator circuit (Figure 7) to obtain limiting action.

Because current through the thermistor increases rapidly while the applied voltage is increasing slowly, the resulting voltage drop across the thermistor (which constitutes the signal output voltage in this instance) is maintained constant while the amplitude of the signal input voltage fluctuates.

Choice of resistances R_1 and R_2 for a particular type of thermistor will yield efficient limiting action minus the high distortion encountered with simple limiters of some other types.

Expander. The opposite action is obtained with the circuit shown in



EXPANDER
FIG.14

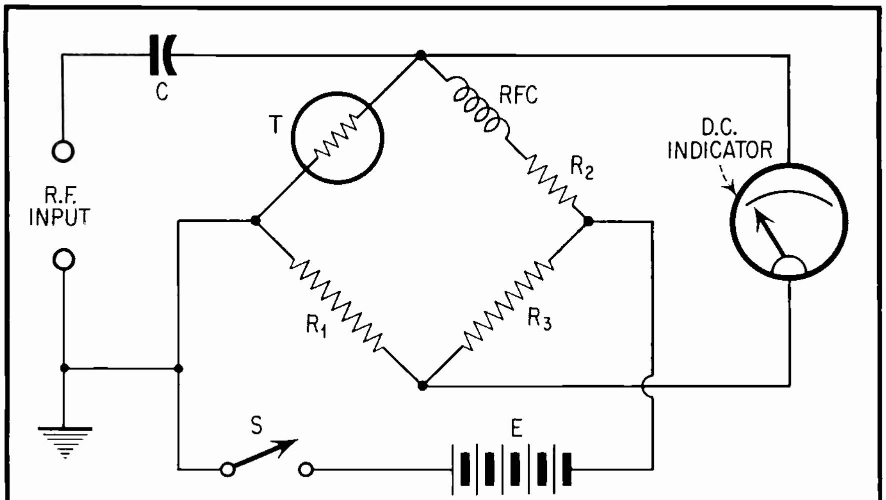
Figure 14. Here, the output signal is the voltage drop due to the flow of non-linear thermistor current through a series resistance (R_L). A small increase in applied voltage (signal input) causes a large current to flow through R_L. producing a large *increase* in signal output. We italicize the word "increase" here to prevent giving the impression that amplification is taking place. Amplification does not occur because the amplitude of the input signal is not increased by the circuit action, only its rate of change. In fact, the absolute amplitude is *decreased* by potentiometer action between R_1, T, and R_L.

U-H-F, Microwave Wattmeter. The thermistor bridge shown in Figure 15 is invaluable for measuring a-c power, since the low internal capacitance of the thermistor enables these measurements to be made anywhere in the frequency spectrum from low, power-line frequencies to microwaves.

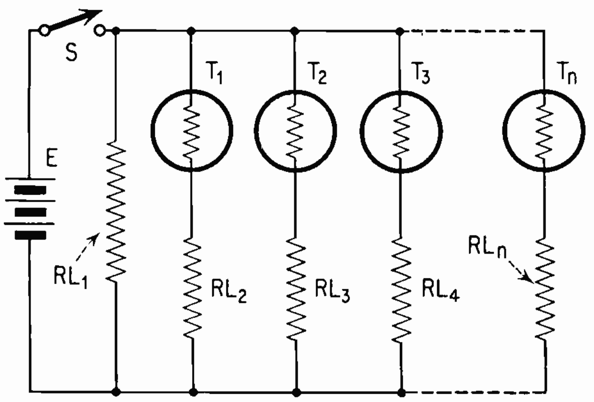
The signal energy is applied to the thermistor only, through the isolating capacitor, C. The radio-frequency choke, RFC, prevents passage of this energy through the other arms of the bridge. The signal current heats the thermistor and thus changes its resistance proportionately.

The thermistor resistance may be checked by adjustment of the bridge to null, whereupon $R = (R_1 R_2)/R_3$, and this resistance value referred to a resistance-vs-power calibration curve to determine the signal watts. Or the scale of the indicating meter may be graduated directly in watts.

It is customary to employ a d-c bridge supply, E, when measuring a-c watts. When checking d-c watts with a thermistor bridge, capacitor C is omitted from the circuit and an a-c bridge supply and a-c meter may be employed.

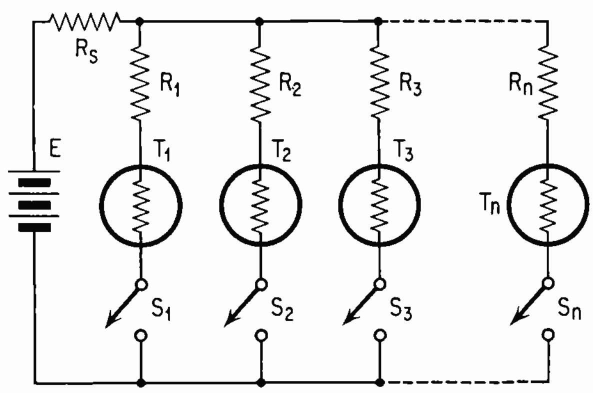


U-H-F AND MICROWAVE WATTMETER
FIG.15



AUTOMATIC SEQUENCE SWITCHING

FIG.10



"LOCKOUT" SWITCHING SYSTEM

FIG.11

closure of the switch. The length of the time interval may be selected by adjustment of R.

Voltage Regulator. Within its power handling limitations, the thermistor may be employed as a voltage regulator, especially at low voltages, in the simple circuit of Figure 7, to stabilize an output voltage against input voltage variations.

R_1 is a current-limiting resistor similar to the same resistor in a gaseous-tube regulator circuit. The value of R_2 must be chosen, with respect to the EI characteristic of the type of thermistor in use, for maximum regulating effect.

The voltage regulating action results from the fact that current through a thermistor, and therefore the resultant voltage drop across it, increases at a rate somewhat greater than linearly with applied voltage. A small change in output voltage (voltage drop across the thermistor) thus results from a rather large change in input (applied) voltage.

A particular desirable feature of this circuit is that it may be used to regulate either ac or dc.

Vacuum Gauge. In Figure 8, thermistors T_1 and T_2 form two of the arms of a Wheatstone bridge. Thermistor T_1 is placed inside the vacuum chamber, while T_2 is mounted outside.

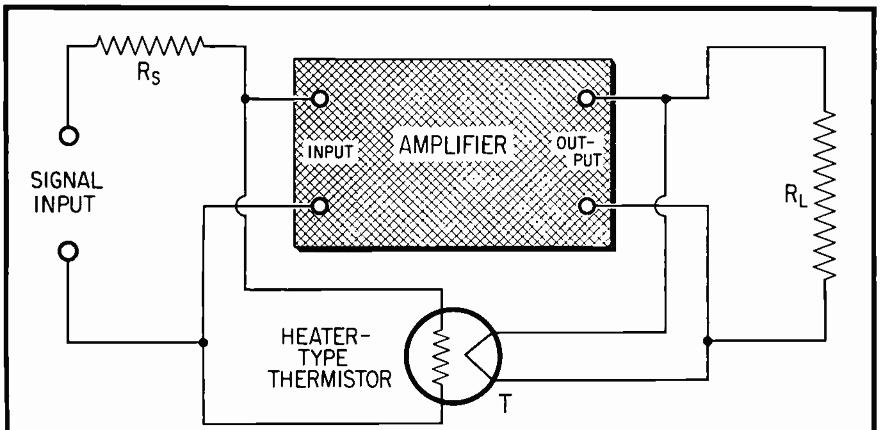
Before evacuating the chamber, the bridge is balanced (meter M nulled) by adjustment of resistor R_2. As the evacuation then progresses, thermistor T_2 can dissipate its heat due to current flow faster than can T_1 inside the chamber because T_1 is surrounded by progressively thinner air. Consequently, the resistance of the hotter T_1 differs from that of T_2, the bridge unbalances, and the meter deflects. The meter scale may be calibrated to read chamber pressure.

Flow Meter. Figure 9 shows a flow meter operating on somewhat the same principle as the vacuum gauge just described.

Here again, there is a 4-arm bridge with thermistors in two of its arms. In this instance, one thermistor (T_1) is mounted so as to be directly in the flow of a fluid (liquid or gas), while thermistor T_2 is mounted in the fluid but outside of the flow. The bridge is balanced with the fluid quiet, by adjustment of R_2. As the flow progresses, T_1 can dissipate its heat due to current flow rapidly because of the surrounding flow. But T_2 becomes hot because of its quieter ambient. Consequently, the bridge unbalances, deflecting the meter which may be calibrated to read flow units.

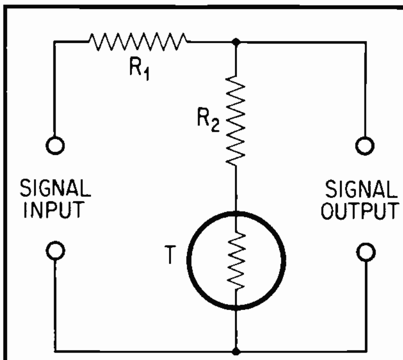
A similar thermistor circuit has been used as an anemometer.

Sequence-Switching Circuit. In Figure 10, several load devices, represented by RL_1 to RL_n, are connected across a line supplied by source E and controlled by switch S. All except RL_1 are connected in series with thermistors (T_1 to T_n).



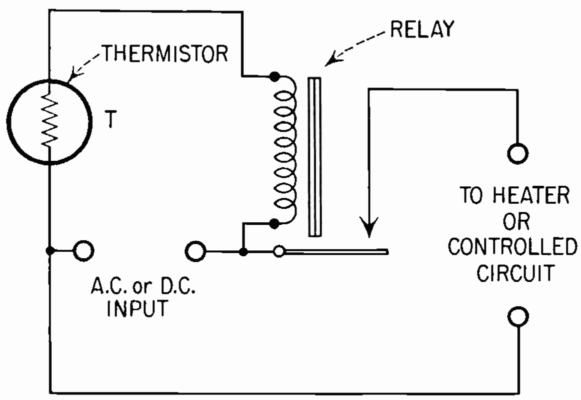
THERMISTOR FEEDBACK
FOR AMPLIFIER OVERLOAD CONTROL

FIG.12



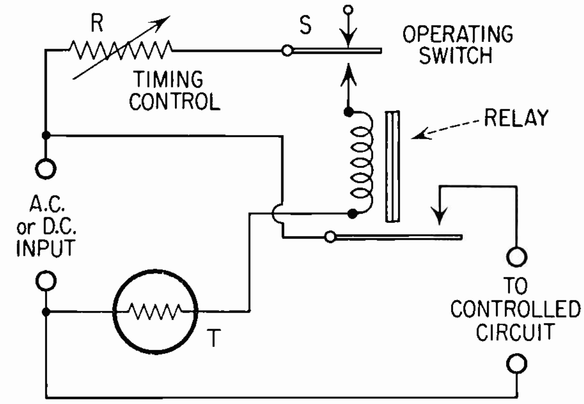
LIMITER (COMPRESSOR)

FIG.13



TEMPERATURE CONTROL

FIG. 5

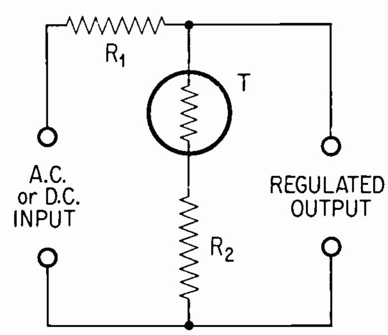


TIME-DELAY RELAY

FIG. 6

mistor (T) forms one arm of the bridge, while the other three arms are conventional resistors. One resistance arm, R_2, is made variable for nulling meter M or setting it to some predetermined level at ambient temperature or zero degrees. As the thermistor resistance alters in response to temperature, the bridge unbalances and the meter is deflected. The bridge may be re-balanced and the thermistor resistance measured in terms of the bridge arms (that is: $R = (R_1 R_3)/R_2$. Or the meter scale may be graduated directly in degrees.

Temperature Control. In addition to temperature measurement, a number of thermistor circuits are available for direct temperature control. Figure 5 shows a simple arrangement utilizing the temperature-sensitive resistance of a thermistor in series with the coil of a control relay.



VOLTAGE REGULATOR

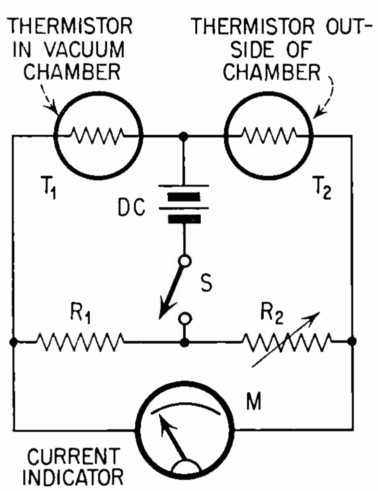
FIG. 7

Rising temperature lowers the thermistor resistance, allowing the latter to pass more current to the relay which eventually is actuated. The supply voltage may be either ac or dc, provided the relay is chosen accordingly.

For greater sensitivity to small changes in temperature, a sensitive relay may be substituted for the indicating meter in the bridge circuit in Figure 4(C).

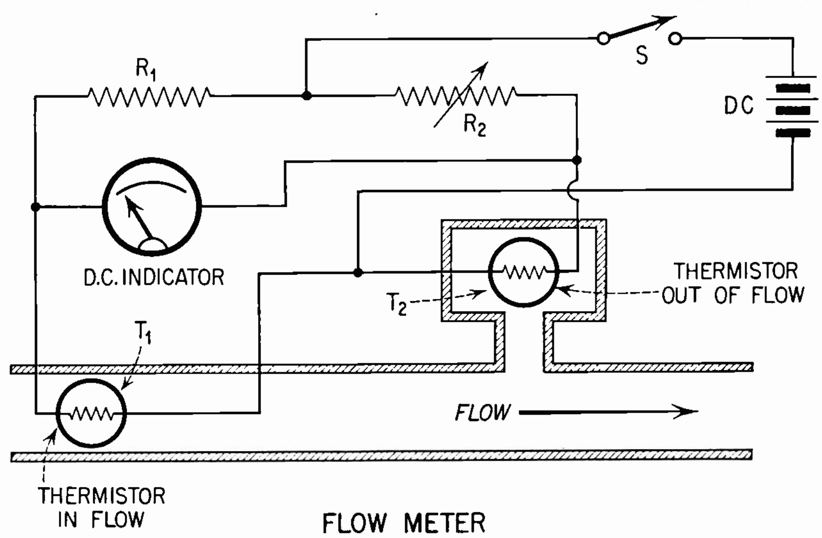
Time Delay. The thermistor delay characteristic illustrated by Figure 3 may be utilized to obtain time delay effects in a simple manner.

In Figure 6, for example, a thermistor is connected in series with an a-c or d-c source and a corresponding relay coil. Resistor R limits current and accordingly modifies the current-time curve of the thermistor. When switch S is closed, the relay current gradually increases, according to the current-time curve of the thermistor-resistor combination. The current reaches a level sufficient to actuate the relay some time after



VACUUM GAUGE

FIG. 8



FLOW METER

FIG. 9

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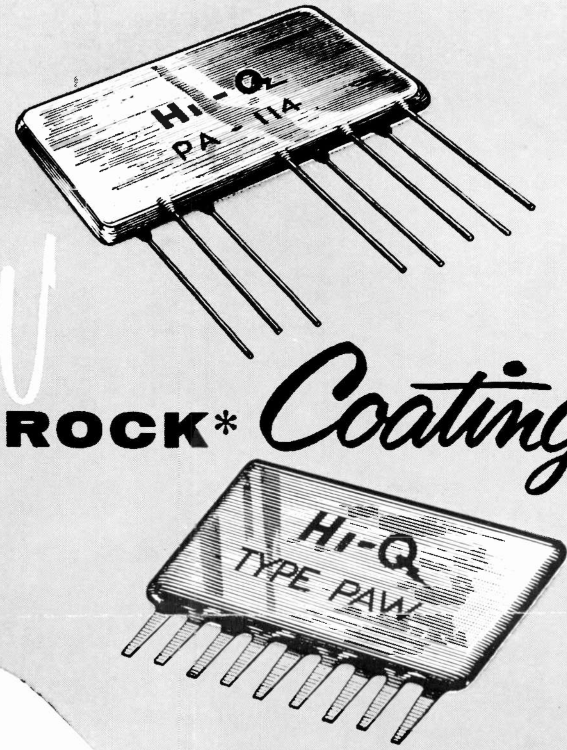

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