ELECTRONICS NOTEBOOK

Experimenting With Thermistors

By Forrest M. Mims III

Thermistors are temperature-sensitive resistors that are extensively used in electronics. Detection of temperatures of liquids, gases (both indoor and outdoor air included), machinery, electronic components, soil, plants and animal tissue are among the many applications in which they can be found playing central roles. Thermistors can also be used as surge protectors and timing devices.

In this column, I'll discuss the various kinds of thermistors and how they work. I'll follow this with several examples of applications for these simple but very versatile components.

Thermistor Operation

A thermistor is a resistor. When its temperature is increased, the opposition to the flow of current (resistance) through it decreases. Therefore, a thermistor is said to have a negative temperature coefficient (NTC). The resistance of copper increases and, as a result, copper has a positive temperature coefficient (PTC).

The NTC of a thermistor might at first appear to be an unusual characteristic. However, if you are familiar with photoresistors, the NTC of a thermistor should seem perfectly ordinary. Just as the resistance of a thermistor falls as temperature rises, the resistance of a photoresistor falls as light intensity rises.

Shown in Fig. 1 are the resistance characteristics of a typical thermistor as a function of temperature. At room temperature, this thermistor has a resistance of approximately 500 ohms. Other thermistors have room-temperature resistances ranging from a few hundred ohms to several megohms.

The curve in Fig. 1 shows that a thermistor is very sensitive to small temperature changes. Indeed, a thermistor can exhibit a resistance change of up to eight decades (10,000,000 to 1) over the temperature range it is designed to monitor.

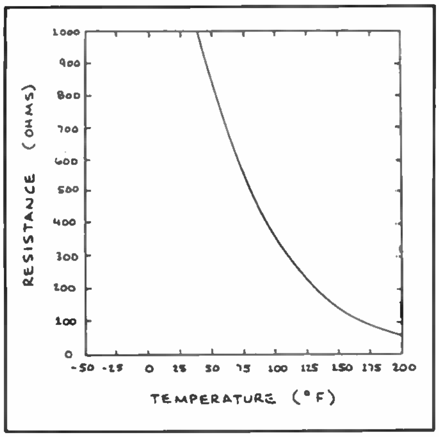

Fig. 1. Plot of the resistance of a typical thermistor as a function of temperature.

Another important feature of the curve shown in Fig. 1 is its nonlinearity. If a thermistor is intended to monitor relatively small temperature changes, its nonlinearity is usually not important. That's because the resistance of a thermistor is often linear with respect to temperature over small temperature ranges. However, in applications where wide temperature ranges are encountered, some form of compensation to adjust for nonlinearity is usually required.

I recently purchased a chart recorder, an instrument I have long needed for monitoring various atmospheric and solar phenomena. A chart recorder is ideal for observing the behavior of a thermistor. Figure 2 is based on a chart recording I made by connecting a tiny bead thermistor in series with the current input of a recorder. The thermistor had a room-temperature resistance of 2,000 ohms.

When I touched the thermistor with my index finger, the current flowing through it increased from almost nothing to 250 microamperes in just a few seconds. After 25 seconds or so, the current peaked at about 350 microamperes. When I removed by finger, the current flow fell back to a negligible value after around 90 seconds.

How Thermistors are Made

The active element of a thermistor is a semiconducting ceramic that is made from the powdered oxide of a metal like nickel, copper, magnesium, iron, titanium or manganese. Each metal gives a different resistance range.

The first step in manufacturing a thermistor is to mix the powdered metallic oxide with a binder to form a paste. Bead thermistors are made by depositing a tiny dollop of semiconductor paste at intervals along two closely spaced platinum-alloy wires. The wires and beads of paste are then heated in a furnace, which action sinters the paste and bonds it to the wires.

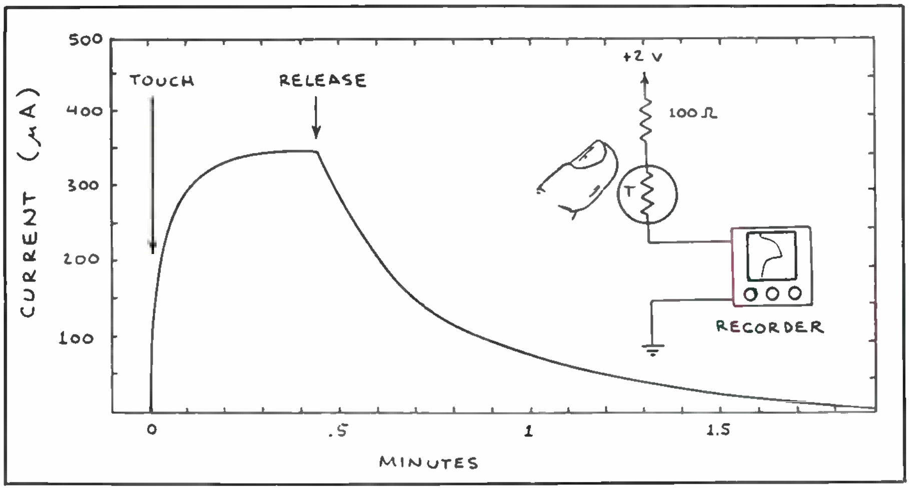

Fig. 2. Plot of the current flow through a thermistor as it is being touched by a finger and after finger is removed.

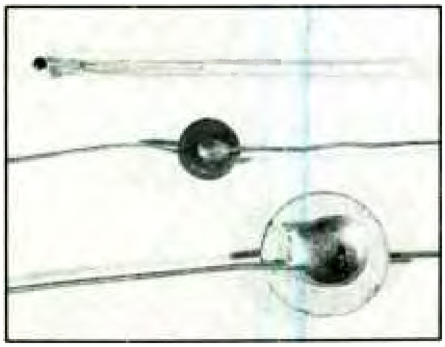

Fig. 3. Examples of two wafer and a miniature bead thermistors.

The wires emerging from one end of each bead are then cut to form individual thermistors. The ceramic bead is then usually encapsulated in a protective glass or epoxy coating.

Wafer and surface-mount chip thermistors are made by casting thermistor paste into thin sheets. The paste is then fired in a furnace and coated on opposite sides with silver or some other conductive material. If they are required, external leads are soldered directly to the silver terminals. Wafer thermistors may be given a protective coating of epoxy.

The sensitivity, response time and resistance range of a thermistor are determined by the metallic oxide from which it is formed, its size, the encapsulant used, and the presence of external leads. For example, external leads and a thick encapsulating layer can slow down a thermistor's response time. So if rapid response time is important in a given application, the active element and its leads and encapsulant should have as little mass as possible. This will permit the active element to rapidly respond to very subtle variations in temperature.

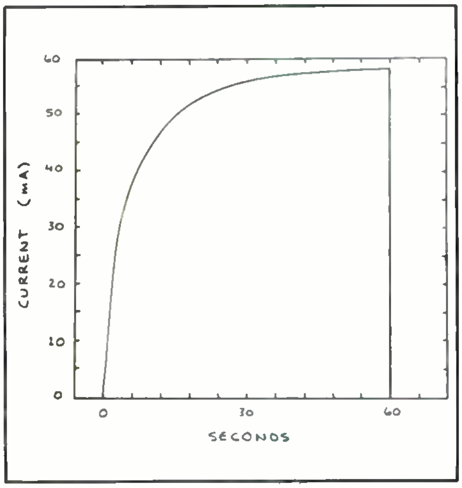

Fig. 4. Plot of thermistor current versus time.

The photo in Fig. 3 is of two wafer thermistors and one bead thermistor. The bead thermistor, which is the one I used to generate the response curve shown in Fig. 2, is encapsulated in the end of a glass capillary tube. Since its active area is quite small, it responds relatively rapidly to temperature changes.

Thermistor Applications

All of the hundreds of applications for thermistors can be divided into just two categories: those in which the thermistor is heated by current flowing through it and those in which the thermistor is heated or cooled by external means. The first category includes surge-protection and timer circuits. The latter category includes many different temperature-sensing and temperature-compensation applications.

- **Surge Protection.** An important application for self-heated thermistors is surge suppression. The delicate filaments of some lamps and tubes can be damaged or destroyed by rapid application of current. If a thermistor is placed in series with the current-sensitive component and a source of current, its resistance will limit the initial current. As the current passing through the thermistor raises its temperature, the device's resistance eventually decreases and allows more current to reach the component. Careful selection of the thermistor will provide both an appropriately low initial current and an adequate operating current.

To test the ability of a thermistor to function as a surge protector, I connected one in series with a 100-ohm resistor and a chart recorder. When 10 volts was connected across this network, the curve shown in Fig. 4 was generated by the recorder. Three seconds after application of the voltage, the current through the circuit reached 35 milliamperes. After 30 seconds, the current reached 58 milliamperes. Various other thermistors will produce different time-delay curves.

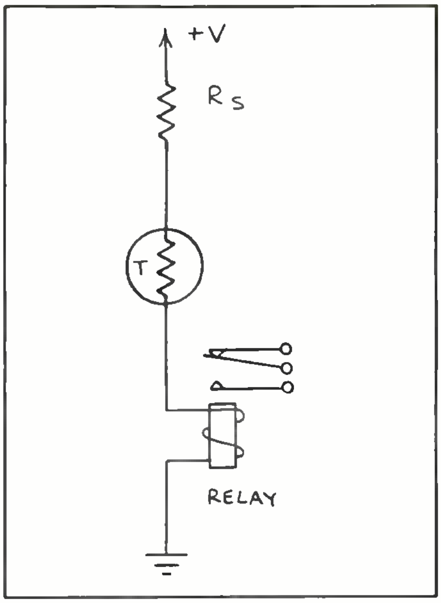

Fig. 5. A simple thermistor time-delay circuit.

A possible application for a thermistor surge suppresser is to protect laser diodes and other very delicate semiconductors that can easily be damaged by very brief current spikes. The Fig. 4 curve shows a current level close to that required to operate many CW laser diodes.

- **Time-Delay Circuits.** The reduction of resistance that results from self-heating that permits thermistors to serve as surge protectors also allows them to function in simple timer circuits. Shown in Fig. 5 is a simple circuit I tried to verify this application. Here, resistor R_S's 100-ohm value limits current through the thermistor and relay. The low-voltage relay pulls in when its coil current exceeds approximately 20 milliamperes at 9 volts. Radio Shack's Cat. No. 275-005 relay works well in this circuit; the company's Cat. No. 275-232 reed relay should also work.

When power is first applied to the Fig.

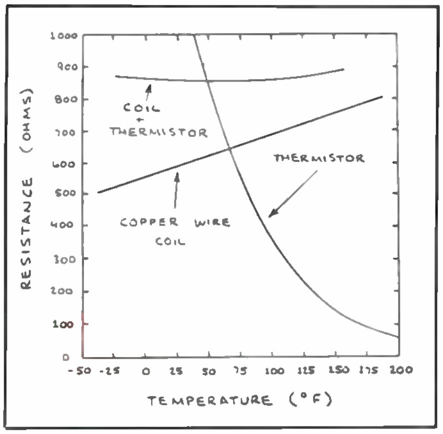

Fig. 6. Graphical depiction of how a thermistor temperature compensates a meter coil.

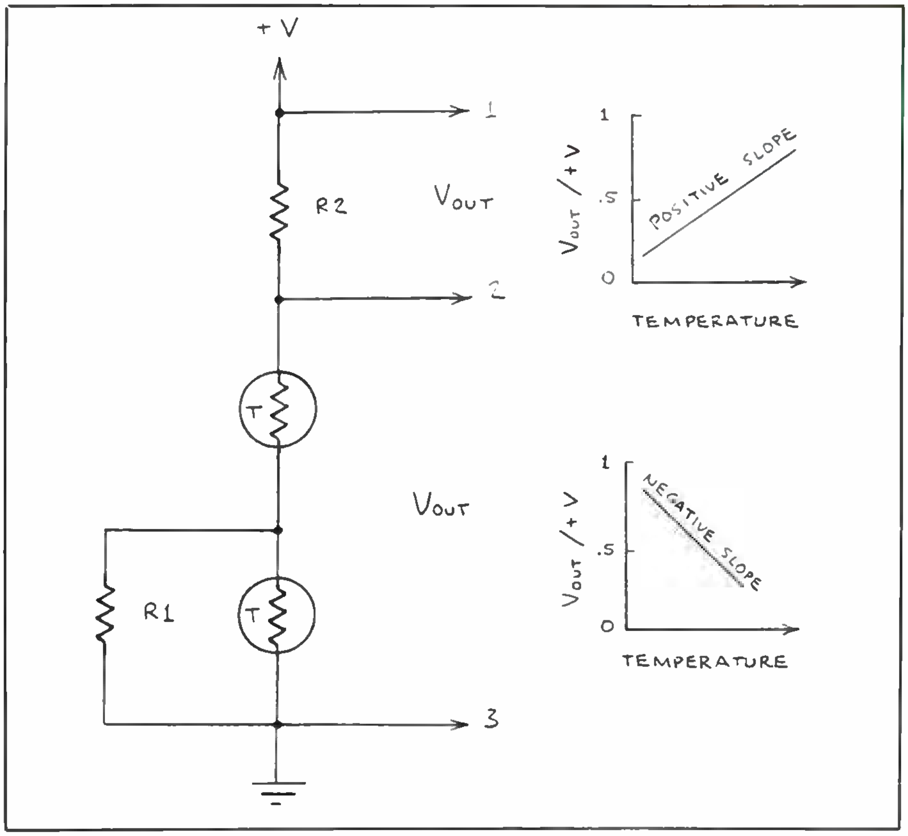

Fig. 7. Voltage outputs from a linear thermistor network.

5 circuit, the relay does not energize. As the thermistor warms up as a result of the current flowing through it, its resistance eventually falls to a point where the current flow is sufficient to energize it. Depending on the thermistor and relay used, the delay period can range from a fraction of a second to several minutes. The thermistor I used had a room temperature resistance of about 2,000 ohms and yielded a delay of about 15 seconds.

The basic Fig. 5 circuit can be easily modified to drive high-current relays. All that is required is to monitor the current flow with an operational amplifier. The output from the op amp can then be used to switch on a power transistor that, in turn, drives the relay.

Since ambient temperature can vary considerably, a thermistor is not suitable for use if you require a precision repeatable timing interval. For applications that are not critical, the thermistor approach provides one of the simplest timing circuits available.

• **Temperature Compensation.** A thermistor's NTC makes this device very useful as a temperature-compensating device. For example, a thermistor can be used to correct the PTC error of the copper wire in the coil of an electromechanical meter movement or the winding of a relay, motor or generator. Figure 6 is a graphic depiction of the resistance of a copper-wire meter coil as a function of temperature. The resistance of an NTC thermistor is plotted on the same graph.

Figure 6 also shows the combined resistance of the coil and the thermistor when the latter is connected across the former. As this illustration clearly reveals, the thermistor almost eliminates the meter coil's temperature error. The curves shown in Fig. 6 are adapted from "NTC Thermistors," a brochure published by Sensors Scientific, Inc.

• **Linear Thermistor Networks.** Parallel connection of a thermistor across the coil of a meter movement that provides the linear curve shown in Fig. 6 is a simple form of a linear thermistor network. This and many other thermistor/resistor networks can be made from individual components or be purchased as integrated networks. For example, Fenwal Electronics makes a series of miniature linear thermistor networks that incorporate two thermistors and two resistors connected as shown in Fig. 7. This circuit produces an output voltage that varies linearly with temperature. The output voltage across *R2* increases linearly with temperature (positive slope). The output voltage across the two thermistors decreases linearly as temperature increases (negative slope).

The Fig. 7 circuit can be converted into a thermistor whose resistance decreases linearly as temperature increases. All that's required is to connect together Outputs 1 and 3. The resistance then appears between Outputs 1/3 and 2.

• **The Voltage Divider.** Thermistors can easily be used in resistor networks like voltage dividers and bridges. As shown in Fig. 8, a voltage divider consists of two resistors connected in series with each

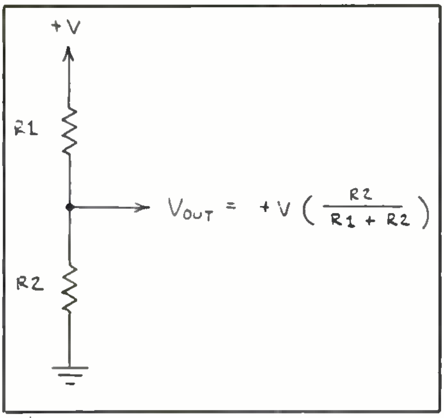

Fig. 8. The schematic of the basic voltage-divider network.

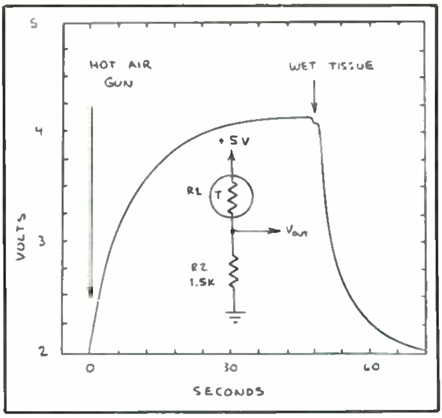

Fig. 9. Plot of a thermistor voltage divider's output.

other. The output voltage from the divider is $V_{out} = +VR2/(R1 + R2)$. If the two resistance values are the same, output voltage V_{out} will be exactly half input voltage +V.

The voltage divider is often used to transform the variable resistance of a thermistor into a variable voltage. Shown in Fig. 9 is a simple thermistor voltage divider, along with the output voltage it produced when the thermistor was warmed by a hot-air gun and then cooled with a damp tissue.

I chose the resistance of *R2* to approximately match that of the thermistor at room temperature. Therefore, the output potential was around 2 volts with the thermistor at room temperature. This standby voltage can be increased by increasing the resistance of *R2*. Conversely, it can be decreased by decreasing the value of this resistor.

The voltage divider's ability to provide an adjustable standby voltage makes possible many applications in which a component or circuit is triggered by a change in voltage caused by a change in temperature. We'll look at some simple circuits to do this later. First, it's important that we examine a special form of voltage divider.

- **The Wheatstone Bridge.** A Wheatstone bridge is composed of two voltage dividers connected in parallel with each other, as illustrated in Fig. 10. When the voltage from the first divider, $V_{out}1$, equals that from the second divider, $V_{out}2$, the bridge is said to be balanced and R1/R3 = R2/R4. It is important to monitor the voltage with a high-impedance meter; otherwise, the meter's internal resistance will affect operation of the bridge.

A common use of the Wheatstone bridge is the measurement of an unknown resistance. Referring to Fig. 10, assume that the values of *R1* and *R2* are accurately known, that potentiometer *R4*'s scale is accurately calibrated, and that *R3* is an unknown resistance. After *R3* is connected into the bridge, *R4* is adjusted until the bridge is balanced. The resistance of *R3* is then (R1 × R4)/R2.

Figure 11 shows how a thermistor becomes the unknown resistance. Initially, *R4* is adjusted to balance the bridge. Then tiny changes in the thermistor's resistance—hence, its temperature—will be indicated by the voltmeter, which should have a high-impedance input to minimize loading the circuit.

The values of the resistors aren't critical, as long as they are known. For example, if the thermistor has a resistance of 5,000 ohms at room temperature, you might select 5,000-ohm resistors for *R1* and *R2*. To permit a wide adjustment range, *R4* should have an adjustment range greater than 5,000 ohms—say, 10,000 ohms.

Figure 12 illustrates how to use a Wheatstone bridge as a differential tem-

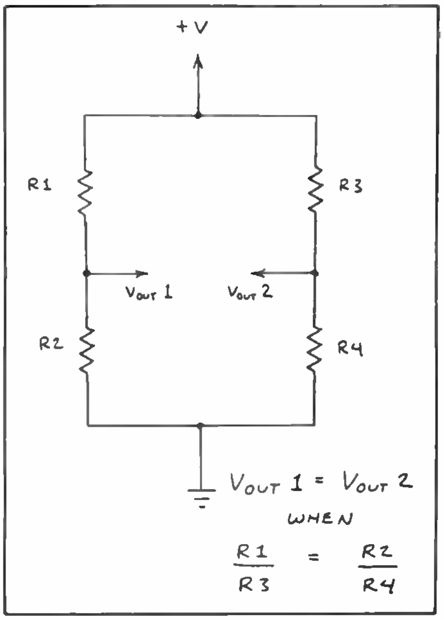

Fig. 10. The schematic of the Wheatstone bridge circuit.

perature monitor. Assume the bridge is initially balanced. This can be achieved within a few tenths of millivolts or so by using a pair of matched thermistors for *R1* and *R3* and identical precision resistors for *R2* and *R4*.

For the test circuit I assembled, the thermistors each had a resistance of 2,000 ohms at room temperature, and *R2* and *R4* each had a resistance of 2,200 ohms. Since I didn't use matched thermistors and precision resistors, the bridge gave a "balanced" output of around 82 millivolts. Substituting precision resistors or potentiometers for *R2* and *R4* would have provided a better balance.

If the temperature of thermistor *R1* is greater than that of thermistor *R3*, the output will be a positive voltage. Conversely, if the temperature of *R1* is less than that of *R3*, the output will be a negative voltage. In either case, the magnitude of the output voltage coincides with the overall temperature difference between the two thermistors.

Temperature Alarms

As you've probably figured out by now, thermistor voltage dividers and bridges can be easily connected to operational amplifiers and comparators to implement many interesting and useful applications. Comparators are particularly easy to use with thermistors.

Shown in Fig. 13 is a schematic diagram for a simple low-temperature alarm. If you examine this circuit carefully, you'll see that the voltage divider made up of thermistor *R1* and resistor *R2* is actually half of a Wheatstone bridge. The other half of the bridge is made up of potentiometer (or adjustable voltage divider) *R3*. In this application, *R3* is considered to be the source of an adjustable reference voltage.

In operation, *R3* is set so that the comparator switches and the buzzer is activated when the temperature drops to a predetermined point. For example, the circuit can be set to sound the buzzer when the temperature is at or near freezing by adjusting *R3* when the thermistor is immersed in ice water.

The thermistor should be selected to respond over the temperature range you wish to monitor. In most applications, the resistance of *R2* should be approximately equal to the resistance of the thermistor at room temperature. The thermistor I selected had a resistance of 2,000 ohms at room temperature. Therefore, I used a 2,200-ohm value for *R2*.

I used a 741 operational amplifier for a comparator only because it is inexpensive and readily available. For very-low standby power consumption, use a CMOS comparator or op amp. For details about how to use these low-power chips, see the December 1988 "Electronics Notebook" column in this magazine. As for *Q1*, any general-purpose npn switching transistor should work fine.

The piezoelectric buzzer should be the type that includes a built-in driver oscillator. If its maximum operating potential is less than 9 volts, reduce the potential delivered by the power supply accordingly.

Though the circuit shown in Fig. 13 is configured as a low-temperature alarm, it can easily be modified to function as a high-temperature alarm. All that's necessary is to reverse the input connections to the comparator. The alarm will then sound when the thermistor's temperature exceeds the value set by adjusting *R3*.

Going Further

Applications for thermistors are limited only by your imagination. Want to detect

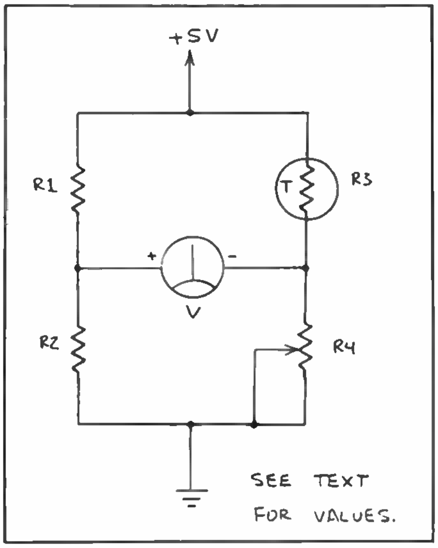

Fig. 11. Circuit details of a Wheatstone bridge temperature sensor.

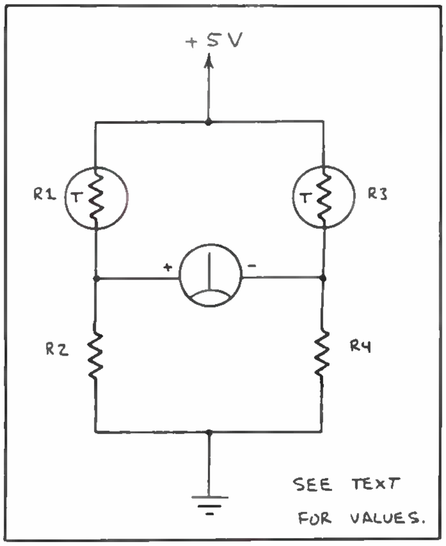

Fig. 12. A Wheatstone bridge differential temperature sensor.

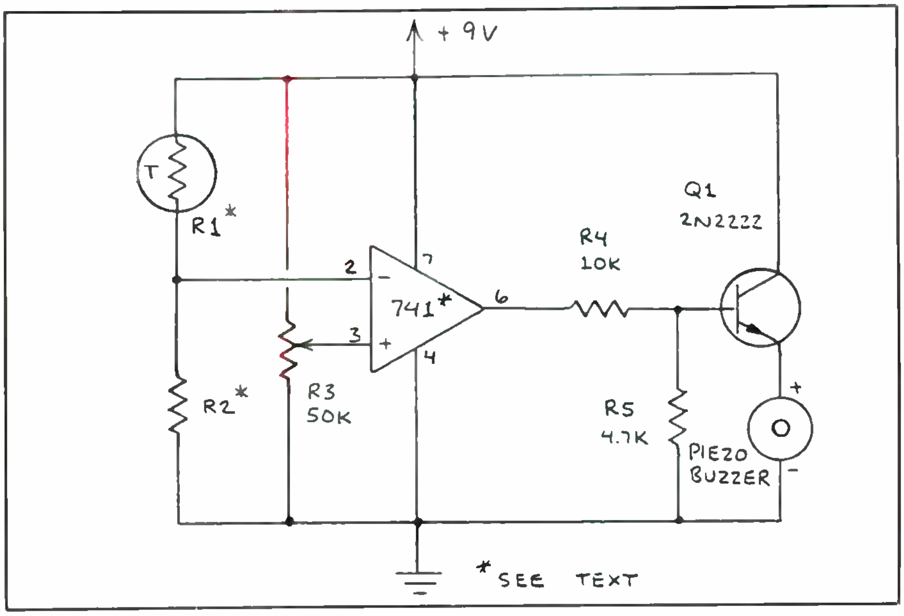

Fig. 13. Schematic diagram of a low-temperature alarm circuit.

infrared sources with a thermistor? If so, use a parabolic reflector from a discarded flashlight as an infrared-energy collector. Use clay or hot-melt adhesive to mount a bead thermistor in the opening for the lamp in the reflector. For best results, make sure the thermistor is positioned so that it's as close as possible to reflector's focal point (where the lamp filament would otherwise be located).

Figure 14 is taken from a chart recording I made of the current through a thermistor installed in a small reflector. The peaks were caused by passing a flame several inches in front of the reflector.

Ricardo Jiminez-G of San Diego State University has developed a respiration-rate sensor in which a thermistor responds to the temperature of a subject's exhaled breath. His circuit is described in detail in *EDN*, "Thermistor Measures Respiration Rate" (August 1988, pages 214 through 217).

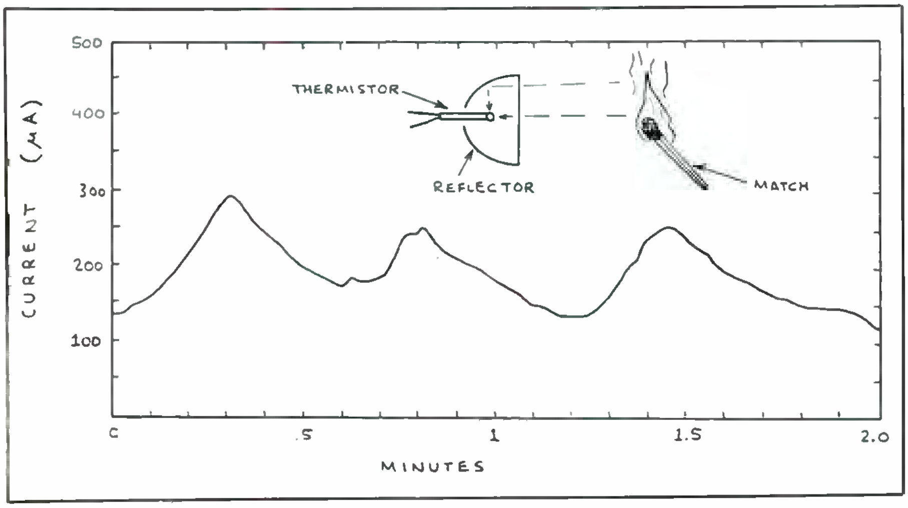

Fig. 14. Plotted response of a thermistor to the flame of a lighted match.

Several years ago, I devised a thermistor-based temperature sensor to monitor temperature changes at distances up to 100 feet away. This circuit, which was flown from a helium-filled BPTB (otherwise known as a "black plastic trash bag"), transmitted temperature data to ground over a single optical fiber. You can find the details of the design and construction of this 1-ounce circuit in the June 1985 installment of this column. It is also described in *Forrest Mims' Circuit Scrapbook II* (Howard W. Sams, 1987, pp. 121 through 126).

So how do you plan to use thermistors? To get you started, a list of some of the many thermistor manufacturers appears elsewhere in this column. These and other manufacturers make many different types of thermistors that cover many different temperature ranges. Some companies also publish brochures and manuals about thermistors.

Thermistor Manufacturers

Dale Electronics, Inc.
P.O. Box 26718
El Paso, TX 79926

Fenwal Electronics
450 Fortune Blvd.
Milford, MA 01757

Keystone Carbon
1935 State St.
St. Marys, PA 15857

Omega Engineering
Box 4047
Stamford, CT 06907

Sensor Scientific, Inc.
1275 Bloomfield Ave.
Fairfield, NJ 07006

Thermometrics, Inc.
808 U.S. Hwy. 1
Edison, NJ 08817

Yellow Springs Instrument Co.
Box 279
Yellow Springs, OH 45387