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Analysis of Temperature Sensors That Transmit Data in Automation Systems

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Annotation: This article describes the properties and applications of temperature sensors. Analysis of different types of temperature sensors from the most common sensors.

Key words: Thermistors, Temperature, Sensors, Resistance, TMP36, Thermocouples, Analog Output Thermometer ICs, Thermometer.

Temperature

Temperature sensors are one of the most common types of sensors. Computers and many types of equipment will sense their own temperature to prevent overheating.

In addition, as well as electronic thermometers, there are thermostats that keep temperature constant by controlling the power to a load, usually just turning it on and off. **Figure 1** shows a variety of temperature sensors.

Figure 1 Temperature Sensors

Thermistors

The term "thermistor" is a combination of the words "thermal" and "resistor." A thermistor is a resistor whose resistance changes markedly with temperature.

Thermistors come in two flavors: negative temperature coefficient (NTC) and positive temperature coefficient (PTC). An NTC thermistor's resistance will decrease with increasing temperature, and a PTC thermistor will behave the opposite way, with the resistance increasing as temperature increases. The NTC is the more common type.

The relationship between temperature and resistance in a thermocouple is not a linear one. Even over relatively short temperature ranges—say 0 to 100°C, a linear approximation will introduce considerable errors

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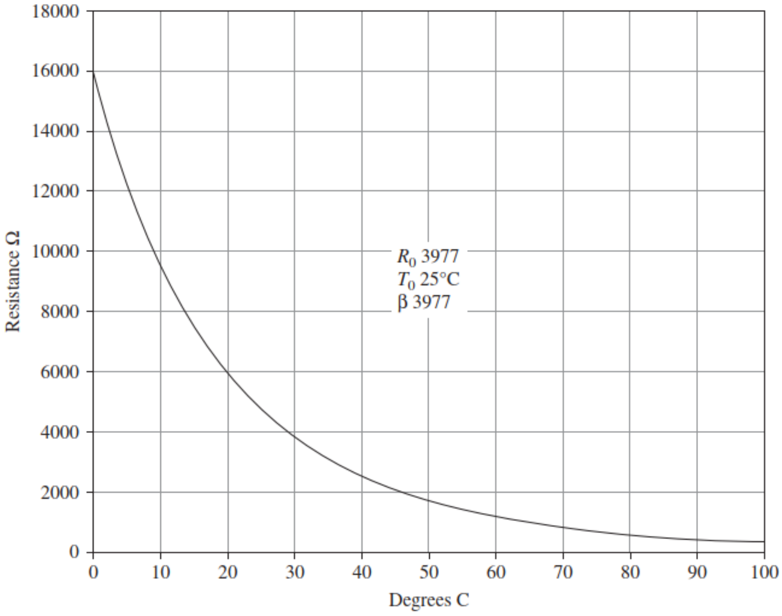

Figure 2 . Resistance against temperature for an NTC thermistor.

The Steinhart-Hart equation is a third-order approximation used to determine the temperature as a function of the thermistor's resistance. It works for both NTC and PTC devices. It is normally stated as:

$$\frac{1}{T} = A + B\ln(R) + C\ln^3(R)$$

T is the temperature in Kelvin; R is the resistance of the thermistor; and A, B, and C are constants specific to that thermistor. The manufacturer of a thermistor will give all three constant values.

An alternative and more common model for this relationship uses a single parameter (Beta) and assumes constants of T0 and R0, where T0 is usually 25°C and R0 is the resistance of the thermistor at that temperature.

Using this equation, the temperature can be approximated to:

$$\frac{1}{T} = \frac{1}{Beta}\ln\left(\frac{R}{R_0}\right) + \frac{1}{T_0}$$

Rearranging this, we can also derive an expression for R:

$$R = R_0 e^{Beta\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

As well as providing Beta, T0, and R0, the data sheet will also specify a temperature range and accuracy.

To use a thermistor as a thermometer for input to a microcontroller, a voltage is required that can be measured by the analog-to-digital converter of the microcontroller. Figure 2 shows a typical arrangement using a potential divider with a fixed-value resistor of the same value as R0.

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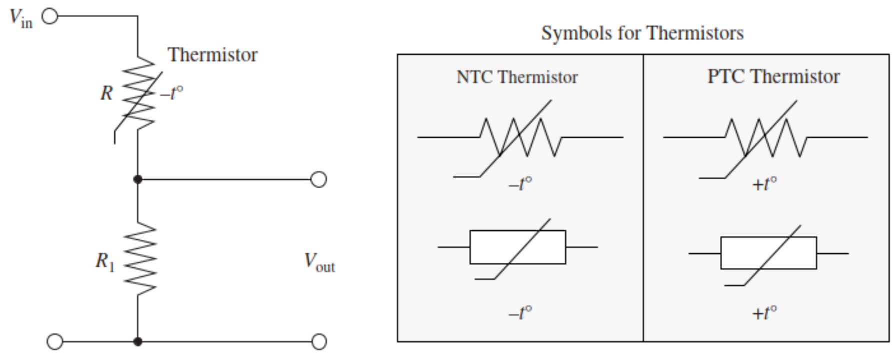

FIGURE 3. Using a thermistor as a thermometer.

If we place a NTC thermistor at the top of the potential divider, then as the temperature of the thermistor increases, its resistance falls and Vout rises.

Looking at Fig. 3

$$V_{out} = \frac{R_1}{R_1 + R} V_{in}$$

Combining Formula 3 with Formula 4, we have:

$$V_{out} = \frac{R_1}{R_1 + \left(R_0 e^{Beta\left(\frac{1}{T} - \frac{1}{T_0}\right)} \right)} V_{in}$$

Example 1: Using a potential divider as shown in Fig.1 with a fixed resistor of 4.7 kΩ and an NTC thermistor with a T0 of 25°C, an R0 of 4.7 kΩ, and a Beta of 3977, what is the formula for calculating V_{out}?

Answer 1: Just substituting the values into the equation, we get:

$$V_{out} = \frac{(5 \times 4700)}{4700 + \left(4700 e^{3977\left(\frac{1}{T} - \frac{1}{(25+273)}\right)} \right)}$$

$$V_{out} = \frac{5}{1 + \left(e^{3977\left(\frac{1}{T} - \frac{1}{(25+273)}\right)} \right)}$$

Note that 273 is added to the temperature in °C to give a temperature in °K.

Example 2: Using the same setup as Example 1, what is Vout at 25°C?

Answer 2: In one way, this is a trick question, since by definition the thermistor's resistance at 25°C will be 4.7 kΩ, so the voltage will be 2.5 V. However, we can apply the formula as a sanity check:

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$$V_{\text{out}} = \frac{5}{1 + \left(e^{3977 \times 0}\right)}$$

$$V_{\text{out}} = \frac{5}{1+1} = 2.5 \text{ V}$$

Example 3: Using the same setup as Examples 1 and 2, what is Vout at 0°C?

Thermocouples

While thermistors are good for measuring relatively small ranges in temperature typically –40 to +125°C, for much higher temperatures and temperature ranges, thermocouples are used (see Fig.2).

Any conductor subjected to a thermal gradient will experience something called the Seebeck effect; that is, it will generate a small voltage. The magnitude of this voltage is dependent on the type of metal, so if two different metals are joined, the temperature of that junction can be measured by measuring the voltage across the metal leads, at the far end from the junction. It is also necessary to measure the temperature at the other end of the thermocouple leads (often using a thermistor, since this will probably be at room temperature). This second temperature is called the "cold-junction" temperature.

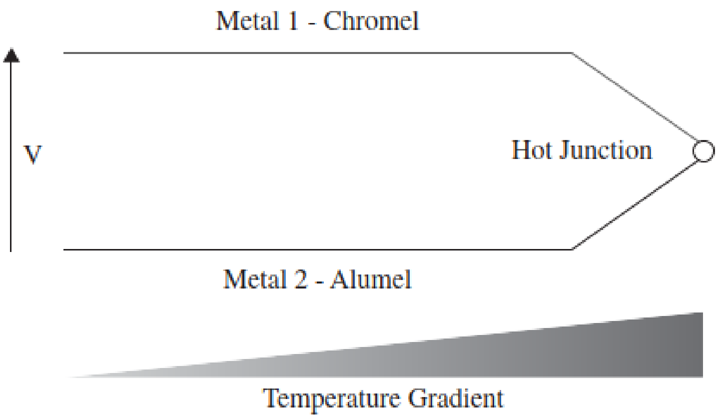

FIGURE 4. Thermocouples.

Lookup tables are often used to calculate the absolute temperature at the junction, based on the voltage and the cold-junction temperature, as the relationship is not completely linear and needs a fifth-order polynomial to model it accurately.

Manufacturer's data sheets for thermocouples will normally contain large tables for calculating the temperature.

The most commonly used metals for a thermocouple are the alloys chromel (90 percent nickel and 10 percent chromium) and alumel (95 percent nickel, 2 percent manganese, 2 percent aluminum, and 1 percent silicon). A thermocouple made with these materials will typically be able to measure temperatures over the range –200˜C to +1350˜C. The sensitivity is 41 µV/˜C for these metals.

Resistive Temperature Detectors

Resistive temperature detectors (RTDs) are perhaps the simplest temperature sensors to understand. Like thermistors, RTDs rely on their resistance changing with temperature. However, rather than use a special material that is sensitive to temperature changes (like a thermistor), they simply use a coil of wire (normally platinum) around a glass or ceramic core. The resistance of the core is often contrived to be 100 ˚ at 0˜C.

RTDs are much less sensitive than thermistors and can therefore be used over a much wider range of temperatures. The resistance of platinum changes in a relatively linear manner, and can be assumed to be linear for a range of 100˜C or so. For the range 0 to 100˜C, the resistance of a platinum RTD will vary by 0.003925 ˚ /˚ /˜C.So, a 100 ˚ (at 0˜C) platinum RTD will, at a temperature of 100˜C, have a resistance of:
100 ˚ ˛ 100˜C ˙ 100 ˚ ˙ 0.003925 ˚ /˚ /˜C ˆ 139.25 ˚

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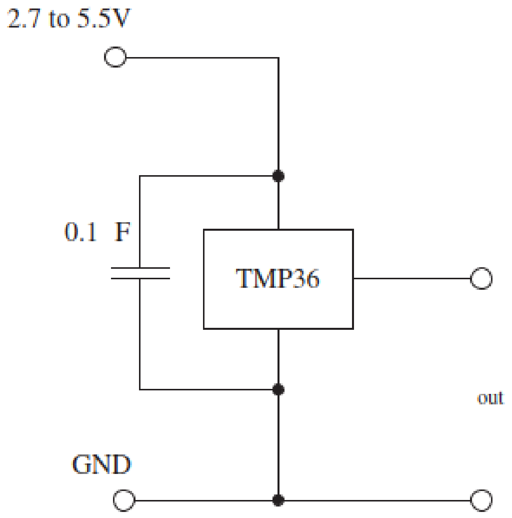
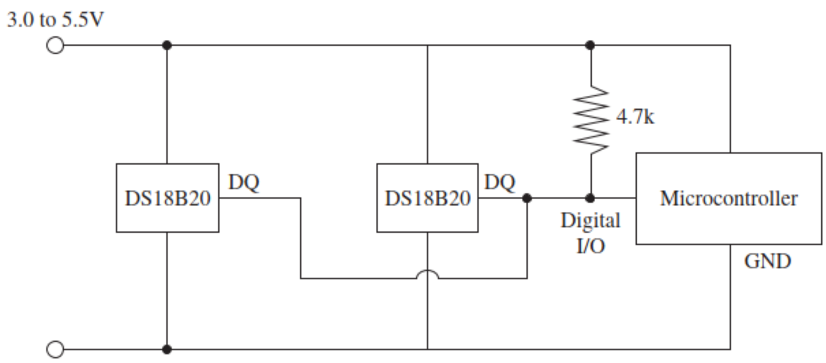
The first 100 ˚ in the equation above is for the base resistance of the RTD at 0˜C.
This can be arranged in a potential divider in the same way as a thermistor.

Analog Output Thermometer ICs

An alternative to using a thermistor and fixed-value resistor in a potential divider arrangement is to use a special-purpose temperature measurement IC. Devices such as the TMP36 come in a three-pin package and are used as shown in Fig.3.



Digital Thermometer ICs



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