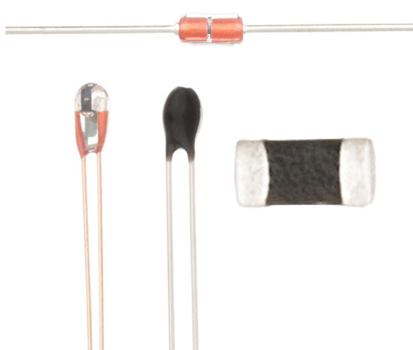
Eaton NTC thermistors for industrial applications



Overview

Negative temperature coefficient (NTC) thermistors are thermally sensitive resistors whose resistances decrease with increasing temperature. This feature allows engineers to use NTC thermistors as temperature sensing devices. Previously, the non-linear relationship between current and resistance in NTC thermistors resulted in challenges with analog circuit-based temperature measurements. However, with the rapid development of digital circuits, designers can now compute precise temperature values using table-based interpolation or NTC curve equation-based approximations. With wide operating temperatures from −55 °C to +300 °C, NTC thermistors are ideal for temperature measurement in industrial applications.

Types of NTC thermistors

NTC thermistors are designed using various materials, including epoxy-coated, glass-sealed, printed circuit board (PCB) surface mount, and disc and chip. Manufacturers produce epoxy-coated NTC thermistors by dipping the devices in epoxy and soldering them between PVC wires or Teflon. These thermistors are ideal for temperature sensing in an array of electronic applications. Similarly, sealing NTC thermistors in glass allows them to deal with harsh environmental conditions and boosts stability. PCB-mounted thermistors are ideal for PCB and IC temperature compensation-related applications. This thermistor type is typically available in a couple of configurations that include two-sided, for top and bottom connection, and chip style that is similar to other chip-type passive components. Often, these are installed in PCB applications, but designers and users of these configurations can leverage their integration and packaging methods to best suit their own needs. All of these types of NTC thermistors offer a broad resistance range and resistance vs temperature profile.

Definitions/formulas

The following are essential terms associated with NTC thermistors:

Resistance calculation: The measured thermistor DC resistance value at a specific temperature and adequate low power dissipation. Standard NTC thermistor resistance values range from 100 Ω to 100 KΩ. Although NTC thermistors experience changes in resistance due to self-heating, the extent of the change is negligible compared to the overall measurement error. The following equation shows the relationship between temperature and resistance:

$$R_1 = R_2 e^{B(\frac{1}{T_1} - \frac{1}{T_2})}$$

Where: B = B constant (K)

R_1 = Resistance (Ω) at temperature T_1 (°C)

R_2 = Resistance (Ω) at temperature T_2 (°C)

Beta constant: The extent of the thermistor's resistance change rate (or sensitivity) with temperature changes. Reference temperatures differ with each manufacturer. This constant is commonly denoted by "B" or beta value or B constant and calculated with the following equation:

$$B = \frac{\ln(\frac{R_{T1}}{R_{T2}})}{(\frac{1}{T_1} - \frac{1}{T_2})}$$

Where: B = material coefficient

R_{T1} = thermistor resistance at temperature 1 (Ω)

R_{T2} = thermistor resistance at temperature 2 (Ω)

T_1 = thermistor temperature 1 (°C)

T_2 = thermistor temperature 2 (°C)

Although the material constant of a thermistor varies with different fabrication materials, its value ranges from 3500 to 4500. The resistance-temperature chart below compares two B constant values at varying thermistor sensitivity.

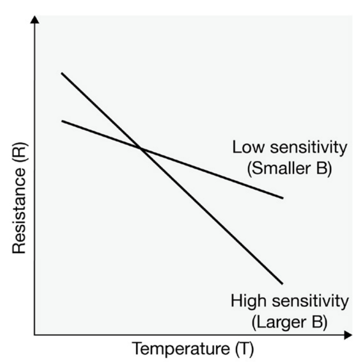


Figure 1. Resistance-temperature chart for varying sensitivities

Thermal dissipation: The power requirement for increasing the thermistor's temperature by 1°C in a heat equilibrium through self-heating, commonly denoted by "δ" and calculated using the following equation:

$$\delta = \frac{P}{T_1 - T_2} \quad (\mathrm{mW/°C})$$

$$※ \ (P = I^2 \cdot R = I \cdot V)$$

Where: δ = thermal dissipation constant (mW/°C)

P = power (mW)

T_1 = thermistor temperature (°C)

T_2 = ambient temperature (°C)

Thermal time constant: The thermal time constant represents the time it takes NTC thermistors to respond to ambient temperature changes. The following equation represents a change in the ambient temperature from T_1 to T_2 within the timeframe, t (sec). The equation shows the relationship between the thermistor's temperature and its response time during temperature changes.

$$T = (T_2 - T_1)\left(1 - \exp(-t/\tau)\right) + T_1$$

Where: T = temperature of the thermistor (°C)

t = time elapsed during temperature change (sec)

τ = thermal time constant (sec)

T_2 - T_1 = ambient temperature change

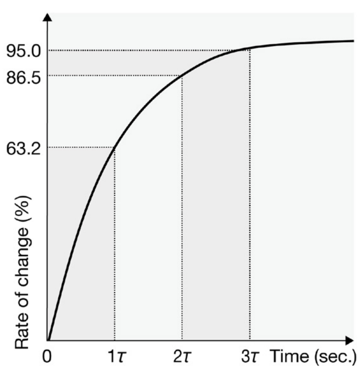


Figure 2. Thermal time constant

Figure 2 visually represents the thermal time constant, τ, as the time the NTC thermistor takes to reach 63.2% of its total temperature change. Nevertheless, this constant does not determine the time the thermistor's temperature reaches its conventional ambient temperature. Moreover, generally speaking, a thermistor's size directly impacts the thermal time constant; the smaller the thermistor, the lower its thermal time constant value.

Resistance vs temperature coefficient – alpha value: Also known as the temperature coefficient of resistance (TCR), the alpha value is the ratio of resistance with temperature to the resistance of a thermistor at a specified temperature. In other words, this value is the rate of change of thermistor resistance per 1 °C. This value is calculated using the following equation:

$$\alpha = \frac{\frac{R}{R_{ref}} - 1}{T - T_{ref}}$$

Note: Variable definitions are listed on next page.

Where: α = temperature coefficient of resistance (%/°C)

R = thermistor resistance at temperature "T" (Ω)

R_{ref} = thermistor resistance at reference temperature (Ω)

T = thermistor temperature (°C)

T_{ref} = reference temperature specified by thermistor (°C)

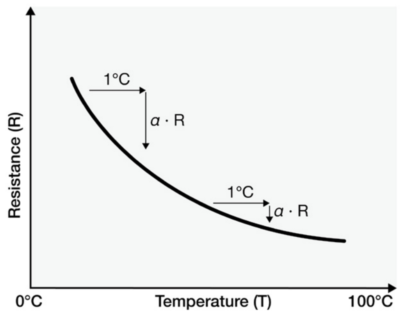


Figure 3. Resistance-temperature curve with alpha value as a constant

The negative resistance-temperature curve above shows that a thermistor's resistance reduces with increasing temperature.

Selection considerations

The following are essential considerations for NTC thermistor selection:

Nominal resistance value: To curve match or point match a thermistor to specific applications, engineers must consider its nominal resistance value at a specified temperature. With varying nominal resistance values for different thermistor solutions, engineers can identify the ideal solution for an application.

Resistance-temperature characteristics: The following equation shows the relationship between the resistance of a thermistor and its temperature:

$$R_{T1} = R_{T2}\, e^{[\beta(1/T_1 - 1/T_2)]}$$

Where: B = B constant

R_{T1} = thermistor resistance at temperature 1 (Ω)

R_{T2} = thermistor resistance at temperature 2 (Ω)

T_1 = thermistor temperature (°C)

T_2 = thermistor temperature 2 (°C)

Figure 4 shows the negative relationship between a thermistor's resistivity and temperature changes

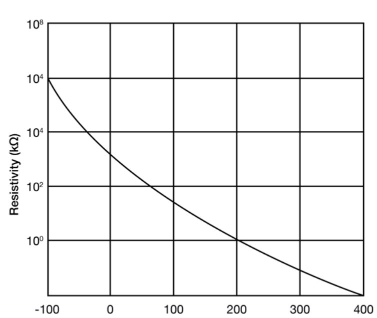


Figure 4. Resistivity-temperature curve for NTC thermistors

Figure 4 is an example of a resistance-temperature curve. [Contact Eaton](#) for support on R-T curves on specific part numbers.

Resistance tolerance: The resistance tolerance is a function of the base resistance. More critical applications require smaller tolerances.

Temperature range: A thermistor's operating temperature range is critical for temperature-sensitive applications. NTC thermistors with operating temperatures ranging from -55 °C to 300 °C are suitable for use in a wide range of industrial applications.

Packaging: Epoxy-coated or glass-sealed NTC thermistors can be applied in most electronic applications, depending on the operating environment. Unlike epoxy-coated thermistors, glass-sealed types offer a wider operating temperature range. Low-temperature measurement requires low resistance thermistors (e.g., between 2252 and 10 kΩ in ≤70 °C). Thus, engineers must select the appropriate packaging suitable for resistance-based applications. However, both packaging types protect thermistors against corrosion, humidity, and other environmental impacts.

Stability: To incorporate NTC thermistors into long-term applications, engineers should consider the packaging, design, and material stability. Generally speaking, glass encapsulated thermistors are more stable than epoxy-coated. For more stability information on our NTC thermistors, please contact Eaton.

Accuracy: Designers favor NTC thermistors with industry-leading accuracy within the −55 °C to +300 °C operating temperature range. An accuracy range between 0.05 and 1 °C allows engineers and designers to achieve higher performance in their temperature measurement applications. Incorporating thermistors with appropriate resistance tolerance and beta values into designs is essential for achieving high levels of accuracy in their applications. Generally speaking, NTC thermistors with low resistance tolerance of ±1% and B-value of ±0.5% offer high precision temperature measurement for a wide temperature range.

Basic circuit diagram - How to use NTC thermistors

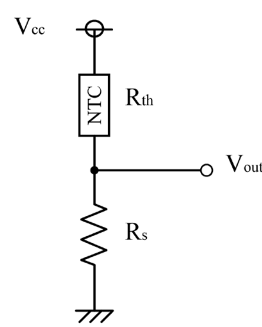


Figure 6. Basic circuit diagram for thermistor linearization

Thermistors are well suited for voltage dividing, as well as voltage drop measurement. Because of the non-linear nature of resistance change in thermistors, most engineers incorporate thermistors and resistors into their designs to linearize voltage output as seen in figure 6. With the aid of a resistance/temperature table and the equation below, designers can accurately determine thermistor temperature measurements.

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$$V_{out} = \frac{V_{cc}}{R_{th} + R_s} \times R_s$$

Where:

V_{out} = voltage output (V)

R_{th} = thermistor resistance (Ω)

R_s = resistor resistance (Ω)

Benefits and key applications

Key applications of NTC thermistors include fluid level gauging, temperature compensation, battery pack protection, current limiting, temperature measurement, and digital thermostats. By detecting varying dissipation constants between liquid and gas in a container, an NTC thermistor can sense the presence of a fluid, which is critical for fluid level gauging. The need for temperature compensation in electronics, such as LCDs, oscillators, and rechargeable batteries, results from temperature variation from the environment. Using NTC thermistors, designers can achieve temperature compensation and stabilization, which provides additional protection against damage. NTC thermistors are critical for protecting rechargeable batteries from damage and fire as batteries are susceptible to overheating.

Besides high sensitivity to temperature, thermistors can also detect changes in power levels. Thus, engineers can incorporate these components to minimize inrush surge currents that can damage sensitive electronic components. Moreover, NTC thermistors are ideal for low-cost, high-accuracy temperature measurements. Digital thermostats require high levels of efficient temperature monitoring. Thus, incorporating NTC thermistors into their design allows them to meet these requirements. Additionally, some common benefits NTC thermistors offer to a wide range of industrial applications include small footprint, reliability, low costs, stability, and high sensitivity. Moreover, the devices have fast response times and inertness to magnetic and electrical interferences, making them preferred to thermocouples, RTDs, etc.

Eaton NTC thermistors in industrial process control

Eaton NTC thermistors are ideal for use in a host of industrial applications, e.g., oil tanks, solar heating systems, surface temperature sensing, voltage regulation, volume control, etc. Eaton's epoxy-coated and glass-sealed NTC thermistors can withstand extreme temperatures while offering high-accuracy sensing. The figure below shows an NTC thermistor used to achieve temperature-based DC fan control.

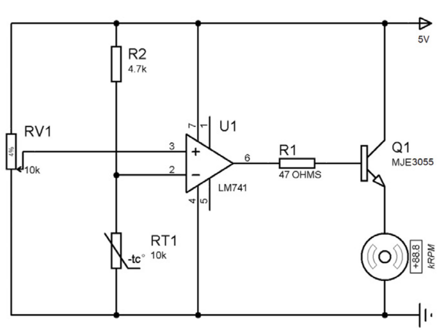

Figure 7. Circuit diagram of temperature-based fan control with an Eaton NTC thermistor

In this design, a 10k Eaton NTC thermistor detects temperature rise, causing a corresponding decrease in its resistance and an increase in voltage. This increase causes the DC fan to turn on. However, the fan automatically turns off when the thermistor detects a lower temperature.

Eaton NTC thermistors in HVAC systems

Eaton NTC thermistors are well suited for extreme temperature measurements (up to 300 °C), in high-efficiency space heating, ventilation, air conditioning, and refrigeration. Thermostats are essential to HVAC systems. These devices measure, maintain and regulate the temperatures of HVAC systems, e.g., water heaters, refrigerators, ovens, etc. Figure 8 shows an Eaton NTC thermistor used as a thermostat.

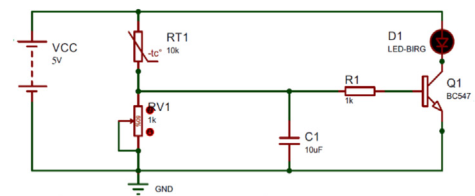

Figure 8. Thermistor-based thermostat circuit diagram

Figure 8 also shows a 10k thermistor operated by a 5 Vdc supply. Eaton's NTC thermistor switches on the LED at a sufficiently high trigger temperature. The LED switches off when the thermistor senses a lower temperature.

Eaton NTC thermistor in Internet of Things (IoT) applications

IoT applications require an array of sensors. NTC thermistors offer high sensitivity, tolerance, and long-term stability for high sensing accuracy in IoT applications. For example, engineers can incorporate Eaton NTC thermistors into fire alarm systems in smart buildings.

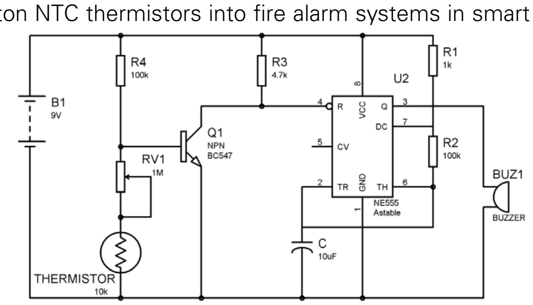

Figure 9. Thermistor-based fire alarm circuit

At ambient temperature, the thermistor maintains 10k ohms, the transistor remains in the ON state, leaving the 555 timer IC inactive. A temperature rise due to a fire outbreak will cause the thermistor's resistance to decrease, leading to the transistor's switch from ON to OFF state. Consequently, the 555 timer becomes active, causing the buzzer to beep.

Conclusion

Eaton's PCB surface-mounted, glass-sealed, epoxy-coated NTC thermistors offer several benefits in industrial applications with an optimal balance of cost and high performance for a wide range of temperature-sensitive applications. Multiple resistance and beta values ensure integration with virtually any type of application. Eaton's solutions exhibit high precision temperature sensing due to their non-linear change in resistance-temperature characteristics.

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