

# What are NTC Thermistors?

NTC stands for "Negative Temperature Coefficient". NTC thermistors are resistors with a negative temperature coefficient, which means that the resistance decreases with increasing temperature. They are primarily used as resistive temperature sensors and current-limiting devices. The temperature sensitivity coefficient is about five times greater than that of silicon temperature sensors (silistors) and about ten times greater than that of resistance temperature detectors (RTDs). NTC sensors are typically used in a range from  $-55$  to  $+200$  °C.



The non-linearity of the relationship between resistance and temperature exhibited by NTC resistors posed a great challenge when using analog circuits to accurately measure temperature. However, rapid development of digital circuits solved that problem through enabling computation of precise values by interpolating lookup tables or by solving equations which approximate a typical NTC curve.

## NTC Thermistor Definition

*An NTC thermistor is a thermally sensitive resistor for which the resistance exhibits a large, precise and predictable decrease as the core temperature of the resistor increases over the operating temperature range.*

## Characteristics of NTC Thermistors

Unlike RTDs (Resistance Temperature Detectors), which are made from metals, NTC thermistors are generally made of ceramics or polymers. Different materials used in the manufacture of NTC thermistors result in different temperature responses, as well as other different performance characteristics.

### Temperature response

Most NTC thermistors are typically suitable for use within a temperature range between  $-55$  and  $200$  °C, where they give their most precise readings. There are special families of NTC thermistors that can be used at temperatures approaching absolute zero ( $-273.15$  °C) as well as those specifically designed for use above  $150$  °C.

The temperature sensitivity of an NTC sensor is expressed as "percentage change per degree C" or "percentage change per degree K". Depending on the materials used and the specifics of the production process, the typical values of temperature sensitivities range from  $-3\%$  to  $-6\%$  / °C.

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## Heat capacity

The heat capacity represents the amount of heat required to increase the temperature of the thermistor by 1 °C and is usually expressed in mJ/°C. Knowing the precise heat capacity is of great importance when using an NTC thermistor sensor as an inrush-current limiting device, as it defines the response speed of the NTC temp sensor.

## Curve Selection and Calculation

The thermistor selection process must take care of the thermistor's Dissipation Constant, Thermal Time Constant, Resistance value, Resistance-Temperature curve and Tolerances, to mention the most important factors.

Since the relationship between resistance and temperature (the R-T curve) is highly nonlinear, certain approximations have to be utilized in practical system designs.

## First-order approximation

One approximation, and the simplest to use, is the first-order approximation which states that:

$$\Delta R = k \cdot \Delta T$$

Where  $k$  is the negative temperature coefficient,  $\Delta T$  is the temperature difference, and  $\Delta R$  is the resistance change resulting from the change in temperature. This first-order approximation is only valid for a very narrow temperature range, and can only be used for such temperatures where  $k$  is nearly constant throughout the whole temperature range.

## Beta formula

Another equation gives satisfying results, being accurate to  $\pm 1$  °C over the range of 0 to +100°C. It is dependent on a single material constant  $\beta$  which can be obtained by measurements. The equation can be written as:

$$R(T) = R(T_0) \cdot e^{\beta(\frac{1}{T} - \frac{1}{T_0})}$$

Where  $R(T)$  is the resistance at the temperature  $T$  in Kelvin,  $R(T_0)$  is a reference point at temperature  $T_0$ . The Beta formula requires a two-point calibration, and it is typically not more accurate than  $\pm 5$  °C over the complete useful range of the NTC thermistor.

## Steinhart-Hart equation

The best approximation known to date is the Steinhart-Hart formula, published in 1968:

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

Where  $\ln R$  is the natural logarithm of the resistance at temperature  $T$  in Kelvin, and  $A$ ,  $B$  and  $C$  are coefficients derived from experimental measurements. These coefficients are usually published by thermistor vendors as part of the datasheet. The Steinhart-Hart formula is typically accurate to around  $\pm 0.15$  °C over the range of -50 to +150 °C, which is plenty for most applications. If superior accuracy is required, the temperature range must be reduced and accuracy of better than  $\pm 0.01$  °C over the range of 0 to +100 °C is achievable.

## Choosing the right approximation

The choice of the formula used to derive the temperature from the resistance measurement needs to be based on available computing power, as well as actual tolerance requirements. In some applications, a first-order approximation is more than enough, while in others not even the Steinhart-Hart equation fulfills the requirements, and the thermistor has to be calibrated point by point, making a large number of measurements and creating a lookup table.

# Construction and Properties of NTC Thermistors

Materials typically involved in the fabrication of NTC resistors are platinum, nickel, cobalt, iron and oxides of silicon, used as pure elements or as ceramics and polymers. NTC thermistors can be classified into three groups, depending on the production process used.

## Bead thermistors

These NTC thermistors are made from platinum alloy lead wires directly sintered into the ceramic body. They generally offer fast response times, better stability and allow operation at higher temperatures than Disk and Chip NTC sensors, however they are more fragile. It is common to seal them in glass, to protect them from mechanical damage during assembly and to improve their measurement stability. The typical sizes range from 0.075 – 5 mm in diameter.



## Disk and Chip thermistors

These NTC thermistors have metalized surface contacts. They are larger and, as a result, have slower reaction times than bead type NTC resistors. However, because of their size, they have a higher dissipation constant (power required to raise their temperature by 1 °C). Since the power dissipated by the thermistor is proportional to the square of the current, they can handle higher currents much better than bead type thermistors. Disk type thermistors are made by pressing a blend of oxide powders into a round die and then sintering at high temperatures. Chips are usually fabricated by a tape-casting process where a slurry of material is spread out as a thick film, dried and cut into shape. The typical sizes range from 0.25 to 25 mm in diameter.



## Glass encapsulated NTC thermistors

These are NTC temperature sensors sealed in an airtight glass bubble. They are designed for use with temperatures above 150 °C, or for printed circuit board mounting, where ruggedness is a must. Encapsulating a thermistor in glass improves the stability of the sensor and protects the sensor from the environment. They are made by hermetically sealing bead type NTC resistors into a glass container. The typical sizes range from 0.4 to 10 mm in diameter.



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