NTC Thermistor General Information - Technical Overview

1. What is an NTC Thermistor?

NTC (Negative Temperature Coefficient) thermistors are thermally sensitive semiconductor resistors which show a sharp decrease in resistance as temperature increases. At the heart of the NTC Thermistor is a polycrystalline semiconductor ceramic material with a spinel structure mainly composed of metal oxides such as manganese, nickel, cobalt, iron, and copper.

In general, when the metal temperature become high, the frequency of the metal atom's vibration increases which in turn prevents free electron transfer. As a result, the resistance of the metal will be increased.

On the other hand, NTC thermistor semiconductorized with precise composition control has active hopping conductivity by free electrons and electron holes pair when the temperature increases, and this decreases resistance. The electrical conductivity of NTC thermistors is normally explained by band theory.

2. Characteristics

The resistance change of the NTC thermistor is caused by changes in ambient temperature and self-heating. Note: Ambient heating includes all forms of heat external to the NTC Thermistor.

When an electric current flows through the thermistor, Joule heat causes the self-heating. Self-heating influence is small enough to be negligible and is called a "no-load" characteristics.

2.1. No-load NTC thermistor

2.1.1. Resistance Temperature (R/T) characteristics

The relationship between the resistance value and absolute temperature of the NTC thermistor within an NTC's operating temperature range is approximated by an exponential function (See Formula 1).

$$R_1 = R_2 \cdot \exp(B \cdot (1/T_1 - 1/T_2)) \qquad \text{(Formula 1)}$$

R_1	NTC Resistance in Ω at temperature T_1 in K
R_2	NTC Resistance in Ω at reference temperature T_2 in K
B	B value in K, Material Constant of NTC thermistor

However, in practice, a resistance/temperature relationship table (R/T table) within the operating temperature range of the NTC will be given.

2.1.2. B value

The B value is determined by the NTC material and is expressed as the slope of the R/T curve. The B value is represented below in Formula 2 which is another form of expressing Formula 1 solved for B.

$$B = (\ln R_1 - \ln R_2)/(1/T_1 - 1/T_2) \quad \text{(Formula 2)}$$

Since Formula 1 is an approximation, the B value is a "constant", but it actually varies slightly depending on the temperature range. Therefore, the B value calculated from 25°C and 85°C is expressed with the denotation $B_{25/85}$.

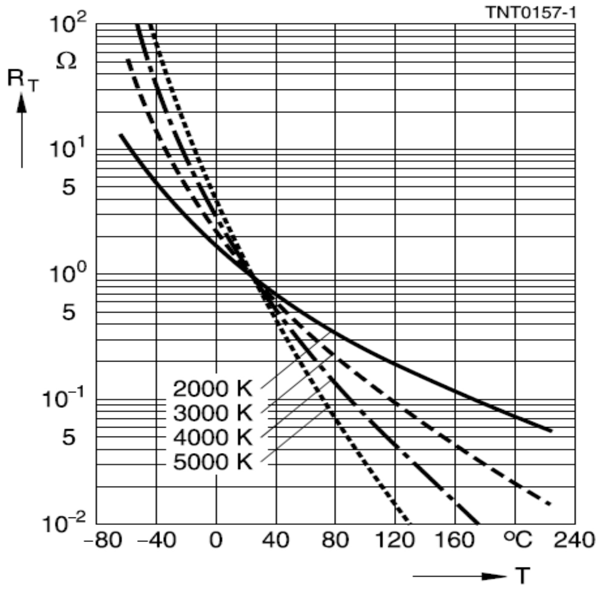

Figure 1. Temperature-resistance characteristics (parameter: B value)

The B values of common NTC materials range is from 3000K to 5000K. Figure 1 shows the R/T characteristic dependence of the B value. Choosing a B value is application specific and selecting the correct B value must be balanced when selecting nominal resistance along with other constraints as not all B values are available for all NTC packaging's and types.

2.1.3. Temperature coefficient

The temperature coefficient of the resistance value is defined by the relative change in the resistance value due to the temperature change.

$$\alpha = 1/R \cdot dR/dT \quad \text{(Formula 3)}$$

2.1.4. Tolerance

Resistance tolerance

The resistance tolerance for an NTC thermistor is specified for one temperature point, which is application specific and the standard value is usually 25°C. It is also possible to specify at the other temperatures upon customer request.

In general, the resistance tolerance can be expressed by the following Formula:

$$\Delta R_1 = |\partial R(T) / \partial R_2| \cdot \Delta R_2 + |\partial R(T) / \partial B| / \Delta B + |\partial R(T) / \partial T| \cdot \Delta T \quad \text{(Formula 4)}$$

If the third temperature-dependent term in Formula 4 can be neglected, the formula can be simplified as follows:

$$|\Delta R_1 / R_1| = |\Delta R_2 / R_2| + |\Delta R_B / R_1| \quad \text{(Formula 5)}$$

In this formula, ΔR_B denotes the resistance tolerance resulting from the spread of the B value. This means the resistance tolerance at a certain temperature is influenced by two variables: the tolerance of rated resistance value and the variation of the B value. The resistance tolerance characteristics for different rated tolerances of resistance $\Delta R_R/R_R$ is shown in figure 2. The curves are displaced by a constant value. Figure 3 shows the influence of different rated B value tolerances on the resistance tolerance characteristics. A higher B means a higher slope of the resistance tolerance curve.
Selecting the tolerance of an NTC is another decision point as many customers often have a target precision window that needs to be balanced with the full range of temperature functionality.

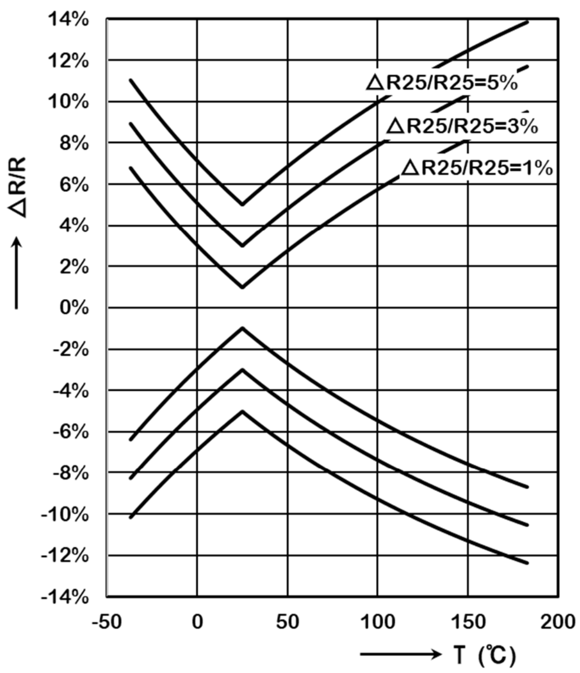

Figure 2. Change in resistance tolerance by ΔR25/R25=1%, 3% and 5%.
(R25=10kohm, B value=3400K, ΔB/B=2%)

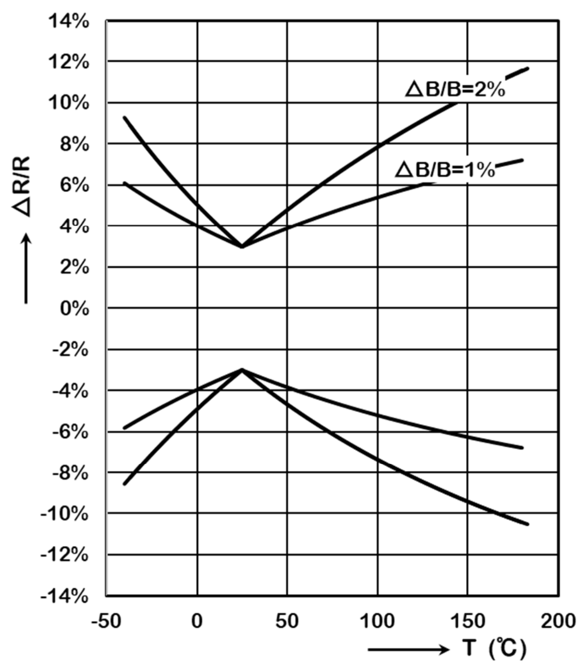

Figure 3. Change in resistance tolerance by ΔB/B=1% and 2%
(R25=10kohm, B value=3400K, ΔR25/R25=3%)

Temperature tolerance

By means of Formula 3, the temperature tolerance can be calculated for small temperature interval as following formula:

$$\Delta T = 1 / \alpha \cdot \Delta R / R \quad \text{(Formula 6)}$$

For practical application, we recommend that the standardized R / T table be used.

2.2. Electrical load on NTC thermistors

2.2.1. Heat dissipation constant: δ_{th}

When an electric current flows through a thermistor, the thermistor itself heats up due to Joule heat. This self-heating can be expressed as follows:

$$P_{el} = V \cdot I = \delta_{th} \cdot (T - T_A) \quad \text{(Formula 7)}$$

$$\delta_{th} = P_{el} / (T - T_A) = V \cdot I / (T - T_A) = R_T \cdot I^2 / (T - T_A) \quad \text{(Formula 8)}$$

P_{el}	Power Supplied
V	Voltage applied on the thermistor
I	Current flowing through the thermistor
δ_{th}	NTC Thermistor Heat Dissipation Constant
T	Temperature reached at thermal equilibrium
T_A	Ambient temperature
R_T	Thermistor resistance at temperature T

The Heat Dissipation Constant δ_{th} is expressed in mW/K and serves as a measure of the load that causes a thermistor in steady state to raise its body temperature by 1 K. The higher the dissipation factor, the more heat is dissipated by the thermistor to its surroundings.

When using the NTC thermistor, some error due to the temperature increase of the thermistor itself always occurs. To keep this measurement error small, make sure the power usage is minimized well below the NTC's maximum power rating. However, as the thermistor has various resistance values and electrical properties, there is no general optimal design method. Please note that all figures for the thermal characteristic value of NTC thermistors typically refers to still air. Thermal characteristics may change under other atmospheric conditions such as stirring air or when customer processed after shipment.

2.2.2. Voltage/current characteristics

If constant electrical power is applied to a thermistor, the temperature of the thermistor will be sharply increased, but this change declines with time. After some time, the NTC temperature will reach a steady state where power is consumed by heat conduction and convection.

In case of thermal equilibrium $dT/dt = 0$

$$V \cdot I = \delta_{th} \cdot (T - T_A) \quad \text{(Formula 9)}$$

With Ohm's Law $V = I \cdot R$, the Formula 9 can be written as

$$I = \sqrt{(\delta_{th} \cdot (T - T_A) / R(T))} \quad \text{(Formula 10a)}$$

or

$$V = \sqrt{(\delta_{th} \cdot (T - T_A) \cdot R(T))} \quad \text{(Formula 10b)}$$

This is a parametric description of the voltage/current characteristics with R(T) being the temperature-dependent NTC thermistor. Using the Formula above, these curves can be calculated for different ambient temperatures.

By plotting the voltage value obtained at a constant temperature as a function of the current, the voltage/current characteristics of the NTC thermistor are obtained. (Figure 4)

The curves of constant power and constant resistance are straight lines at log-log scale. The voltage/current characteristics of the NTC thermistor have four sections.

1. The straight "constant" rise section where the dissipation power only produces negligible self-heating.
   Voltages and currents are proportional to each other. The resistance value is determined by the ambient temperature. In this section, the NTC thermistor is used as a temperature sensor. → (dV/dI = R = constant)

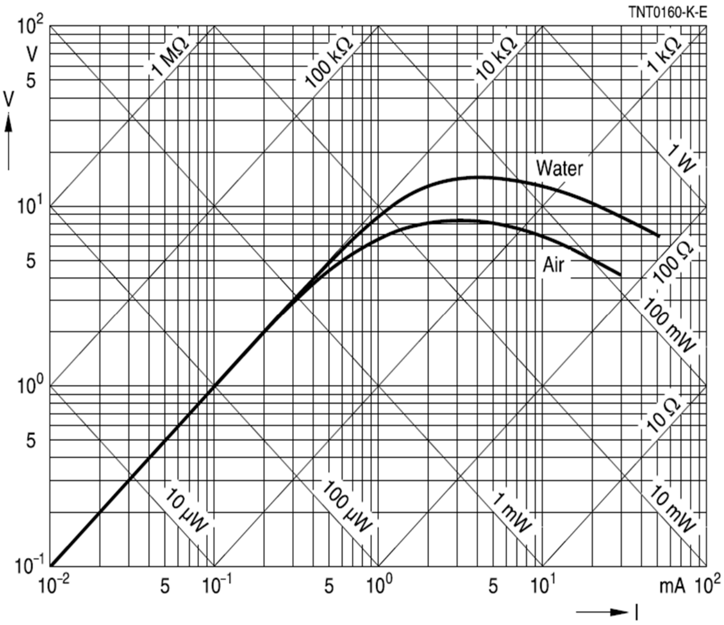

Figure 4. Current-Voltage characteristics

2. The section of non-linear rise up to maximum voltage where resistance already beings to drop. → (R > dV/dI > 0)

3. Zero resistance increase at maximum voltage. → (dV/dI = 0)

4. The falling-edge section where the decrease in resistance is greater than the relative increase in current. In this section, NTC thermistors can employ a self-heating effect is desired. (e.g., inrush current limiters, liquid level sensors) → (dV/dI < 0)

2.2.3. Maximum power P_{25}

P_{25} is the maximum power an NTC thermistor is capable of handling at ambient temperatures of 25°C in still air. When the maximum power P_{25} is applied to the NTC thermistor, it operates in the self-heating section. Unless directly targeted operating in the self-heating section should be avoided. In most applications proper circuit design allows the NTC to operate well within its maximum power rating.

2.2.4. Thermal Time Constant τ

When a temperature sensor with temperature T_1 is placed in an environment of temperature T_2 (air, water), the change in temperature of the sensor as a function of time in an exponential function.

$$T(t) = T_2 + (T_1 - T_2) \cdot e^{-t/\tau a} \qquad \text{(Formula 11)}$$

When time $t = \tau$,

$$T(\tau) = T_1 + (T_2 - T_1) / (1 - 1/e) \qquad \text{(see Figure 5)}$$

The temperature change of the NTC thermistor at time τ is $1 - 1/e = 63.2\%$ of the temperature difference T_1-T_2. This time τ is defined as the Thermal Time Constant and often spoken as "Tau 63.2" or simply "Tau 63".

The Thermal Time Constant τ is an essential parameter when selecting a temperature sensor, but it is mainly affected by the following conditions:

■ Design (e.g. sensor elements, assembly materials for elements in sensor cases, connection methods, housings)

■ Mounting form (e.g. immersion, surface mount)

■ Environment (e.g. airflow, still air, liquids)

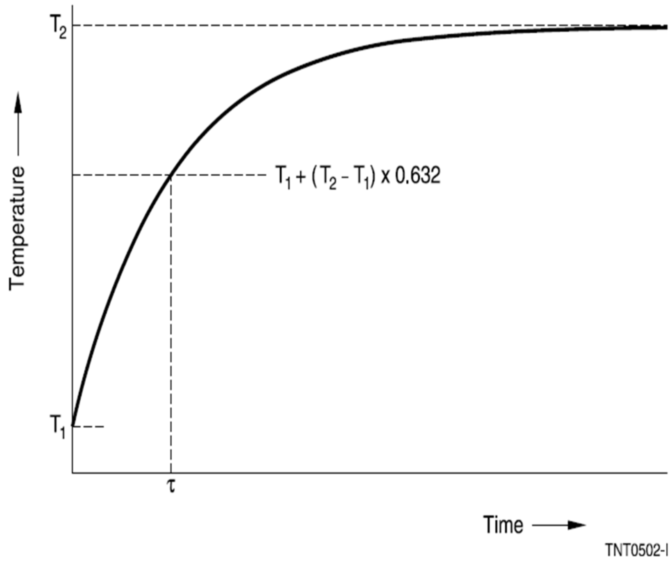

Figure 5. Sensor temperature change when ambient temperature increases from T_1 to T_2 (exponential approximation)