General Technical Information

1   Definition

As defined by IEC 60539 and EN 143000, NTC (Negative Temperature Coefficient) thermistors are thermally sensitive semiconductor resistors which show a decrease in resistance as temperature increases. With −2%/K to −6 %/K, the negative temperature coefficients of resistance are about ten times greater than those of metals and about five times greater than those of silicon temperature sensors.

Changes in the resistance of the NTC thermistor can be brought about either externally by a change in ambient temperature or internally by self-heating resulting from a current flowing through the device. All practical applications are based on this behavior.

NTC thermistors are made of polycrystalline mixed oxide ceramics. The conduction mechanisms in this material are quite complex, i.e. either extrinsic or intrinsic conduction may occur. In many cases NTC thermistors have a spinell structure and then show valence conduction effects.

2   Manufacture

EPCOS thermistors are produced from carefully selected and tested raw materials. The starting materials are different oxides of metals such as manganese, iron, cobalt, nickel, copper and zinc, to which chemically stabilizing oxides may be added to achieve better reproducibility and stability of the thermistor characteristics.

The oxides are milled to a powdery mass, mixed with a plastic binder and then compressed into the desired shape. Standard shapes are:

Disks: The thermistor material is compressed under very high pressure on pelleting machines to produce round, flat pieces.

Wafers: The ceramic material is compression-molded or drawn and then cut to the required shape.

The blanks are then sintered at high temperatures (between 1000 and 1400 °C) to produce the polycrystalline thermistor body. Disks are contacted by baking a silver paste onto the flat surfaces. Depending on the application, the thermistors are fitted with leads or tab connectors, coated or additionally incorporated in different kinds of housing. Finally the thermistors are subjected to a special ageing process to ensure high stability of the electrical values. Otherwise the NTC resistance would possibly change even at room temperature due to solid-state reactions in the polycrystalline material.

SMD NTC thermistors are produced in ceramic multilayer technology with and without inner electrodes and different outer terminations.

Flow charts in the quality section of this book (see "Quality", page 197) show the individual processing steps in detail. The charts also illustrate the extensive quality assurance measures taken during manufacture to guarantee the constantly high quality level of our thermistors.

3   Characteristics

A current flowing through a thermistor may cause sufficient heating to raise the thermistor's temperature above the ambient. As the effects of self-heating are not always negligible (or may even be intended), a distinction has to be made between the characteristics of an electrically loaded thermistor and those of an unloaded thermistor. The properties of an unloaded thermistor are also termed "zero-power characteristics".

3.1 Unloaded NTC thermistors

3.1.1 Temperature dependence of resistance

The dependence of the resistance on temperature can be approximated by the following equation:

$$R_T = R_N \cdot e^{B \cdot \left(\frac{1}{T} - \frac{1}{T_N}\right)} \tag{1}$$

R_T NTC resistance in Ω at temperature T in K

R_N NTC resistance in Ω at rated temperature T_N in K

T, T_N Temperature in K

B B value, material-specific constant of the NTC thermistor

e Base of natural logarithm ($e = 2,71828$)

The actual characteristic of an NTC thermistor can be roughly described by the exponential relation. This approach, however, is only suitable for describing a restricted range around the rated temperature or resistance with sufficient accuracy.

For practical applications a more precise description of the real R/T curve is required. Either more complicated approaches (e.g the Steinhart-Hart equation) are used or the resistance/temperature relation is given in tabulated form. Subsequent to the data sheet section you will find tables for real R/T curves (see "Standardized R/T Characteristics", page 150 ff). These standardized curves have been experimentally determined with utmost accuracy; they are also available for temperature increments of 1 degree.

3.1.2 *B* value

The B value is determined by the ceramic material and represents the slope of the R/T curve. In equation 1 the B value is defined by two points of the R/T curve (R_T, T) and (R_N, T_N). In other words:

$$B = \frac{T \cdot T_N}{T - T_N} \cdot ln\frac{R_N}{R_T} \tag{2}$$

The specifications in this databook refer to resistance values at temperatures of 25 °C (T_1) and 100 °C (T_2): $B_{25/100}$ (equation 2a). For SMD NTCs B values at other temperatures are given as well: $B_{25/50}$ (equation 2b) and $B_{25/85}$ (equation 2c). Glass encapsulated NTCs refer also to other temperatures (e. g. $B_{0/100}$, $B_{100/200}$). The B values can be calculated according to equation (2).

The B value for a particular NTC thermistor can be determined by measuring the resistance at 25 °C (R_1) and 100 °C (R_2) and inserting these resistance values into the following equation:

$$B_{25/100} = \frac{T_1 \cdot T_2}{T_2 - T_1} \cdot ln\frac{R_1}{R_2} = \frac{(25 + 273,15) \cdot (100 + 273,15)}{75} \cdot ln\frac{R_{25}}{R_{100}} = 1483,4 \cdot ln\frac{R_{25}}{R_{100}} \tag{2a}$$

For SMD NTC thermistors also $B_{25/50}$ and $B_{25/85}$ are commonly used and therefore specified in addition:

$$B_{25/50} = 3853,9 \cdot ln\frac{R_{25}}{R_{50}} \tag{2b}$$

$$B_{25/85} = 1779,7 \cdot ln\frac{R_{25}}{R_{85}} \tag{2c}$$

The *B* values for common NTC materials range from 2000 through 5000 K. Figure 1 illustrates the dependence of the *R/T* characteristic on the *B* value.
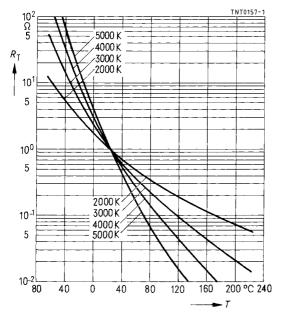

Figure 1

Resistance/temperature characteristics
(Parameter: *B* value)

3.1.3   Tolerance

The rated resistance R_N and the *B* value are subject to manufacturing tolerances. Due to this tolerance of the *B* value, an increase in resistance spread must be expected for temperatures that lie above or below the rated temperature T_N.

With regard to the tolerance of resistance a distinction is made between two basic types of NTC thermistor:

a) Point-matching NTC thermistors

With point-matching NTC thermistors a particular resistance tolerance is specified for one temperature point, which is usually 25 °C. In principle, NTC thermistors can also be point-matched to other temperatures than those specified in the data sheets (upon customer request). Point-matching NTC thermistors are ideal for applications where exact measurements are to be performed within a tight range around the rated values. Example: refrigerator sensor at 0 °C (M2020).
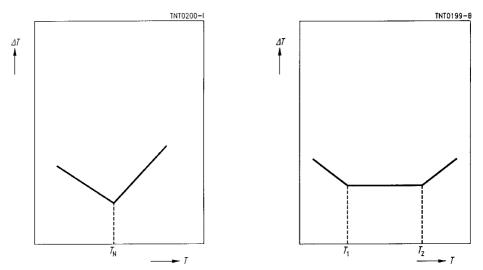
b) Uni curve NTC thermistors

Uni curve NTC thermistors are used when a high measuring accuracy is required over a wide temperature range (T_1 … T_2). For this kind of application we offer several standard types for which measuring accuracies between 0,2 and 0,5 K (depending on requirements) can be guaranteed over a temperature range of 0 through 70 °C. Thus only one NTC thermistor is required to measure different temperatures with the same accuracy. Uni curve thermistors are available as mini-sensors (S863, S869).

Typical curves for the temperature tolerances of point-matching and uni curve thermistors
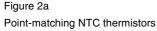

Figure 2a

Point-matching NTC thermistors

Figure 2b

Uni curve NTC thermistors

Generally, the resistance tolerance can be expressed by the following relation:

$$\Delta R_T = \left| \frac{\partial R(T)}{\partial R_N} \right| \cdot \Delta R_N + \left| \frac{\partial R(T)}{\partial B} \right| \cdot \Delta B + \left| \frac{\partial R(T)}{\partial T} \right| \cdot \Delta T \tag{3}$$

If the third temperature-dependent term in (3) is neglected, the equation can be simplified as follows:

$$\left| \frac{\Delta R_T}{R_T} \right| = \left| \frac{\Delta R_N}{R_N} \right| + \left| \frac{\Delta R_B}{R_T} \right| \tag{4}$$

In this formula ΔR_B denotes the resistance tolerance resulting from the spread of the B value.

As can be seen from the equation, the resistance tolerance at a certain temperature is influenced by two variables: the manufacturing tolerance of the rated resistance and the variation of the B value with temperature.

For a practical estimate of resistance and temperature tolerances see "Standardized R/T Characteristics", page 147 ff).

3.1.4 Temperature coefficient α

The temperature coefficient of resistance is defined as the relative change in resistance referred to the change in temperature.

$$\alpha = \frac{1}{R} \cdot \frac{dR}{dT} \tag{5}$$

By means of this equation resistance and temperature tolerances can be calculated for small temperature intervals.

$$\Delta T = \frac{1}{\alpha \cdot R} \cdot \Delta R \qquad\qquad \Delta R = \alpha \cdot R \cdot \Delta T \tag{6}$$

For practical application we recommend that the standardized R/T curves (see the "Standardized R/T Characteristics", page 147 ff) are used; the temperature steps tabulated there are small enough to permit calculation by the approximation formulae given above.

3.1.5 Zero-power measurement

The zero-power resistance is the resistance value measured at a given temperature T with the electrical load kept so small that there is no noticeable change in the resistance value if the load is further decreased. At too high a measuring load the test results will be distorted by the self-heating effect (see 3.2). When a low-resistance NTC thermistor is to be measured, the resistance of the measuring lines must be taken into account.

Example: For S861, R_{25} = 10 kΩ the measuring current I_{Meas} is $\leq$100 μA.

3.2 Electrically loaded NTC thermistors

When a current flows through the thermistor, the device will heat up more or less by power dissipation. This self-heating effect depends not only on the load applied, but also on the thermal dissipation factor δ and the geometry of the thermistor itself.

The general rule is:

The smaller the device, the smaller is the permissible maximum load and the measuring load (zero power).

The following general rule applies to self-heating of an NTC thermistor by an electrical load:

$$P = V \cdot I = \frac{dH}{dt} = \delta_{th} \cdot (T - T_A) + C_{th} \cdot \frac{dT}{dt} \tag{7}$$

P	Electrical power applied
V	Instantaneous value of NTC voltage
I	Instantaneous value of NTC current
dH/dt	Change of stored thermal energy with time
δ	Dissipation factor of NTC thermistor
T	Instantaneous temperature of NTC thermistor
T_A	Ambient temperature
C_{th}	Heat capacity of NTC thermistor
dT/dt	Change of temperature with time

3.2.1 Voltage/current characteristic

If a constant electrical power is applied to the thermistor, its temperature will first increase considerably, but this change declines with time. After some time a steady state will be reached where the power is dissipated by thermal conduction or convection.

In case of thermal equilibrium dT/dt equals 0 and thus one obtains

$$V \cdot I = \delta_{th} \cdot (T - T_A) \tag{8}$$

and with $V = R \cdot I$:

$$I = \sqrt{\frac{\delta_{th} \cdot (T - T_A)}{R(T)}} \tag{9a}$$

or
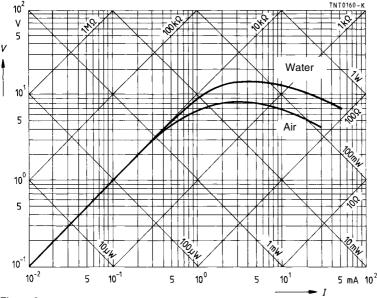
$$V = \sqrt{\delta_{th} \cdot (T - T_A) \cdot R(T)} \tag{9b}$$

This is the socalled parametric description of the voltage/current curve with $R(T)$ being the temperature-dependent NTC resistance. With the aid of the above equations these curves can be calculated for different ambient temperatures.

By plotting the voltage values obtained at constant temperature as a function of current one gets the voltage/current characteristic of the NTC thermistor.

Figure 3

Current/voltage characteristic

Measurement at constant ambient temperature, still air

On a log-log scale the curves for constant power and constant resistance take the shape of a straight line.

The voltage/current characteristic of an NTC thermistor has three different sections:

1. The section of straight rise where the dissipation power only produces negligible self-heating. Voltage and current are proportional to each other and follow Ohm's law. The resistance value is exclusively determined by the ambient temperature. Use of this curve section is made when NTC thermistors are employed as temperature sensors.
($dV/dI = R$ = constant)

2. The section of non-linear rise up to maximum voltage where resistance already begins to drop. At maximum voltage the relative decrease in resistance $\Delta R/R$ resulting from self-heating is equal to the relative increase in current $\Delta I/I$.
($R > dV/dI \geq 0$)

3. The falling-edge section where the decrease in resistance is greater than the relative increase in current. This curve section in the operating area of NTC thermistors using the self-heating effect (e.g. inrush current limiters, liquid level sensors).
($dV/dI \leq 0$)

3.2.2 Behavior in different media

As shown by equations (9a) and (9b) the voltage/current curve is influenced not only by the NTC resistance R (T) but also by the dissipation factor δ_{th}. The dissipation factor, in turn, depends on size, shape and leads of the device as well as on the medium surrounding the thermistor.

The voltage/current curves specified in the data sheets apply to still air. In stirred air or in a liquid the dissipation factor increases and the V/I curve shifts towards higher values of voltage and current. The opposite applies when the thermistor is suspended in a vacuum.

The voltage/current curve thus indicates by which medium the thermistor is surrounded. This means that NTC thermistors can be used for sensing the flow rate of gases or liquids, for vacuum measurement or for gas analysis.

3.2.3 Maximum power rating P

P is the maximum power an NTC thermistor is capable of handling at a particular ambient temperature with its own temperature not exceeding the maximum category temperature. In addition to the ambient temperature, mainly the dissipation factor δ_{th} determines the power handling capability.

With known dissipation factor δ_{th} the maximum power handling capability can be calculated by:

$$P_{max} = \delta_{th} \, (T_{max} - T_A) \tag{10}$$

3.2.4 Dissipation factor δ_{th}

The dissipation factor δ_{th} is defined as the ratio of the change in power dissipation and the resultant change in the thermistor's body temperature. It is expressed in mW/K and serves as a measure for the load which 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 the environment.

$$\delta_{th} = dP/dT \tag{11}$$

For measuring δ_{th} the thermistor is loaded such that the ratio V/I corresponds to the resistance value measured at $T_2 = 85\ °C$.

$$\delta_{th} = \frac{V \cdot I}{T - T_A} = \frac{P}{T - T_A} \tag{12}$$

T Body temperature of the NTC thermistor (85 °C)
T_A Ambient temperature

3.2.5 Heat capacity C_{th}

The heat capacity C_{th} is a measure for the amount of heat required to raise the NTC's mean temperature by 1 K. C_{th} is stated in mJ/K.

$$C_{th} = \frac{\Delta H}{\Delta T} \tag{13}$$

The relationship between heat capacity, dissipation factor and thermal time constant is expressed by:

$$C_{th} = \delta_{th} \cdot \tau_c \tag{14}$$

3.2.6   Thermal cooling time constant τ_c

The thermal cooling time constant refers to the time necessary for an unloaded thermistor to vary its temperature by 63,2 % of the difference between its mean temperature and the ambient temperature.

τ_c depends to a large extent on the component design. The values of τ_c specified in this data book have been determined in still air at an ambient temperature of 25 °C.

The NTC thermistor is internally heated to 85 °C to measure subsequently the time it requires to cool down to 47,1 °C at an ambient temperature of 25 °C. This adjustment to the ambient is asymptotic and occurs all the faster, the smaller the device is.

3.2.7   Thermal time constant τ_a

The thermal time constant refers to the time it takes an unloaded thermistor to raise its body temperature from 25 °C to 62,9 °C when it is immersed in a medium having a temperature of 85 °C. Equally to thermal cooling time constant, τ_a depends on the medium surrounding the device. The medium used for measuring τ_a (e.g. water) is specified in the data sheets.

Determining the thermal time constant:

a) The zero-power-resistance is measured at 25 °C.
   The zero-power resistance is measured at 62,9 °C.

b) The NTC thermistor is immersed in a liquid bath with a temperature of $(25 \pm 0,1)$ °C until it has assumed the same temperature as the liquid.

c) The NTC thermistor is then immediately transferred into a second bath with a temperature of $(85 \pm 0,1)$ °C. Subsequently the time is measured it takes the thermistor to reach again the zero-power resistance measured under a) for 62,9 °C.

The resulting time is the thermal time constant for an *external* temperature change.

3.2.8   Ageing and stability

At room temperature the polycrystalline material shows solid-state reactions which lead to an irreversible change in the characteristics (usually resistance increase, change of *B* value etc).

Physical reasons for this may be thermal stress causing a change in concentration of lattice imperfections, oxygen exchange with the environment (with unprotected, non-glass-encapsulated thermistors) or diffusion in the contact areas of metallized surface contacts. At low temperatures these reactions slow down, but at high temperatures they accelerate and finally decline with time. To enhance long-term stability, our NTC thermistors are subjected to an ageing process directly after manufacture.

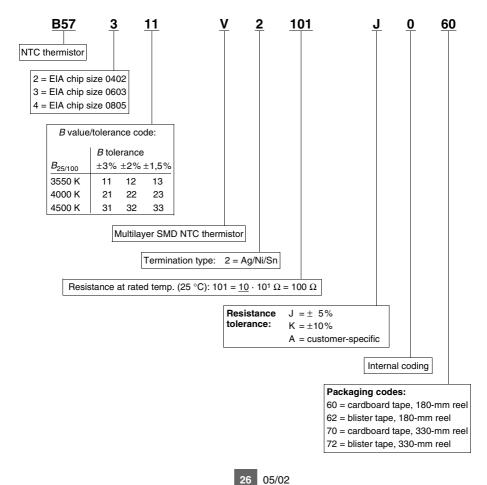## 4 How to determine the ordering code for SMD NTC thermistors

A component and the packing in which it is to be delivered are unambiguously defined by the ordering code (part number), which has up to 15 digits.

For all NTC thermistors the ordering codes are explicitly stated (together with the corresponding tolerance and/or packing variants) in the data sheets.

Should there be any doubt about the coding system, however, then it is better to order the component using a plain text description (i.e. without a code). In this case, the translation into the part number, which is required for internal handling of the order, will be done by us. The components are delivered by part numbers only.
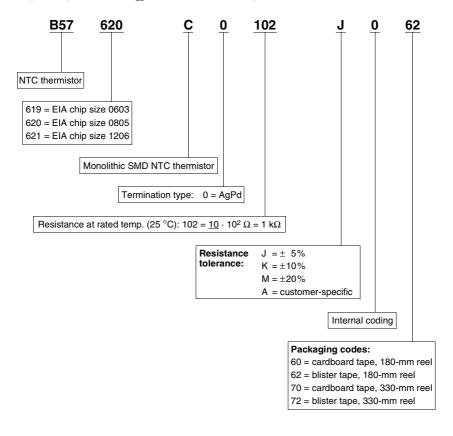
SMD NTC thermistors with nickel barrier termination

Example: Chip size 0603, $B_{25/100}$ = 3550 K $\pm$ 3%, R_{25} = 100 Ω $\pm$ 5%, cardboard tape, 180-mm reel

B57   3   11   V   2   101   J   0   60

NTC thermistor

2 = EIA chip size 0402
3 = EIA chip size 0603
4 = EIA chip size 0805

B value/tolerance code:

$B_{25/100}$	*B* tolerance		
	$\pm$3%	$\pm$2%	$\pm$1,5%
3550 K	11	12	13
4000 K	21	22	23
4500 K	31	32	33

Multilayer SMD NTC thermistor

Termination type: 2 = Ag/Ni/Sn

Resistance at rated temp. (25 °C): 101 = $\underline{10}$ · 10^1 Ω = 100 Ω

Resistance tolerance: J = $\pm$ 5%
K = $\pm$10%
A = customer-specific

Internal coding

Packaging codes:
60 = cardboard tape, 180-mm reel
62 = blister tape, 180-mm reel
70 = cardboard tape, 330-mm reel
72 = blister tape, 330-mm reel

SMD NTC thermistors with silver palladium termination

Example: Chip size 0805, R_{25} = 1 k$\Omega \pm$ 5%, blister tape, 180-mm reel

B57	620	C	0	102	J	0	62

NTC thermistor

619 = EIA chip size 0603
620 = EIA chip size 0805
621 = EIA chip size 1206

Monolithic SMD NTC thermistor

Termination type: 0 = AgPd

Resistance at rated temp. (25 °C): 102 = <u>10</u> · 10^2 Ω = 1 kΩ

Resistance tolerance:
J = $\pm$ 5%
K = $\pm$10%
M = $\pm$20%
A = customer-specific

Internal coding

Packaging codes:
60 = cardboard tape, 180-mm reel
62 = blister tape, 180-mm reel
70 = cardboard tape, 330-mm reel
72 = blister tape, 330-mm reel