SMD NTC Thermistors
Temperature Measurement
and Compensation for General Use

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A TDK Group Company
Piezo and Protection Devices Business Group
Munich, Germany
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What does 'NTC' mean?

**Definition**

NTC = Negative Temperature Coefficient

**Component**

NTC Thermistor

- The resistance of an NTC thermistor decreases exponentially to the temperature (negative R/T curve).
- The R/T curve is non-linear.
- The temperature coefficient $a$ is $\sim 2\ldots 6\% /K$ and also temperature-depending.
- The B value is used to characterize the R/T curve and is a material constant.
- The nominal resistance $R_R$ for NTC ranges from some mW to $>1$ MW.

NTC thermistors are simple but very sensitive and accurate sensing elements for measuring and control circuits.
## Terms and description

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_R )</td>
<td>Rated resistance in Ω of an unstressed thermistor at the rated temperature ( T_R ) (@ 25 °C)</td>
</tr>
<tr>
<td>( R_T )</td>
<td>Resistance value in Ω at ambient temperature</td>
</tr>
<tr>
<td>( T_R )</td>
<td>Rated temperature in Kelvin [K] @ 25 °C (= 298.15 K)</td>
</tr>
<tr>
<td>( T )</td>
<td>Ambient temperature in K</td>
</tr>
<tr>
<td>( B )</td>
<td>Material-specific constant of NTC thermistor which shows the change in the resistance. Since the B value changes slightly with the temperature, the value of the B constant changes by the defined temperature.</td>
</tr>
<tr>
<td>( B_{25/100} )</td>
<td>The specifications in the data sheets refer to resistance values at temperatures of 25 °C ( (T_R) ) and 100 °C ( (T) ).</td>
</tr>
<tr>
<td>( B_{25/50} )</td>
<td>Additionally given for information.</td>
</tr>
</tbody>
</table>
| \( \alpha \) | The temperature coefficient is a rough guide value within a small temperature range in percent per temperature degree (%/K or %/ °C). It is the relative change in resistance referred to the change in temperature (~2...6%/K): \[
\alpha = \frac{1}{R_1} \cdot \frac{R_2 - R_1}{T_2 - T_1} = \frac{1}{R_R} \cdot \frac{dR}{dT}
\] |

It is calculated between two specified ambient temperatures according to the following formula:

\[
B = \frac{T \cdot T_R}{T_R - T} \cdot \ln \frac{R_T}{R_R} = \frac{T \cdot T_R}{T - T_R} \cdot \ln \frac{R_R}{R_T}
\]
R/T calculation

Small temperature range

\[ \alpha = \frac{1}{R} \cdot \frac{dR}{dT} \]

Large temperature range

\[ R_T = R_R \cdot e^{B \cdot \left( \frac{1}{T} - \frac{1}{T_R} \right)} \]

Steinhart-Hart equation

\[ R_T = e^{\left( a + b \frac{1}{T} \right) + c \frac{1}{T^2} + d \frac{1}{T^3} + e \frac{1}{T^4}} \]

...simply use our R/T calculation tool under http://en.tdk.eu and go to ‘design support/NTC thermistors’.

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A2 PPD MLV/NTC 05/16 4
**Physics of NTC ceramics**

- NTC are polycrystalline (mixed) oxide ceramics.
- The crystal structure is basically a Spinel structure which is formed during the sintering process.
- At high sinter temperatures (~1200 °C) Ni and Mn atoms ‘share’ both A and B places whereby they change their valence.

Spinel structure $\text{NiMn}_2\text{O}_4 \,(\text{AB}_2\text{O}_4)$

For NTC

- A places = Ni, (Co, Zn, Al, Fe) – grey
- B places = Mn, (Ni) - rose

- A metastable crystal state with both Ni and Mn atoms on A and B places. Electrons can be exchanged $\rightarrow$ Hopping conductivity

- The amount of ‘exchanged’ electrons increases proportional with the ambient temperature $\Rightarrow$ the NTC effect is created.
Comparison of NTC and PTC thermistors

**PTC thermistors**

- A PTC is a limit temperature sensors to protect over temperatures (resp. overcurrent) – no competition to NTC.
- The resistance of an PTC thermistor INCREASES drastically at a specific $T_{\text{Ref}}$ (positive R/T curve).
- $T_{\text{Ref}}$ and $R_N$ is used to characterize the R/T curve. $T_{\text{Ref}}$ is a material constant.
- The temperature coefficient $a$ is $\sim 30...50\%/K$ above $T_{\text{Ref}}$ (material constant).
- The resistance ranges from some $\Omega$ to $k\Omega$.
- Material: Ceramic BaTiO$_3$.

**NTC thermistors**

- A NTC is a simple but very sensitive and accurate sensing elements for measuring and control circuits.
- The resistance of an NTC thermistor DECREASES with increasing temperature (negative R/T curve).
- The B value is used to characterize the R/T curve and is a material constant.
- The temperature coefficient $a$ is $\sim 2...6\%/K$ and also temperature depending.
- The resistance ranges from some $\Omega$ to $>1\ \text{M}\Omega$.
- Material: Ceramic metal oxide.
# LED: Temperature protection concepts

<table>
<thead>
<tr>
<th>Fixed resistor</th>
<th>PTC</th>
<th>NTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low cost solution</td>
<td>Medium cost solution</td>
<td>Medium cost solution</td>
</tr>
<tr>
<td>Bad light efficiency</td>
<td>Better light efficiency</td>
<td>Excellent light efficiency</td>
</tr>
<tr>
<td>Change of LED color</td>
<td>Change of LED color</td>
<td>No change of LED color</td>
</tr>
<tr>
<td>Limited life time</td>
<td>Limited life time</td>
<td>Extension of Life time</td>
</tr>
</tbody>
</table>

- **Black**: LED derating curve
- **Red**: The maximum light efficiency is not reached at lower temperatures.
- **Green**: The light efficiency can be increased over a large temperature range.
- **Blue**: Light efficiency = LED derating curve with 1% accuracy

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**Black LED derating curve**

- **Red**: The maximum light efficiency is not reached at lower temperatures.
- **Green**: The light efficiency can be increased over a large temperature range.
- **Blue**: Light efficiency = LED derating curve with 1% accuracy
Resistance $R_T$ as function of temperature

The higher the $B$ value the steeper the curve the larger the resistance change.
It is important to know the operating temperature range and therefore the tolerance (both R and B value tolerance). With this information the best fitting NTC thermistor can be selected for the application.

\[ \Delta T = \frac{1}{\alpha} \cdot \Delta R \]

<table>
<thead>
<tr>
<th>R₂₅</th>
<th>B₂₅/10₀</th>
<th>ΔT @ 25 °C</th>
<th>ΔT @ 100 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 k ±1%</td>
<td>3455 K ±1%</td>
<td>±0.3 °C</td>
<td>±1.3 °C</td>
</tr>
<tr>
<td>10 k ±5%</td>
<td>3455 K ±3%</td>
<td>±0.3 °C</td>
<td>±4.7 °C</td>
</tr>
<tr>
<td>10 k ±5%</td>
<td>3455 K ±3%</td>
<td>±1.3 °C</td>
<td>±2.9 °C</td>
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</tbody>
</table>
Resistance accuracy $\Delta R$

The resistance tolerance is specified for one temperature point, which is usually 25 °C. Upon customer request other temperatures are possible.

![Graph showing resistance accuracy for temperatures 25 °C and 100 °C.]

- $\Delta R$ @ 25 °C = ± 5.0%
- $\Delta R$ @100 °C = ± 16.4%
- $\Delta R$ @ 25 °C = ± 14.1%
- $\Delta R$ @ 100 °C = ± 5.0%
How to find the best fitting SMD NTC thermistor

- Which **temperature range** is needed for the application?
- What **temperature accuracy** is needed at which temperature range?
- What is the required **resistance** and **tolerance** in which temperature range?
- What are the **qualification standards**?
- What is the **soldering** process?
- Any customer **specific requirements**?
# SMD NTC product overview

## Standard series

<table>
<thead>
<tr>
<th>EIA case size</th>
<th>$R_{25}$ [kΩ]</th>
<th>$\Delta R_R$ [%]</th>
<th>$B_{25/50}$ [K]</th>
<th>$B_{25/85}$ [K]</th>
<th>$B_{25/100}$ [K]</th>
<th>$\Delta B_{25/100}$ [%]</th>
<th>Ordering code</th>
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</thead>
<tbody>
<tr>
<td>0402</td>
<td>10 ±1, ±5</td>
<td>3380</td>
<td>3435</td>
<td>3455 ±1</td>
<td>B57230V2103+260</td>
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<td></td>
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<tr>
<td>0402</td>
<td>10 ±5</td>
<td>3940</td>
<td>3980</td>
<td>4000 ±3</td>
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<tr>
<td>0402</td>
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<td>4548</td>
<td>4575 ±3</td>
<td>B57261V2223J060</td>
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<tr>
<td>0402</td>
<td>47 ±5</td>
<td>3940</td>
<td>3980</td>
<td>4000 ±3</td>
<td>B57221V2473J060</td>
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<tr>
<td>0402</td>
<td>47 ±1, ±3, ±5</td>
<td>4050</td>
<td>4108</td>
<td>4131 ±1</td>
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<td>3435</td>
<td>3455 ±1</td>
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<td>0603</td>
<td>22 ±3, ±5</td>
<td>4386</td>
<td>4455</td>
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<tr>
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<td>4455</td>
<td>4480 ±3</td>
<td>B57371V2473+060</td>
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<tr>
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<td>4334 ±2</td>
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<tr>
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<tr>
<td>0805</td>
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<td>4455</td>
<td>4480 ±3</td>
<td>B57471V2223+062</td>
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<td></td>
</tr>
</tbody>
</table>

All SMD NTC thermistors are listed under UL, file number E69802.

### Features
- Accurate temperature sensing up to +125 °C
- Excellent long-term stability

### Applications
- Smart phone
- Wearable device
- Healthcare
- Smart meter
- Engine control unit
- Air-conditioning
- Radiator cooling fan control unit
- Battery sensor
- Industrial automation
- Security and safety
- White good
- Lighting, e.g. LED lighting modules, LED retrofit bulb & tube

+ = resistance tolerance
Application examples for SMD thermistors in non-automotive applications

- Household electronics, e.g. refrigerators and deep freezers, washing machines, water boilers
- Heating and air-conditioning e.g. thermostats
- Industrial electronics
- Displays
- Battery packs
- LED lighting

EPCOS does offer a broad portfolio of NTC thermistors which can be found in every application.
Application example: Thermostat

Function
- SMD NTC EIA 0402 ... 0603 1% tolerance
  High accuracy temperature measurement
- Proposed types
  - B57230V2103F260, EIA 0402 10 kΩ ±1%, 3455 K ±1%
  - B57330V2103F260, EIA 0603 10 kΩ ±1%, 3455 K ±1%

Application/ circuit

Operating temperature range: -40 °C ... +125 °C
Battery package and charger

Function

SMD NTC

Battery pack using NTC thermistors

- Detects temperature rises of the battery cell during charging.
- Detects the ambient temperature for optimized charging.
- Detects heat generation of a battery cell caused by abnormal current.
- Performs temperature compensation for voltage measurement for display of the remaining amount of energy.

Typical schematic

Charging control unit of a battery pack using NTC thermistors as temperature sensor
Application example: Displays, e.g. LCD

Function

SMD NTC

LCD using a NTC thermistor as temperature sensor

- LCDs are sensitive to temperature and have a limited operating temperature range.
- If a constant voltage is applied to the LCD, the contrast increases with temperature and power is wasted at high temperature.
- Low temperature on the other hand means a low unclear display.
- For these LCD modules often a temperature compensation circuit is used, consisting of NTC thermistors and resistors.
- The thermistor as main temperature-sensitive device with its characteristic resistance temperature curve provides a high driving voltage in the cold and a low driving voltage in the hot temperature region, compensating in this way the LCD temperature characteristic.

NTC thermistors provide an accurate temperature sensing up to +125 °C.
Temperature protection of LEDs with NTCs

Why controlling the LED junction temperature?

**Advantage**
- No change of color
- No reduction of lumens
- Extension of lifetime
- Performance efficiency optimization
- Optimum design (reduction number of LEDs)

**Function**
- Over temperature sensing for LED driver
- The resistance of an NTC thermistor decreases with increasing temperature (negative R/T curve).
- The R/T curve is non-linear.
- The temperature coefficient $\alpha$ is $\sim 2…6%/K$ and also temperature depending.
- The B value is used to characterize the R/T curve and is a material constant.
- The maximum power (@25 °C) ranges from mW to MW.

NTC = Negative temperature coefficient

NTC thermistors are simple but very sensitive and accurate sensing elements for measuring and control circuits.
Optimization of LED efficiency with NTCs

By high accurate temperature sensing

Task of NTC
Control optimum junction temperature $T_{\text{jun}}$ for max. lumen/ watt & lifetime

Accuracy of the LED thermal management can be strongly optimized using an NTC sensor for the control of the module temperature.

- LED array can be driven very close to the derating temperature.

Benefits
Increase of efficiency by 5% / 10 K higher driving temperature
- Strong cost impact, reduction of LEDs
- Increase of lifetime
SMD NTC development and production

Product range

Piezo and protection devices business group
- Multilayer ceramic components
- Piezo actuators

Systems, acoustics, waves business group
- Integrated HF components based on LTCC technology
- Microwave ceramic components
- DSSP packaging technology

Sensors business group
- NTC sensor elements

Certifications
- ISO 9001
- ISO/TS 16949
- ISO 14001

Founded in 1970
71000 m²
Process flow in production

| Slurry preparation | Frontend | Deutschlandsberg, AT |
| Mixing and milling |          |                      |
| Tape casting       |          |                      |
| Stacking and printing |      |                      |
| Pressing/ cutting  |          |                      |
| Debindering/ sintering |    |                      |

| Glass-coating process | Backend | Kutina, HRV |
| Burn-in of glass coating |      |            |
| Ag metalization       |          |            |
| Burn-in of termination |        |            |
| Electroplating of Ni/Sn |      |            |
| Measuring and taping  |          |            |