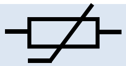
Attracting Tomorrow TDK

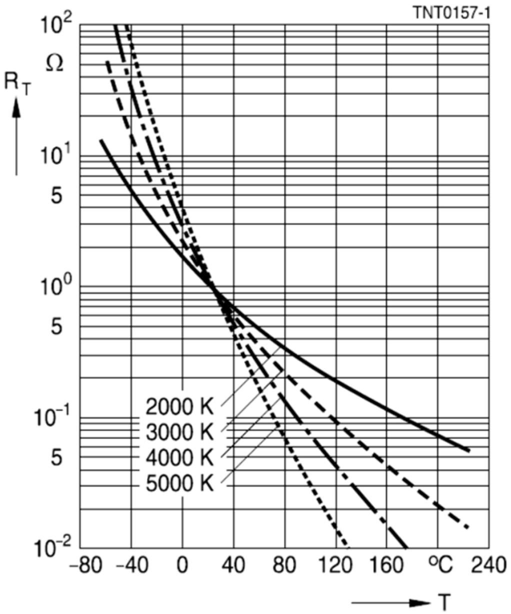
# SMD NTC Thermistors

## Temperature Measurement and Compensation for General Use


**EPCOS AG**
A TDK Group Company
Piezo and Protection Devices Business Group
Munich, Germany
May 19, 2016

# What does ‚NTC' mean?

| | |
|---|---|
| **Definition** | NTC = <u>N</u>egative <u>T</u>emperature <u>C</u>oefficient |
| **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 ~2…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

| | |
|---|---|
| $R_R$ | Rated resistance in Ω of an unstressed thermistor at the rated temperature $T_R$ (@ 25 °C) |
| $R_T$ | Resistance value in Ω at ambient temperature |
| $T_R$ | Rated temperature in Kelvin [K] @ 25 °C (= 298.15 K) |
| T | Ambient temperature in K |
| B value | 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. It is calculated between two specified ambient temperatures according to the following formula: $B = \frac{T \cdot T_R}{T_R - T} \cdot \ln \frac{R_T}{R_R} = \frac{T \cdot T_R}{T - T_R} \cdot \ln \frac{R_R}{R_T}$ |
| $B_{25/100}$ | The specifications in the data sheets refer to resistance values at temperatures of 25 °C ($T_R$) and 100 °C (T). |
| $B_{25/50}$ $B_{25/50}$ | Additionally given for information. |
| ∝ | 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): $\alpha = \frac{1}{R_1} \cdot \frac{R_2 \cdot R_1}{T_2 - T_1} = \frac{1}{R_R} \cdot \frac{dR}{dT}$ |

# R/T calculation


## Small temperature range

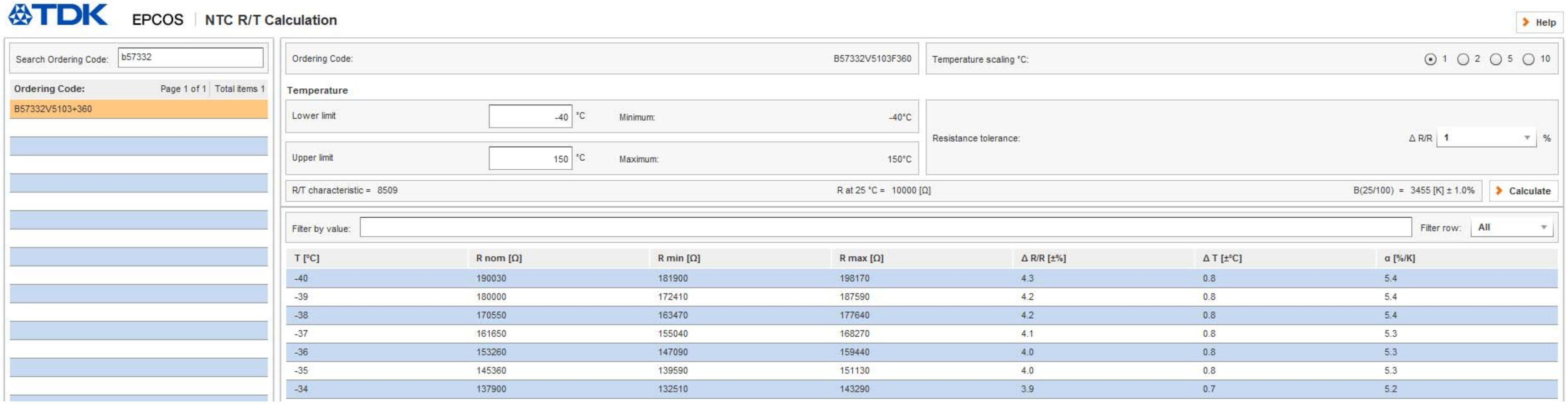
$$\alpha = \frac{1}{R} \cdot \frac{\mathrm{dR}}{\mathrm{dT}}$$

## Large temperature range

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

## Steinhart-Hart equation

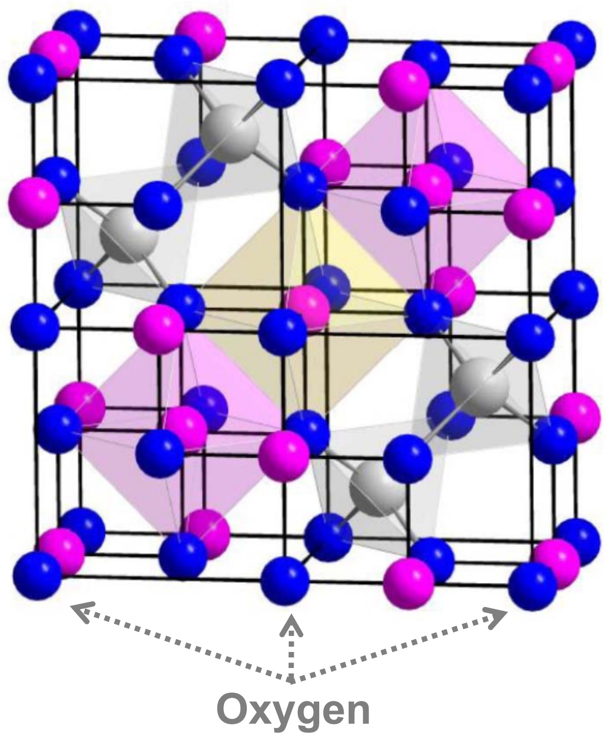
$$\mathrm{R_T} = e^{\left(a + b \cdot \frac{1}{T}\right) + \left(c \cdot \frac{1}{T_2}\right) + \left(d \cdot \frac{1}{T_3}\right) + \left(e \cdot \frac{1}{T_4}\right)}$$




| T [°C] | R nom [Ω] | R min [Ω] | R max [Ω] | Δ R/R [±%] | Δ T [±°C] | α [%/K] |
|---|---|---|---|---|---|---|
| -40 | 190030 | 181900 | 198170 | 4.3 | 0.8 | 5.4 |
| -39 | 180000 | 172410 | 187590 | 4.2 | 0.8 | 5.4 |
| -38 | 170550 | 163470 | 177640 | 4.2 | 0.8 | 5.4 |
| -37 | 161650 | 155040 | 168270 | 4.1 | 0.8 | 5.3 |
| -36 | 153260 | 147090 | 159440 | 4.0 | 0.8 | 5.3 |
| -35 | 145360 | 139590 | 151130 | 4.0 | 0.8 | 5.3 |
| -34 | 137900 | 132510 | 143290 | 3.9 | 0.7 | 5.2 |

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

# Physics of NTC ceramics




Spinel structure $NiMn_2O_4$ ($AB_2O_4$)

For NTC

A places = Ni, (Co, Zn, Al, Fe) – grey

B places = Mn, (Ni) - rose

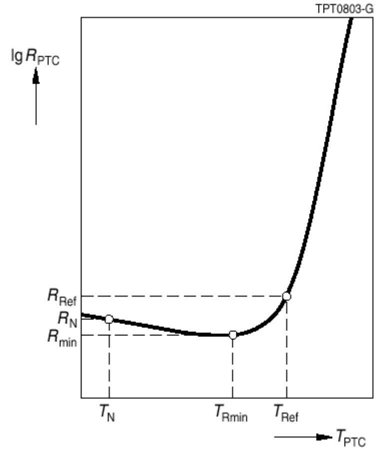
- NTC are polycrystalline (mixed) oxide ceramics.
- The crystal structure is basically a Spinel structure which is formed during the sintering process.
- At high sinter temperatures (~1200 °C) Ni and Mn atoms ‘share’ both A and B places whereby they change their valence.

**~1200 °C**
**rapid cooling**
**< 900 °C**

- A metastable crystal state with both Ni and Mnatoms on A and B places. Electrons can be exchanged → Hopping conductivit-y
- The amount of ‘exchanged’ electrons increases proportional with the ambient temperature
➔ the NTC effect is created.

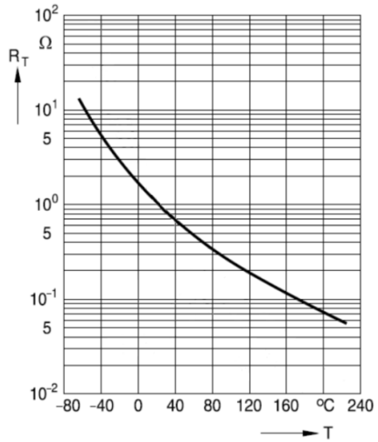
# Comparison of NTC and PTC thermistors

## PTC thermistors Positive temperature coefficient




- 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 $T_{Ref}$ (positive R/T curve).
- $T_{Ref}$ and $R_N$ is used to characterize the R/T curve. $T_{Ref}$ is a material constant.
- The temperature coefficient a is ~30…50%/K above $T_{Ref}$ (material constant).
- The resistance ranges from some Ω to kΩ.
- Material: Ceramic $BaTiO_3$.

## NTC thermistors Negative temperature coefficient




- 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 ~2…6%/K and also temperature depending.
- The resistance ranges from some Ω to >1 MΩ.
- Material: Ceramic metal oxide

# LED: Temperature protection concepts

## Fixed resistor

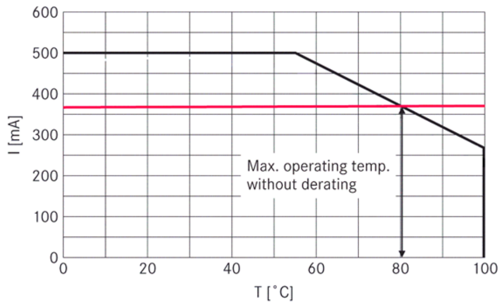
- Low cost solution
- Bad light efficiency
- Change of LED color
- Limited life time

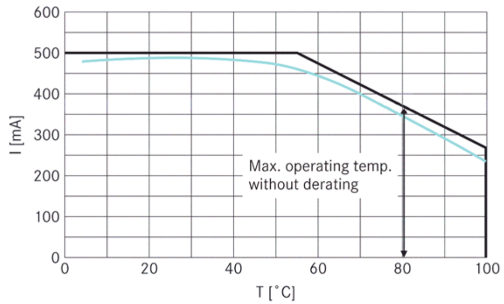
## PTC

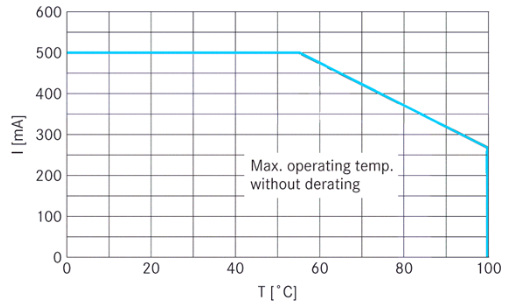
- Medium cost solution
- Better light efficiency
- Change of LED color
- Limited life time

## NTC

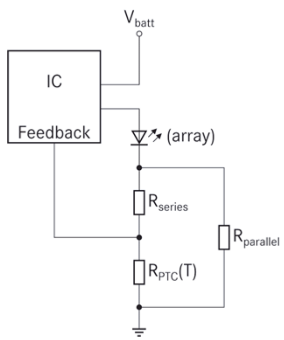
- Medium cost solution
- Excellent light efficiency
- No change of LED color
- Extension of Life time
- Optimum design (less number of LEDs)

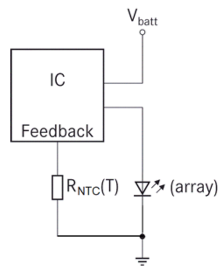


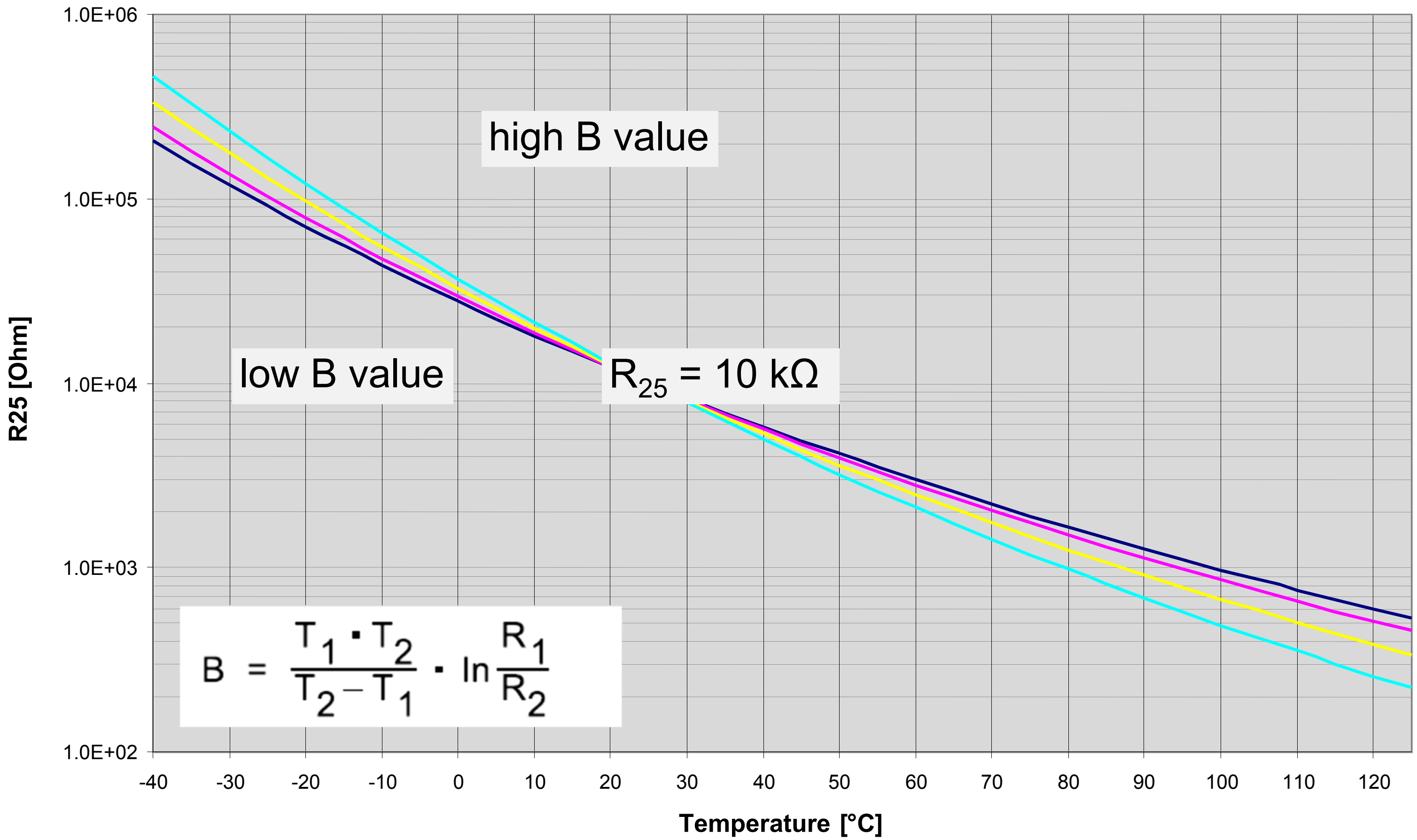




| | |
|---|---|
| Black | LED derating curve |
| Red | The maximum light efficiency is not reached at lower temperatures. |
| Green | The light efficiency can be increased over a large temperature range. |
| Blue | Light efficiency = LED derating curve with 1% accuracy |



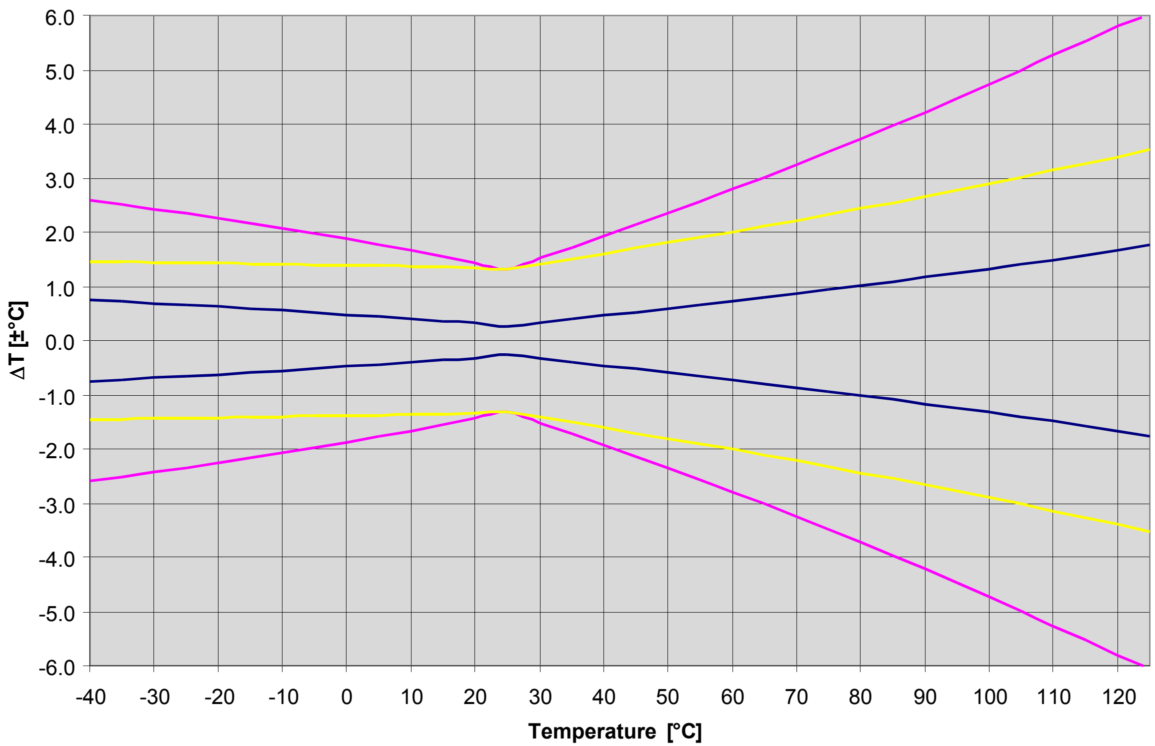
# Resistance $R_T$ as function of temperature




**The higher the B value the steeper the curve the larger the resistance change.**

# Temperature accuracy ΔT

$$\Delta T = \frac{1}{\propto} \cdot \frac{\Delta R}{R}$$




$R_{25}$ = 10 k ±5%
$B_{25/100}$ = 3455 K ±3%

ΔT @ 25 °C = **± 1.3 °C**
ΔT @ 100 °C = **± 4.7 °C**

$R_{25}$ = 10 k ±1%
$B_{25/100}$ = 3455 K ±1%

ΔT @ 25 °C = **± 0.3 °C**
ΔT @ 100 °C = **± 1.3 °C**

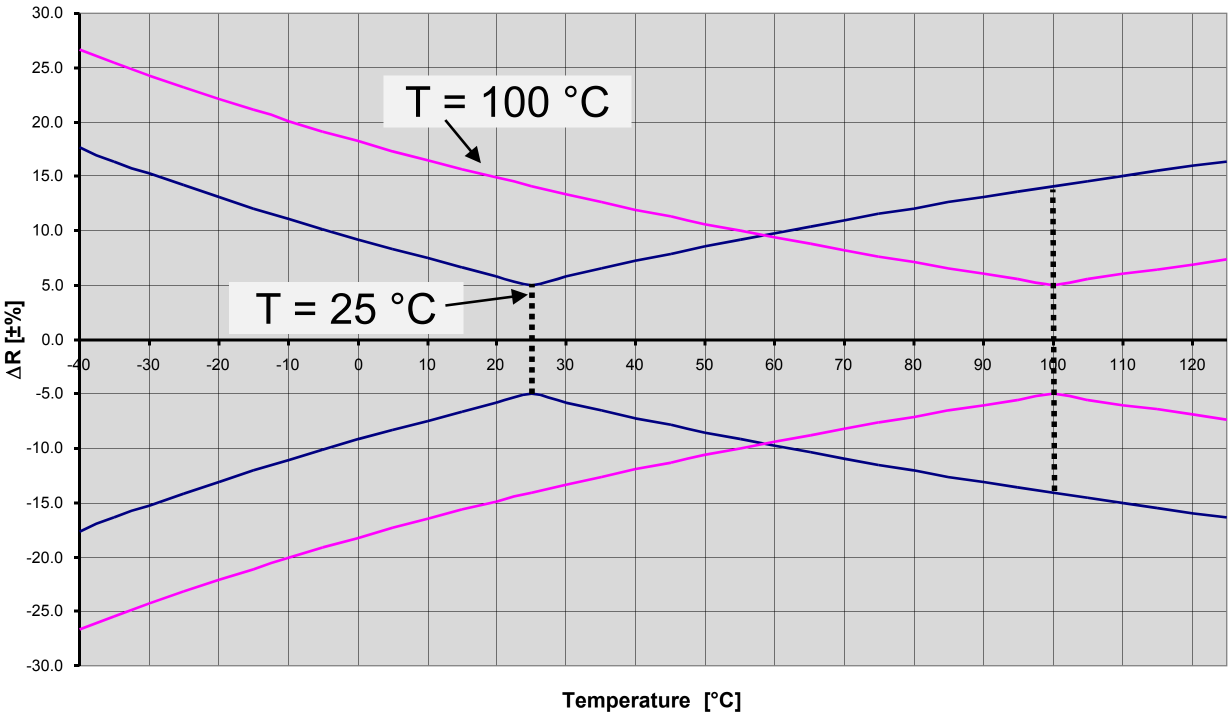
$R_{25}$ = 10 k ±5%
$B_{25/100}$ = 3455 K ±1%

ΔT @ 25 °C = **± 1.3 °C**
ΔT @ 100 °C = **± 2.9 °C**

**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.**

# Resistance accuracy ΔR

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




**T = 25 °C**

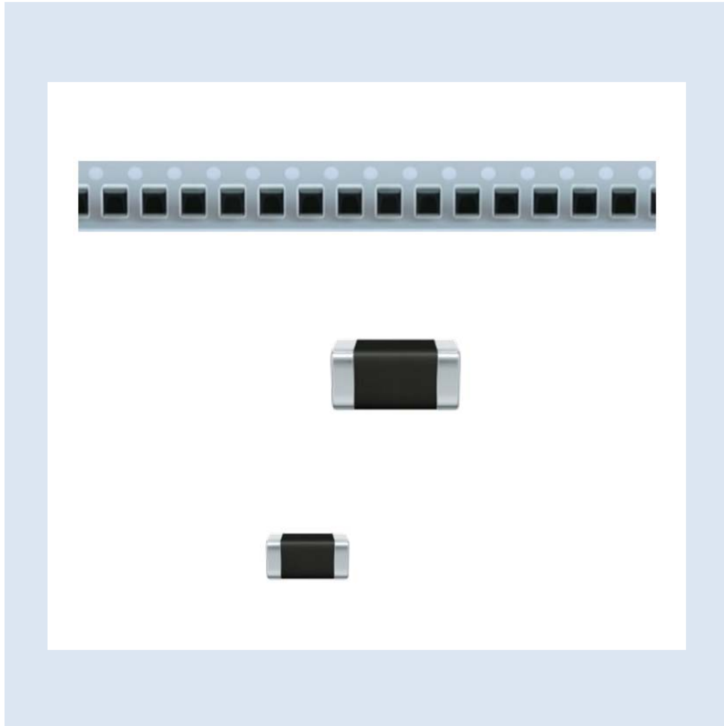
ΔR @ 25 °C = ± 5.0%
ΔR @100 °C = ± 16.4%

**T = 100 °C**

ΔR @ 25 °C = ± 14.1%
ΔR @ 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

| EIA case size | $R_{25}$ [kΩ] | $\Delta R_R$ % | $B_{25/50}$ [K] | $B_{25/85}$ [K] | $B_{25/100}$ [K] | $\Delta B_{25/100}$ % | Ordering code | |
|---|---|---|---|---|---|---|---|---|
| 0402 | 10 | ±1, ±5 | 3380 | 3435 | 3455 | ±1 | B57230V2103+260 | |
| 0402 | 10 | ±5 | 3940 | 3980 | 4000 | ±3 | B57221V2103J060 | |
| 0402 | 22 | ±5 | 4473 | 4548 | 4575 | ±3 | B57261V2223J060 | |
| 0402 | 47 | ±5 | 3940 | 3980 | 4000 | ±3 | B57221V2473J060 | |
| 0402 | 47 | ±1, ±3, ±5 | 4050 | 4108 | 4131 | ±1 | B57250V2473+560 | NEW! |
| 0402 | 100 | ±1, ±3, ±5 | 4250 | 4311 | 4334 | ±1 | B57250V2104+360 | NEW! |
| 0603 | 10 | ±1, ±5 | 3380 | 3435 | 3455 | ±1 | B57330V2103+260 | |
| 0603 | 10 | ±3, ±5 | 3940 | 3980 | 4000 | ±3 | B57321V2103+060 | |
| 0603 | 22 | ±3, ±5 | 4386 | 4455 | 4480 | ±3 | B57371V2223+060 | |
| 0603 | 47 | ±3, ±5 | 4386 | 4455 | 4480 | ±3 | B57371V2473+060 | |
| 0603 | 47 | ±1, ±3, ±5 | 4050 | 4108 | 4131 | ±1.5 | B57357V2473+560 | NEW! |
| 0603 | 47 | ±3, ±5 | 4050 | 4108 | 4131 | ±2 | B57358V2473+560 | NEW! |
| 0603 | 100 | ±3, ±5 | 4386 | 4455 | 4480 | ±1 | B57374V2104+060 | |
| 0603 | 100 | ±1, ±3, ±5 | 4200 | 4260 | 4282 | ±1 | B57350V2104+460 | NEW! |
| 0603 | 100 | ±3, ±5 | 4250 | 4311 | 4334 | ±2 | B57358V2104+460 | NEW! |
| 0603 | 470 | ±3, ±5 | 4386 | 4455 | 4480 | ±3 | B57371V2474+060 | |
| 0805 | 1 | ±3, ±5 | 3940 | 3980 | 4000 | ±3 | B57421V2102+062 | |
| 0805 | 10 | ±3, ±5 | 3590 | 3635 | 3650 | ±3 | B57401V2103+062 | |
| 0805 | 10 | ±3, ±5 | 3940 | 3980 | 4000 | ±3 | B57421V2103+062 | |
| 0805 | 10 | ±3, ±5 | 4386 | 4455 | 4480 | ±3 | B57471V2103+062 | |
| 0805 | 22 | ±3, ±5 | 4386 | 4455 | 4480 | ±3 | B57471V2223+062 | |
| 0805 | 47 | ±3, ±5 | 4386 | 4455 | 4480 | ±3 | B57471V2473+062 | |
| 0805 | 100 | ±3, ±5 | 4386 | 4455 | 4480 | ±3 | B57471V2104+062 | + = resistance |
| 0805 | 470 | ±3, ±5 | 4386 | 4455 | 4480 | ±3 | B57471V2474+062 | tolerance |

### Features

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

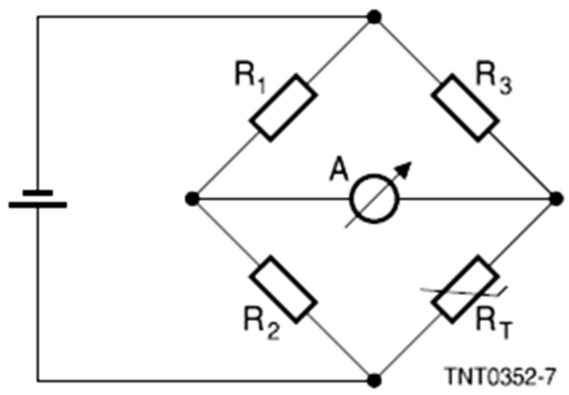
### Applications

- 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

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

# 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



Wheatstone bridge circuit

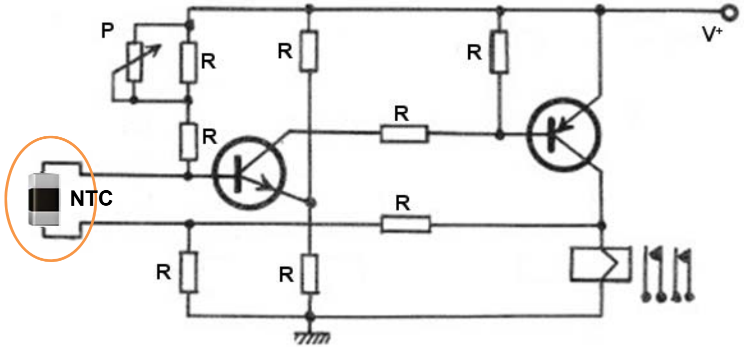
**EPCOS does offer a broad portfolio of NTC thermistors which can be found in every application.**

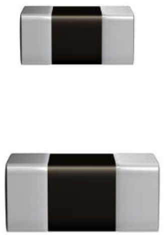
# Application example: Thermostat

## 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

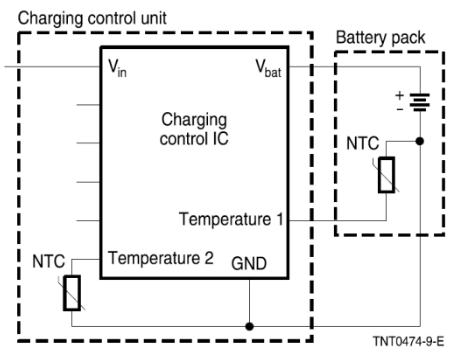
## Function

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.

Operating temperature range: up to 150 °C

## Typical schematic



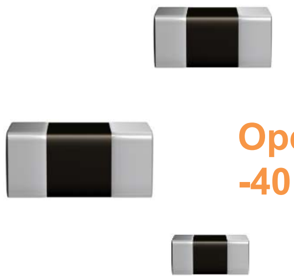

Charging control unit of a battery pack using NTC thermistors as temperature sensor

# Application example: Displays, e.g. LCD

## Function

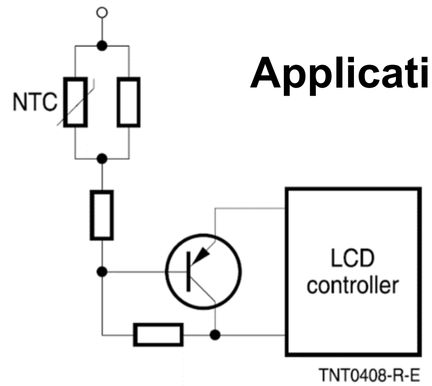
SMD NTC
LCD using a NTC thermistor as temperature sensor

- 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.



**Operating temperature range: -40 °C … +125 °C**

**Application/ circuit**




**NTC thermistors provide an accurate temperature sensing up to +125 °C.**

# Temperature protection of LEDs with NTCs

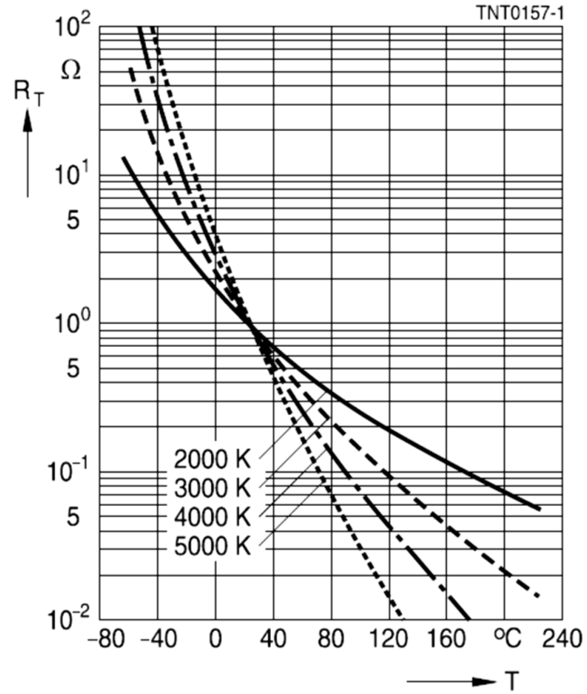
## Why controlling the LED junction temperature?

### 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 a is ~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**

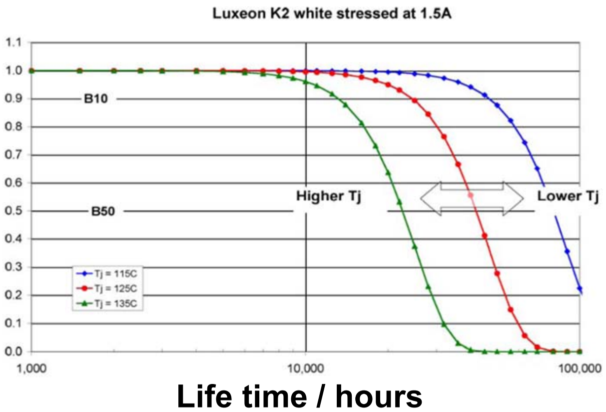
**NTC thermistors are simple but very sensitive and accurate sensing elements for measuring and control circuits.**

# Optimization of LED efficiency with NTCs

## By high accurate temperature sensing

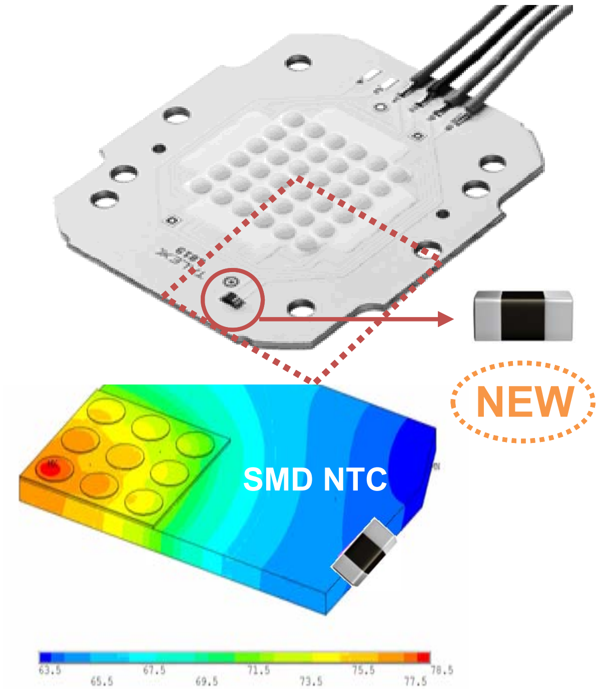
### Task of NTC

Control optimum junction temperature $T_{jun}$ for max. lumen/ watt & lifetime




With a NTC $T_{jun}$ can be reduced

➔ Higher temperature with higher lifetime possible




Example: High power LED module

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


Founded in 1970

71000 $m^2$

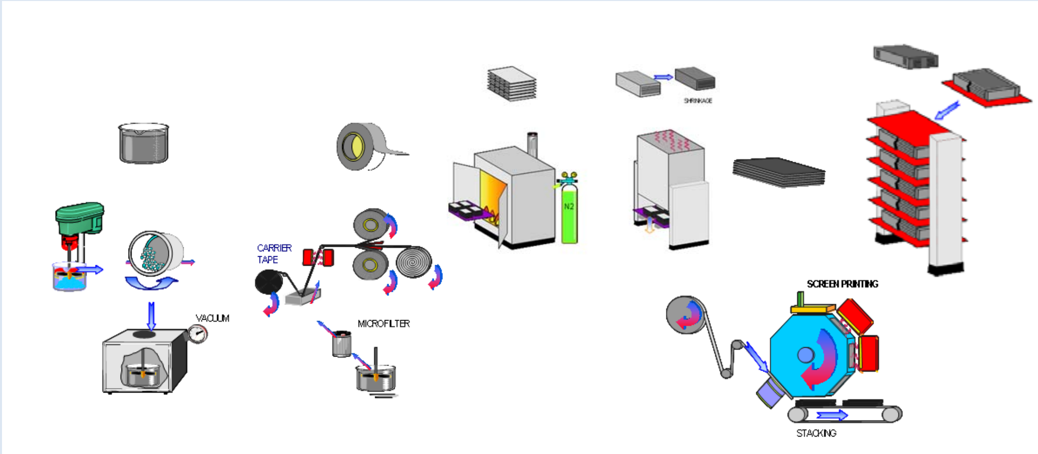
## Certifications

- ISO 9001
- ISO/TS 16949
- ISO 14001

# Process flow in production

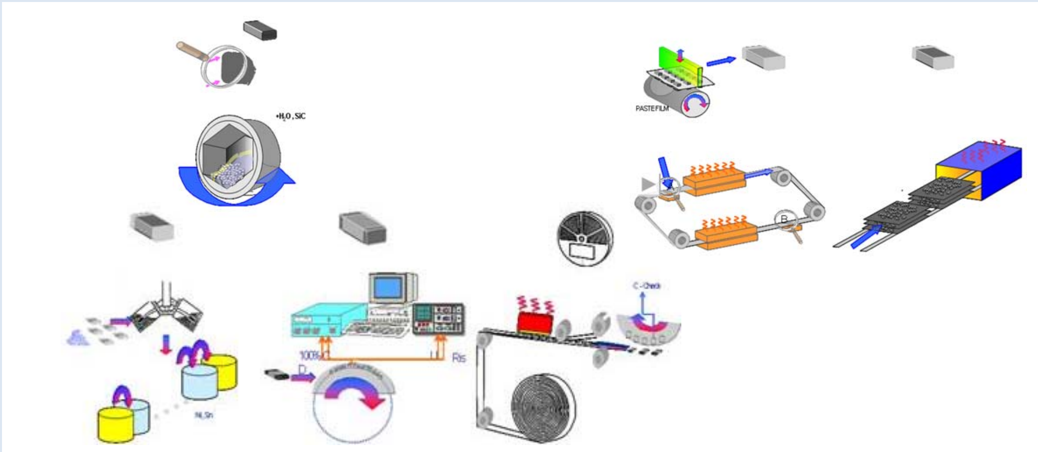
- Slurry preparation
- Mixing and milling
- Tape casting
- Stacking and printing
- Pressing/ cutting
- Debindering/ sintering

Frontend
Deutschlandsberg, AT




- Glass-coating process
- Burn-in of glass coating
- Ag metalization
- Burn-in of termination
- Electroplating of Ni/Sn
- Measuring and taping

Backend
Kutina, HRV



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