

NTC Thermistors

Application notes

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Application notes

1 Applications utilizing the influence of ambient temperature on resistance (self-heating negligible)

1.1 Temperature measurement

The high sensitivity of an NTC thermistor makes it an ideal candidate for temperature sensing applications. These low-cost NTC sensors are normally used for a temperature range of $-40\text{ }^{\circ}\text{C}$ to $+300\text{ }^{\circ}\text{C}$.

Selection criteria for NTC thermistors are

- temperature range
- resistance range
- measuring accuracy
- environment (surrounding medium)
- response time
- dimensional requirements.

One of the circuits suitable for temperature measurement is a Wheatstone bridge with an NTC thermistor used as one bridge leg.

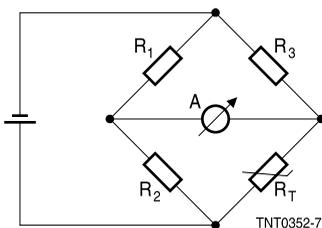


Figure 1
Wheatstone bridge circuit

With the bridge being balanced, any change in temperature will cause a resistance change in the thermistor and a significant current will flow through the ammeter. It is also possible to use a variable resistor R_3 and to derive the temperature from its resistance value (in balanced condition). An example of a circuit including an NTC thermistor and microcontroller is given in figure 2.

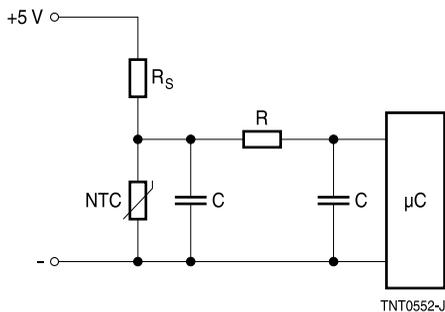


Figure 2
Practical application for a circuit with NTC thermistor and microcontroller

1.2 Linearizing the R/T characteristic

NTC thermistors exhibit a distinctly non-linear R/T characteristic. If a fairly linear curve is required for measurements over a (wide) temperature range, e.g. for a scale, series-connected or paralleled resistors are quite useful. The temperature range to be covered should, however, not exceed 50 K to 100 K.

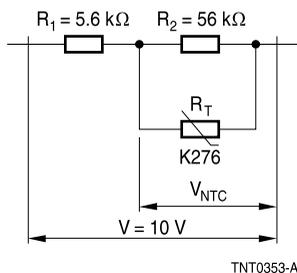


Figure 3

Linearization of the K276/12 kΩ NTC thermistor by a paralleled resistor

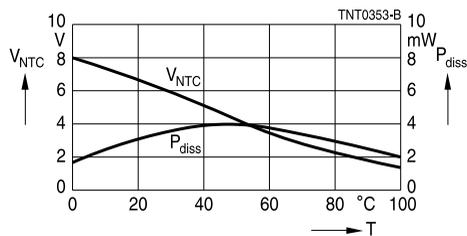


Figure 4

Signal voltage and power dissipation curves of the linearized NTC thermistor

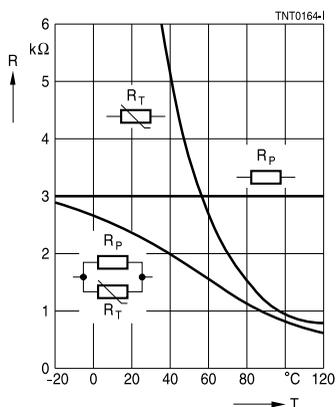


Figure 5

Resistance/temperature characteristic linearized by a paralleled resistor

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The combination of an NTC thermistor and a paralleled resistor has an S-shaped R/T characteristic with a turning point. The best linearization is obtained by laying the turning point in the middle of the operating temperature range. The resistance of the paralleled resistor can then be calculated by the exponential approximation:

$$R_P = R_T \cdot \frac{B - 2T}{B + 2T}$$

The total resistance of $R_T \parallel R_P$ is:

$$R = \frac{R_P \cdot R_T}{R_P + R_T}$$

R_T Resistance value of the NTC thermistors at mean temperature T
(in $K \cong \text{temperature in } ^\circ\text{C} + 273.15$)

B B value of the NTC thermistor

The rate of rise of the (linearized) R/T characteristic is:

$$\frac{dR}{dT} = - \frac{R_T}{\left(1 + \frac{R_T}{R_P}\right)^2} \cdot \frac{B}{T^2}$$

The circuit sensitivity however decreases with linearization.

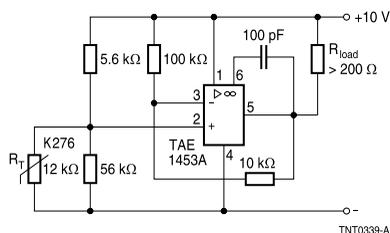


Figure 6

Linearization of the R/T characteristic:
simple amplifier circuit

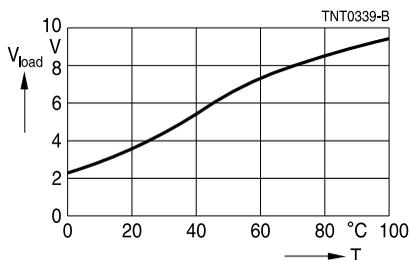


Figure 7

Linearization of the R/T characteristic:
output voltage at the load resistor as a function
of temperature

1.3 Temperature compensation

Virtually all semiconductors and the circuits comprised of them exhibit a temperature coefficient. Owing to their high positive temperature coefficient, NTC thermistors are particularly suitable for compensating this undesired response to temperature changes (examples: working point stabilization of power transistors, brightness control of LC displays). Resistors in series or shunt plus suitable voltage dividers and bridge circuits provide an excellent and easy-to-implement compensation network.

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It is important to match the temperature of the compensating NTC thermistor to that of the component causing the temperature response. Temperature-compensating thermistors are therefore not only available in conventional leaded styles, but also incorporated in screw-type housings for attachment to heat sinks and as chip version for surface mounting.

Figure 8 shows a simple circuit configuration for a thermostat.

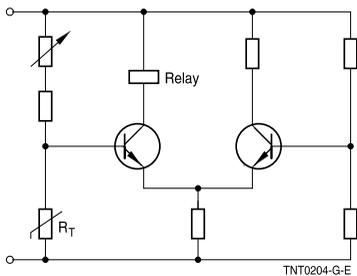


Figure 8
Circuit for a temperature controller

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1.4 Application examples

NTC thermistors for temperature measurement are suitable for a large variety of applications

Mobile communication devices:	temperature monitoring and compensation for - TCXO (temperature compensated crystal oscillator) - power amplifier modules - liquid crystal displays (LCD) - temperature monitors - battery packs
Computer and consumer electronics:	temperature monitoring and compensation for - hard disk drive (HDDs) - optical disk drive (ODD) - central processing unit (CPU) - liquid crystal display (LCD) - battery pack and battery management systems (BMS) - printers - PC main boards - audio and video systems, medical devices
Household electronics:	refrigerators and deep-freezers, washing machines, electric cookers, hair-dryers, electronic ballast, power tools, LED lighting etc.
Heating and air-conditioning:	heating systems, thermostats, room temperature monitoring, underfloor heating and water boilers, outdoor temperature sensors
Industrial electronics:	temperature stabilization of laser diodes and photo elements, temperature compensation in copper coils or reference point compensation in thermo elements, LED and semiconductor overheating protection
Automotive electronics:	electronic control units (ECUs), e.g. motor management, airbags, cooling control units, gearbox controls, cylinder head or braking systems, temperature controls for the battery pack in conventional and hybrid automobiles
	sensor systems, e.g. temperature controls in tire air-pressure modules, temperature sensors for air-conditioning and passenger compartment
	headlights, e.g. LED lighting
	displays, e.g. dashboard, car radio, navigation, GPS, in-car TV

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1.4.1 Temperature control in mobile communication devices

The use of mobile communication devices in a wide temperature range (e.g. from $-40\text{ }^{\circ}\text{C}$ up to $+85\text{ }^{\circ}\text{C}$) requires the control of the temperature-sensitive elements of the system. This includes the crystal oscillator (XO), the LCD, the power amplifier and the battery pack. NTC thermistors as temperature sensors fulfill different tasks e.g. temperature compensation or temperature sensing in an overtemperature protection circuitry.

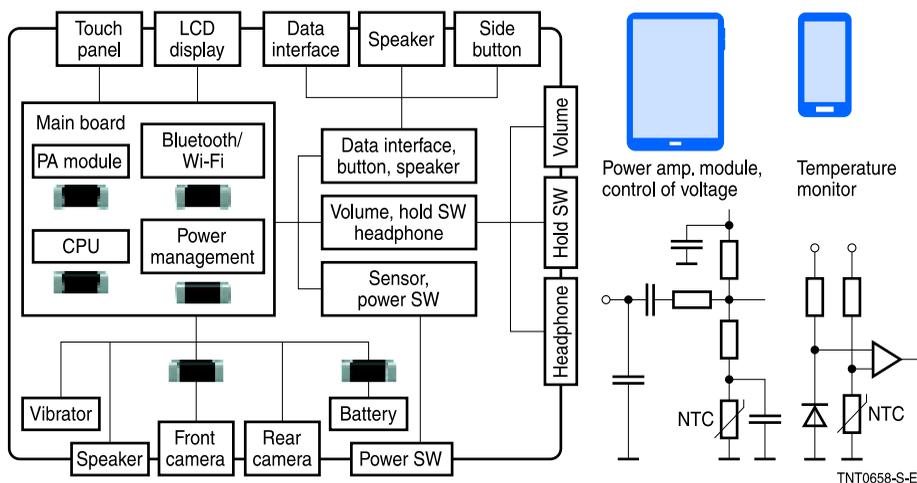


Figure 9
Circuit examples for cellular phone and tablet terminal.

1.4.2 Battery packs

All rechargeable batteries and lithium ion batteries in particular must be monitored and protected by smart charging circuits, as the mobile communication device drawing power from the batteries must operate in a variety of environments, including low and high-temperature operation.

As preferred temperature detection devices NTC thermistors are used in the protective circuitry. NTC thermistors can detect the ambient temperature for different purposes, depending on the battery system. Especially for quick charging the ambient temperature has to be measured, as not all batteries allow the charging in the hot and cold temperature region. Usually charging temperatures of $0\text{ }^{\circ}\text{C}$ up to $45\text{ }^{\circ}\text{C}$ for slow charging, and $5\text{ }^{\circ}\text{C}$... $10\text{ }^{\circ}\text{C}$ up to $45\text{ }^{\circ}\text{C}$ for quick charging are recommended by the battery pack manufacturers depending on the battery chemistry.

The NTC thermistor is part of a smart charging control unit (see figure 10), which assures that the ambient temperature is in the range allowing quick charging. During charging the NTC thermistor repeatedly measures the temperature all 5 to 10 seconds and can detect a rise in the battery cell's temperature at the end of the charging cycle or caused by abnormal charging conditions.

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During discharging NTC thermistors also perform temperature compensation for the voltage measurement, which helps to measure the remaining charge in the battery.

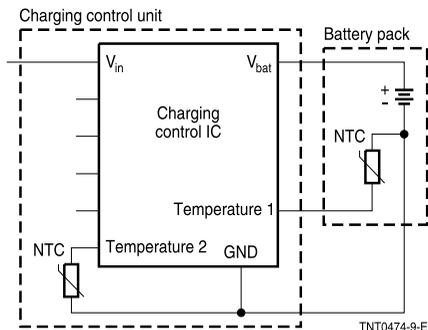


Figure 10
Schematic drawing of the charging control unit of a battery pack using NTC thermistors as temperature sensors

Recommended part numbers for industrial battery packs:

B57703M0103G040	10 k Ω , $B_{25/100} = 3988 \text{ K} \pm 1\%$, cable length: 45 mm
B57703M0103A017	10 k Ω , $B_{25/100} = 3988 \text{ K} \pm 1\%$, cable length: 115 mm
B57703M0103A018	10 k Ω , $B_{25/100} = 3988 \text{ K} \pm 1\%$, cable length: 200 mm
B57703M0103A019	10 k Ω , $B_{25/100} = 3988 \text{ K} \pm 1\%$, cable length: 500 mm

1.4.3 Liquid crystal displays (LCD)

LCDs are widely used in portable electronics. As the fluid used in liquid crystal displays is sensitive to temperature, LCD modules 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.

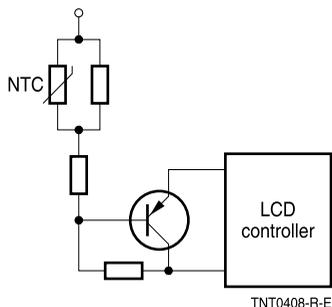


Figure 11
Schematic drawing of the compensation circuit of an LCD using an NTC thermistor as temperature sensor

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For these LCD modules often a temperature compensation circuit is used (see figure 11), 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.

1.4.4 Temperature control in hard disk drives (HDD)

An important factor which must be considered in the development of HDDs is reliability. Operating electronic components such as disk drives at high temperatures can dramatically reduce their reliability. The resulting stress can lead to unexpected failures and even data loss. Continuous or sustained operation above the normally specified ambient temperature of 5 °C to 55 °C may decrease the mean time between failures (MTBF).

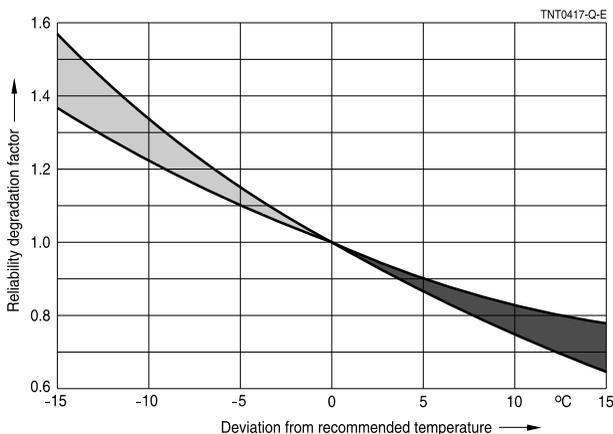


Figure 12
HDD reliability:
typical temperature
sensitivity

A NTC sensor can be used to monitor the temperature within the drive and to warn the drive controller when the drive exceeds its maximum permissible temperature. The NTC thermistor is mounted on the logic board. The typical set-up point is the maximal operating temperature of 55 °C.

Normally the sensor is designed not only for warning, but also to trigger actions. If the temperature exceeds the configured limits, possible actions may be the activation of a cooling fan, a slow-down of drive activity or even a stop of the drive.

1.4.5 LED lighting

In many portable electronic solutions, light-emitting diodes (LEDs) are now widely used in general lighting and automotive lighting, where high brightness becoming increasingly popular. The solution is high-brightness LEDs (HBLEDs), presenting numerous advantages over conventional lighting, but like any other semiconductor device generating heat. One of the challenges is consequently thermal management. Generally speaking, high-quality LEDs are robust devices that can operate in excess of 100,000 hours when properly handled. However, it is a familiar fact that high temperatures can significantly shorten LED lifetime as well as negatively impact brightness. That calls for accurate temperature control.

To guarantee sufficient lifetime, LED manufacturers usually recommend that current derating start at temperatures between 50 °C and 80 °C. Without temperature control the designer must ensure that the temperature never exceeds the recommended derating threshold of the LED, or limit current by a resistor to about 57% of the maximum rating, which sacrifices the full LED brightness (Figure 13). That makes NTC thermistors the preferred choice for temperature sensing and control in lighting due to their attractive price/performance ratio. They enable LEDs to be used at full operating capability for a given lifetime, meaning higher current at lower ambient temperature and adapted lower current when temperature increases (Figure 14). While enhancing lifetime, this still guarantees good lumen output. For the best performance the NTC sensing thermistor should be located close to the LEDs or in the hot spot of the LED board.

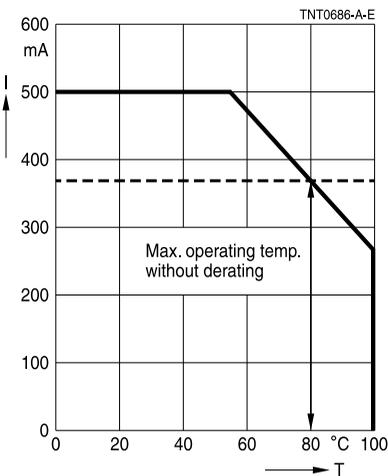


Figure 13
Permissible LED current derating curve (above curve). Current control by fixed resistor (below curve).

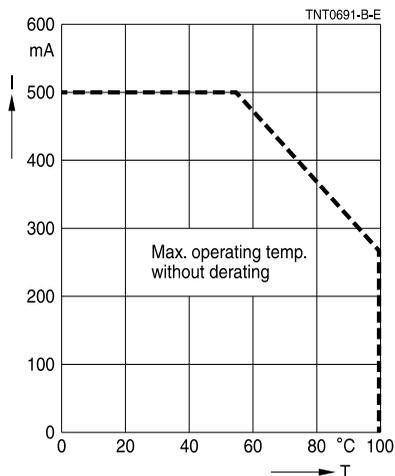


Figure 14
Current compensation by NTC

Application notes

Different topologies can be used based on specific IC LED drivers. As shown in Figure 15, an NTC thermistor can operate in a resistor network where the sense voltage can indirectly control the LED current by influencing pulse-width modulation (PWM) ratio.

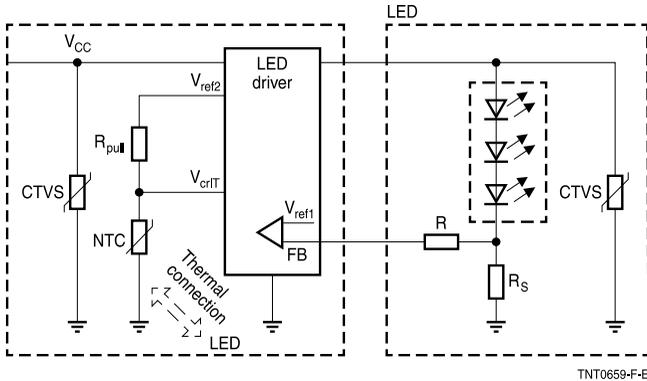


Figure 15
NTC used to control PWM as a function of temperature

Another option is shown in Figure 16. Here the NTC thermistor is used in the LED current sense branch to influence the feedback signal at higher temperatures. In this configuration the NTC must be connected to a constant voltage source, e.g. a reference output voltage provided by the driver.

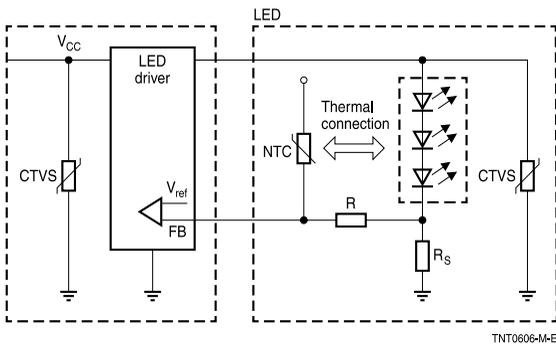


Figure 16
NTC used for control current sense signal of higher LED temperature

Application notes

The LED current in this setup is calculated as follows:

$$I_{LED} = \frac{V_{ref} - \frac{R + R_s}{R + R(T) + R_s} \cdot V}{R_s}$$

- V_{ref} Reference voltage of feedback voltage input of LED driver
- R Resistance of additional resistor
- R_s Resistance of shunt resistor
- $R(T)$ Resistance of NTC at rated temperature (see chapter 3.1 in "General technical information")
- V Voltage applied to NTC

The rate at which the LED current decreases with increasing temperature is defined by the B value of the NTC and the additional resistance R. Higher values of both lead to a steeper course of the LED current. Ratings of the NTC resistance R_{25} between 10 Ω and 100 k Ω enable minimization of the transverse current.

Recommended part numbers for standard applications:

B57230V2103+260	0402, 10 k Ω , $B_{25/100} = 3455 \text{ K} \pm 1\%$
B57250V2104+360	0402, 100 k Ω , $B_{25/100} = 4334 \text{ K} \pm 1\%$
B57330V2103+260	0603, 10 k Ω , $B_{25/100} = 3455 \text{ K} \pm 1\%$
B57351V5103+060	0603, 10 k Ω , $B_{25/100} = 4000 \text{ K} \pm 3\%$
B57350V2104+460	0603, 100 k Ω , $B_{25/100} = 4282 \text{ K} \pm 1\%$
B57354V5104+160	0603, 100 k Ω , $B_{25/100} = 4334 \text{ K} \pm 2\%$

Recommended part numbers for automotive applications:

B57232V5103+360	0402, 10 k Ω , $B_{25/100} = 3455 \text{ K} \pm 1\%$
B57254V5104+360	0402, 100 k Ω , $B_{25/100} = 4334 \text{ K} \pm 1\%$
B57332V5103+360	0603, 10 k Ω , $B_{25/100} = 3455 \text{ K} \pm 1\%$
B57355V5104+360	0603, 100 k Ω , $B_{25/100} = 4282 \text{ K} \pm 1\%$

For a production process without soldering, bondable NTC thermistors can be used:

B57860S0103J200	L/ W = 0.53 ± 0.1 mm, 10 k Ω , $B_{25/100} = 3625 \text{ K} \pm 1\%$
B57860S0853J200	L/ W = 0.55 ± 0.1 mm, 85 k Ω , $B_{25/100} = 4092 \text{ K} \pm 1\%$

Depending on the application, additional ESD protection by a ceramic transient voltage suppressor (CTVS) may be necessary for both, the LEDs and V_{cc} . For more information about ESD protection please refer to the ceramic transient voltage suppressor (CTVS) data book.

Application notes

1.4.6 Thermostats

The use of thermostats is a common, modern solution to monitor the room temperature efficiently. Inside a thermostat an NTC thermistor provides the essential high sensitivity to monitor ambient temperature fluctuations. Due to miniaturization and additional features introduced on the thermostat PCB, the temperature needs to be monitored with higher accuracy. Depending on the proximity of electronic components to one another, an NTC thermistor with ultra-tight tolerance might be necessary. A typical R value of an NTC thermistor is 10 k Ω , with resistance tolerance of the order of 1% or even 0.5%.

1.4.7 Thermal protection of semiconductors

Semiconductors need to be protected from excessive temperature during operation. An NTC is placed on the substrate inside the power module to monitor the heatsink temperature onto which the module is mounted. The terminals of the NTC will be connected to the comparator of the controller. As soon as the resistance of the NTC falls below a predetermined value, the controller will reduce the power through all semiconductors to decrease temperature inside the package.

Especially when wide-bandgap material (GaN/ SiC) is used for semiconductor devices in power modules, this leads to higher operating temperatures compared to standard silicon, and different mounting methods of the components might be necessary. While soldering or gluing was adequate for standard silicon, the higher operating temperatures now mainly require sintering processes to attach components to the DCB (direct copper bonded) and bond connections, with gold, silver or aluminum wire used to implement the interconnect.

Example: (Intelligent) power module IGBT

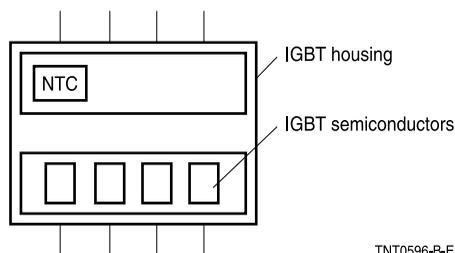


Figure 17

The IGBT must be turned off when the junction temperature 125 °C is reached so that it does not become too hot and is subsequently damaged. This temperature control is performed by the SMD NTC contained in the IGBT package.

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Recommended part numbers for power module applications:

B57451V5103+062 0805 10 k Ω B25/100 = 4000 K
 B57471V2103+062 0805 10 k Ω B25/100 = 4480 K

Alternative types in other package sizes, other resistance values and tighter tolerances are available upon request. Due to the harsh environments of power modules as well as high operating temperature demands, EPCOS recommends automotive grade types, qualified for operating temperatures up to 150 °C. Contact us for more details.

These SMD NTC thermistors have a very robust design by glass coating technology, enabling a 100% lead-free component. Also important is that these types feature high temperature measurement accuracy at 100 °C.

Given the high operating temperature of power modules, larger package size can be an advantage. So it might be necessary to consider components with high dissipation factor and high heat capacity. An overview of heat capacity and dissipation factor for different package sizes can be found in table below.

EIA case size	Heat capacity C_{th}	Thermal cooling time constant τ_c	Dissipation factor δ_{th}
0402	7.5 mJ/K	3 s	2.5 mW/K
0603	12 mJ/K	4 s	3 mW/K
0805	35 mJ/K	10 s	3.5 mW/K
1206	50 mJ/K	10 s	5 mW/K

Approximate heat capacity, thermal cooling time constant and dissipation factor of different package sizes.

Recommended part numbers for applications where bond connections are required:

B57860S0103J200 10 k Ω , R100: 868 Ω , B_{25/100} = 3625 K \pm 1%
 B57860S0223J100 21.5 k Ω , R100: 1.486 k Ω , B_{25/100} = 3964 K \pm 1%
 B57860S0853J200 85 k Ω , R100: 5.388 k Ω , B_{25/100} = 4092 K \pm 1%

1.4.8 Automotive electronics

Most of our NTC thermistors are qualified according to AEC-Q200, and are widely used in many automotive applications. For SMD NTC thermistors the automotive series can be identified by the characters "V5" in the middle of the part number.

Many current trends in automotive require precise and sensitive temperature measurement or sensitive detection of temperature deviation.

SMD NTC thermistors are easily integrated into automotive power electronic circuits such as electronic power steering (EPS), LED headlights, ABS or DC/DC converters. Assembly of an SMD

Application notes

NTC together with heat producing power electronics (MOSFET, IGBT) provides good thermal contact with the sensitive NTC ceramic. When insulated metal substrates (IMS) are used, even an SMD NTC placed at the edge of the substrate will quickly detect the junction temperature of active components.

Infotainment	Display control
Body and security	<ul style="list-style-type: none"> - ABS/ ESP - Regebrative braking - Climate control units
Lighting	<ul style="list-style-type: none"> - LED power headlight - Adaptive LED headlight - LED daylight (DLR)
Power and steering	<ul style="list-style-type: none"> - Engine control unit (ECU) - Electronic power steering (EPS) - Dual clutch transmission (DCT) - Continuous variable transmission (CVT)
HEV/ EV/ Eco drive	<ul style="list-style-type: none"> - HV batteries - DC/ DC converters - Inverters

2 Applications utilizing the influence of the dissipation factor on the voltage/current characteristic

2.1 Liquid level sensors

The temperature of an electrically loaded NTC thermistor depends on the medium surrounding the device. When the thermistor is immersed in a liquid the dissipation factor increases, the temperature decreases and the voltage lying across the NTC rises. Owing to this effect NTC thermistors are able to sense the presence or absence of a liquid. The NTC must be carefully selected (tested) with respect to resistivity against liquids to be detected. In case of water a suitable housing made of stainless steel is recommended.

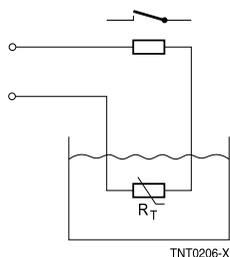


Figure 18
Circuit configuration for liquid level control

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3 Applications utilizing the current/time characteristic

If an NTC thermistor is connected to a voltage source via a series resistor and the current is measured as a function of time, an increase in current will be observed.

At first the thermistor is cold, i.e. in high-resistance mode, and only a low current is flowing through the device. But this current starts to heat up the thermistor and the wattage increases with the resistance value of the thermistor approaching that of the series resistor. Thus the increase in current becomes faster and faster till the two resistance values are equal. With further decreasing NTC resistance the wattage will also decrease due to the growing mismatch and the current reaches a final value. The entire wattage is consumed in maintaining the overtemperature.

Relay delay

To delay relay pick-up thermistor and relay are connected in series. When applying a voltage V_{op} the current flowing through the relay coil is limited to a fraction of the pick-up current by the high cold resistance of the thermistor. With the thermistor heating up, its resistance decreases and the current rises until the pick-up value is reached.

To delay relay drop-out relay and thermistor are connected in parallel.

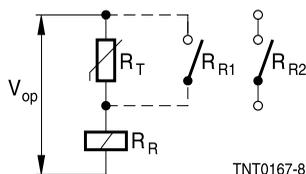


Figure 19
Delay of relay pick-up

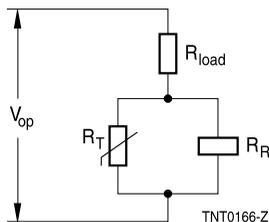


Figure 20
Delay of relay drop-out

The operating sequence of a relay delayed by a thermistor depends on the recovery time of the thermistor. The thermistor has to cool down before it can cause second delay. If the thermistor remains unloaded for a time $t = 3 \cdot \tau_c$ (3 times the thermal cooling time constant) between two operations, the time for the second delay will be 80% to 90% of that for the first delay. It is therefore useful to short-circuit or switch off the thermistor by additional relay contacts, so that the thermistor has sufficient time to cool down (see dashed section in figure 19).

4 Further application notes

Further application notes are given on the Internet (<http://www.epcos.com> → Product Catalog → Sensors and Sensor Systems → Temperature Measurement Sensors, Data Sheets → Application Notes).