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 to +300 °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.

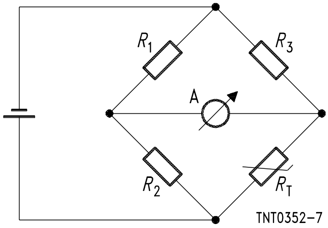


Figure 1
Wheatstone bridge circuit

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).

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 to 100 K.

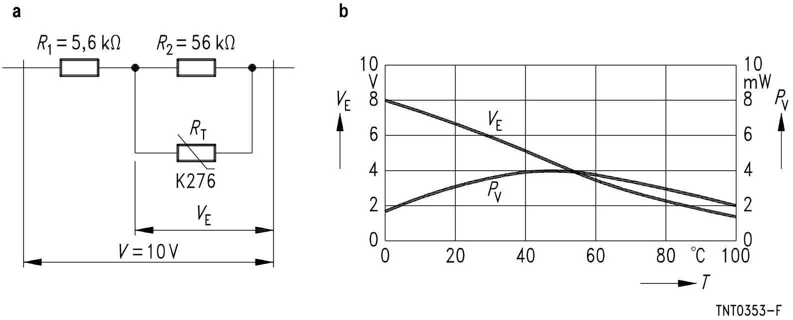


Figure 2

Linearization of the K276/12k NTC thermistor by a paralleled resistor (a). Signal voltage and power dissipation curves of the linearized NTC thermistor (b).

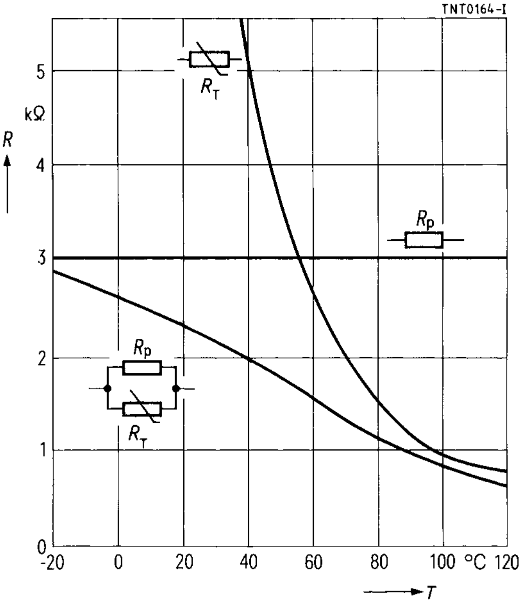


Figure 3

Resistance/temperature characteristic linearized by a paralleled resistor

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 thermistor at mean temperature T (in K ≅ temperature in °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.

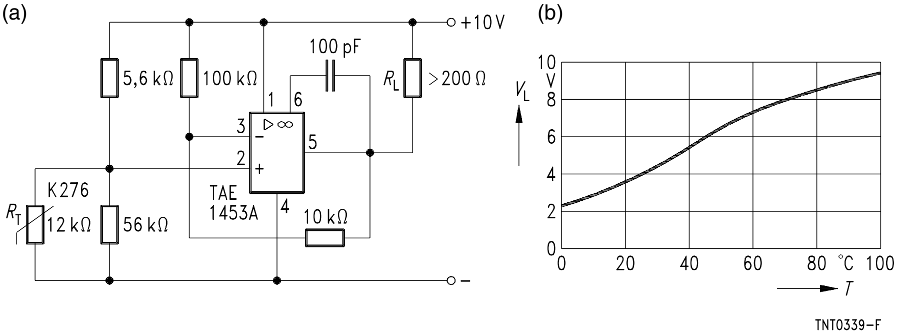


Figure 4

Linearization of the R/T characteristic
a) simple amplifier circuit
b) 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.

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 5 shows a simple circuit configuration for a thermostat.

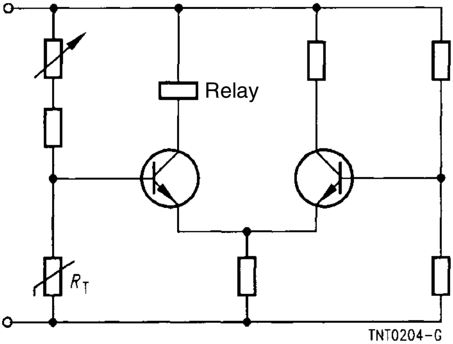


Figure 5
Circuit for a temperature controller

1.4 Application examples

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

- in household electronics: in refrigerators and deep freezers, washing machines, electric cookers, hair-driers, etc.
- in automotive electronics: for measuring the temperature of cooling water or oil, for monitoring the temperature of exhaust gas, cylinder head or braking system, for controlling the temperature in the passenger compartment, etc.
- in heating and air conditioning: in heating cost distributors, for room temperature monitoring, in underfloor heating and gas boilers, for determining exhaust gas or burner temperature, as outdoor temperature sensors, etc.
- in industrial electronics: for temperature stabilization of laser diodes and photoelements, for temperature compensation in copper coils or reference point compensation in thermoelements, etc.
- in telecommunications: for temperature measurement and compensation in mobile phones.

1.4.1 Temperature control in mobile phones

The use of mobile phones in a wide temperature range (e.g. from –40 °C up to +85 °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.

TCXO

Temperature-compensated crystal oscillators (TCXO) provide the reference signal in the mobile phone. Commonly used frequencies standards are 13 and 26 MHz. In an analog TCXO a compensation network consisting of thermistors, capacitors and resistors is required in order to compensate the temperature characteristic of the crystal oscillator's reference frequency.

The frequency temperature response of an AT-cut crystal, which is commonly used in TCXOs, is generally described by a third order curve. The frequency temperature deviation of an uncompensated crystal is typically of the order $\Delta f/f = \pm 10 \ldots \pm 30$ ppm in the temperature range –40 °C to +85 °C. In a mobile phone, however, a frequency stability of approximately ±2,5 ppm is required.

A cost-effective technique to achieve this is the analog compensation of the temperature change using a temperature-controlled VCXO (voltage-controlled oscillator). A temperature compensation network delivers the appropriate voltage for compensation by changing the reactance with temperature (see figure 6). The main temperature sensing element in the system is an NTC thermistor, which is well suited for this task due to its characteristic resistance/temperature curve. Combining two or more NTC thermistors in the network an accurate compensation smaller than 1 ppm can be achieved.

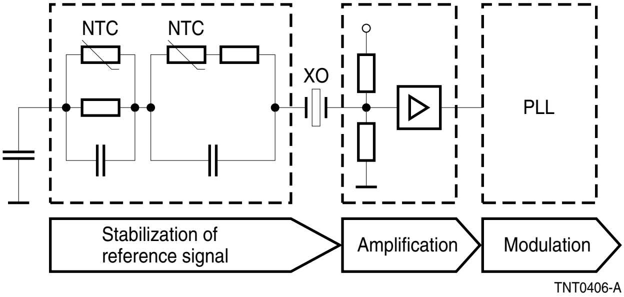


Figure 6

Circuit for direct temperature compensation of the reference signal in mobile phones using NTC thermistors

There are two methods to design the compensation network. The direct compensation method consists of thermistors, resistors and capacitors, which provide an equivalent reactance response to temperature. This results in a frequency change (curve TC), compensating the frequency deviation of the crystal (curve XO) as shown in figure 7.

In the indirect compensation method an additional varactor diode is inserted into the oscillation loop. The thermistor delivers an appropriate bias voltage for the varactor diode, which changes the varactor capacitance, compensating the resonator frequency temperature characteristic.

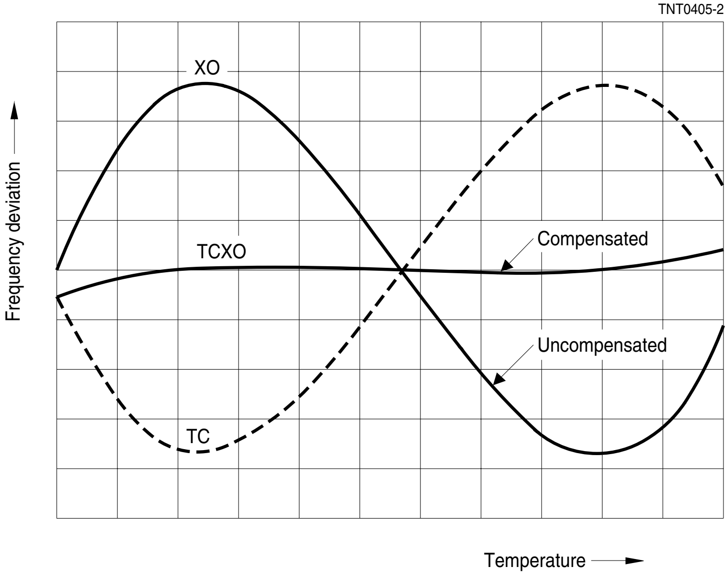


Figure 7

Temperature characteristic of the crystal oscillator with and without NTC temperature compensation

The direct compensation method is more cost-efficient as it uses fewer parts and makes smaller TCXOs possible. The indirect compensation provides more accurate temperature compensation than the direct method, with a frequency stability of <1 ppm and <2,5 ppm, respectively.

Battery packs

All rechargable batteries and lithium ion batteries in particular must be controlled and protected by smart charging circuits, as the mobile phone 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 hat to be measured, as not all batteries allow the charging in the hot and cold temperature region. Usually charging temperatures of 0 °C up to 45 °C for slow charging, and 5 – 10 °C up to 45 °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 8), 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 precipitated from abnormal charging conditions. During discharging NTC thermistors also perform temperature compensation for the voltage measurement, which helps to measure the remaining charge in the battery.

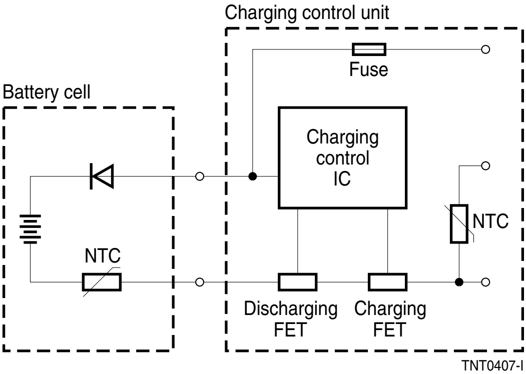


Figure 8

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

In a mobile phone the charging control unit is either placed on the main board or it is integrated in the battery pack on a small PCB.

LCD

Liquid crystal displays (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. The LCD in a mobile phone, however, must operate over a temperature region of –20 °C up to 70 °C.

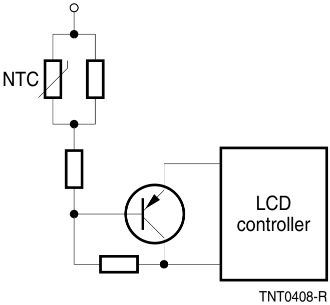


Figure 9

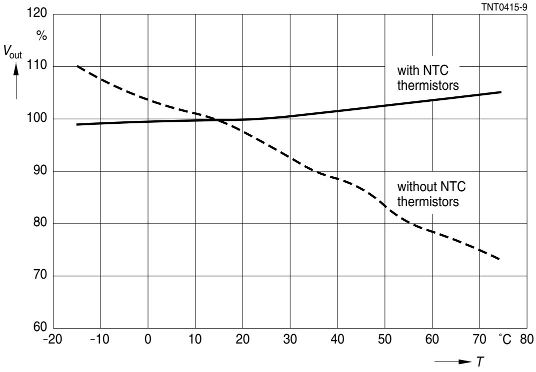
Schematic drawing of the compensation circuit of an LCD using an NTC thermistor as temperature sensor

For these LCD modules often a temperature compensation circuit is used (see figure 9), 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.

1.4.2 Temperature control in HDD applications

Reliability and high data density are key features of modern hard disk drives (HDD). The most significant advances towards high data density have been made with GMR (giant magnetoresistive) read/write heads.

The GMR effectiveness, however, decreases with increasing temperature due to the thermal simulation of the internal structure. The GMR effect (ΔR) has a linear temperature dependence. The temperature coefficient of the output voltage is approx. –0,4 %/C (see figure 10). This allows effective electronic temperature compensation by means of a temperature-dependent supply, which is implemented by a multilayer NTC thermistor with nickel barrier termination. As the temperature rises, a current flows, enabling the Vout/T characteristic to be compensated.



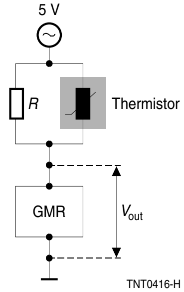


Figure 10

Output voltage versus temperature in GMR sensors

Figure 11

Temperature compensation circuit for GMR sensors

Another 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 MTBF (mean time between failures).

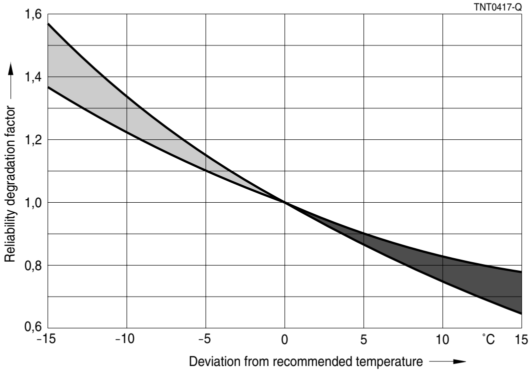


Figure 12

HDD reliability:
typical temperature sensitivity

An 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.

EPCOS high-precision temperature sensors are available with an accuracy smaller than ±1 °C over an operating temperature range of 5 °C to 55 °C, which allows a precise temperature monitoring.

2 Applications utilizing the non-linear voltage/current characteristic (in self-heated mode)

2.1 Inrush current limiting

Many items of equipment like switch-mode power supplies, electric motors or transformers exhibit excessive inrush currents when they are turned on, meaning that other components may be damaged or fuses may be tripped. With NTC thermistors it is possible to effectively limit these currents, at attractive cost, by connecting a thermistor in series with the load.

The NTC thermistors specially developed for this application limit the current at turn-on by their relatively high cold resistance. As a result of the current load the thermistor heats up and reduces its resistance by a factor of 10 to 50; the power it draws reduces accordingly.

NTC thermistors are able to effectively handle higher inrush currents than fixed resistors with the same power consumption.

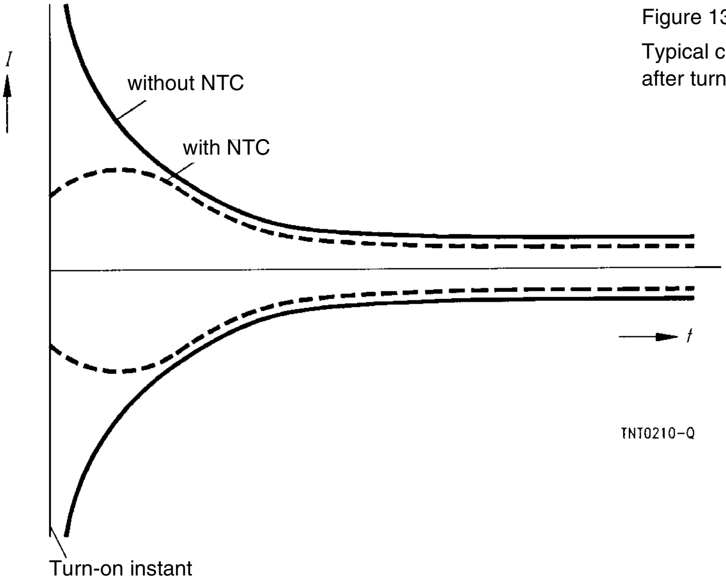


Figure 13

Typical current curve of a load after turn-on (envelope curve)

The NTC thermistor thus provides protection from undesirably high inrush currents, while its resistance remains negligibly low during continuous operation.

2.2 Series and parallel connection

An NTC thermistor is always connected in series with the load to be protected. If the inrush current cannot be handled by one thermistor alone, two or more thermistor elements can be connected in series.

Paralleling several NTC thermistors is inadmissible, since the load will not be evenly distributed. The thermistor carrying the largest portion of current will heat up until it finally receives the entire current (which may result in destruction of the device), while the other paralleled thermistors remain cold.

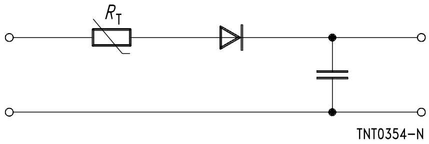


Figure 14

Basic circuit diagram for diode protection

Figure 15 shows a typical example of an inrush protection circuit:

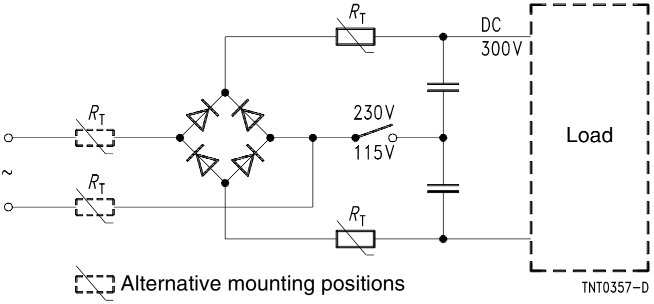


Figure 15

Mounting positions for NTC thermistors in a protective circuit

Selection of the most appropriate NTC thermistor is the precondition for effective circuit protection. The first and most important criterion is the maximum current during continuous operation, which is determined by the load.

2.3 Self-heating

The self-heating of a thermistor during operation depends on the load applied. Although some heat is being dissipated, the NTC thermistor may in extreme cases reach a mean temperature of up to 250 °C. The dissipation factor δ_{th} specified in the data sheets has been measured in still air at T_A = 25 °C on devices with clamp contacts. A change in the measuring conditions (e.g. stirred air = blower increases the dissipation factor) will influence the dissipation factor.

The heat developed during operation will also be dissipated through the lead wires. When mounting NTC thermistors it should therefore be considered that the contact areas may become quite hot at maximum load.

2.4 Load derating

The power handling capability of an NTC thermistor cannot be fully utilized over the entire temperature range. For circuit dimensioning the derating curve given below provides information on the extent to which the current must be reduced at a certain ambient temperature.

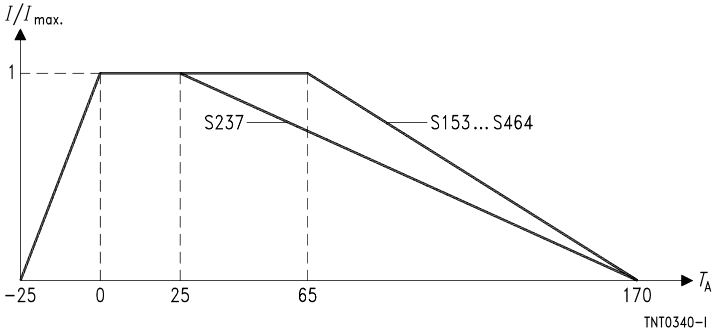


Figure 16

Derating curve

The I_{max} values specified in the data sheets denote the maximum permissible continuous current (dc or rms values for sine-shaped ac) in the temperature range 0 °C to 65 °C.

2.5 Restart

When the load has been switched off the thermistor slowly cools down. Its resistance increases steadily, but the full resistance value is only reached after 1 to 2 minutes (depending on ICL type).

It may therefore be useful in some applications to bypass the thermistor after restart. Operation can thus be faster resumed and system performance will not be affected by the thermistor.

2.6 Dependence of NTC resistance on current

The resistance effective in the usual current range can be approximated as follows:

$$R_{NTC} = k \cdot I^n \qquad 0{,}3 \cdot I_{max} < I \leq I_{max}$$

R_{NTC}	Resistance value to be determined at current I [Ω]
k, n	Fit parameter, see individual data sheets
I	Current flowing through the NTC (insert numerical value in A)

The calculated values only serve as an estimate for operation in still air at an ambient temperature of 25 °C.

Note: With the equation above sufficiently accurate results are only obtained for the limited current range stated above.

2.7 Pulse strength

The currents during turn-on are much higher than the rated currents during continuous operation. To test the effects of these current surges EPCOS uses the following standard procedure:

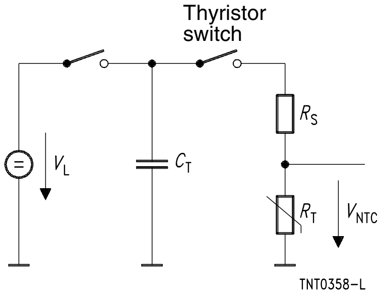


Figure 17

Test circuit for evaluating the pulse strength of an NTC thermistor

V_L	Load voltage [V]
C_T	Test capacitance [µF]
R_S	Series resistance [$R_S = 1\ \Omega$]
V_{NTC}	Voltage drop across the NTC under test [V]

In the pulse test the capacitor C_T is discharged via the series resistor R_S and the NTC thermistor. The load voltage is chosen such that the voltage applied to the thermistor at the start of discharge is $V_{NTC} = 358$ V (corresponds to $(230\ \text{V} + \Delta V) \cdot \sqrt{2}$).

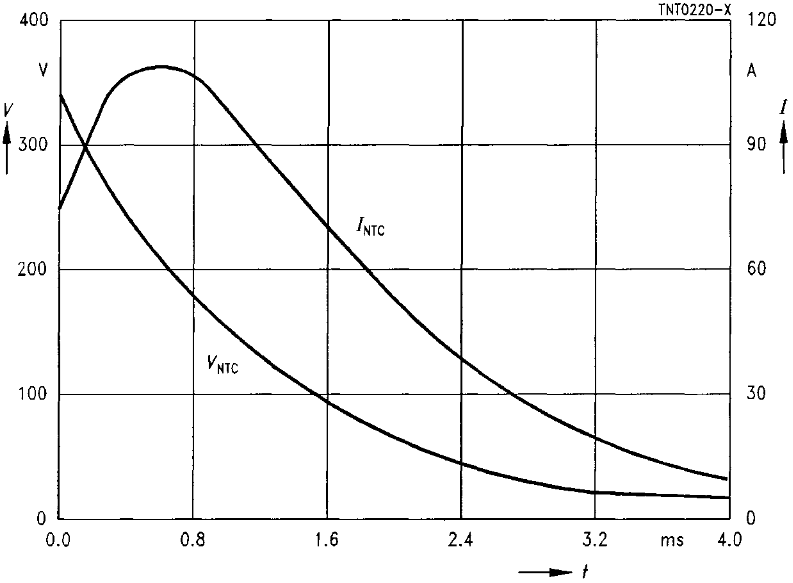


Figure 18

Pulse strength test : typical curves

The maximum capacitances that can be switched depend on the individual thermistor type and are given in the data sheets.

2.8 Application examples

Inrush current limiters are primarily used in industrial electronics and equipment engineering. Application examples are:

Inrush current limiting in fluorescent, projector and halogen lamps, rotational speed limiting in kitchen machines, soft start of motors and switch-mode power supplies etc.

EPCOS thermistors are available in a variety of sizes and rated resistances to optimally match your application. The product line ranges from the small-size S153 with a maximum power of 1,4 W through to the at present largest S464 with a maximum power of 6,7 W. Maximum continuous AC currents of 20 A are reached. Inrush current limiters are presented on pages 128 to 144.

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

3.1 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.

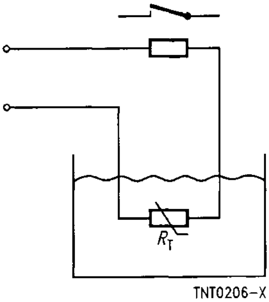


Figure 19

Circuit for liquid level sensing

3.2 Flow rate and vacuum measurement

Here too, the thermistor is operated by means of an electrical load. Its temperature and resistance are influenced by the surrounding medium. Stirred air lowers the NTC's temperature and thus increases its resistance. A vacuum, in contrast, increases the NTC's temperature and thus causes a decrease in resistance. Hence NTC thermistors can be used to monitor ventilators, to measure the flow rate of gases or for vacuum measurement.

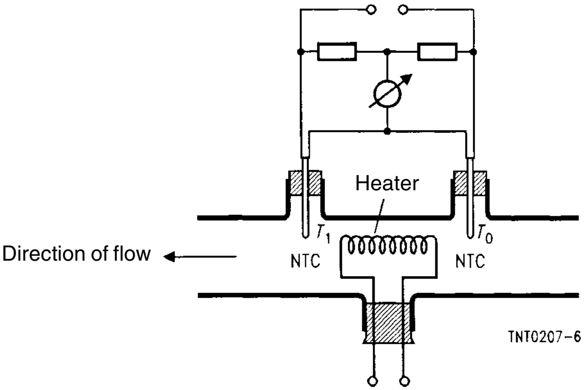


Figure 20

Experimental circuit for flow rate measurement

Application examples are found in

- physics and chemistry: level control of various liquids, as for example liquid nitrogen, measurement of the thermal conductivity or flow rate of gases, vacuum and radiation measurement
- in automotive electronis for tank content indication

etc.

4 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.

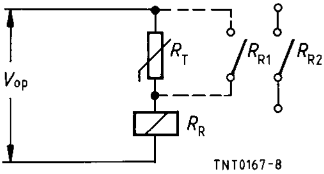


Figure 21

Delay of relay pick-up

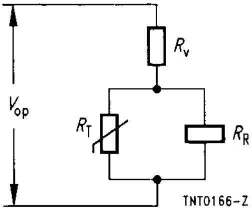


Figure 22

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 21).

5 Further application notes

Further application notes are given on Internet (http://www.epcos.com → Product Catalog → Ceramic Components → NTC Thermistors, Data Sheets → Further Information) and on the CD-ROM “Data Book Library” (Please order via Internet: Publications → General Publications).

Herausgegeben von EPCOS AG
Unternehmenskommunikation, Postfach 80 17 09, 81617 München, DEUTSCHLAND
☎ ++49 89 636 09, FAX (0 89) 636-2 26 89

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