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.

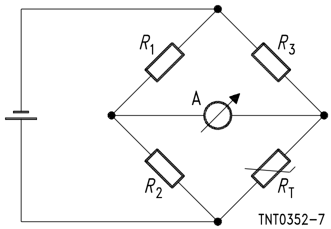

Figure 1
Wheatstone bridge circuit

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.

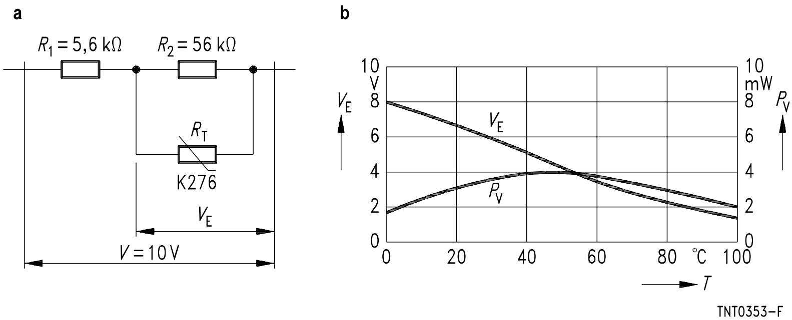

Figure 2

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

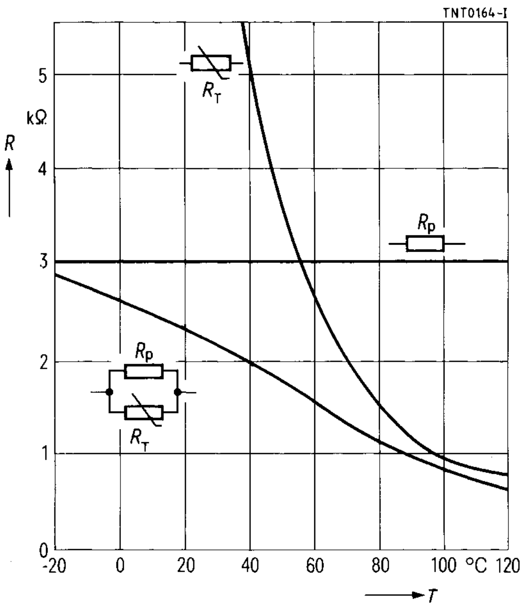

Figure 3

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.

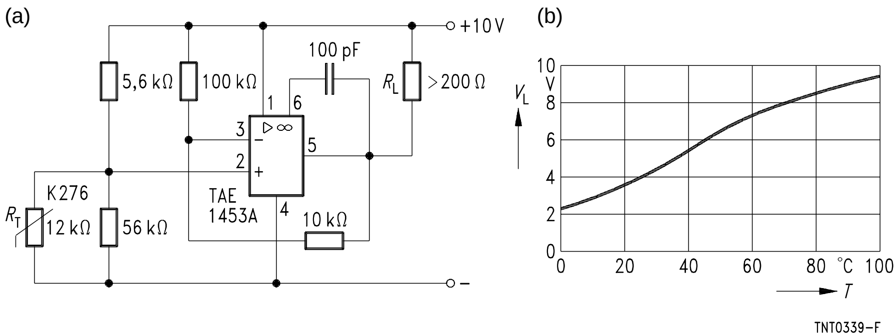

Figure 4

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.

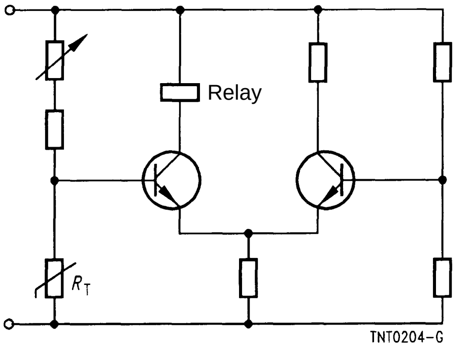

Figure 5
Circuit for a temperature controller

NTC thermistors for temperature measurment 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, …
- 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, …
- in industrial electronics: for temperature stabilization of laser diodes and photoelements, for temperature compensation in copper coils or reference point compensation in thermoelements, etc.

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.

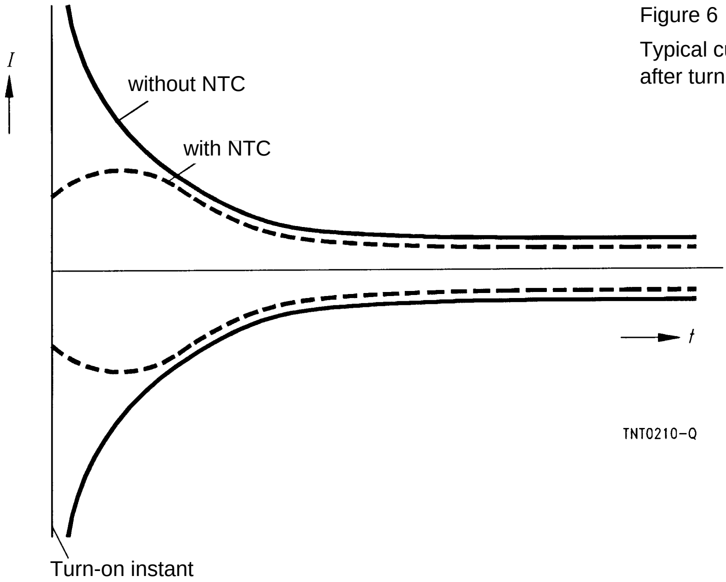

Figure 6

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.

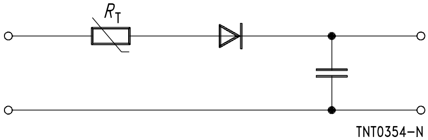

Figure 7

Basic circuit diagram for diode protection

Figure 8 shows a typical example of an inrush protection circuit:

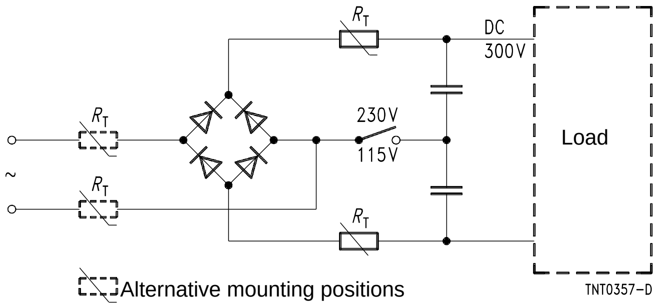

Figure 8
Mounting positions for NTC thermistors in a protective circuit

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. The rated resistance of the thermistor results from this current value.

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.

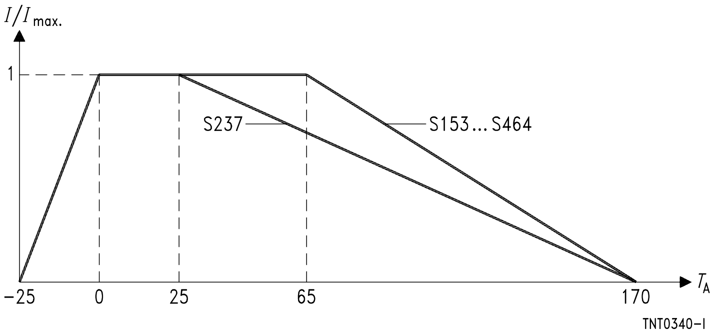

Figure 9

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 ambient temperature and type).

It may therefore be useful in some applications to bypass the thermistor during 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:

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

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 S+M uses the following standard procedure:

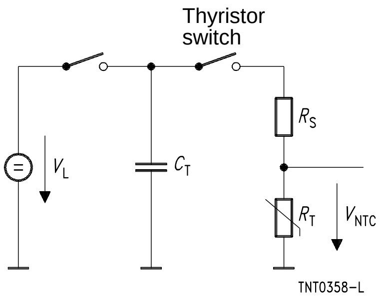

Figure 10

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 $(230\ \text{V} + \Delta V) \times \sqrt{2}$).

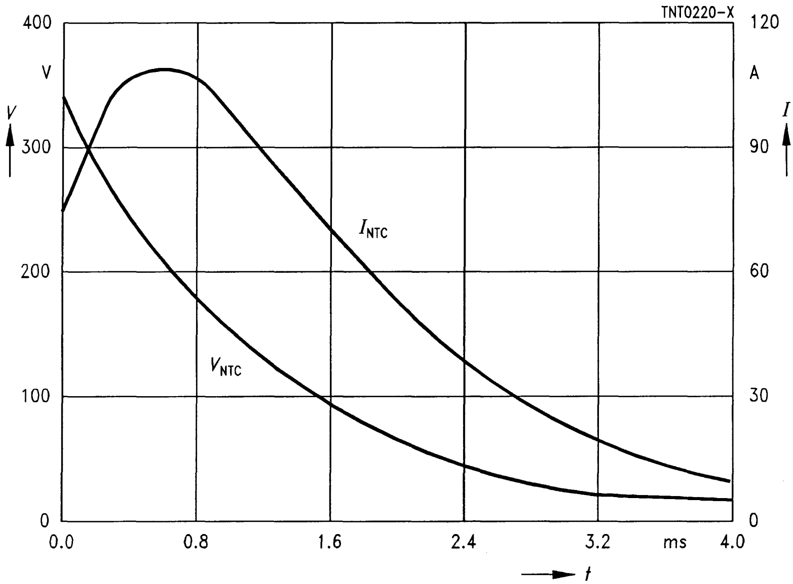

Figure 11

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 Applications

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.

S+M 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 76 to 84.

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.

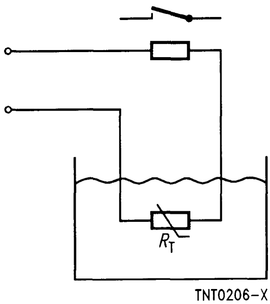

Figure 12
Circuit for liquid level sensing

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.

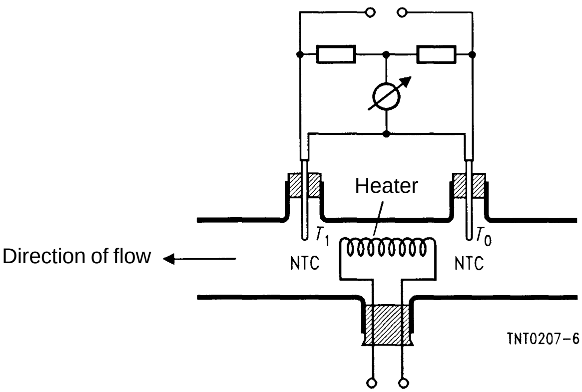

Figure 13

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.

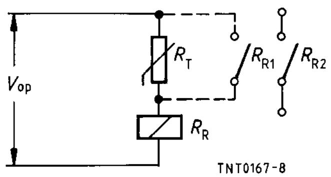

Figure 14

Delay of relay pick-up

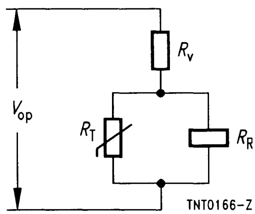

Figure 15

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 14).

5 Further application notes

Further application notes are given on Internet (http://www.siemens.de/pr/inf/50/d0000000.htm) and on the CD-ROM “Data Book Library” (ordering no. B465-P6593-X-X-7600).