GENERAL

Definition and composition

Negative Temperature Coefficient thermistors (NTCs) are resistive components, of which the resistance decreases as temperature increases. They are made from polycrystalline semiconductors, the composition of which is a mixture of chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co) and nickel (Ni).

Manufacture

The manufacturing process is comparable to that of ceramics. After intensive mixing and the addition of a plastic binder, the mass is shaped into the required form, e.g. pressing (discs), and fired at a temperature high enough to sinter the constituent oxide. New technologies have led to the sawing of isostatic pressed wafers, the compositions of which are very stable, with as a result, high accuracy and high reproducibility.

Electrical contacts are then added by burning them in with silver paste or by other methods, such as evaporation. Finally, leads (isolated or not) are fitted. Different encapsulations are possible, depending on the size of the ceramic and the application of the component.

Miniature NTC thermistors are made by placing a bead of oxide paste between two parallel platinum alloy wires and then drying and sintering. The platinum alloy wires are 60 µm in diameter and spaced 0.25 mm apart. During sintering, the bead shrinks onto the wires to make a solid and reliable contact. Miniature NTC thermistors are usually mounted in glass to protect them against aggressive gases and fluids.

Relationship of resistance with temperature

The conductivity (σ) of the material is its capacity to drive a current when a voltage is applied to it. As the current is driven by carriers that are free to move (i.e. which are not bound to atoms), then it follows that the conductivity will be proportional to the number of carriers (n) that are free and also to the mobility (µ) that those carriers can acquire under the influence of electrical fields.

Thus:

$$\sigma = n \times e \times \mu$$

where e is the unit of electrical charge stored by each carrier.

Both n and µ are functions of temperature. For µ, the dependency on temperature is related to the interactions of a carrier with other carriers and with the total net amount of vibrating atoms, the vibration varying with temperature.

It can be shown that:

$$\mu \div T^{-c} \times e^{-q_2/kT}$$

For n, the dependency on temperature can be explained as follows: electrons are bound to atoms by certain energies. As one gives the electron an energy equal to, or greater than, the binding energy (e.g. by raising its temperature), there is a probability that the electron will become free to move. As for many semiconductors, this probability has the form of the well-known Maxwell-Boltzmann distribution. Thus:

$$n \div e^{-q_1/kT}$$

The total temperature dependency of the conductivity is:

$$\sigma \div T^{-c} \times e^{-(q_1 + q_2)/kT}$$

In practice, the exponential factor is the most important. Remembering that resistivity is the inverse of conductivity, the following can be derived:

$$R = A \times e^{B/T}$$

where $B = q_1 + q_2$

or

$$\log R = A + \frac{B}{T}$$

where A and B are parameters depending on each component (resistivity and shape).

Shape of an NTC curve and determination of B-value

In Fig.1, the resistance is plotted as a function of the inverse of the temperature. Even in semi-logarithmic scale, it can be seen that this curve is not a straight line. This is due to the fact that A and B are not perfectly constant with temperature. However, over a wide range of temperatures, it may be assumed that these parameters are constant. If this range is defined between T_1 and T_2, and it is assumed that the curve for this range could be approximated with a straight line, the slope of which will be B, this last value between T_1 and T_2 can be found as follows:

The resistance value is measured at T_1 and T_2:

$$R_1 = A \times e^{B/T_1}$$

and

$$R_2 = A \times e^{B/T_2}$$

Dividing yields:

$$\frac{R_1}{R_2} = e^{(B/T_1 - B/T_2)}$$

or

$$\log R_1 - \log R_2 = B\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\log e$$

Hence:

$$B = \frac{\ln(R_1/R_2)}{1/T_1 - 1/T_2}$$

In practice, B varies slightly with increasing temperature.

The temperature coefficient of an NTC may be derived from: $\alpha = \frac{1}{R} \times \frac{dR}{dT} = -\frac{B}{T^2}$

For the different materials, the constant B may vary between 2000 and 5500 K; e.g. a value of 3600 K yields α = –4%/K at a temperature of 300 K.

A and B are assumed to be constant between T_1 and T_2 $\left(B_{T_1/T_2}\right)$.

In practice, most NTCs are specified with a reference value at 25 °C and a constant B-value between 25 °C and 85 °C. For commodity reasons, the curves printed in this handbook show the resistance as a function of temperature, instead of its inverse.

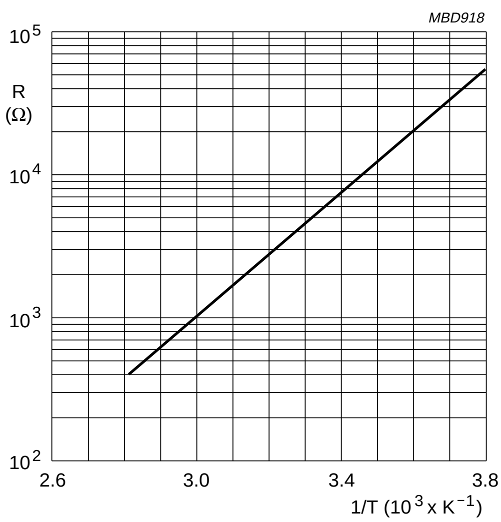


Fig.1 Resistance as a function of the inverse of temperature for a typical NTC.

Voltage (V)/Current (I)-characteristic description

Figure 2 shows the relationship between the current through and the voltage drop across the NTC thermistor heated by this current to a temperature much higher than the ambient temperature.

With very small values of current, it can be seen that the curve remains straight, following an isoresistive line. Remembering that an isoresistive line is in fact an isothermal line (R = f[T]) it indicates that the power consumption is too small to register a distinct rise in temperature.

For higher current intensities, the temperature rises by the Joule-effect (P = V × I). The equilibrium temperature is reached when the power dissipated by the NTC is in equilibrium with the power applied to it. It can be seen that as the dissipated power is dependent on the environment, the equilibrium will also depend on it and thus the V/I-characteristic too. The characteristic shown in Fig.2 was measured at a constant ambient temperature after equilibrium had been reached.

Assuming that:

- a constant temperature is present throughout the body of the thermistor;
- the heat transfer is proportional to the difference in temperature between thermistor and surrounding medium (which is true for low temperatures);

then, in case of equilibrium:

$$W = V \times A = \delta(T - T_0)$$

where T_0 is the ambient temperature and δ the dissipation factor (defined in Chapter “Speed of response”).

From this relationship, it is obvious that the temperature of the component will be that of its surroundings if the power P (W) applied to the component is equal to zero (power-off value). If the applied power is not very low (≥0.01 W), then T is no longer equal to T_0 and will be strongly dependent on δ (power-on conditions).

Because it is not possible to define δ without any doubt (δ is not only dependent on the component itself, but also on special housing if any, convection, turbulence, etc.), all components are specified with their power-off values.

To choose a component that will be used in a ‘power-on’ application, it is necessary to determine δ in that application.

V/I-CHARACTERISTIC

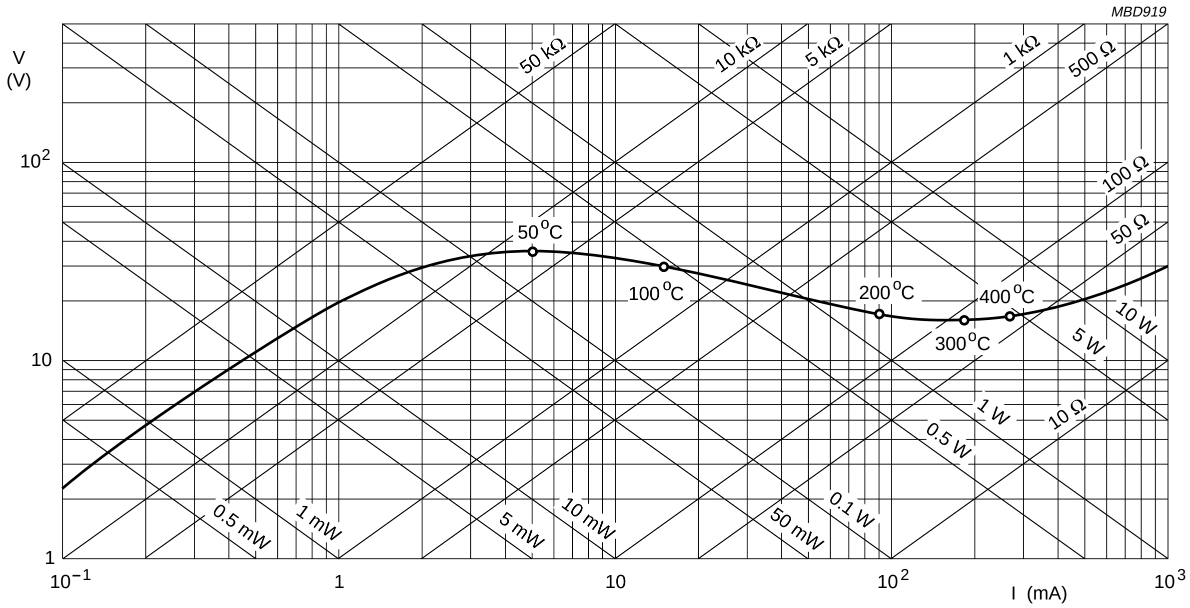


Fig.2 Voltage as a function of the current characteristics of a NTC thermistor.

SPEED OF RESPONSE

Thermal time constant

The thermal time constant is an indication of the time that a component needs to reach thermal equilibrium. This constant depends on two important parameters.

One parameter is the thermal capacity (H) of the component, i.e. the energy that must be applied to the component in order to raise its temperature by 1 Kelvin (or the energy that the component must loose in order to lower its temperature by 1 Kelvin). The units are thus quoted in Joules/Kelvin. The second parameter is called the dissipation factor (δ). If the temperature of a component rises, it will tend to dissipate energy. This dissipation will depend on the surroundings and also on the component itself. The dissipation factor is defined as the ratio of the change in power dissipation with respect to the resultant body temperature change (units in W/K).

If a step change in temperature is applied to a component e.g. from high (T_1) to low (T_0) temperature, the energy lost by the component (–HdT) is equal to the energy dissipated by it ($\delta[T - T_0]dt$):

$$-HdT = \delta(T - T_0)\,dt$$

This equation yields:

$$T - T_1 = (T_0 - T_1)\,e^{-t/\tau}$$

where the thermal time constant (τ) is defined as the ratio of the heat capacity (H) of the thermistor with respect to its dissipation factor (δ).

The temperature value when the time elapsed (t) is equal to τ is given by the formula:

$$T - \frac{T_0}{T_1} - T_0 = \left(1 - e^{-1}\right) = 0.632$$

This equation gives the following definition:

> The thermal time constant is the time required for the temperature of a thermistor to change by 63.2% of the difference between its initial and final body temperatures (in accordance with "*IEC 539*": 85 °C and 25 °C respectively), when subjected to a step function temperature change.

It is entirely dependent on the component design. The thermal time constant depends on δ, which varies for different media.

The thermal time constants referred to in the data sheets are measured as follows; the method used depends on the application:

- By cooling in air under zero power conditions (T_c)
- By heating or cooling, transferring the thermistor from ambient temperature (25 °C) to a bath with fluid with a higher or lower temperature under zero power conditions (T_r, termed ‘response time’ in the data sheets).

Tolerances in the nominal NTC specification

As already mentioned, an NTC thermistor is normally specified by giving a reference value (generally R_{25}) and the B-value ($B_{25/85}$). Unfortunately, the manufacturing process dictates that identical components cannot be guaranteed, so there are some tolerances.
These tolerances can mean an upward or downward shift in the resistance value, equal at all temperatures due to, for example, variations of mechanical dimensions. The entire curve moves equally up or down (see Fig.3).

This tolerance is usually indicated by giving the shift at the reference temperature; for example, R_{25} = 10 kΩ ±5%.

A tolerance also exists on the slope of the curve. Because the B-value is an indication of that slope, it is normally indicated as a tolerance on $B_{25/85}$. This is covered mainly by variations in the material composition and the effect of sintering on the material (see Fig.4).

The effect of the slope or B-value deviation on the resistance at several temperatures can be calculated.

The fundamental equation of an NTC is:

$$R_{nT} = R_{ref}{}^{B(1/T - 1/T_{ref})}$$

where R_n and B are nominal values (specified values without any tolerance).

If B is not a nominal value, it is expressed as:

$$R_T = R_{nT} + \Delta R_T = R_{ref} e^{(B + \Delta B)(1/T - 1/T_{ref})}$$

where ΔR_T is the absolute deviation at temperature T:

$$\Delta R_T = R_{ref}\left[e^{(B + \Delta B)(1/T - 1/T_{ref})} - e^{B(1/T - 1/T_{ref})}\right]$$

If relative deviation is applied:

$$\frac{\Delta R_T}{R_{nT}} = e^{\Delta B(1/T - 1/T_{ref}) - 1}$$

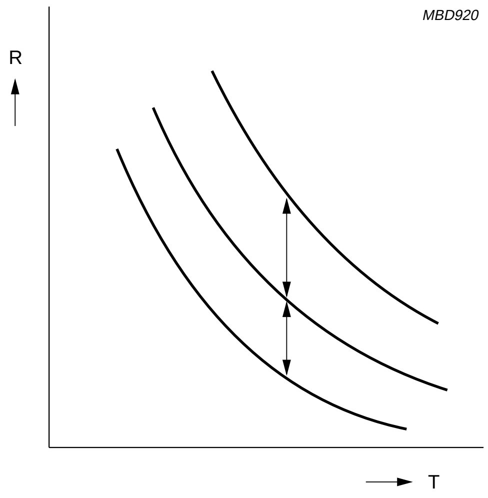


Fig.3 Effect of variations of mechanical dimensions on the resistance as a function of temperature.

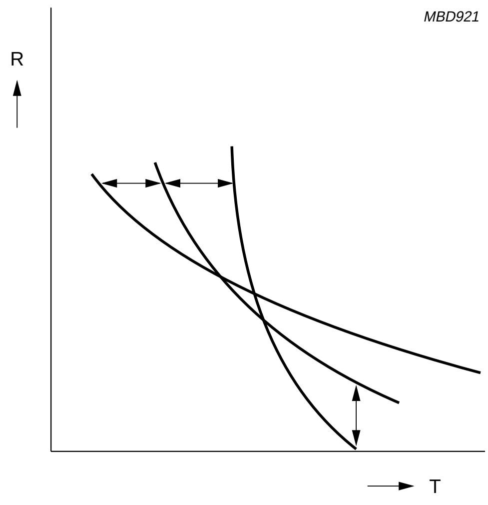


Fig.4 Effect of sintering on the resistance as a function of temperature.

Developing this equation (Taylor's formula), the following simplified expression can be derived:

$$\frac{\Delta R_T}{R_{nT}} \text{(in \%)} = \Delta B\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)$$

This calculation has been performed for all major sensor ranges to be found in this handbook, where 'R-deviation due to B-tolerance' values can be found in the electrical data tables.

If the 'R-deviation due to B-tolerance' is called 'Y' and the tolerance at the reference temperature 'X', then the total tolerance can be calculated as follows:

$$Z = \left[\left(1 + \frac{X}{100}\right) \times \left(1 + \frac{Y}{100}\right) - 1\right] \times 100\%$$

or, after approximation:

$Z \approx X + Y$

If TC is the temperature coefficient and ΔT is the temperature deviation:

$$\Delta T = \frac{Z}{TC}$$

EXAMPLE

At 0 °C, assume X = 5%, Y = 0.089% and TC = 5.08%/K, then:

$$Z = \left\{\left(1 + \frac{5}{100}\right) \times \left(1 + \frac{0.89}{100}\right) - 1\right\} \times 100\%$$

or

$$Z = \{1.05 \times 1.0089 - 1\} \times 100\% = 5.9345\% \ (\approx 5.93\%)$$

$$\Delta T = \frac{Z}{TC} = \frac{5.93}{5.08} = 1.167\ °C\ (\approx 1.17\ K)$$

Hence, an NTC having a R_{25}-value of 10 kΩ has a value of 32.51 kΩ between –1.17 °C and +1.17 °C.

Resistance specified at more than one temperature (2 or 3-point measurement)

Thermistors which are specified at 2 or 3 points of their R/T-characteristic are more accurate. They have a closer tolerance and the spread in B-value has less influence because it is included in the tolerance at the specified points.

The tolerances in the reference points can be expressed either as a temperature deviation for the reference resistance or as a resistance tolerance at the reference temperature. This has no influence on the resulting measuring error which is minimum in the temperature region between the reference points, as illustrated in Fig.5.

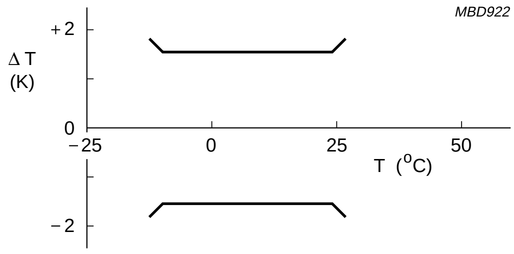


Fig.5 Temperature measurement at more than one point.

The 2 or 3-point sensors are particularly suited for applications with the following characteristics:

- Temperature measurement over a certain temperature range
- High accuracy
- No further calibration for sensor tolerances in the electrical circuitry required.

GLOSSARY OF TERMS

Resistance

Also called nominal resistance. Formerly specified at only one temperature, or sometimes at two or maximum three. Now new technologies allow the specification of resistance values on all application ranges for several types.

Tolerance on resistance

The limits of the values that the resistance can take at the reference temperature.

B-value

The B-value may be calculated using the following formula:

$$\frac{\ln(R_1/R_2)}{1/T_1 - 1/T_2}$$

where R_1 and R_2 are the nominal values of resistance at T_1 and T_2 respectively.

Tolerance on B-value

The limits of the value that B can take due to the process variations.

R-tolerance due to B-deviation

Due to the tolerance on the B-value, the limits of the value that R can take at a certain temperature increase with the difference of that temperature to the reference temperature.

Tolerance on R at a temperature different to T_{ref}

The sum of the tolerances on resistance and tolerance due to B-deviation.

α-value

Variation of resistance (in %) for small variations of temperature around a defined temperature.

Maximum dissipation

Maximum power which could be applied without any risk of failure.

HOW TO MEASURE NTC THERMISTORS

The published R_T-values are measured at the temperature T.

The published B-value at 25 °C is the result of the measurement at 25 °C and that at 85 °C. Hence, these values should be used when checking.

The following general precautions have to be taken when measuring NTC thermistors:

- Never measure thermistors in air; this is quite inaccurate and gives deviations of 1 or 2 K. For measurements at room temperature or below, use petrol or some other non-conductive and non-aggressive fluid. For higher temperatures use oil, preferably silicon oil.
- Use a thermostat with an accuracy of better than 0.1 °C. Even if the fluid is well stirred, there is still a temperature gradient in the fluid. Measure the temperature as close as possible to the NTC.
- After placing the NTC in the thermostat, wait until temperature equilibrium between the NTC and the fluid is obtained. For some types this may take more than 1 minute.
- Keep the measuring voltage as low as possible, otherwise the NTC will be heated by the measuring current. Miniature NTC thermistors are especially sensitive in this respect. Measuring voltages of less than 0.5 V are recommended.
- For high temperature measurements it is recommended that stem correction be applied to the thermometer reading.

CHOICE OF TYPE

Selection of an NTC thermistor

When selecting an NTC thermistor the following main characteristics should be considered:

- Resistance value(s) and temperature coefficient
- Accuracy of resistance value(s)
- Power to be dissipated:
  - Without perceptible change in resistance value due to self-heating
  - With maximum change in resistance value
- Permissible temperature range
- Thermal time constant, if applicable
- Types best suited to the purpose. Basic forms are chip, disc and bead
- Protection against undesired external influences, if necessary.

When it is impossible to find an NTC thermistor to fulfil all requirements, it is often more economical to adapt the values of other circuit components to the value of a series-manufactured NTC. Sometimes, a standard NTC can be used with simple parallel and series resistors where otherwise a special type would have been necessary.

If no suitable combination can be found, the development of a special type can be considered. In this event a specification of the requirements is necessary. A description of the circuit in which the NTC is to be used, is most useful.

Deviating characteristics

The following example explains the resistance values resulting from combinations of an NTC thermistor and normal resistors.

Suppose an NTC must have a resistance of 50 Ω at 30 °C and 10 Ω at 100 °C. A standard type having this characteristic is not included in our programme. The problem may, however, be solved by using a standard NTC and two fixed resistors, e.g. an NTC disc with a cold resistance of 130 Ω mounted in a series and parallel arrangement with two fixed resistors of 6 Ω and 95 Ω respectively. It should be remembered that the temperature coefficient of the combination will always be lower than that of the NTC thermistor alone.

Remarks on the use of NTC thermistors

Do not use unprotected thermistors in conducting fluids or aggressive and reducing gases which may cause a change in thermistor characteristics.

For temperature measurements do not use too high a voltage on the NTC thermistor, as self-heating may cause incorrect readings. The dissipation constant indicates the maximum permissible measuring power, if an error of 1 °C is allowed.

HOW NTC TEMPERATURE SENSORS FUNCTION

NTC temperature sensors are made from pure metal oxides. They respond quickly to temperature changes, even small temperature increases cause their resistance to decrease significantly, as shown in Fig.6.

So, by placing an NTC temperature sensor into one arm of a bridge circuit, accurate temperature measurement is possible.

The main characteristics of an NTC temperature sensor are expressed by three parameters:

- The resistance at 25 °C (R_{25}). Tolerances on the R_{25}-value are mainly caused by manufacturing and material tolerances. By using very precise sawing, tolerances on R_{25} lower than 1% (or 0.25 °C) can be achieved.
- The material constant (B). This constant relates the rate of change of resistance with temperature, and therefore affects the slope of the R/T-characteristic.

  $$R = A \times e^{B/T}$$

  where R is the resistance at absolute temperature T (in Kelvin) and A is a first-approximation constant. In practice, B is defined between two selected temperatures. The B-value is very useful for comparing sensors, but in making this comparison, care must be taken to ensure that the same two temperatures are used (normally 25 and 85 °C).

  Tolerances on B-value are mainly caused by material tolerances and by the effects of the sintering temperature on the material. Our new materials have tolerances on the B-value as low as 0.75%.
- The temperature coefficient of resistance (α), expressed in %/K. This coefficient indicates the sensitivity of the sensor to a change in temperature. Values of α are given in the *“Data sheets”* in this *“Data Handbook”*.

  For calculation purposes holds $\alpha = \frac{\Delta R}{\Delta T}$, where ΔR is the percentage change in resistance at the required temperature (see Fig.7), and ΔT is the temperature deviation (T in Kelvin). So, when ΔR and α are known for any temperature, ΔT (the temperature deviation in °C) can be calculated.

  The plot of ΔR as a function of T is known as the butterfly characteristic, which really shows how good a sensor is (see Fig.7). It shows that a typical Philips sensor is far more accurate than a similar competitor sensor. That is why we are renowned as world leaders in high-accuracy sensor technology.

Tolerance on R_{25} and the resistance tolerance due to B-value combine to affect the performance of the sensor over its operating temperature range (see Fig.8).

However, from an operational point of view, it is far better to express sensor tolerance in terms of temperature deviation ΔT over a temperature range. This plot is shown in Fig.9.

Again we have shown a typical comparison with a similar competitor sensor. Note how Philips outperforms the competitor right across the temperature range.

Two other parameters which are important in specifying NTC temperature sensors are the thermal time constant and the response time:

– The thermal time constant is the time required for the temperature of the sensor to change **in air** by $\left(1 - \frac{1}{e}\right) = 63.2\%$ of the difference between its initial and final body temperatures, when subjected to a step function temperature change (85 °C to 25 °C in accordance with *“IEC 539”*).

– The response time is the time the sensor needs to reach 63.2% of the total temperature difference when subjected to a temperature change from 25 °C **in air** to 85 °C **in silicone oil** (MS 200/50).

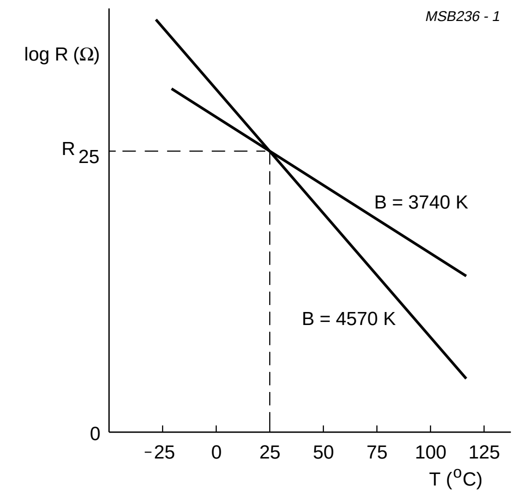


Fig.6 Typical plot of resistance as a function of temperature for an NTC temperature sensor.

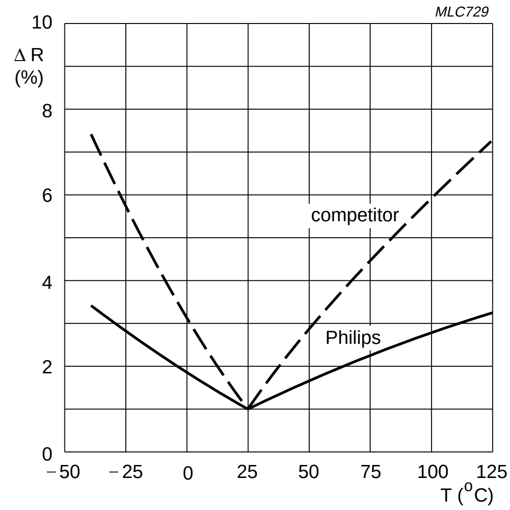


Fig.7 Typical resistance change as a function of temperature for a 1% Philips NTC temperature sensor compared to a competitor sensor.

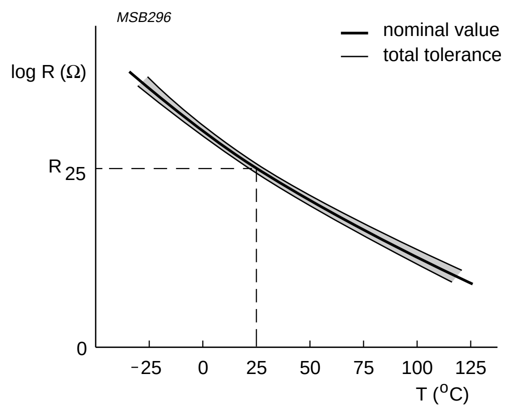


Fig.8 The combined effects of tolerance on R_{25} and resistance tolerance due to B-value.

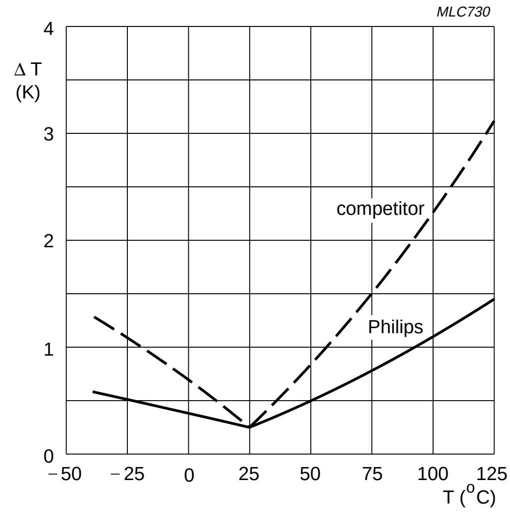


Fig.9 Temperature deviation as a function of temperature.

APPLICATIONS

General

Temperature is one of the variables that must be measured most frequently. There are as many as nineteen recognized ways of measuring it electrically, most commonly by thermocouples, platinum-bulb thermometers and NTC (Negative Temperature Coefficient) temperature sensors. For general-purpose temperature measurement, NTC temperature sensors are accurate over a wide temperature range (–55 to +300 °C). They are stable throughout a long lifetime, have a high impedance and are small and inexpensive. In fact, they are the first choice for most temperature measurements. Typically, they have a negative temperature coefficient of approximately –4.5%/K at room temperature (25 °C), more than ten times the sensitivity of a platinum-bulb thermometer of the same nominal resistance at the same temperature.

When you are aiming for accuracy, Philips has the NTC temperature sensors to help you achieving it. We have been making NTC temperature sensors for many years and we have gained an enviable reputation for our value-for-money ranges. Our component manufacturing and marketing activities are represented in more than 60 countries. This worldwide commitment ensures security of supply, guaranteed quality and technical support in every major industrial market. Recent developments in ceramics technology have allowed us to introduce sensors with resistance tolerances lower than 1% and B-value tolerances down to 0.75%. They add precision to your applications and allow you to design-in even more attractive features. And because you are dealing with Philips, you can be sure of excellent quality, design-in support and service.

Application areas

AUTOMOTIVE SYSTEMS

NTC temperature sensors are widely used in cars. For example in:

- Electronic fuel injection, in which air-inlet, air/fuel mixture and cooling water temperatures are used to determine fuel concentration for optimum injection
- Fan motor control, based on cooling water temperature
- Oil and water temperature controls
- Climatization systems, such as air-conditioning and seat temperature controls
- Frost sensors for outside temperature measurement
- Oil level indication
- ABS.

GENERAL INDUSTRIES

NTC temperature sensors are used in thermal switches, measuring systems and detectors in all segments of industry, notably the following:

- Aerospace/military
- Biomedical/health care
- Education/research
- Electronics/edp
- Energy/environmental
- Food processing
- Heating and ventilating
- Metallurgy
- Petrochemical/chemical
- Weather forecasting
- Fire and smoke detection
- Battery temperature control
- Instrumentation
- Air conditioning.

DOMESTIC APPLIANCES

NTC temperature sensors are used extensively in domestic appliances. You will find at least one NTC temperature sensor in just about anything in the home that gets cold, warm or hot, such as:

- Fridges and freezers
- Cookers and microwave ovens
- Deep-fat fryers
- Coffee makers
- Food warmers and processors
- Washing machines
- Electric irons
- Dish washers
- Electric blankets
- Hair dryers
- Smoke and heat detectors
- Central heating
- Boilers
- Air conditioning
- Aquariums
- Water beds.

Application grouping

Applications of NTCs may be classified into three main groups depending on their physical properties:

1. Applications in which advantage is taken of the dependence of the resistance on the temperature, shown in the formula:

   $R = f(T)$

   This group is split into two sub sections:

   a) The temperature of the NTC thermistor is determined only by the temperature of the ambient medium (or by the current in a separate heater winding).

   b) The temperature of the NTC thermistor is also determined by the dissipation in the NTC thermistor itself.

2. Applications in which the time dependence is decisive, when the temperature is considered as a parameter and is written:

   $R = f(t)$

   This group comprises all applications which make use of the thermal inertia of NTC thermistors.

3. The third group of applications uses mainly the property of the temperature coefficient being highly negative:

   $\alpha < 0$

   Also in this group, applications are listed which take advantage of the fact that the absolute value of the temperature is so high, that a part of the V = f(I) characteristic shows a negative slope.

The classifications given above are supported by practical examples in Figs 10 to 23.

Examples

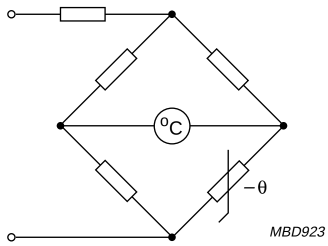


Fig.10 Temperature measurement in industrial and medical thermometers.

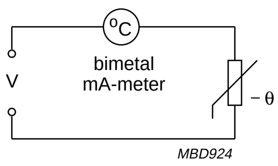


Fig.11 Car cooling water temperature measurement with bimetal.

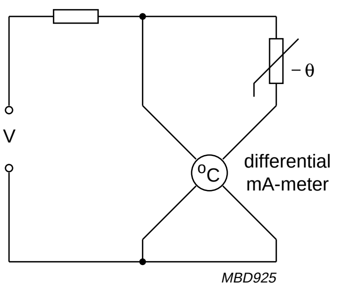


Fig.12 Car cooling water temperature measurement with differential mA-meter.

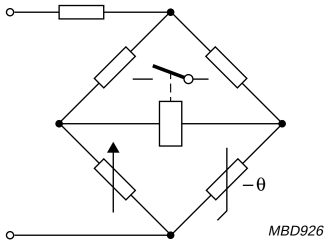


Fig.13 Temperature measurement with a bridge incorporating an NTC thermistor and a relay or a static switching device.

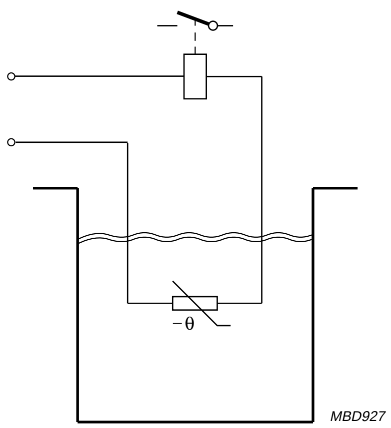


Fig.14 Liquid level control.

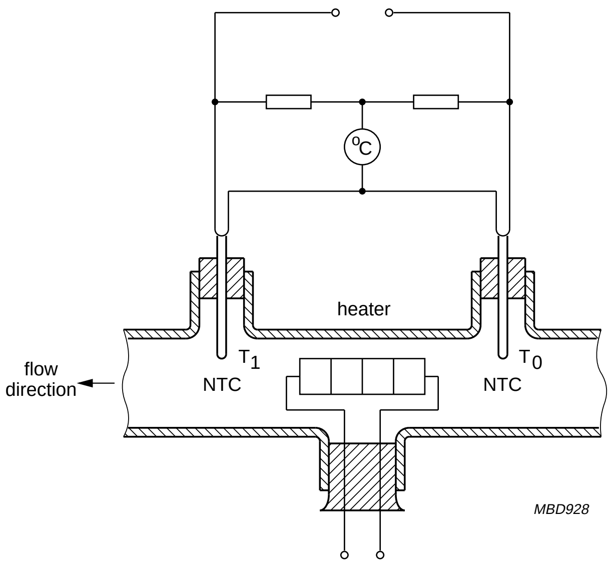


Fig.15 Flow measurement of liquids and gases. The temperature difference between T_1 and T_0 is measured for the velocity of the fluid.

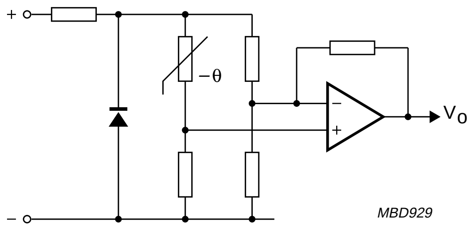


Fig.16 Temperature sensing bridge with op-amp which acts as differential amplifier. The sensitivity can be very high.

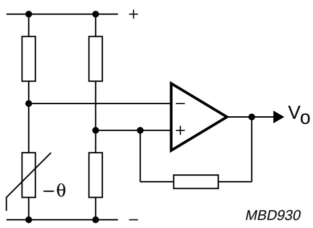


Fig.17 Basic temperature sensing configuration. The op-amp (e.g. NE532) acts as a Schmitt-trigger. The transfer characteristic is shown in Fig.18.

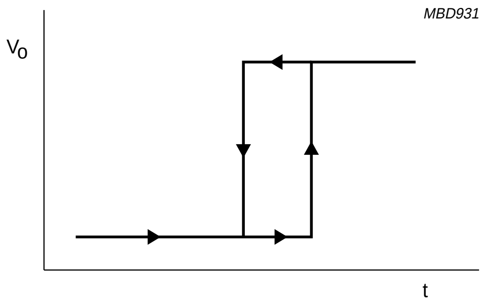


Fig.18 Transfer characteristic of the circuit shown in Fig.17.

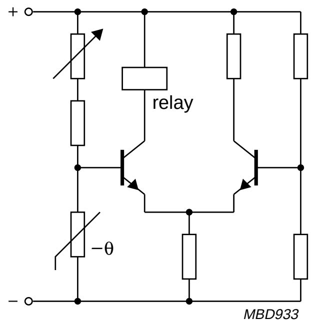


Fig.19 Simple thermostat.

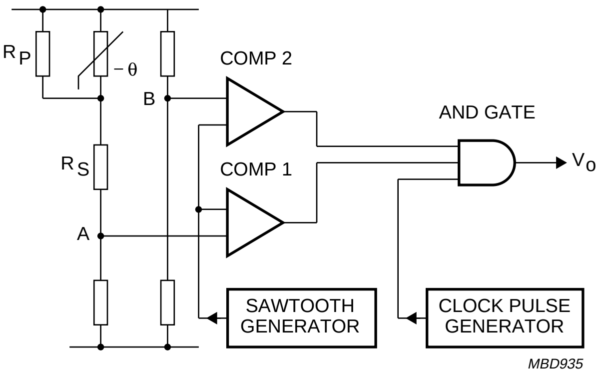


Fig.20 Temperature sensing bridge with 0 °C offset and ADC. Due to R_P and R_S the voltage at A varies linearly with the NTC thermistor temperature. The voltage at B is equal to that at A when the NTC thermistor temperature is 0 °C. Both voltages are fed to the comparator circuit. See also Fig.21.

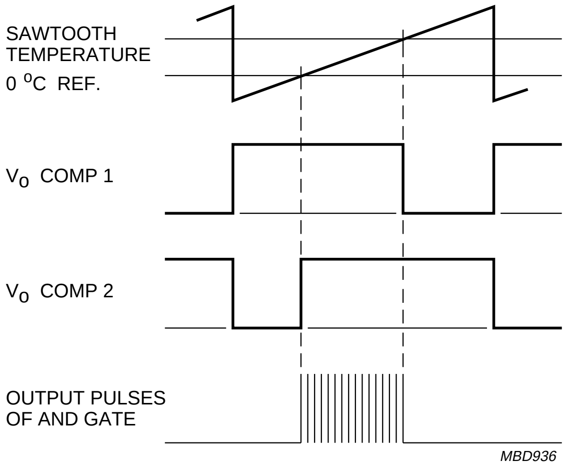


Fig.21 Pulses occurring at various points in the circuit shown in Fig.20.

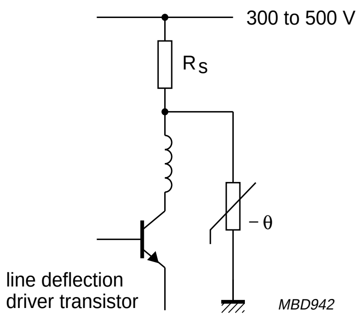


Fig.22 Constant current circuit (sure start-up) for line deflection stage.

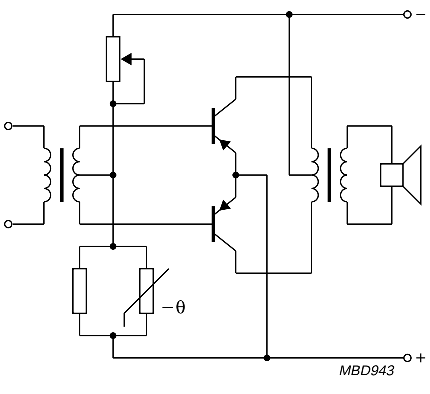


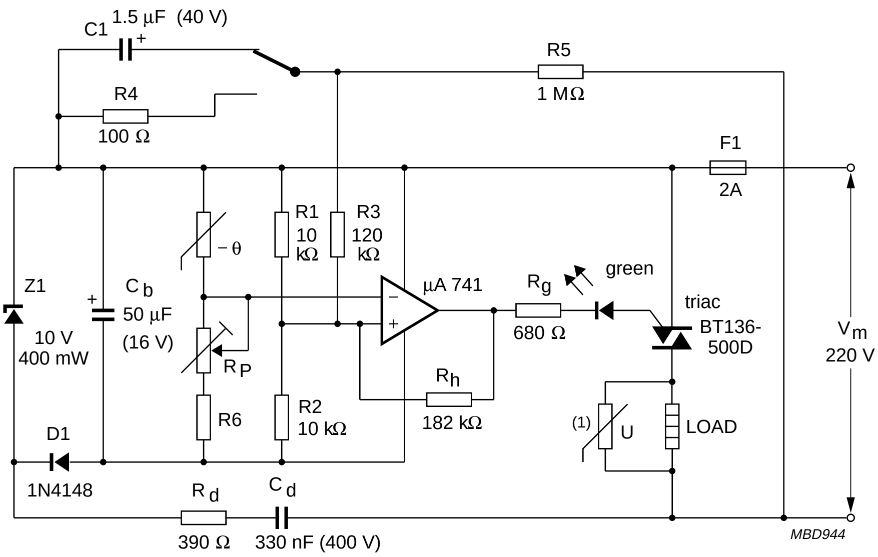
Fig.23 Temperature compensation in transistor circuits. Push-pull compensation.

NTC temperature sensors used as a thermal switch

A common use of an NTC temperature sensor is in one of the bridge arms of a thermal switch circuit using an operational amplifier such as the µA741. Figure 24 shows a typical thermal switch circuit for a refrigerator thermostat.

The circuit consists of a 10 V (DC) zener diode stabilized power supply, a Wheatstone Bridge (containing the NTC temperature sensor) and an integrated comparator circuit controlling a triac. The circuit is designed to switch a maximum load current of 2 A off at –5 °C and on at +5 °C.

TEMPERATURE SENSING IN REFRIGERATORS



(1) Catalogue number: 2322 593 32312.
All resistors are 0.25 W.

Fig.24 Refrigerator thermostat using an NTC temperature sensor.

HEAT DETECTION IN FIRE ALARMS

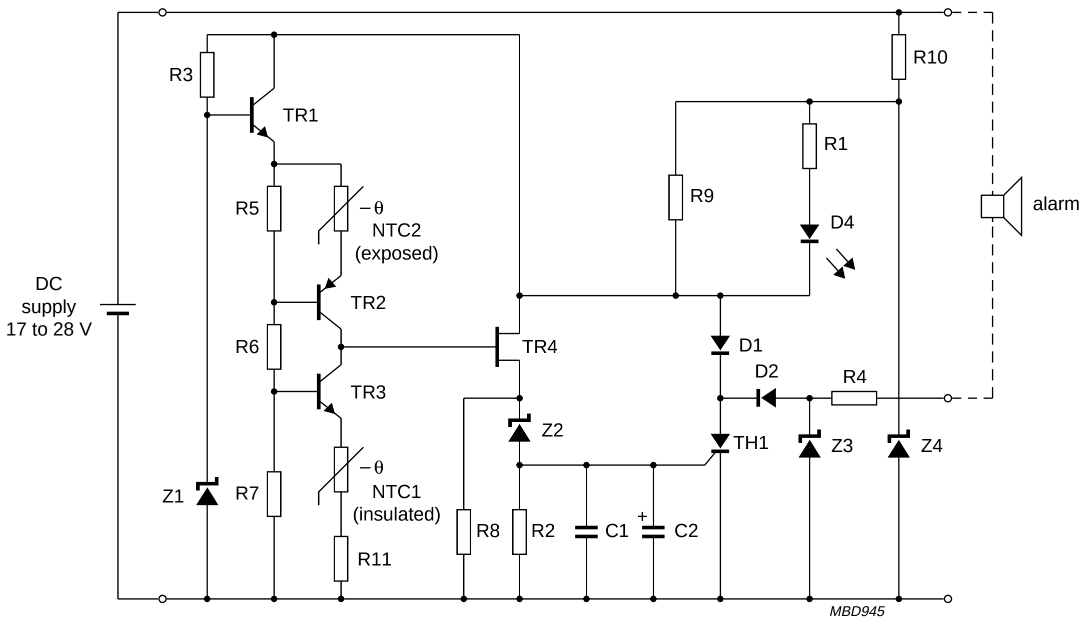


Fig.25 Circuit diagram of a typical heat detector using a matched pair of NTC thermistors.

NTC temperature protection of rechargeable batteries

Figure 26 shows the circuit diagram of an 'intelligent' charger designed to charge, within 1 hour, a NiCd or NiMH battery pack containing up to six AA-type cells. The TEA110X allows any type of power regulator to be used. In Fig.26, the unregulated 12 V (DC) supply is passed through a linear power regulator to charge the batteries under the control and management of the TEA110X. The BYD13D diode inhibits further charge (and prevents discharge) when the battery pack is full. For further information refer to *"Application Note NTC temperature protection of rechargeable batteries, code number 9398 082 91011"*.

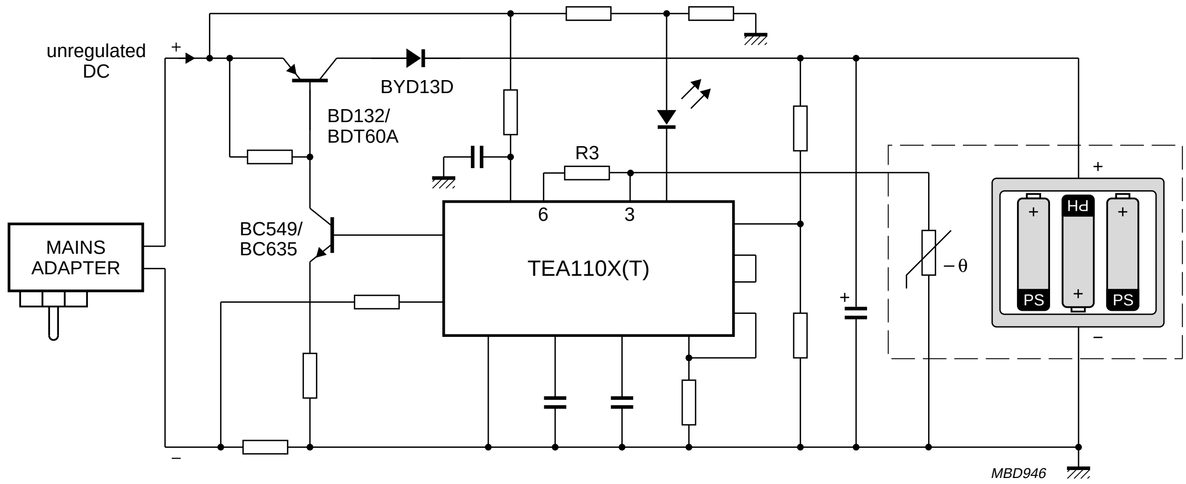


Fig.26 'Intelligent' charger based on the TEA110X with NTC battery temperature sensing.

SELECTING A SENSOR

Use the following steps in the specified order to select the required sensor:

1. What temperature range is required? Refer to Fig.27.
2. What R_{25} is required? Refer to the *"Data sheets"* in this *"Data Handbook"*.

   This *"Data Handbook"* gives the resistance/temperature characteristics for each sensor. In practice, the circuit surrounding the sensor will determine the required resistance at room temperature (R_{25}). This value will usually be between 10 and 20 kΩ for the optimum operating temperature range of the sensor. Simply select the sensor having the most suitable R_{25} value.
3. Are there any other important parameters? Refer to Tables 1 and 2.
4. Can you fulfil your need from our standard ranges (particularly from the Accuracy Line, see Table 1) or do you need a special accuracy (calculation) or encapsulation?

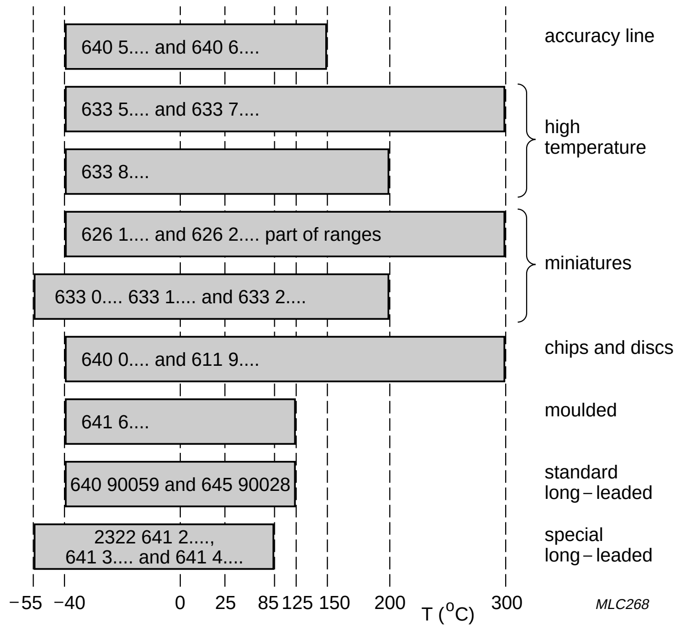


Fig.27 Temperature selection chart for the standard NTC temperature sensor ranges.

Table 1 Parameter selection chart

PARAMETER	ACCURACY LINE 2322				HIGH-TEMPERATURE SENSORS 2322			MINIATURE SENSORS 2322				UNIT
	640 5....	**640 6....**	**645 0....**	**642 6....**	**633 5....**	**633 7....**	**633 8....**	**626 1....**	**626 2....**	**633 0.... 633 1....**	**633 2....**	
R_{25}	2.2 to 470	0.47 to 470	5 to 10	0.0033 to 1.5	10, 20, 30, 100	100, 220	10, 20, 30, 100	1 to 1000	1 to 1000	1 to 1000	1 to 1000	kΩ
Tolerance on R_{25}	1, 2, 3, 5	2, 3, 5, 10	5	5, 10	5, 10	5, 10	5, 10	5, 10	5, 10	5, 10	5, 10	%
B-value	3740 to 4570	3740 to 4570	3965	2675 to 3975	3977	3977	3977	2075 to 4100	2075 to 4100	2075 to 4100	2075 to 4100	K
Tolerance on B-value	0.75 to 2.5	0.50 to 2.5	±0.75	–	1.3	1.3	1.3	5	5	5	5	%
Max. body diameter	3.4	3.3 ±0.5	3.3 ±0.5	5 ±0.3	1.7	1.85	1.85	2.5	1.6	0.7 to 1	3	mm
Lead diameter	0.4	0.6	0.6	0.6	–	0.56	0.56	0.3	0.24	0.06	0.24	mm
Min. lead length	38	17	17	22 ±1	–	25.4	25.4	30	19	5	20	mm

Table 2 Parameter selection chart (continued)

PARAMETER	CHIPS AND DISCS 2322		MOULDED SENSORS 2322	STANDARD LONG-LEADED SENSORS 2322		SPECIAL LONG-LEADED SENSORS 2322			UNIT
	640 0....	**611 9....**	**641 6....**	**640 90059 (insulated)**	**645 90028 (non-insulated)**	**641 2.... (epoxy)**	**641 3.... (water-resistant)**	**641 4.... (pipe)**	
R_{25}	2.2 to 470	2.2 to 470	2.2 to 470	2.77	10	2.2 to 470	2.2 to 470	2.2 to 470	kΩ
Tolerance on R_{25}	1, 2, 3, 5	–	3	3.82	5	3	3	3	%
B-value	3740 to 4570	3500 to 4093	3740 to 4570	3977	3993	3740 to 4570	3740 to 4570	3740 to 4570	K
Tolerance on B-value	0.75 to 2.5	–	0.75 to 2.5	–	1, 2	0.75 to 2.5	0.75 to 2.5	0.75 to 2.5	%
Max. body diameter	2.7	5.2	4 ±0.2	2.5 to 2.6	2.5 to 2.6	6	6	6	mm
Lead diameter	–	–	0.6	0.58	0.3	–	–	–	mm
Min. lead length	–	–	21 ±1	110 ±5	110 ±5	400 ±10	400 ±10	400 ±10	mm

Examples

To illustrate the method of selecting an NTC temperature sensor for your application, consider the following two examples, applying the selection procedure.

EXAMPLE 1

A sensor is required to measure temperatures from 0 to 100 °C with an accuracy of ±3 °C:

1. Step 1 (temperature range)

   Figure 27 shows that all our sensors will operate over the temperature range from 0 to 100 °C.

2. Step 2 (R_{25} value) and Step 3 (other important parameters)

   The sensor will normally be connected into an arm of a bridge. The resistance of the other arms of the bridge will determine the approximate ‘cold’ resistance value R_{25}. Let us assume that the resistance is 4.7 kΩ and that there are no other critical parameters (response time, etc.).

3. Step 4 (can you fulfil your need from our standard ranges?)

   Our range of low-cost Accuracy line sensors 2322 640 5.... and 640 6.... should be checked first, referring to Tables 1 and 2. From the data sheets you will find that the 2322 640 6.472 and the 640 5.472 may be suitable and that they are available with a 2%, 3%, 5% and 10% or a 1%, 2% and 3% tolerance on R_{25}.

From the equation $\alpha = \frac{\Delta R}{\Delta T}$ you can calculate ΔT. But since α depends on temperature, you need to know the temperature coefficients α_0 and α_{100}.

In this *“Data Handbook”* you will find that α_0 = –5.08%/K and α_{100} = –2.94%/K. In addition, you can find that the resistance tolerance due to the B-value is 0.89% at 0 °C and 2.04% at 100 °C.

So, the ±3 °C accuracy on temperature imposes a maximum allowable resistance variation at 0 °C of $\Delta R_0 = \alpha_0 \times \Delta T = -5.08 \times \pm 3 = \pm 15.24\%$ (of nominal resistance at 0 °C).

Similarly, the maximum allowable resistance variation at 100 °C is $\alpha_{100} \times \Delta T = -2.94 \times \pm 3 = \pm 8.82\%$ (of nominal resistance at 100 °C).

The actual resistance tolerance of the sensor is the sum of two components:

- The tolerance on the R_{25}-value
- The resistance tolerance due to the B-value (being zero at 25 °C but increasing at temperatures other than 25 °C).

Considering the lower-cost 5% tolerance sensor first: at 0 °C the worst case tolerance is 5% + 0.89% = 5.89%, which is well within the 15.24% imposed by the temperature tolerance. And at 100 °C the worst case tolerance is 5% + 2.04% = 7.04%, which again is well within the 8.82% requirement.

So, assuming that no special encapsulation is required, the 2322 640 63472 sensor fulfils the requirements.

EXAMPLE 2

A sensor is required to measure temperatures from 0 to 250 °C. It must be able to measure at 25 °C with an accuracy of ±2 °C. Its R_{25} value must be 10 kΩ and it must have a radial lead configuration and a minimum body length of 25 mm for encapsulation in a special housing:

1. Step 1 (temperature range)

   The high-temperature requirement (see Fig.27) restricts the choice of leaded sensors to 2322 626 1.... or 626 2.... or 633 8.... sensors.

2. Step 2 (R_{25}-value) and Step 3 (other important parameters)

   R_{25} = 10 kΩ is available for the 2322 626 1...., 626 2.... and 633 8.... ranges. All types have radial lead configurations, but body length dictates the selection of the 2322 626 1.... range, and in particular the 2322 626 1.103 sensor.

3. Step 4 (can you fulfil your need from our standard ranges?)

   The calculation of tolerance is: ±2 °C accuracy imposes a maximum resistance tolerance at 25 °C of $\alpha_{25} \times \Delta T$.

For the 2322 626 1.103 sensor it holds that the maximum resistance tolerance is 4.2 × 2 = 8.4% (α_{25} = 4.2). So the 5% sensor 2322 626 13103 will satisfy the requirement.

RANGE SUMMARY

- **Accuracy Line**
  - 2322 640 5.... and 640 6....

    The flagship of our ranges. The Accuracy Line sensors offer real value for money. They have low tolerances (as low as ±1% on the R_{25}-value and ±0.75% on the B-value) and an operating temperature range from –40 to +150 °C. In addition, they are very stable over a long life.
  - 2322 645 ..... series

    This range is our American standard line with an excellent accuracy over a wide temperature range (±0.75% on the B-value). R_{25}-values are available from 5 kΩ to 10 kΩ with an operating temperature range from –40 to +150 °C.
  - 2322 642 6.... series

    This range is mainly used for compensation purposes with R_{25}-values between 3.3 Ω and 1.5 kΩ.
- **High-temperature sensors**
  - 2322 633 5...., 633 7.... and 633 8....

    This range of high-quality glass-encapsulated NTC temperature sensors are price-competitive for general use. Not only can these sensors be used at up to 300 °C, but their glass encapsulation makes them ideal for use in corrosive atmospheres and harsh environments, even down to –40 °C. This makes them an attractive alternative to other more expensive sensing methods. In addition, they are very small. Two types of tiny glass envelopes are available: SOD27 for sensors with leads, and SOD80 (the so-called MELF execution) for leadless, surface-mount sensors.
- **Miniature sensors**
  - 2322 626 ..... and 633 .....

    These ranges pack extremely high performance in very small size. And they are fast and stable in the temperature range from as low as –55 °C to as high as +300 °C.
- **Chips and discs**
  - 2322 640 0.... and 611 9....

    When leaded components cannot be used, there is always the possibility of mechanical fixing. For this purpose we supply metallized square chips with R_{25}-values from 2.2 to 470 kΩ and five types of circular disc sensors
- **Moulded sensors**
  - 2322 641 6....

    Designed for harsh environments, our moulded sensors are ideal where good surface contact is essential. The range has recently been enhanced, and can be extended further on customer request, based on the 2322 640 0.... series.
- **Standard long-leaded sensors**
  - 2322 640 90059 and 645 90028

    These sensors combine the features of the Accuracy Line with long non-insulated or insulated leads for remote sensing applications. On request these sensors can be customized, based on the 2322 640 0.... range.
- **Special long-leaded sensors**
  - 2322 641 2...., 3.... and 4.....

    For special applications we can supply three types of long-leaded sensors: water-resistant sensors for permanent immersion in water, pipe sensors for use in corrosive atmospheres and epoxy-coated sensors for general use.

PREFERRED TYPES

NTC thermistors for temperature sensing

For specific details refer to the relevant section in this data handbook.

CATALOGUE NUMBER 2322	R_{25} (kΩ)	NOMINAL B-VALUE (K)
2322 640 6.... 5% tolerance		
63471	0.47	3560 ±0.75%
63102	1	3528 ±0.5%
63152	1.5	3528 ±0.5%
63202	2	3528 ±0.5%
63222	2.2	3977 ±0.75%
63332	3.3	3977 ±0.75%
63472	4.7	3977 ±0.75%
63682	6.8	3977 ±0.75%
63103	10	3977 ±0.75%
63153	15	3740 ±2%
63223	22	3740 ±2%
63333	33	4090 ±1.5%
63473	47	4090 ±1.5%
63683	68	4190 ±1.5%
63104	100	4190 ±1.5%
63154	150	4370 ±2.5%
63224	220	4370 ±2.5%
63474	470	4570 ±1.5%
2322 640 6.... 3% tolerance		
66272	2.7	3977 ±0.75%
66472	4.7	3977 ±0.75%
66103	10	3977 ±0.75%
66473	47	4090 ±1.5%
66104	100	4190 ±1.5%
66474	470	4570 ±1.5%
2322 640 5.... 2% tolerance		
54103	10	3977 ±0.75%
54473	47	4090 ±1.5%
54104	100	4190 ±1.5%
2322 640 5.... 1% tolerance		
55103	10	3977 ±0.75%
55473	47	4090 ±1.5%
55104	100	4190 ±1.5%

CATALOGUE NUMBER 2322	R_{25} (kΩ)	NOMINAL B-VALUE (K)
2322 642 6.... 10% tolerance		
62338	.0033	2675
62478	.0047	2750
62229	.022	3025
62339	.033	3100
62479	.047	3150
62101	.10	3300
62151	.15	3375
62221	.22	3475
2322 633 5..../7..../8.... 5% tolerance		
SMD VERSION		
53103	10	3977 ±1.3%
53203	20	3977 ±1.3%
53303	30	3977 ±1.3%
53104	100	3977 ±1.3%
LEADED VERSION		
73104; nickel-plated	100	3977 ±1.3%
83103; tinned-coppper	10	3977 ±1.3%
83203; tinned-coppper	20	3977 ±1.3%
83303; tinned-coppper	30	3977 ±1.3%
83104; tinned-coppper	100	3977 ±1.3%
2322 641 6.... moulded		
66272	2.7 kΩ ±3%	3977 K ±0.75%
66123	12 kΩ ±3%	3740 K ±2%
66153	15 kΩ ±3%	3740 K ±2%
66223	22 kΩ ±3%	3740 K ±2%
66104	100 kΩ ±3%	4190 K ±1.5%
66474	470 kΩ ±3%	4190 K ±1.5%

NTC thermistors for temperature sensing (continued)

CATALOGUE NUMBER 2322 641			R_{25} (kΩ)	$B_{25/85}$-VALUE (K)
EPOXY-COATED TYPE	WATER-RESISTANT TYPE	BRASS-PIPE TYPE		
26222	36222	46222	2.2 kΩ ±3%	3977 K ±0.75%
26502	36502	–	5 kΩ ±3%	3977 K ±0.75%
26103	36103	46103	10 kΩ ±3%	3977 K ±0.75%
26473	36473	–	47 kΩ ±3%	4090 K ±2%
26104	36104	46104	100 kΩ ±3%	4190 K ±1.5%