NTC Thermistors

[From Philips Data Handbook PA02 – 1989]

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 compositions of which are 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. extrusion (rods) or 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 a 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:

$$\sigma = n \cdot e \cdot \mu$$

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

Both n and μ are functions of temperature. For μ, the dependance 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:

$$\mu \sim (e^{-q2/kT})/T$$

For n, the dependance on temperature can be explained in the following way: 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:

$$n \sim e^{-q1/KT}$$

The total temperature dependence of the conductivity is:

$$\sigma = T^{-C} \cdot e^{-(q1 + q2)/kT}$$

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

$$R = A\,e^{B/T} \text{ or } \log R = A+(B/T)$$

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

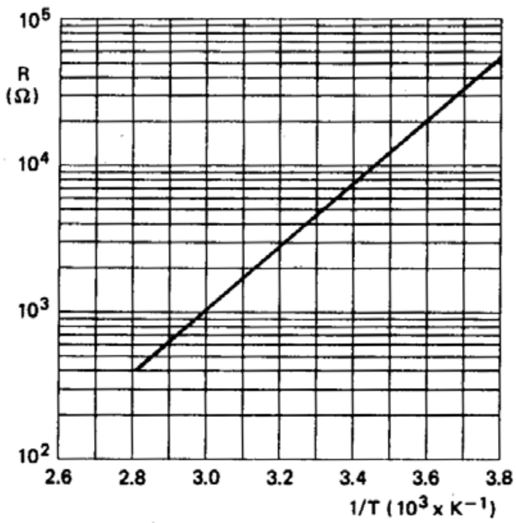

Fig.1 Resistance (in ohms) as a function of inverse of temperature (in 10^3 x K^{-1}) for a typical NTC.

Shape of a NTC curve and determination of B value

In Fig.l, resistance is plotted as a function of the inverse of temperature. Even in semi-log 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 T1 and T2, and it is assumed that the curve on this range could be approximated with a straight line, the slope of which will be B, this last value between T1 and T2 may be found as follows:

The resistance value is measured at T1 and T2.

$R1 = A\,e^{B/T1}$ and $R2 = A\,e^{B/T2}$

Dividing yields:

$R1/R2 = e^{(B/T1-B/T2)}$

or:

$\log R1 - \log R2 = B(1/T1 - 1/T2)\log e$

solving for B gives:

$B = 1n\ R1/R2/(1/T1-1/T2)$

In practice, B varies slightly with increasing temperature.
The temperature coefficient of a NTC may be derived from:

$\alpha = 1/R \cdot dR/dT = - B/T2$

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

A and B are assumed to be constant between T1 and T2 ($B_{T1/T2}$)

In practice, most NTC's 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 ot temperature, instead of its inverse.

V/I characteristics

Figure 2 shows the relationship between current and voltage drop through 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 = fct[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 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 also. The characteristic shown in Fig.2 was measured at a constant ambient temperature after equilibrium had been reached.

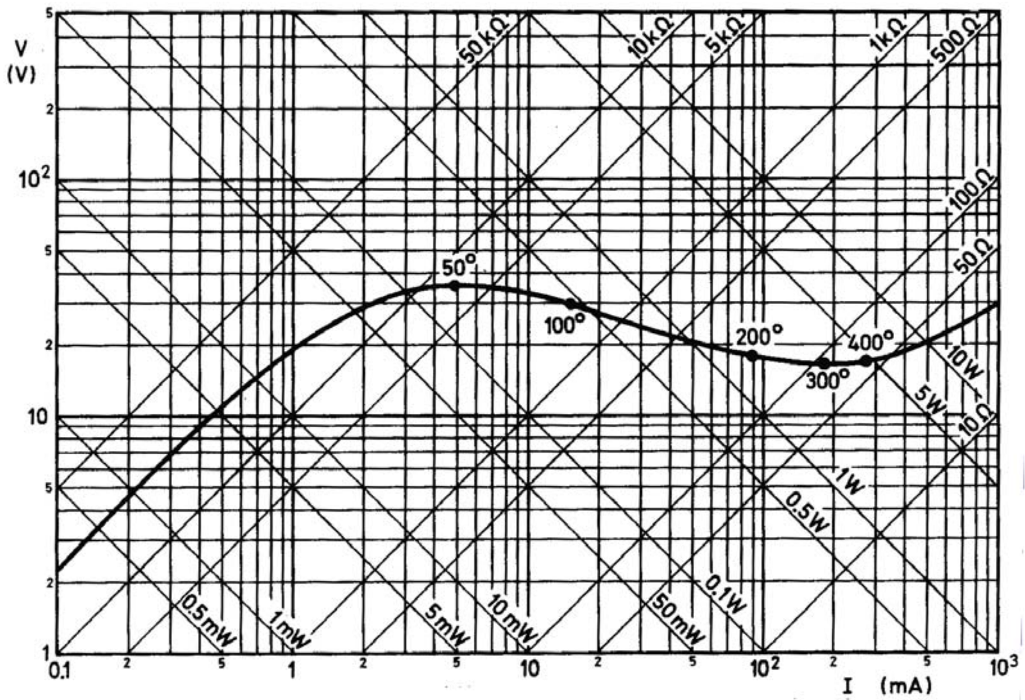

Fig.2 Voltage as a function of the current characteristics of an NTC thermistor.

Assuming:

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

In case of equilibrium:

$$W = VI = \delta \cdot (T - To)$$

in which To is the ambient temperature and δ the dissipation factor (defined in the following paragraph).

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

Because it is not possible to define δ without any doubt, (δ is not 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.

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 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 lose 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 (T1) to low (To) temperature, the energy lost by the component (-HdT) is equal to the energy dissipated by it (δ [T-To]dt).

$-HdT = \delta\ (T-To)dt$

This equation yields:

$T-T1 = (To-T1)\ e^{-t/\tau}$

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 is ($t = \tau$) is given in the formula:

$T - To/T1 - To = (1 – e^{-1}) = 0.632$

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 wit 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 depending on the application:

- by cooling in air under zero power conditions (Tc)
- by warming or cooling, transferring the thermistor from ambient temperature of +25 °C to a bath with a fluid with a higher or lower temperature under zero power conditions (Tr, termed 'response time' in the data sheets).

Tolerances on 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, soldering tolerances. The entire curve moves equally up or down:

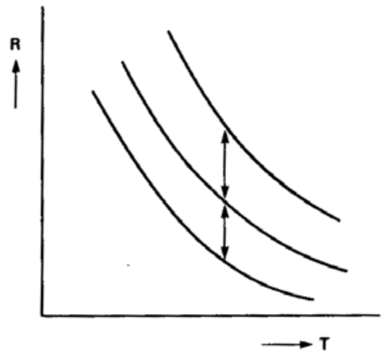

Fig.3 Effect of soldering as a function of resistance against time.

This tolerance is usually indicated by giving the shift at the reference temperature, so 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 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.

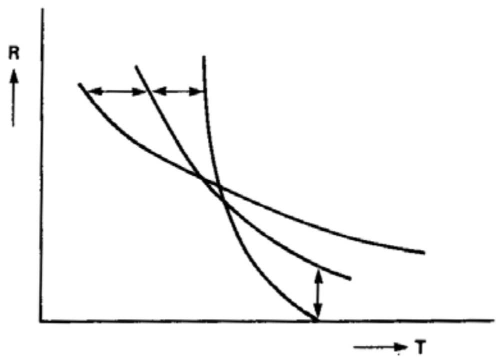

Fig.4 Effect of sintering on resistance against time.

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

The fundamental equation of a NTC is:

$Rn\ (T) = Rref^{\ B(1/T - 1/Tref)}$

where Rn and B are nominal values (specified values without any tolerance). If B is not a nominal value, it is expressed as:

$R\ (T) = Rn\ (T) + \Delta R\ (T) = Rref\ e^{\ (B + \Delta B)\ (1/T - 1/Tref)}$

where $\Delta R(T)$ is ihe absolute deviation at temperature T.

$\Delta R\ (T) = Rref\ [\ e^{\ (B+\Delta B)\ (1/T-1/Tref)} - e^{\ B(1/T - 1/Tref)}]$

If relative deviation is applied:

$\Delta R\ (T) / Rn\ (T) = e^{\Delta B(1/T - 1/Tref)\ -1}$

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

$\Delta R\ (T) / Rn\ (T)\ (\text{in } \%) = \Delta B\ (1/T - 1/Tref)$

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

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

$Z = [(1 + X/100) \cdot (1 + Y/100) - 1] \cdot 100$

or, $Z = X + Y$ (approximation)

If TC = temperature coefficient and ΔT = temperature deviation, ~T = Z/TC

Example: at 0 °C, let X = 5%, Y = 0.089% and TC = 5.08%/K, then:

$Z =\{[1 + (5/100)] \cdot [1 + (0.89/100)] - 1\} \cdot 100$

$= \{1.05 \cdot 1.0089 - 1\} \cdot 100 = 5.9345$ or 5.93%

$\Delta T = Z/TC = 5.93/5.08 = 1.167$ or 1.17 °C

Hence, a 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 sensors)

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 minimal in the temperature region between the reference points, as illustrated in Fig.5.

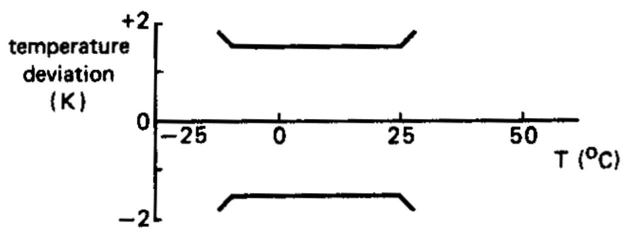

Fig.5 Temperature measurement at more than one point.

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.

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 a measurement at 25 °C and one 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 measurement 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 liquid 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

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

- Resistance values) and temperature coefficient
- Accuracy of resistance value(s)
- Power to be dissipated
  (a) without perceptible change in resistance value due to self heating
  (b) with maximum change in resistance value
- Permissible temperature range
- Thermal time constant, if applicable
- Types best suited to the purpose: basic forms are rod, 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 case a specification of the requirements is necessary. A description of the circuit in which the NTC has to be used is most useful.

Deviating characteristics

The following example explains the resistance values resulting from combinations of NTC with 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 program. The problem may, however be solved by using a standard NTC and two fixed resistors if a NTC disc with a cold resistance of 130 Ω is mounted in a series and parallel arrangement with two fixed resistors of 6 Ω and 95 Ω. 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.

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:

(In R1/R2) / (1/T1 – 1/T2)

where R1 and R2 are the nominal values of resistance at T1 and T2.

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 Tref

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.

APPLICATIONS

Applications of NTC's 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. In that case the temperature ìs 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) curve shows a negative slope.

The classifications given above are supported by practical examples in Figs 6 to 29.

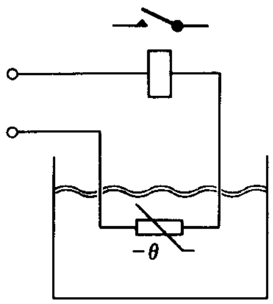

Fig. 6. Liquid level control

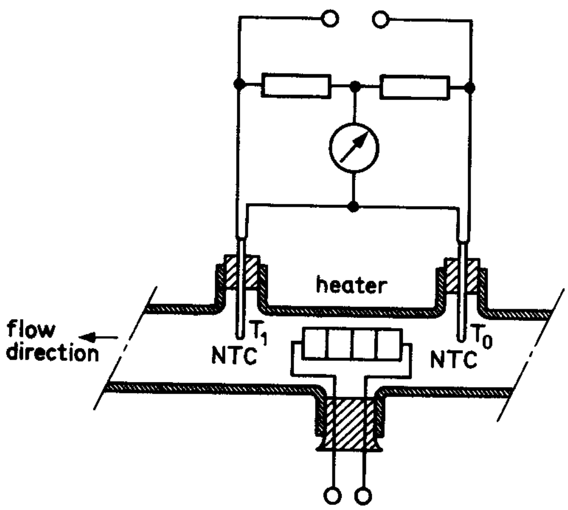

Fig.7. Flow measurement of liquid and gases. The temperature difference between T_1 and T_O is measured for the velocity of the fluid.

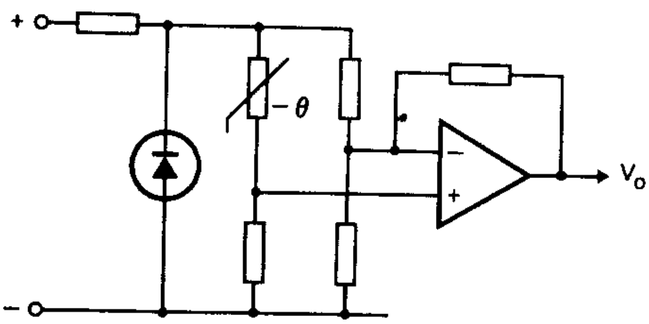

Fig. 8. Temperature sensing bridge with amplifier. The op-amp acts as differential amplifier. The sensitivity can be very high.

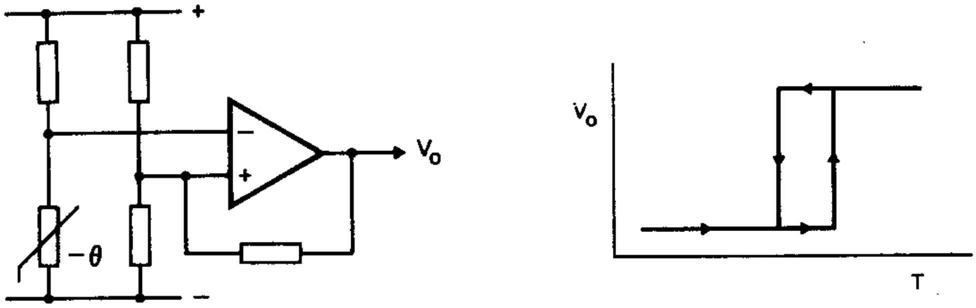

Fig.9. Basic temperature sensing configuration. The operational amplifier acts as Schmitt trigger. The transfer characteristic is shown to the right.

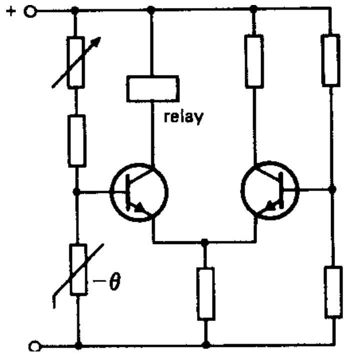

Fig. 10. Simple thermostat.

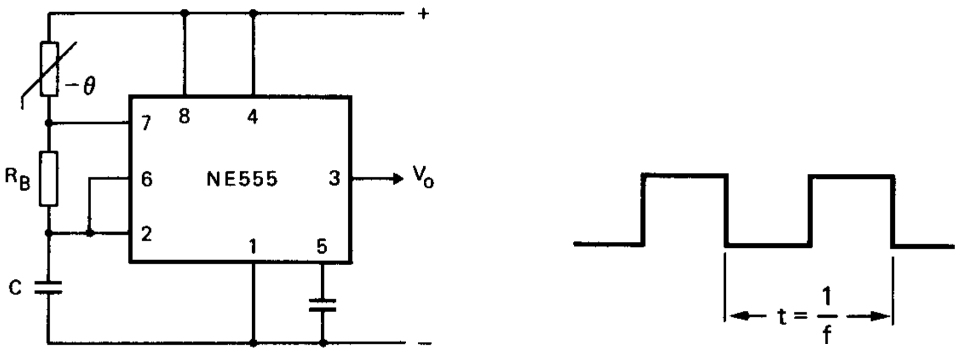

Fig.11. Temperature-controlled oscillator. This is a simple interface circuit for digital and microcomputer-controlled systems. The frequency of the output pulses is proportional to the temperature of the NTC thermistor (see the right side).

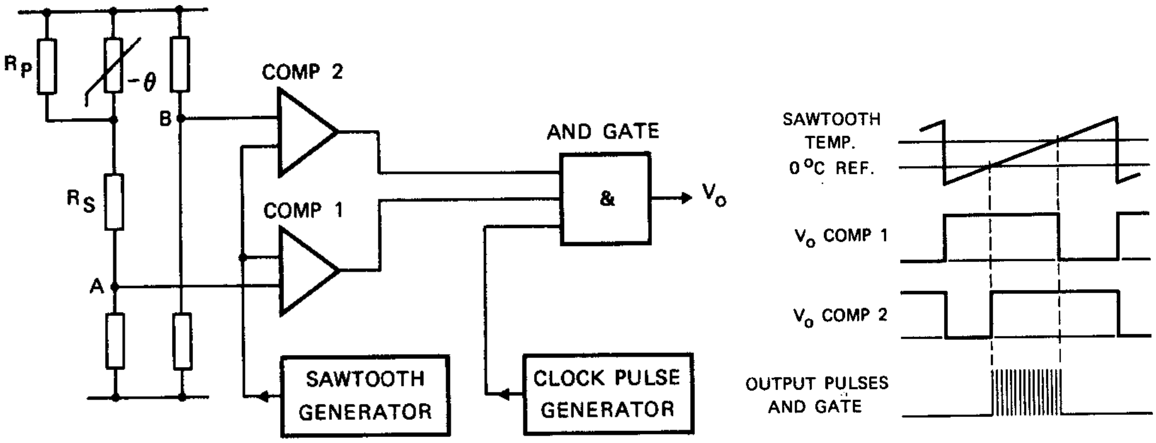

Fig.12. Temperature-sensing bridge with 0°C offset and analog-to-digital conversion. Due to Rp and Rs the voltage at point A varies linearly with the temperature of the NTC thermistor. The voltage at point B is equal to the voltage at point A when the temperature of the NTC is 0°C. Both voltages are fed to the comparator circuit. The characteristic of the circuit is shown to the right side.

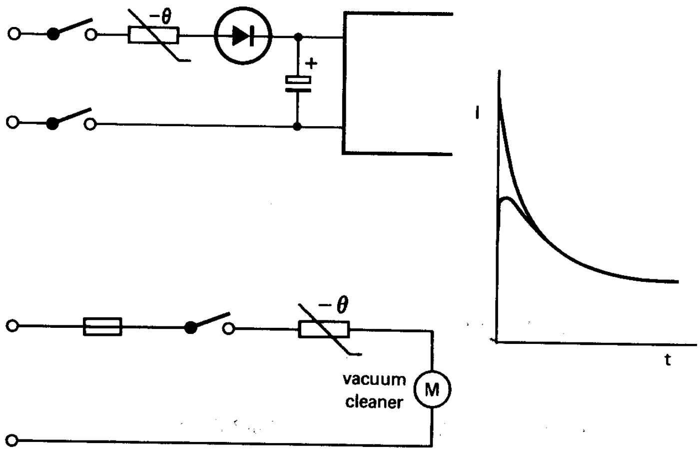

Fig.13. Inrush current limiter. E.g for protection of diodes, fuses and switches in applications where are present components that requires high initial peak current, like filter capacitors, motors, lamps, etc.

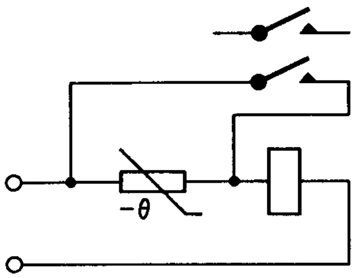

Fig.14. Delaying action of relays. Due to the thermal inertia of the NTC, it takes some time before the relay is activated. If necessary, the NTC can be short-circuited after the relay is activated, thus leaving the NTC time for cooling.

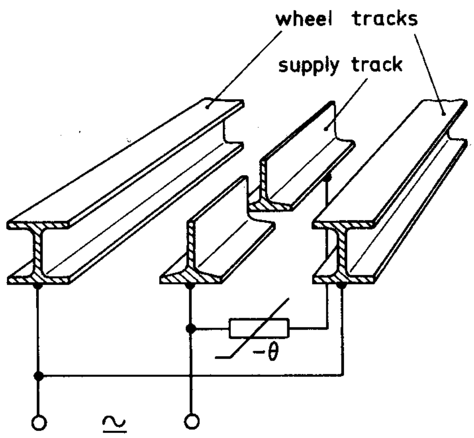

Fig. 15. Model trains. As soon as the train comes on the isolated supply trip, it stop. The NTC heats up and gradually the train starts again.

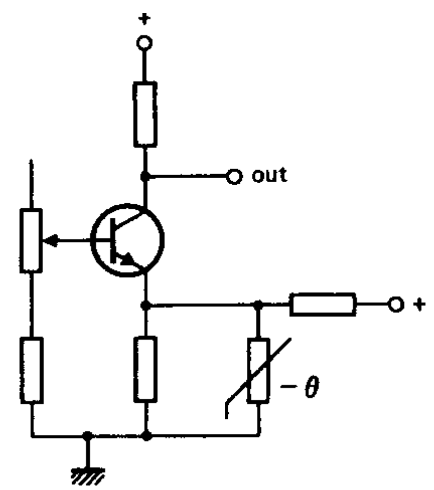

Fig. 16. Stabilization with temperature of an AGC (automated gain control) amplifier e.g in television set.

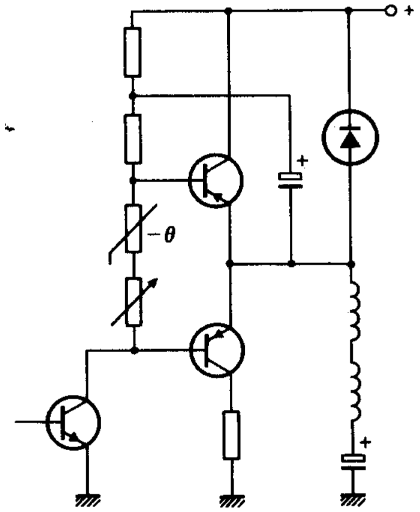

Fig. 17. Compensation of drift in field deflection coils. The influence of the positive temperature coefficient of the copper windings is compensated by means of an NTC thermistor.

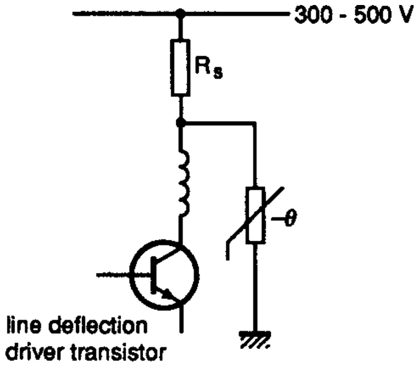

Fig.18. Constant current (sure start-up) for line deflection stage.

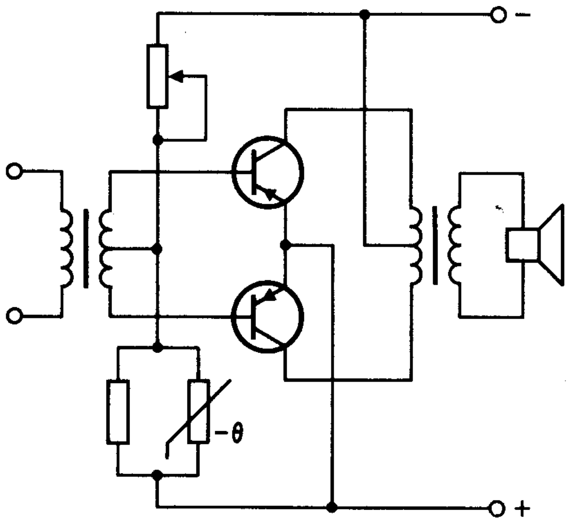

Fig. 19. Temperature compensation in transistor circuits. Push-pull compensation.

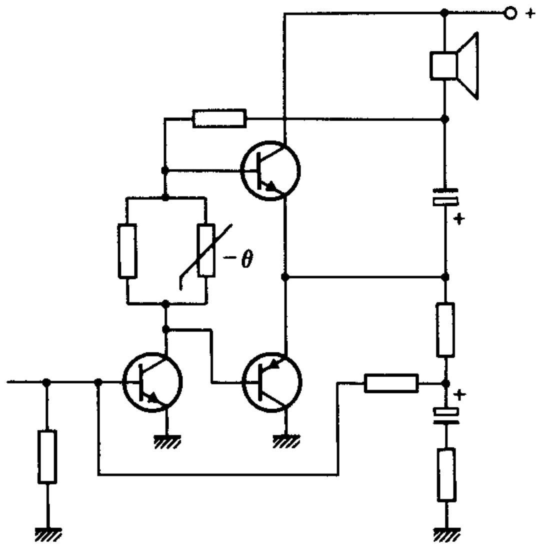

Fig.20. Transformerless audio output stage with temperature compensation.

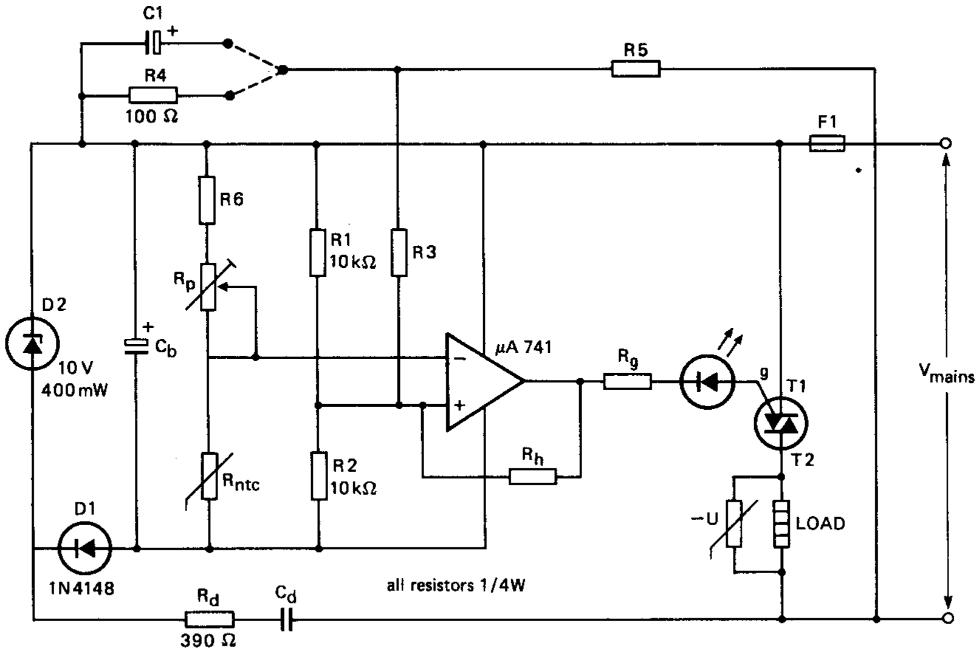

Fig.21. Thermostat for room temperature control.