Thermistors

The Thermistor is a special type of variable resistive element that changes its physical resistance when exposed to changes in temperature.

The **Thermistor** is a solid state temperature sensing device which acts a bit like an electrical resistor but is temperature sensitive. Thermistors can be used to produce an analogue output voltage with variations in ambient temperature and as such can be referred to as a transducer. This is because it creates a change in its electrical properties due to an external and physical change in heat.

The thermistor is basically a two-terminal solid state thermally sensitive transducer constructed using sensitive semiconductor based metal oxides with metallised or sintered connecting leads formed into a ceramic disc or bead. This allows the thermistor to change its resistive value in proportion to small changes in ambient temperature. In other words, as its temperature changes, so too does its resistance and as such its name, “Thermistor” is a combination of the words THERM-ally sensitive res-ISTOR.

While the change in resistance due to heat is generally undesirable in standard resistors, this effect can be put to good use in many temperature detection circuits. Thus being a non-linear variable-resistive devices, thermistors are commonly used as temperature sensors having many applications to measure the temperature of both liquids and ambient air.

Also, being a solid state device made from highly sensitive metal oxides, they operate at the molecular level with the outermost (valence) electrons becoming more active producing a negative temperature coefficient, or less active producing a positive temperature coefficient as the temperature of the thermistor is increased. This means they have very good resistance verses temperature characteristics allowing them to operate at temperatures upto 200^{o}C.

While the principle use of thermistors are as resistive temperature sensors, they can also be connected in series with another component or device to control an electrical current flowing through them. In other words, they can be used as a thermally sensitive current-limiting devices.

Typical Thermistor

Thermistors are available in a whole range of types, materials and sizes characterised by their response time and operating temperature. Also, hermetically sealed thermistors eliminate errors in resistance readings due to moisture penetration while still offering high operating temperatures and a compact size. The three most common types are: Bead thermistors, Disk thermistors, and Glass encapsulated thermistors.

These heat-dependent resistors can operate in one of two ways, either by increasing or decreasing their resistive value with changes in temperature. Then there are two types of thermistors available: negative temperature coefficient (NTC) of resistance and positive temperature coefficient (PTC) of resistance.

Negative Temperature Coefficient Thermistor

Negative temperature coefficient of resistance thermistors, or *NTC thermistors* for short, reduce or decrease their resistive value as the operating temperature around them increases. Generally, NTC thermistors are the most commonly used type of temperature sensors as they can be used in virtually any type of equipment where temperature plays a role.

NTC temperature thermistors have a negative electrical resistance versus temperature (R/T) relationship. The relatively large negative response of an NTC thermistor means that even small changes in temperature can cause significant changes in their electrical resistance. This makes them ideal for accurate temperature measurement and control.

We said previously that a thermistor is an electronic component whose resistance is highly dependent on temperature so if we send a constant current through the thermistor and then measure the voltage drop across it, we can thus determine its resistance at a particular temperature.

An NTC thermistors reduces its resistance with an increase in temperature and are available in a variety of base resistances and temperature curves. NTC thermistors are usually characterised by their base resistance at room temperature, that is 25^{o}C, (77^{o}F) as this provides a convenient reference point. So for example, 2k2Ω at 25^{o}C, 10kΩ at 25^{o}C or 47kΩ at 25^{o}C, etc.

Another important characteristic of a thermistor is its “B” value. The B value is a material constant which is determined by the ceramic material from which it is made. it describes the gradient of the resistive (R/T) curve over a particular temperature range between two temperature points. Each thermistor material will have a different material constant and therefore a different resistance versus temperature curve.

Then the B value will define the thermistors resistive value at a first temperature or base point, (which is usually 25^{o}C), called T1, and the thermistors resistive value at a second temperature point, for example 100^{o}C, called T2. Therefore the B value will define the thermistors material constant between the range of T1 and T2. That is $B_{T1/T2}$ or $B_{25/100}$ with typical NTC thermistor B values given anywhere between about 3000 and about 5000.

Note however, that both the temperature points of T1 and T2 are calculated in the temperature units of Kelvin where 0^{0}C = 273.15 Kelvin. Thus a value of 25^{o}C is equal to 25^{o} + 273.15 = 298.15K, and 100^{o}C is equal to 100^{o} + 273.15 = 373.15K, etc.

So by knowing the B value of a particular thermistor (obtained from manufacturers datasheet), it is possible to produce a table of temperature versus resistance to construct a suitable graph using the following normalised equation:

Thermistor Equation

$$B_{(T1/T2)} = \frac{T_2 \times T_1}{T_2 - T_1} \times \ln\left(\frac{R_1}{R_2}\right)$$

Where:

T1 is the first temperature point in Kelvin

T2 is the second temperature point in Kelvin

R1 is the thermistors resistance at temperature T1 in Ohms

R2 is the thermistors resistance at temperature T2 in Ohms

Thermistor Example No1

A 10kΩ NTC thermistor has a B value of 3455 between the temperature range of 25°C and 100°C. Calculate its resistive value at 25°C and again at 100°C.

Data given: B = 3455, R1 = 10kΩ at 25°. In order to convert the temperature scale from degrees Celsius, °C to degrees Kelvin add the mathematical constant 273.15

The value of R1 is already given as 10kΩ base resistance, thus the value of R2 at 100°C is calculated as:

$$B_{(25/100)} = \frac{(100+273.15)\times(25+273.15)}{(100+273.15)-(25+273.15)} \times \ln\left(\frac{10000}{R_X}\right)$$

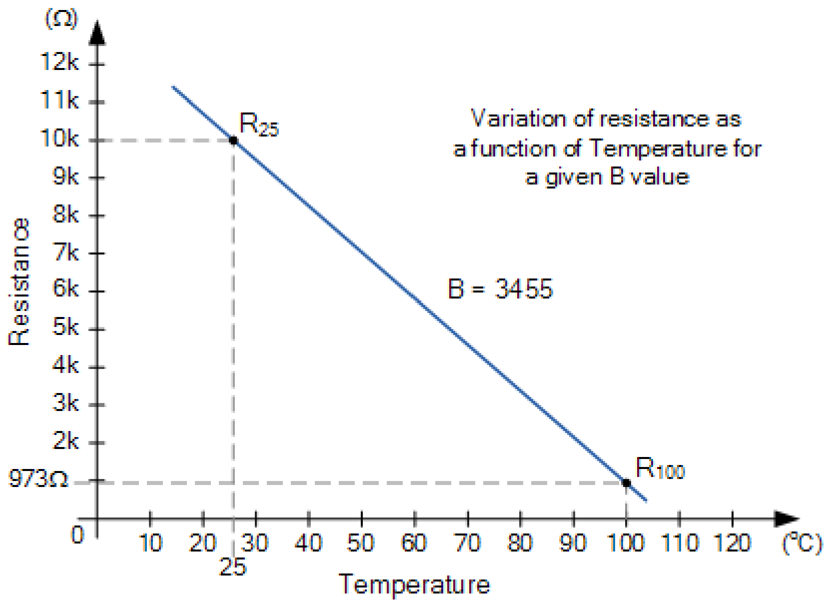
$$3455 = \frac{111254.6725}{75} \times \ln\left(\frac{10000}{R_X}\right)$$

$$3455 = 1483.4 \times \ln\left(\frac{10000}{R_X}\right)$$

$$e^{\left[\frac{3455}{1483.4}\right]} = \frac{10000}{R_X}$$

$$\therefore R_X = \frac{10000}{e^{2.33}} = 973\Omega$$

Giving the following two point characteristics graph of:

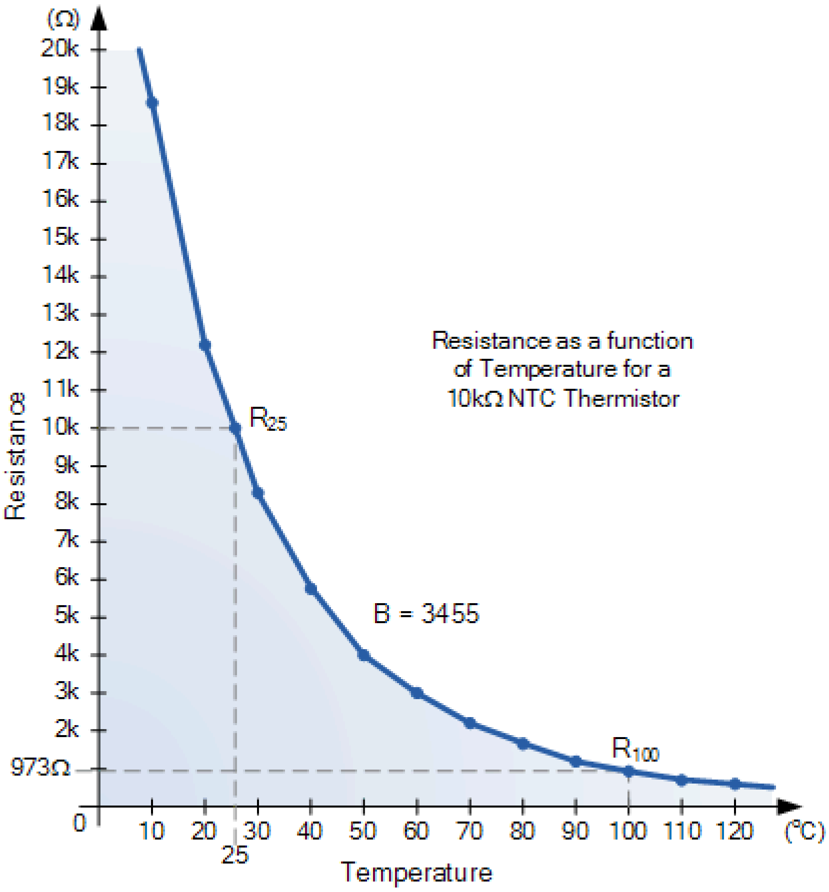


Note that in this simple example, only two points were found, but generally thermistors change their resistance exponentially with changes in temperature so their characteristic curve is nonlinear, therefore the more temperature points are calculated the more accurate will be the curve.

Temperature (°C)	10	20	**25**	30	40	50	60	70	80	90	100	110	120
Resistance (Ω)	18476	12185	**10000**	8260	5740	4080	2960	2188	1645	1257	973	765	608

and these points can be plotted as shown to give a more accurate characteristics curve for the 10kΩ NTC Thermistor which has a B-value of 3455.

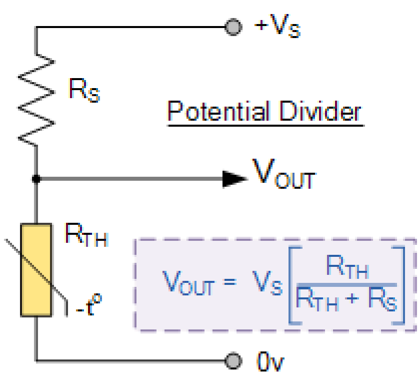
NTC Thermistor Characteristics Curve



Notice that it has a negative temperature coefficient (NTC), that is its resistance decreases with increasing temperatures.

Using a Thermistor to Measure Temperature.

So how can we use a thermistor to measure temperature. Hopefully by now we realise that a thermistor is a resistive device and therefore according to Ohms law, if we pass a current through it, a voltage drop will be produced across it. As a thermistor is an passive type of a sensor, that is, it requires an excitation signal for its operation, any changes in its resistance as a result of changes in temperature can be converted into a voltage change.



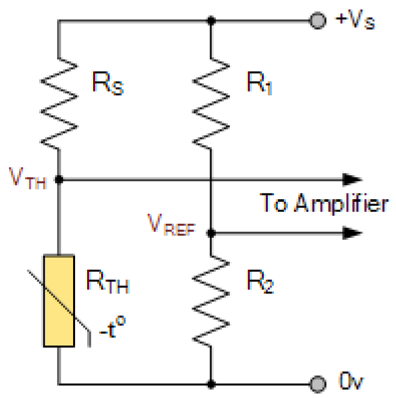
$$V_{OUT} = V_S \left[\frac{R_{TH}}{R_{TH} + R_S} \right]$$

The simplest way of doing this is to use the thermistor as part of a potential divider circuit as shown. A constant supply voltage is applied across the resistor and thermistor series circuit with the output voltage measured from across the thermistor.

If for example we use a 10kΩ thermistor with a series resistor of 10kΩ, then the output voltage at the base temperature of 25°C will be half the supply voltage as 10Ω/(10Ω+10Ω) = 0.5.

When the resistance of the thermistor changes due to changes in temperature, the fraction of the supply voltage across the thermistor will also change producing an output voltage which is proportional to the fraction of the total series resistance between the output terminals. Thus the potential divider circuit is an example of a simple resistance to voltage converter where the resistance of the thermistor is controlled by temperature with the output voltage produced being proportional to the temperature. So the hotter the thermistor gets, the lower the ouput voltage.

If we reversed the positions of the series resistor, R_S and the thermistor, R_{TH}, then the output voltage would change in the opposite direction, that is the hotter the thermistor gets, the higher the output voltage.



We can use NTC thermistors as part of a basic temperature sensing configuration using a bridge circuit as shown. The relationship between resistors R_1 and R_2 sets the reference voltage, V_{REF} to the value required. For example, if both R_1 and $R_2$are of the same resistive value, the reference voltage will be equal to half of the supply voltage as before. That is Vs/2.

As the temperature and therefore the resistive value of the thermistor changes, the voltage at V_{TH} will also change, either higher or lower than that at V_{REF} producing a positive or negative output signal to the connected amplifier.

The amplifier circuit used for this basic temperature sensing bridge circuit could act as a differential amplifier for high sensitivity and amplification, or a simple Schmitt-trigger circuit for ON-OFF switching.

The problem with passing a current through a thermistor in this way, is that thermistors experience what is called a self-heating effect, that is the I^2*R power loss could be high enough to create more heat than can be dissipated by the thermistor affecting its resistive value producing false results.

Thus it is possible that if the current through the thermistor is too high it would result in increased power dissipation and as the temperature increases, its resistance decreases causing more current to flow, which increases the temperature further resulting in what is known as *Thermal Runaway*. In other words, we want the thermistor to be hot due to the external temperature being measured and not by itself heating up.

The value for the series resistor, R_S above should be chosen to provide a reasonably wide response over the expected range of temperatures for which the thermistor is likely to be used while at the same time limiting the current to a safe value at the highest temperature.

One way of improving on this and having a more accurate conversion of resistance against temperature (R/T) is by driving the thermistor with a constant current source. The change in resistance can be measured by using a small and measured direct current, or DC, passed through the thermistor in order to measure the output voltage drop produced.

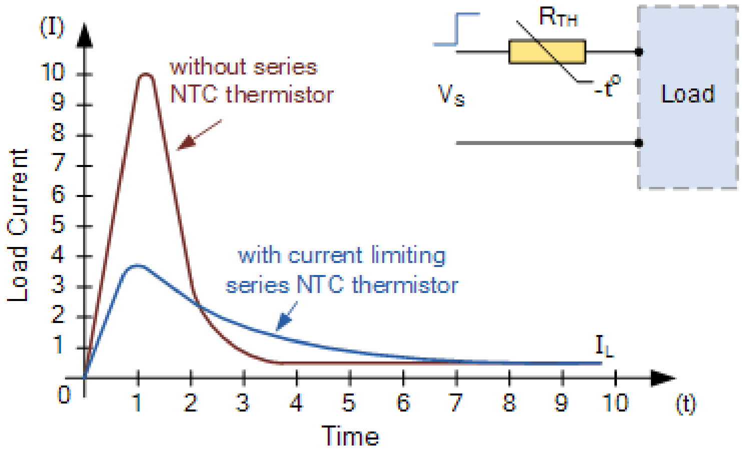
Thermistor Used For Inrush Current Suppression

We have seen here that thermistors are used as resistive temperature sensitive transducers, but the resistance of a thermistor can be changed either by external temperature changes or by changes in temperature caused by an electrical current flowing through them, as after all, they are resistive devices.

Ohm’s Law tells us that when an electrical current passes through a resistance R, as a result of the applied voltage, power is consumed in the form of heat due to the I^2*R heating effect. Because of the self-heating effect of current in a thermistor, a thermistor can change its resistance with changes in current.

Inductive electrical equipment such as motors, transformers, ballast lighting, etc, suffer from excessive inrush currents when they are first turned “ON”. But series connected thermistors can also be used to effectively limit any high initial currents to a safe value. NTC thermistors with low values of cold resistance (at 25^{o}C) are generally used for such current regulation.

Inrush Current Limiting Thermistor



Inrush current suppressors and surge limiters are types of series connected thermistor whose resistance drops to a very low value as it is heated by the load current passing through it. At the initial turn-on, the thermistors cold resistance value (its base resistance) is fairly high controlling the initial inrush current to the load.

As a result of the load current, the thermistor heats up and reduces its resistance relatively slowly to the point were the power dissipated across it is sufficient to maintain its low resistance value with most of the applied voltage developed across the load.

Due to the thermal inertia of its mass, this heating effect takes a few seconds during which the load current increases gradually rather than instantaneously, so any high inrush current is restricted and the power it draws reduces accordingly. Because of this thermal action, inrush current suppression thermistors can therefore operate very hot in their low-resistive state. As such require a cool-down or recovery period once power is removed thus allowing the resistance of the NTC thermistor to recover sufficiently ready for the next time it is needed.

The speed of response of a current limiting thermistor is given by its time constant. That is, the time taken for its resistance to change by by 63% (i.e. 1 to 1/ε) of the total change. For example, suppose the ambient temperature changes from 0 to 100°C, then the 63% time constant would be the time taken for the thermistor to have a resistive value at 63°C.

NTC thermistors provide protection from undesirably high inrush currents, while their resistance remains negligibly low during continuous operation supplying power to the load. The advantage here is that they able to effectively handle much higher inrush currents than standard fixed current limiting resistors with the same power consumption.

Thermistor Summary

We have seen here in this tutorial about thermistors, that a thermistor is a two terminal resistive transducer which can change its resistive value with changes in the surrounding ambient temperature, hence the name thermal-resistor, or simply “thermistor”.

Thermistors are inexpensive, easily-obtainable temperature sensors constructed using semiconductor metal oxides. They are available with either a negative temperature coefficient, (NTC) of resistance or a positive temperature coefficient (PTC) of resistance. The difference being that NTC thermistors reduce their resistance as the temperature increases, while PTC thermistors increase their resistance as the temperature increases.

NTC thermistors are the most commonly used (especially the 10KΩ NTC thermistor) and along with an addition series resistor, R_S can be used as part of a simple potential divider circuit. Thus changes to its resistance due to changes in temperature, produces a temperature-related output voltage.

However, the operating current of the thermistor must be kept as low as possible to reduce any self-heating effects. If their operating current is too high, they can heat up quicker than they can be dissipate it, creating false results.

Thermistors are characterised by their base resistance as well as their “B” value. The base resistance, for example, 10kΩ, is the resistance of the thermistor at a given temperature, usually 25^{o}C so is defined as: R_{25}. The B value is a fixed material constant that describes the shape of the slope of the resistive curve over temperature (R/T).

We have also seen that as well as being used to measure an external temperature, thermistors can also be used to control an electrical current as a result of the I^2R heating effect caused by the current flowing through it. By connecting an NTC thermistor in series with a load, it is possible to effectively limit any high inrush currents.