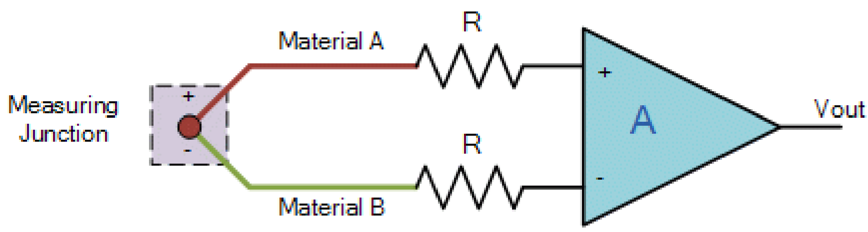


Temperature Sensors

The most commonly used type of all the sensors are those types of sensors which detect **Temperature** or heat.

These types of temperature sensor vary from simple ON/OFF thermostatic devices which control a domestic hot water heating system to highly sensitive semiconductor types that can control complex process control furnace plants.

We remember from our school science classes that the movement of molecules and atoms produces heat (kinetic energy) and the greater the movement, the more heat that is generated. **Temperature Sensors** measure the amount of heat energy or even coldness that is generated by an object or system, allowing us to “sense” or detect any physical change to that temperature producing either an analogue or digital output.

There are many different types of **Temperature Sensor** available and all have different characteristics depending upon their actual application. A temperature sensor consists of two basic physical types:

> Contact Temperature Sensor Types – These types of temperature sensor are required to be in physical contact with the object being sensed and use conduction to monitor changes in temperature. They can be used to detect solids, liquids or gases over a wide range of temperatures.
>
> Non-contact Temperature Sensor Types – These types of temperature sensor use convection and radiation to monitor changes in temperature. They can be used to detect liquids and gases that emit radiant energy as heat rises and cold settles to the bottom in convection currents or detect the radiant energy being transmitted from an object in the form of infra-red radiation (the sun).

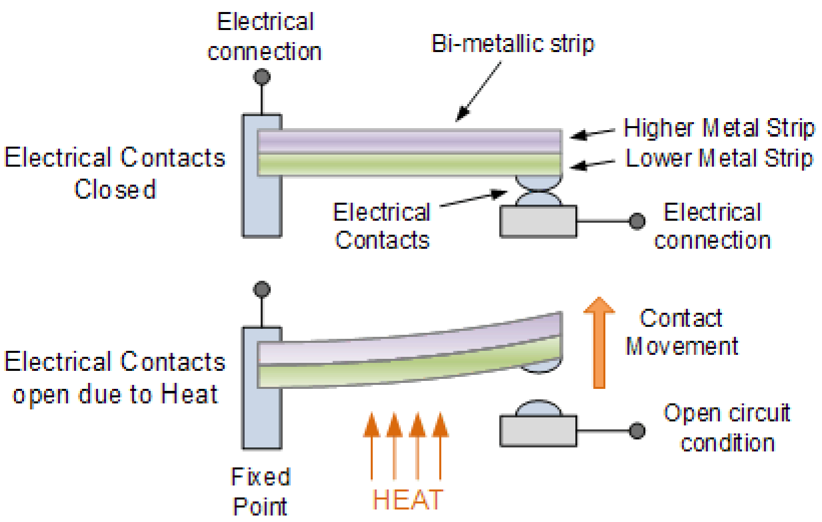
The two basic types of contact or even non-contact temperature sensors can also be sub-divided into the following three groups of sensors, *Electro-mechanical*, *Resistive* and *Electronic* and all three types are discussed below.

The Thermostat

The **Thermostat** is a contact type electro-mechanical temperature sensor or switch, that basically consists of two different metals such as nickel, copper, tungsten or aluminium etc, that are bonded together to form a **Bi-metallic strip**. The different linear expansion rates of the two dissimilar metals produces a mechanical bending movement when the strip is subjected to heat.

The bi-metallic strip can be used itself as an electrical switch or as a mechanical way of operating an electrical switch in thermostatic controls and are used extensively to control hot water heating elements in boilers, furnaces, hot water storage tanks as well as in vehicle radiator cooling systems.

The Bi-metallic Thermostat



The thermostat consists of two thermally different metals stuck together back to back. When it is cold the contacts are closed and current passes through the thermostat. When it gets hot, one metal expands more than the other and the bonded bi-metallic strip bends up (or down) opening the contacts preventing the current from flowing.

There are two main types of bi-metallic strips based mainly upon their movement when subjected to temperature changes. There are the “snap-action” types that produce an instantaneous “ON/OFF” or “OFF/ON” type action on the electrical contacts at a set temperature point, and the slower “creep-action” types that gradually change their position as the temperature changes.

On/Off Thermostat

Snap-action type thermostats are commonly used in our homes for controlling the temperature set point of ovens, irons, immersion hot water tanks and they can also be found on walls to control the domestic heating system.

Creeper types generally consist of a bi-metallic coil or spiral that slowly unwinds or coils-up as the temperature changes. Generally, creeper type bi-metallic strips are more sensitive to temperature changes than the standard snap ON/OFF types as the strip is longer and thinner making them ideal for use in temperature gauges and dials etc.

Although very cheap and are available over a wide operating range, one main disadvantage of the standard snap-action type thermostats when used as a temperature sensor, is that they have a large hysteresis range from when the electrical contacts open until when they close again. For example, it may be set to 20°C but may not open until 22°C or close again until 18°C.

So the range of temperature swing can be quite high. Commercially available bi-metallic thermostats for home use do have temperature adjustment screws that allow for a more precise desired temperature set-point and hysteresis level to be pre-set.

The Thermistor

The **Thermistor** is another type of temperature sensor, whose name is a combination of the words THERM-ally sensitive res-ISTOR. A thermistor is a special type of resistor which changes its physical resistance when exposed to changes in temperature.

Thermistor

Thermistors are generally made from ceramic materials such as oxides of nickel, manganese or cobalt coated in glass which makes them easily damaged. Their main advantage over snap-action types is their speed of response to any changes in temperature, accuracy and repeatability.

Most types of thermistor's have a *Negative Temperature Coefficient* of resistance or *(NTC)*, that is their resistance value goes DOWN with an increase in the temperature, and of course there are some which have a *Positive Temperature Coefficient, (PTC)*, in that their resistance value goes UP with an increase in temperature.

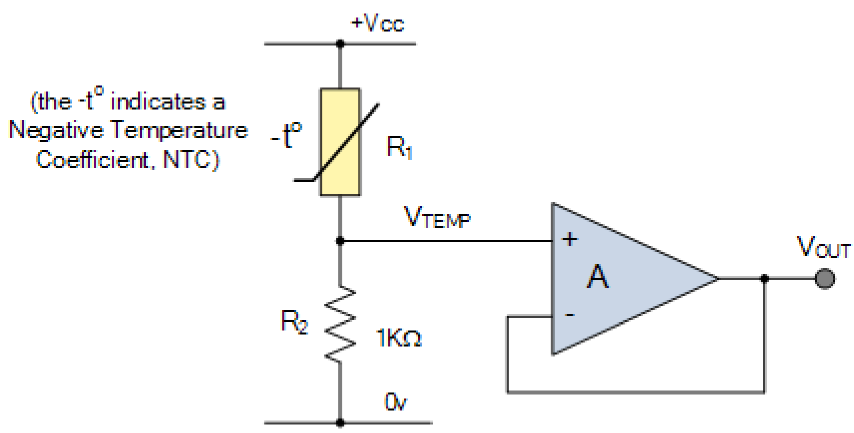
Thermistors are constructed from a ceramic type semiconductor material using metal oxide technology such as manganese, cobalt and nickel, etc. The semiconductor material is generally formed into small pressed discs or balls which are hermetically sealed to give a relatively fast response to any changes in temperature.

Thermistors are rated by their resistive value at room temperature (usually at 25^{o}C), their time constant (the time to react to the temperature change) and their power rating with respect to the current flowing through them. Like resistors, thermistors are available with resistance values at room temperature from 10's of MΩ down to just a few Ohms, but for sensing purposes those types with values in the kilo-ohms are generally used.

Thermistors are passive resistive devices which means we need to pass a current through it to produce a measurable voltage output. Then thermistors are generally connected in series with a suitable biasing resistor to form a potential divider network and the choice of resistor gives a voltage output at some pre-determined temperature point or value for example:

Temperature Sensors Example No1

The following thermistor has a resistance value of 10KΩ at 25^{o}C and a resistance value of 100Ω at 100^{o}C. Calculate the voltage drop across the thermistor and hence its output voltage (Vout) for both temperatures when connected in series with a 1kΩ resistor across a 12v power supply.



At **25°C**

$$Vout = \frac{R_2}{R_1+R_2} xV = \frac{1000}{10000+1000} x12v = 1.09v$$

At **100°C**

$$Vout = \frac{R_2}{R_1+R_2} xV = \frac{1000}{100+1000} x12v = 10.9v$$

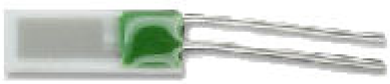
By changing the fixed resistor value of R2 (in our example 1kΩ) to a potentiometer or preset, a voltage output can be obtained at a predetermined temperature set point for example, 5v output at 60°C and by varying the potentiometer a particular output voltage level can be obtained over a wider temperature range.

It needs to be noted however, that thermistor's are non-linear devices and their standard resistance values at room temperature is different between different thermistor's, which is due mainly to the semiconductor materials they are made from. The **Thermistor**, have an exponential change with temperature and therefore have a Beta temperature constant (β) which can be used to calculate its resistance for any given temperature point.

However, when used with a series resistor such as in a voltage divider network or Wheatstone Bridge type arrangement, the current obtained in response to a voltage applied to the divider/bridge network is linear with temperature. Then, the output voltage across the resistor becomes linear with temperature.

Resistive Temperature Detectors (RTD).

Another type of electrical resistance temperature sensor is the **Resistance Temperature Detector** or **RTD**. RTD's are precision temperature sensors made from high-purity conducting metals such as platinum, copper or nickel wound into a coil and whose electrical resistance changes as a function of temperature, similar to that of the thermistor. Also available are thin-film RTD's. These devices have a thin film of platinum paste is deposited onto a white ceramic substrate.



A Resistive RTD

Resistive temperature detectors have positive temperature coefficients (PTC) but unlike the thermistor their output is extremely linear producing very accurate measurements of temperature.

However, they have very poor thermal sensitivity, that is a change in temperature only produces a very small output change for example, 1Ω/°C.

The more common types of RTD's are made from platinum and are called **Platinum Resistance Thermometer** or **PRT**'s with the most commonly available of them all the Pt100 sensor, which has a standard resistance value of 100Ω at 0°C. The downside is that Platinum is expensive and one of the main disadvantages of this type of device is its cost.

Like the thermistor, RTD's are passive resistive devices and by passing a constant current through the temperature sensor it is possible to obtain an output voltage that increases linearly with temperature. A typical RTD has a base resistance of about 100Ω at 0°C, increasing to about 140Ω at 100°C with an operating temperature range of between -200 to +600°C.

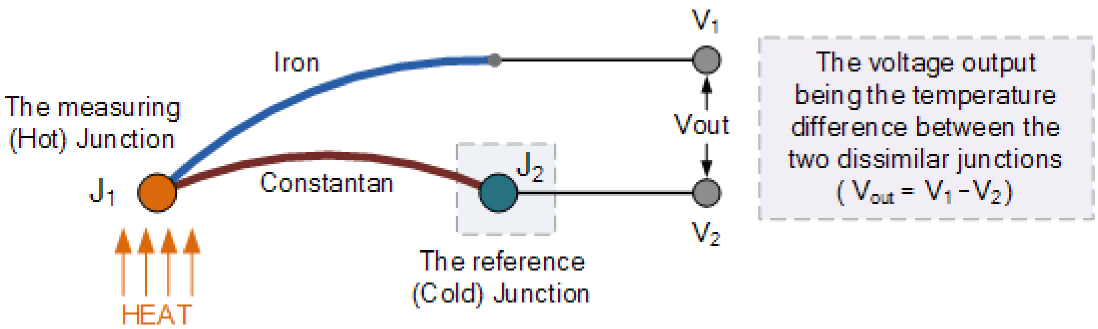
Because the RTD is a resistive device, we need to pass a current through them and monitor the resulting voltage. However, any variation in resistance due to self heat of the resistive wires as the current flows through it, I^2R , (Ohms Law) causes an error in the readings. To avoid this, the RTD is usually connected into a Wheatstone Bridge network which has additional connecting wires for lead-compensation and/or connection to a constant current source.

The Thermocouple

The **Thermocouple** is by far the most commonly used type of all the temperature sensor types. Thermocouples are popular due to its simplicity, ease of use and their speed of response to changes in temperature, due mainly to their small size. Thermocouples also have the widest temperature range of all the temperature sensors from below -200°C to well over 2000°C.

Thermocouples are thermoelectric sensors that basically consists of two junctions of dissimilar metals, such as copper and constantan that are welded or crimped together. One junction is kept at a constant temperature called the reference (Cold) junction, while the other the measuring (Hot) junction. When the two junctions are at different temperatures, a voltage is developed across the junction which is used to measure the temperature sensor as shown below.

Thermocouple Construction



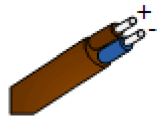
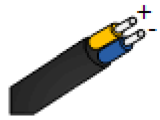
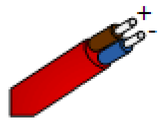
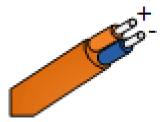
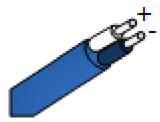
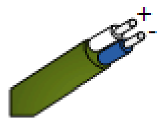
The operating principal of a thermocouple is very simple and basic. When fused together the junction of the two dissimilar metals such as copper and constantan produces a “thermo-electric” effect which gives a constant potential difference of only a few millivolts (mV) between them. The voltage difference between the two junctions is called the “Seebeck effect” as a temperature gradient is generated along the conducting wires producing an emf. Then the output voltage from a thermocouple is a function of the temperature changes.

If both the junctions are at the same temperature the potential difference across the two junctions is zero in other words, no voltage output as $V_1 = V_2$. However, when the junctions are connected within a circuit and are both at different temperatures a voltage output will be detected relative to the difference in temperature between the two junctions, $V_1 – V_2$. This difference in voltage will increase with temperature until the junctions peak voltage level is reached and this is determined by the characteristics of the two dissimilar metals used.

Thermocouples can be made from a variety of different materials enabling extreme temperatures of between -200°C to over +2000°C to be measured. With such a large choice of materials and temperature range, internationally recognised standards have been developed complete with thermocouple colour codes to allow the user to choose the correct thermocouple sensor for a particular application. The British colour code for standard thermocouples is given below.

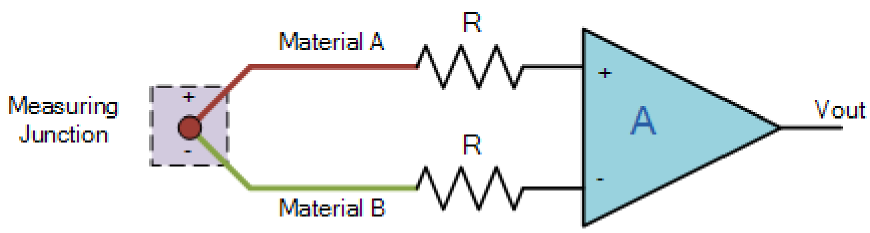
Thermocouple Colour Codes

Thermocouple Sensor Colour Codes*Extension and Compensating Leads*

Code Type	Conductors (+/-)	Sensitivity	British BS 1843:1952
E	Nickel Chromium / Constantan	-200 to 900°C	
J	Iron / Constantan	0 to 750°C	
K	Nickel Chromium / Nickel Aluminium	-200 to 1250°C	
N	Nicrosil / Nisil	0 to 1250°C	
T	Copper / Constantan	-200 to 350°C	
U	Copper / Copper Nickel Compensating for “S” and “R”	0 to 1450°C	

The three most common thermocouple materials used above for general temperature measurement are *Iron-Constantan* (Type J), *Copper-Constantan* (Type T), and *Nickel-Chromium* (Type K). The output voltage from a thermocouple is very small, only a few millivolts (mV) for a 10°C change in temperature difference and because of this small voltage output some form of amplification is generally required.

Thermocouple Amplification



The type of amplifier, either discrete or in the form of an Operational Amplifier needs to be carefully selected, because good drift stability is required to prevent recalibration of the thermocouple at frequent intervals. This makes the chopper and instrumentation type of amplifier preferable for most temperature sensing applications.

Other **Temperature Sensor Types** not mentioned here include, Semiconductor Junction Sensors, Infra-red and Thermal Radiation Sensors, Medical type Thermometers, Indicators and Colour Changing Inks or Dyes.

In this tutorial about “Temperature Sensor Types”, we have looked at several examples of sensors that can be used to measure changes in temperature. In the next tutorial we will look at sensors that are used to measure light quantity, such as Photodiodes, Phototransistors, Photovoltaic Cells and the Light Dependant Resistor.