Temperature Measurement

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INTRODUCTION

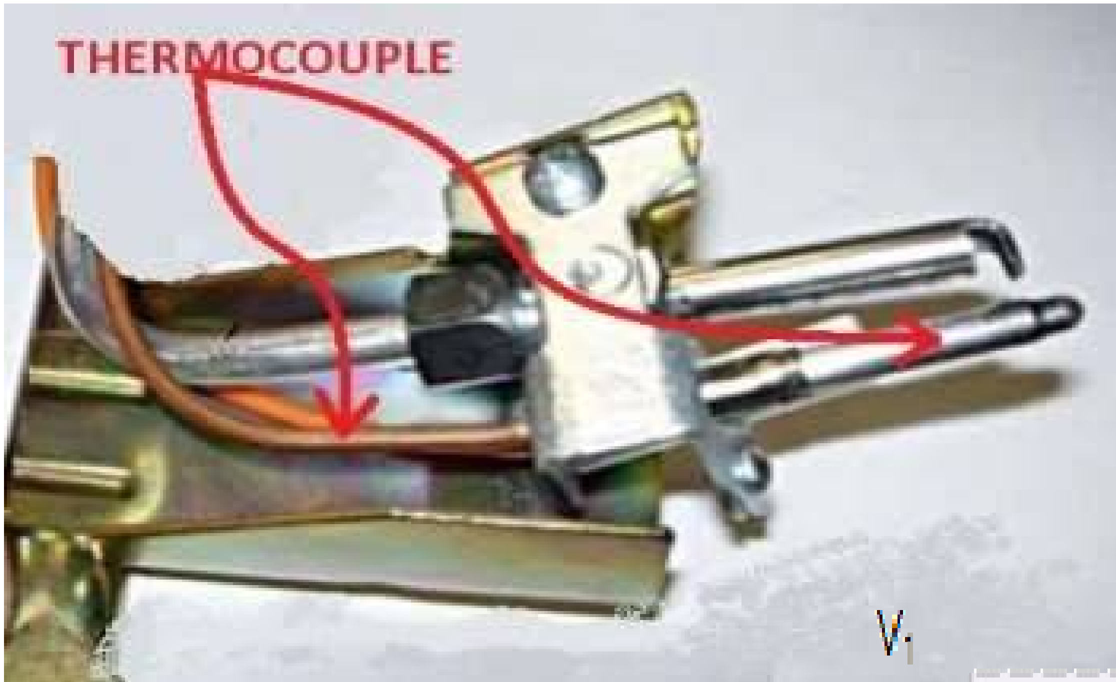
- Temperature is an important parameter in many control systems
- Several distinctly different transduction mechanisms are employed
- These include non electrical as well as electrical methods
- A thermometer is the most common non electrical sensor
- Common electrical sensors include thermocouples, thermistors and resistance thermometers

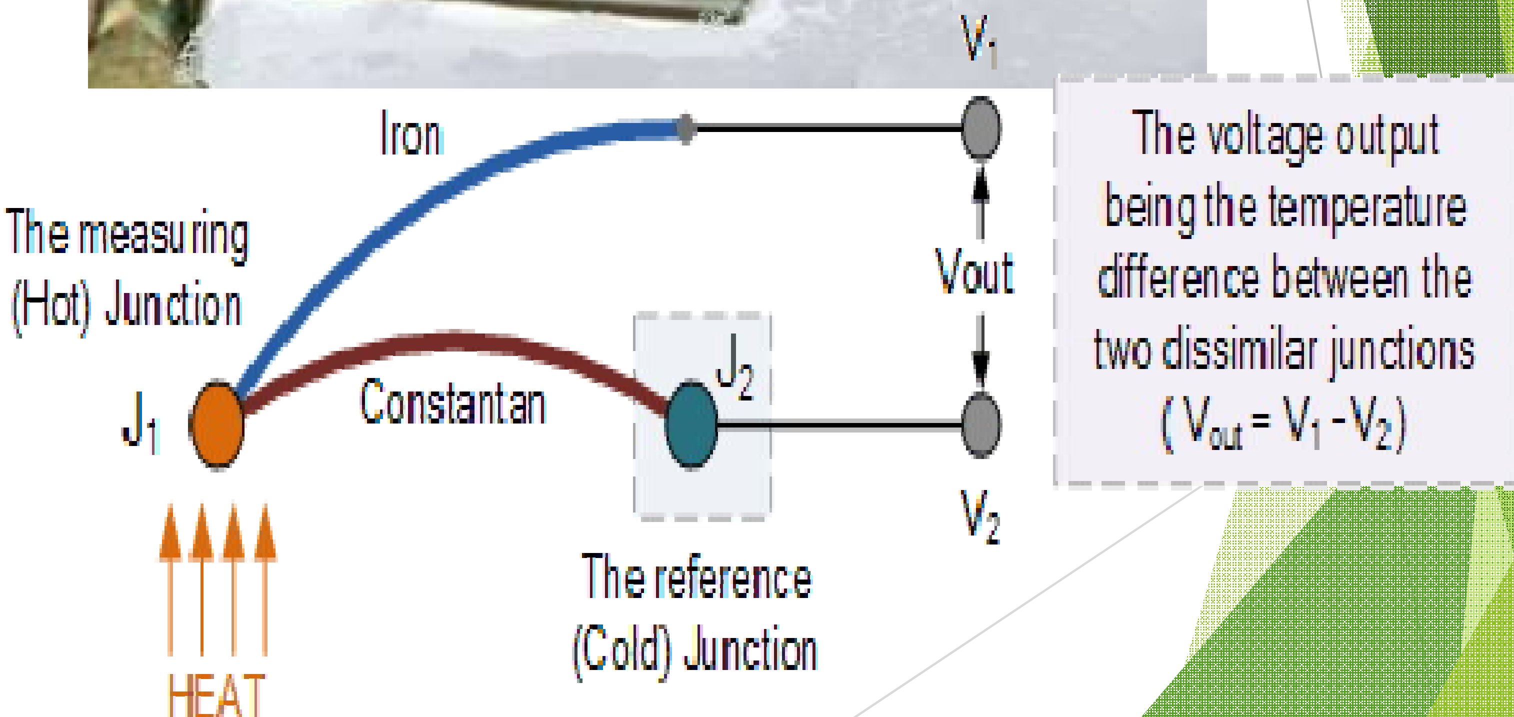
Types of Temperature Sensors

- Thermocouples
- Thermistors
- Resistance - Temperature Detectors (RTD)

What is a thermocouple ?

- A thermocouple is a temperature-measuring device consisting of two dissimilar conductors that contact each other at one or more spots.
- A thermocouple comprises of at least two metals joined together to form two junctions. One is connected to the body whose temperature is to be measured-this is the hot or measuring junction.
- The other junction is connected to a body of known temperature; this is the cold or reference junction. Therefore the thermocouple measures unknown temperature of the body with reference to the known temperature of the other body.


THERMOCOUPLE


V1
Iron
The measuring (Hot) Junction
Vout
J1
Constantan
J2
V2
HEAT
The reference (Cold) Junction
The voltage output being the temperature difference between the two dissimilar junctions
(Vout = V1 - V2)

Where are they used ?

- Thermocouples are a widely used as temperature sensors for measurement, control and can also convert a temperature into electricity.
- Thermocouples are widely used in research and industry; applications include temperature measurement for furnaces, gas turbine exhaust, diesel engines, and other industrial processes.
- Thermocouples are also used in homes & offices as temperature sensors in thermostats and also in flame sensors for fire detection.

Working principle.

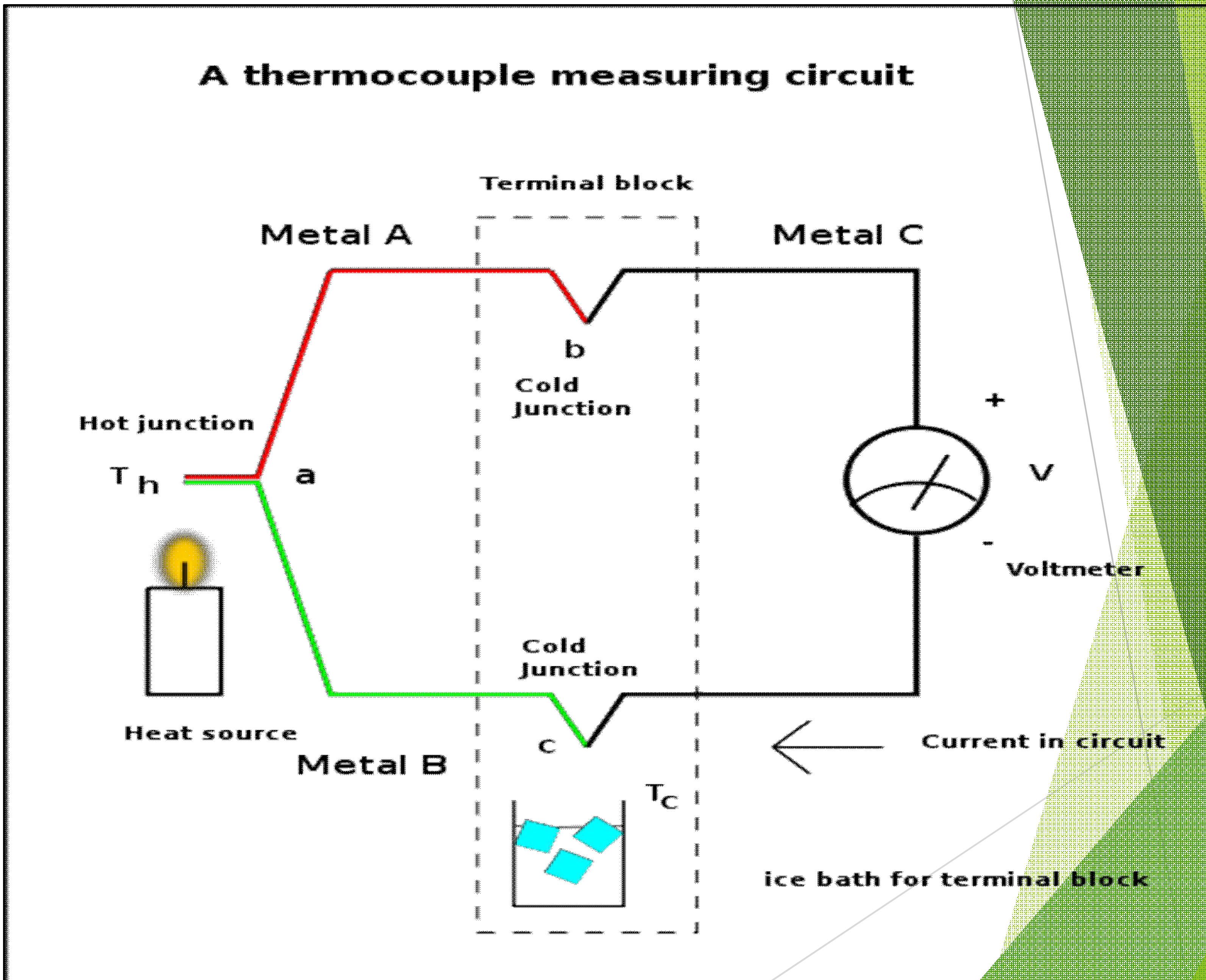
- The working principle of thermocouple is based on three effects discovered by Seebeck, Peltier and Thomson. They are as follows:
- 1) Seebeck effect: The Seebeck effect states that when two different or unlike metals are joined together at two junctions, an electromotive force (emf) is generated at the two junctions. The amount of emf generated is different for different combinations of the metals.
- 2) Peltier effect: when two dissimilar metals are joined together to form two junctions, emf is generated within the circuit due to the different temperatures of the two junctions of the circuit.

- 3) Thomson effect: when two unlike metals are joined together forming two junctions, the potential exists within the circuit due to temperature gradient along the entire length of the conductors within the circuit.

- In most of the cases the emf suggested by the Thomson effect is very small and it can be neglected by making proper selection of the metals. The Peltier effect plays a prominent role in the working principle of the thermocouple.

How does it work ?

- when any conductor is subjected to change in temperature, it will generate a voltage. This is now known as the thermoelectric effect or Seebeck effect.
- Any attempt to measure this voltage necessarily involves connecting another conductor to the "hot" end. This additional conductor experiences the same temperature gradient and also develops a voltage.
- The magnitude of the effect depends on the metal in use, and so a nonzero voltage will be measured if two dissimilar metals are used. After carefully calibrating the temperature-voltage dependence for a given pair of metals, these metals can be used as a thermometer.


A thermocouple measuring circuit
Terminal block
Metal A
Metal C
b
Cold
Junction
Hot junction
T h
a
+
V
-
Voltmeter
Cold
Junction
Heat source
c
Current in circuit
Metal B
TC
ice bath for terminal block

APPLICATIONS OF THERMOCOUPLES

- Thermocouples are most suitable for measuring over a large temperature range, up to 1800 °C
- These are widely used in the steel industry, heating appliances, manufacturing of electrical equipments like switch gears etc.

Advantages of Thermocouple

1. The thermocouple type of instruments accurately indicates the root mean square value of current and voltages irrespective of the waveform. There is a wide varieties of range of thermocouple instruments are available in the market.

2. Thermocouple type of instruments give very accurate reading even at high frequency, thus these types of instruments are completely free from frequency errors.

3. The measurement of quantity under these instruments is not affected by stray magnetic fields.

4. These instruments are known for their high sensitivity.

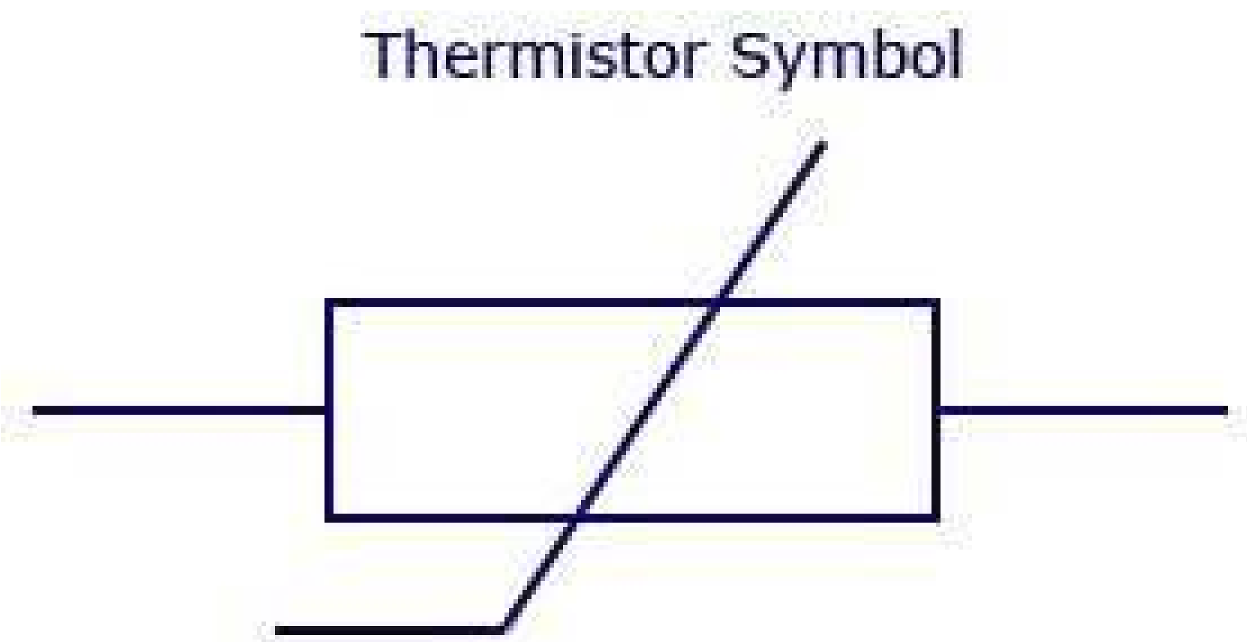
Disadvantages

Instead of many advantages these type of instruments posses one disadvantage, The over load capacity of thermocouple type of instrument is small, even fuse is not able to the heater wire because heater wire may burn out before the fuse blows out.

THERMISTOR

- Thermistor is the short form for 'Thermal Resistor'. The device consists of a bulk semiconductor device that acts as a resistor with a high and negative temperature co-efficient of resistance, sometimes as high as -6% per degree Celsius rise in temperature.
- Due to this property of high sensitivity (that is, huge resistance change for a small change in temperature), the thermistor is mainly applicable in precision temperature measurement, temperature control, and temperature compensation, especially in a lower temperature range of -100 degree Celsius to +300 degree Celsius.

THERMISTOR SYMBOL



THERMISTOR TYPES

- Themistors are broadly divide into two categories according to the temperature coefficient.
- Posistor or Positive Temperature Coefficient Thermistor (PTC).
- Negative Temperature Coefficient Thermistor (NTC).

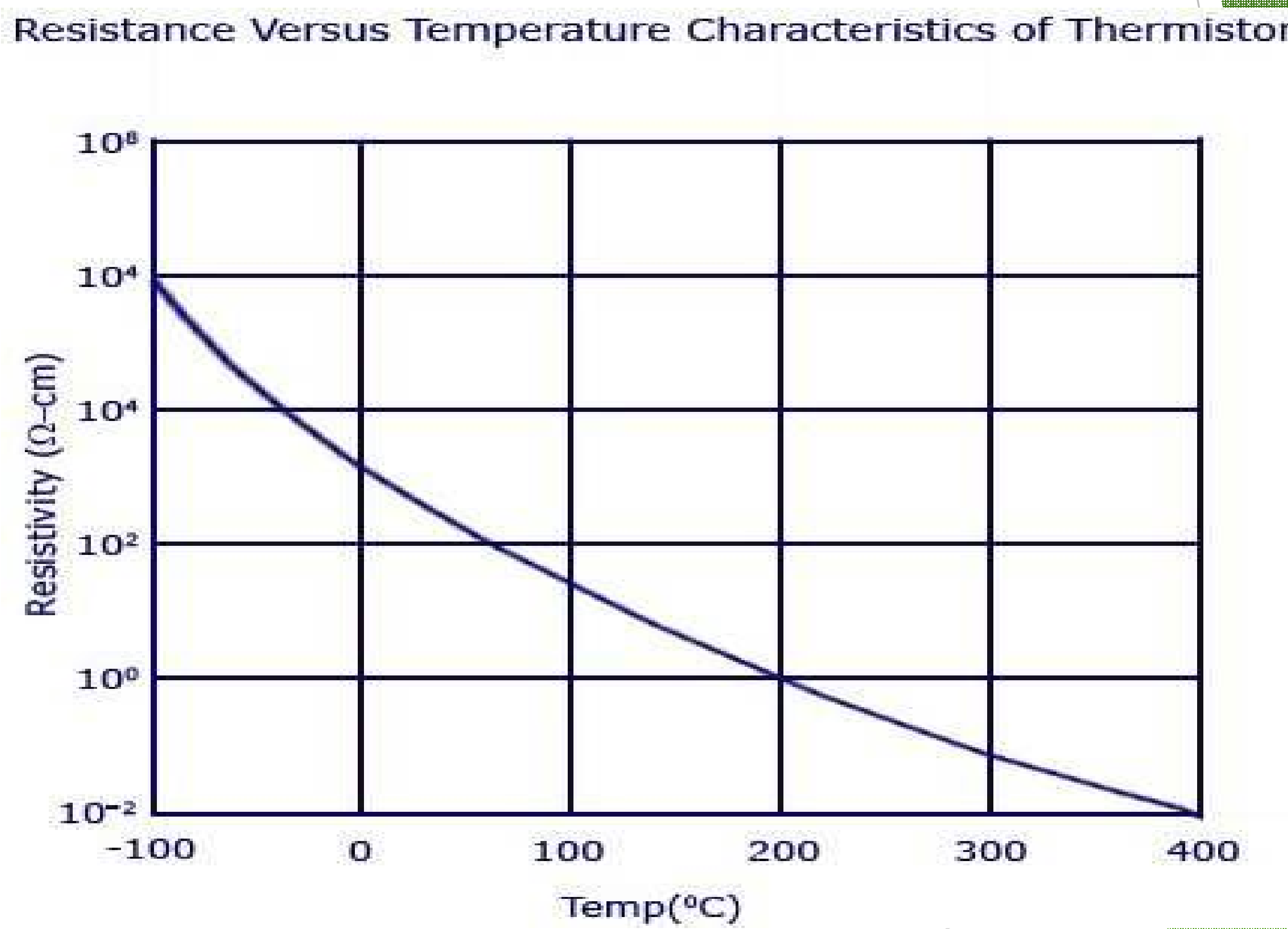
- For studying about the different types of thermistors, it is important to understand the formula which shows the linear relationship between resistance and temperature.
- As a 1st order approximation, the change in resistance is equal to the 1st order temperature co- efficient of resistance times the change in temperature.
- $dR = k.dT$

where, dR – Change in Resistance.

k – 1st Order Temperature Coefficient of Resistance.

- If the value of temperature coefficient of resistance (k) is positive, an increase in temperature increases the resistance. Such a device can be called a Posistor or Positive Temperature Coefficient Thermistor (PTC)
- If the value of k is negative, an increase in temperature will decrease the resistance value. Such a device is called a Negative Temperature Coefficient Thermistor (NTC).

RESISTANCE VS TEMPERATURE CHARACTERISTIC CURVE



CONSTRUCTION OF THERMISTORS

- Thermistor are composed of sintered mixture of metallic oxides such as manganese, nickel cobalt, copper, iron and uranium.
- They are available in variety of sizes and shapes.
- Thermistors may be in the form of beads, probes, rods and discs.

ADVANTAGES AND DISADVANTAGES OF THERMISTORS

- Thermistors, since they can be very small, are used inside many other devices as temperature sensing and correction devices
- Thermistors typically work over a relatively small temperature range, compared to other temperature sensors, and can be very accurate and precise within that range

APPLICATIONS OF THERMISTORS

- PTC thermistors can be used as current-limiting devices for circuit protection, as replacements for fuses.
- PTC thermistors can be used as heating elements in small temperature-controlled ovens.
- NTC thermistors are used as resistance thermometers in low-temperature measurements of the order of 10 K.
- NTC thermistors are regularly used in automotive applications.

RESISTANCE TEMPERATURE DETECTOR (RTD)

- A resistance temperature detector (RTD) can also be called a resistance thermometer as the temperature measurement will be a measure of the output resistance.
- The main principle of operation of an RTD is that when the temperature of an object increases or decreases, the resistance also increases or decreases proportionally.

- The main difference between a RTD and a Thermistors is that the sensing element used in a RTD is a metal and a thermistor uses ceramic or polymer material.
- As platinum is the most commonly used metal for making RTD's, the device can also be called Platinum Resistance Thermometers (PRT's).

TEMPERATURE COEFFICIENT OF RESISTANCE.

- Resistive Temperature Detectors (RTDs) relate resistance to temperature by the following formula:

  $R_T = R_{ref}[1 + \alpha(T - Tref)]$

  Where, R_T = Resistance of RTD at given temperature T (ohms)

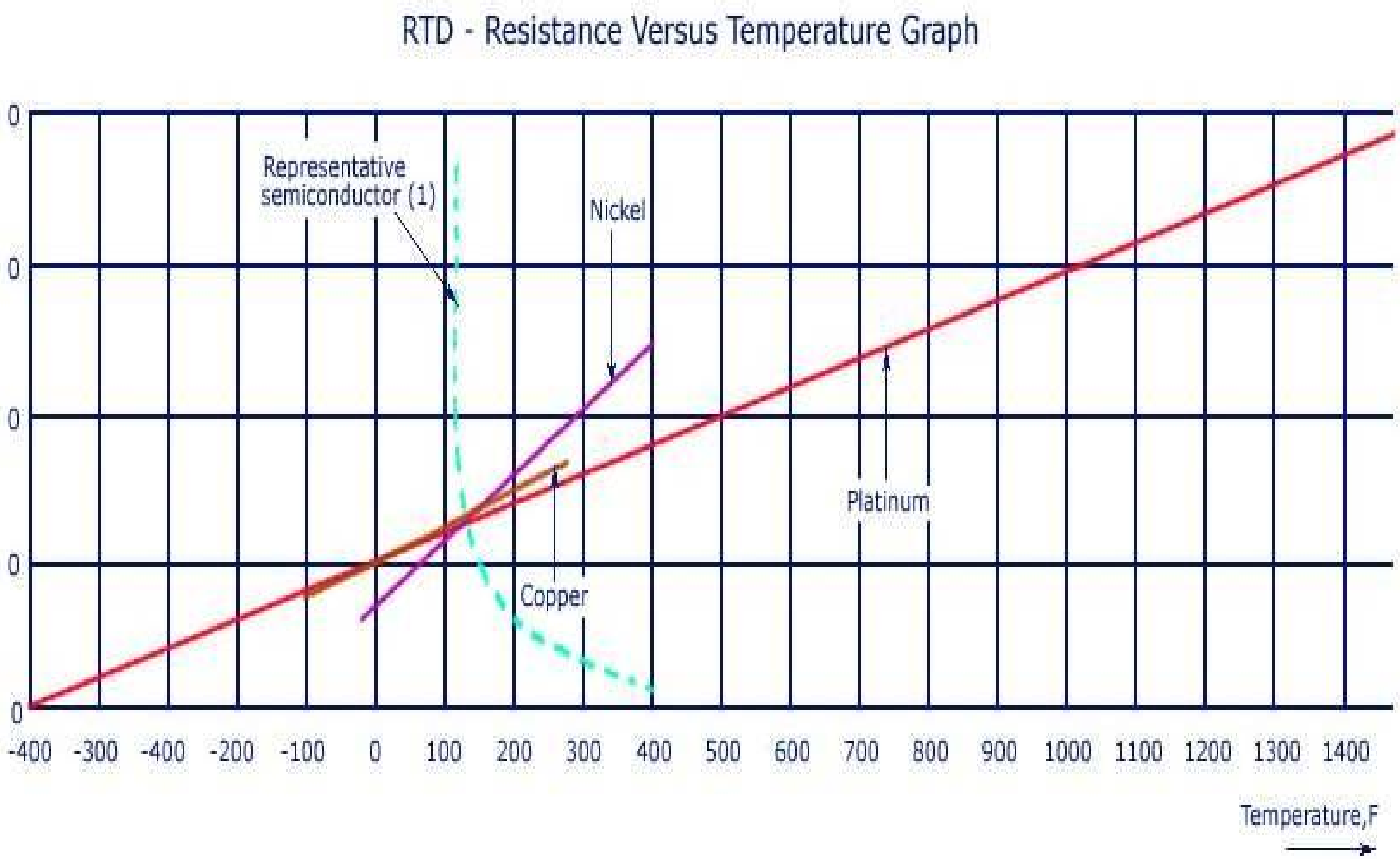
  R_{ref} = Resistance of RTD at the reference temperature Tref (ohms)

  α = Temperature coefficient of resistance (ohms per ohm/degree)

RTD TYPES

- RTD types are broadly classified according to the different sensing elements used. Platinum, Nickel and Copper are the most commonly used sensing elements.
- Platinum is considered the best as it has the widest temperature range.
- In industrial applications, a PRT is known to measure temperatures as high as 1500 degree Fahrenheit while copper and Nickel can measure only to a maximum of 400 degree Fahrenheit.

RTD-RESISTANCE VERSUS TEMPERATURE GRAPH

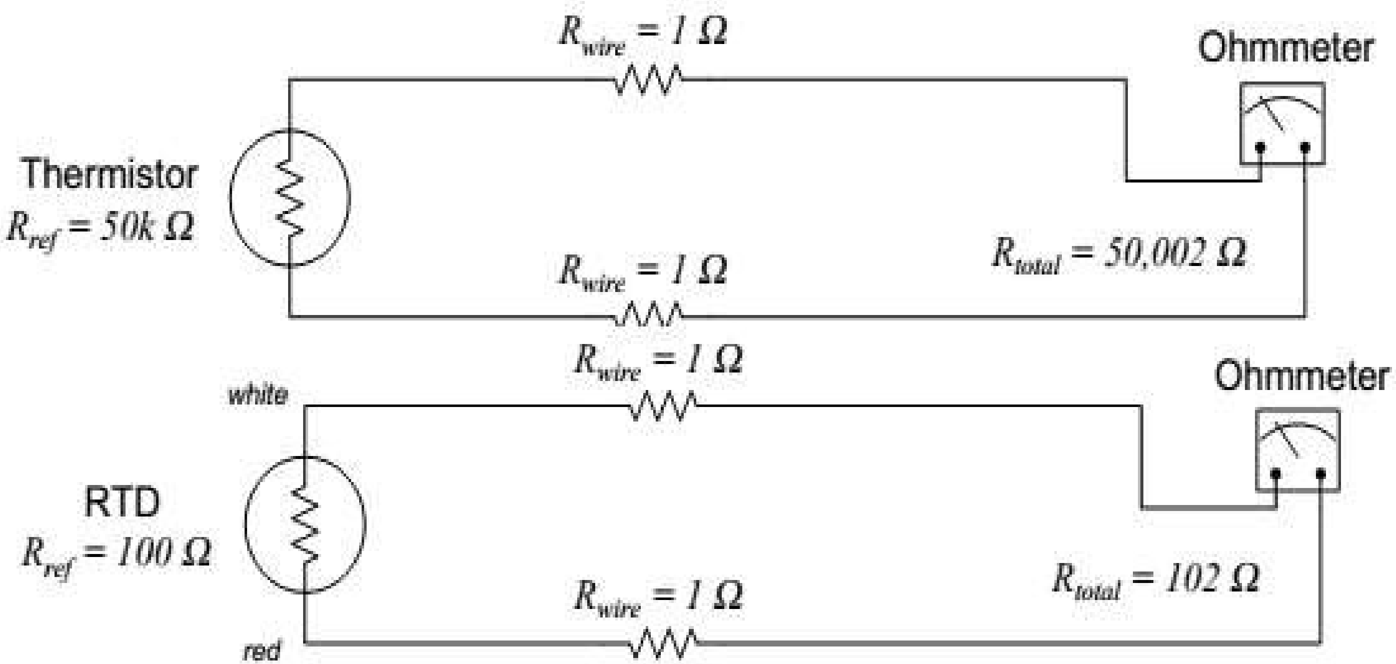


RTD WIRING ARRANGEMENTS

- RTD’s are available with either two, three, or four output wires for connection to the secondary instrument.
- The various wiring arrangements are designed to reduce and/or eliminate any errors introduced due to resistance changes of the lead wires when they also undergo temperature changes.
- RTDs used for electrical equipment generally use either a three-wire system or a four-wire system having paired lead wires.

TWO-WIRE RTD CIRCUITS

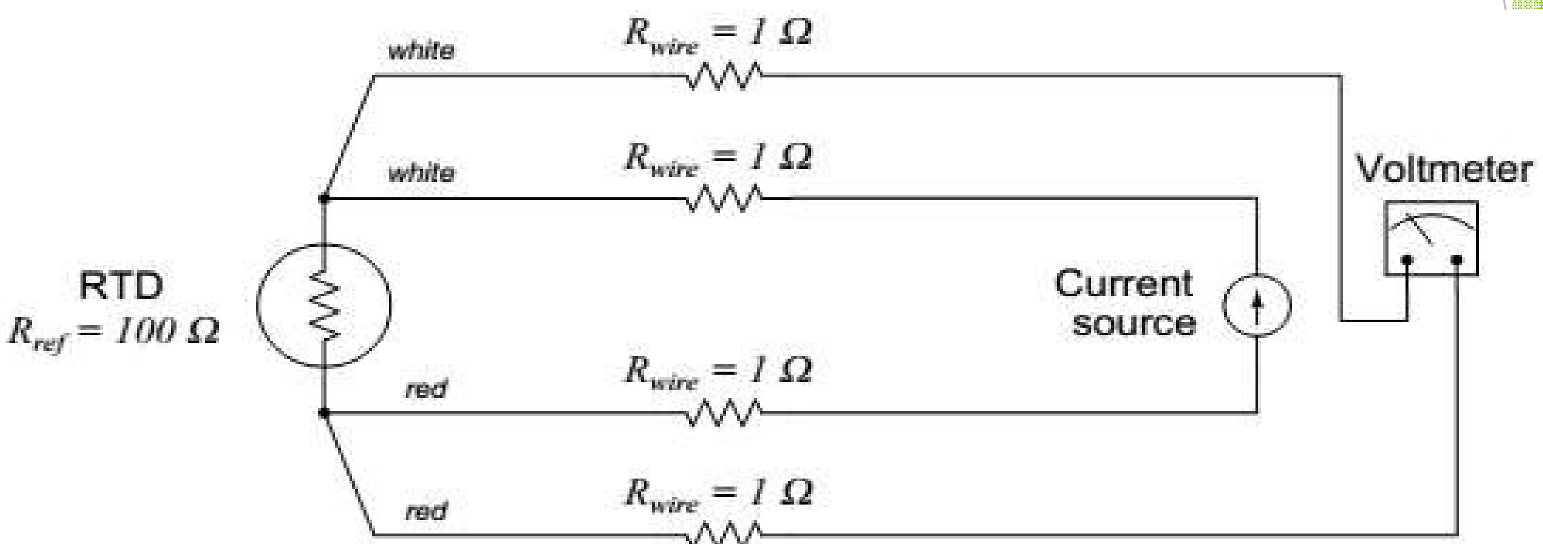
- The following schematic diagrams show the relative effects of 2 ohms total wire resistance on a thermistor circuit and on an RTD circuit:



- Clearly, wire resistance is more problematic for low-resistance RTDs than for high-resistance thermistors.
- In the RTD circuit, wire resistance counts for 1.96% of the total circuit resistance.
- In the thermistor circuit, the same 2 ohms of wire resistance counts for only 0.004% of the total circuit resistance.
- 2-wire construction is the least accurate since there is no way of eliminating the lead wire resistance from the sensor measurement. 2-wire RTD's are mostly used with short lead wires or where close accuracy is not required.

FOUR-WIRE RTD CIRCUITS

- Commonly employed to make precise resistance measurements for scientific experiments in laboratory conditions, the four-wire technique uses four wires to connect the resistance under test (in this case, the RTD)



- Current is supplied to the RTD from a current source, whose job it is to precisely regulate current regardless of circuit resistance.
- A voltmeter measures the voltage dropped across the RTD, and Ohm's Law is used to calculate the resistance of the RTD (R =V/I).
- None of the wire resistances are significant in this circuit.
- The two wires carrying current to the RTD will drop some voltage along their length, but this is of no concern because the voltmeter only "sees" the voltage dropped across the RTD rather than the voltage drop across the current source.

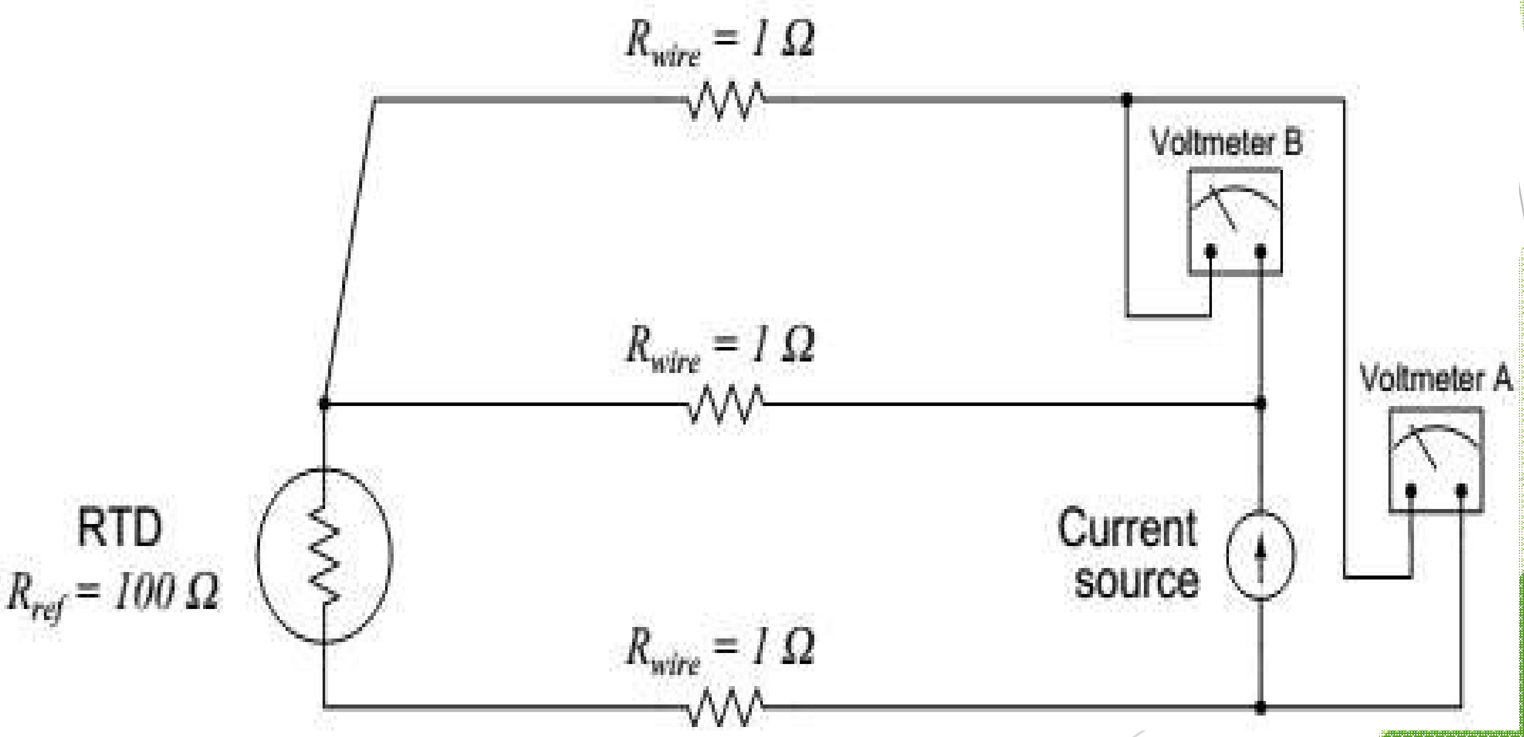
- While the two wires connecting the voltmeter to the RTD do have resistance, they drop negligible voltage because the voltmeter draws so little current through them.
- Thus, the resistances of the current-carrying wires are of no effect because the voltmeter never senses their voltage drops, and the resistances of the voltmeter's sensing wires are of no effect because they carry practically zero current.
- 4-wire construction is used primarily in the laboratory where close accuracy is required. In a 4 wire RTD the actual resistance of the lead wires can be determined and removed from the sensor measurement.

DISADVANTAGE OF THE FOUR-WIRE.

- The only disadvantage of the four-wire method is the sheer number of wires necessary.
- Four wires per RTD can add up to a sizeable wire count when many different RTDs are installed in a process area.
- Wires cost money, and occupy expensive outlet, so there are situations where the four-wire method is a burden.

THREE-WIRE RTD CIRCUITS.

- A compromise between two-wire and four-wire RTD connections is the three-wire connection, which looks



- In a three-wire RTD circuit, voltmeter “A” measures the voltage dropped across the RTD (plus the voltage dropped across the bottom current-carrying wire).
- Voltmeter “B” measures just the voltage dropped across the top current-carrying wire.
- Assuming both current-carrying wires will have (very nearly) the same resistance, subtracting the indication of voltmeter “B” from the indication given by voltmeter “A” yields the voltage
- 3-wire construction is most commonly used in industrial applications where the third wire provides a method for removing the average lead wire resistance from the sensor measurement.

- If the resistances of the two current-carrying wires are precisely identical (and this includes the electrical resistance of any connections within those current-carrying paths, such as terminal blocks),the calculated RTD voltage will be the same as the true RTD voltage, and no wire-resistance error will appear.
- If, however, one of those current-carrying wires happens to exhibit more resistance than the other, the calculated RTD voltage will not be the same as the actual RTD voltage, and a measurement error will result.
- Thus, we see that the three-wire RTD circuit saves us wire cost over a four-wire circuit, but at the "expense" of a potential measurement error.

ADVANTAGES

- Very high accuracy.
- Excellent stability and reproducibility.
- Interchangeability.
- Ability to be matched to close tolerances for temperature difference measurements.
- Ability to measure narrow spans.
- Suitability for remote measurement.

DISADVANTAGES.

- Susceptibility to mechanical damage.
- Need for lead wire resistance compensation.
- Sometimes expensive.
- Susceptibility to self-heating error.
- Susceptibility to signal noise.
- Unsuitability for bare use in electrically conducting substance.
- Generally not repairable
- Need for power supply

Platinum Resistance Thermometer

The platinum thermal resistance (PTR) uses platinum for determining the temperature. It works on the principle that the resistance of platinum changes with the change of temperature. The thermometer measures the temperature over the range of 200°C to1200°C.

The platinum is an unreactive metal and can easily be drawn into fine wires. Because of these properties of platinum, it is used as a sensing element in thermometer.

Why Platinum?

Platinum has been chosen as the standard material for resistance thermometers as it gives an extremely linear resistance change in relation to temperature and is very stable. It is therefore much easier to control accuracy over a wide temperature range. It also has the advantage of having a very wide operating temperature range.

What are the different types?

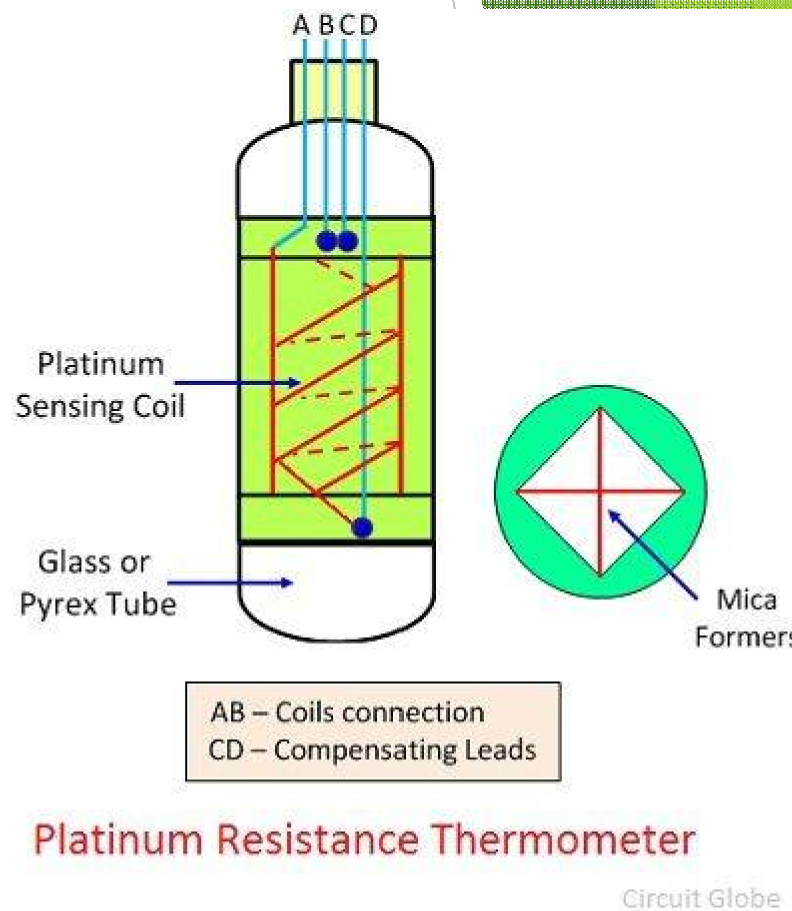
Most users of temperature probes will be familiar with the terminology Pt100, Pt500 or Pt1000.

Pt is the chemical symbol for Platinum and denotes its use in the sensor. Other sensors may use Cu (copper) or Ni (Nickel) accordingly.

The number relates to the resistance value at 0°C. So a Pt100 will have a resistance of 100Ω at 0°C, and it follows that a Pt1000 will be 1000Ω at 0°C.

Construction of Platinum Resistance Thermometer

The platinum sensing coil is enclosed inside a bulb which is either made of glass or Pyrex. The insulator deposit on the surface of the glass tube is also used for sensing the temperature. In this PTR, the double wire of the platinum is wound on the strip of the mica. Here the double wires are used for reducing the inductive effect. The mica is used as an insulator, and it is placed at the ends of the tube.



Advantages of Platinum Resistance Thermometer

- The temperature measurement through platinum resistance thermometer is easier as compared to the gas thermometer.
- The meter gives the precise reading of temperature.
- The thermometer has a wide range from 200 to 1200° Celsius.
- The thermometer is quite sensitive.
- The platinum has same resistance at the same temperature.

Disadvantages of Platinum Resistance Thermometer

- The thermometer gives the slow response.
- The melting point of the thermometer is 1800° Celsius. But when platinum measures the temperature higher than 1200°C they start evaporating.
- When the thermometer constructed carefully, it provides the excellent sensitivity and high range of measurement.