Temperature measuring Transducers

1. Resistance Temperature Detectors (RTD)

The temperature-sensing method of **"Resistance Temperature Detectors"** is based on the fact that the electrical resistance of various conductors (metals) increase in a **reproducible manner** with increase in temperature.

The temperature- resistance characteristics is:

$$R_t = R_{t_o}\left(1+\alpha_1\Delta t+\alpha_2\Delta t^2+\alpha_3\Delta t^3+......++\alpha_n\Delta t^n\right)$$

Over a narrow temperature range, the variation of resistance with temperature approximates a linear relation.

$$R_t = R_{t_o}\left(1+\alpha_1\Delta t\right)$$

RTD Materials

Platinum sensors dominate resistance thermometry because,

- Platinum is stable – measurements can be made from – 20^{o}C to 850^{o}C readily to a stability of hundred this of a degree over several years.
- Platinum is resistant to corrosion and oxidation.
- Platinum is malleable and hence can be drawn into thin wires.
- Platinum can be made to have a high degree of purity.
- Platinum has a high degree of resistivity and hence platinum sensors have small size.
- The non linearity of resistance temperature relationship can be ignored for most industrial purposes (about 0.4% per 100^{o}C span).

Platinum sensors are usually available with **nominal resistance** (i.e. R_o) of 100Ω at 0^{o}C (**Pt.-100**),
but it can also be 200Ω (Pt.-200),
500Ω (Pt.-500) and
1000Ω (Pt.-1000).

The equations for practical use :

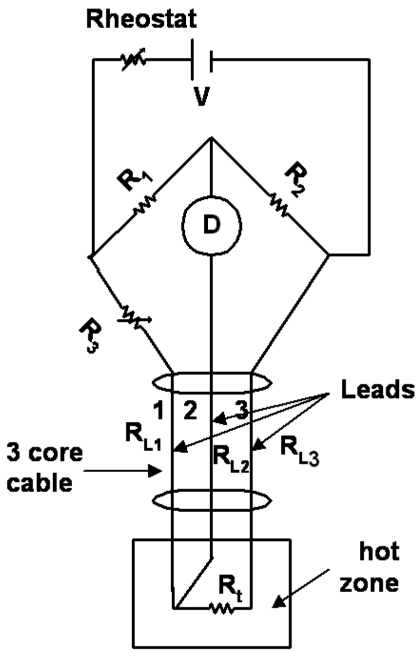
$$R_t = R_o\left[1+3.90801\times10^{-3}t-0.580195\times10^{-6}t^2\right] \text{in the range } 0^oC\le t\le 850^oC$$

and

$$R_t = R_o\left[1+3.90801\times10^{-3}t-0.580195\times10^{-6}t^2+0.42735\times10^{-3}t^3-4.2735\times10^{-12}t^4\right]$$

$$\text{in the range } -200^oC\le t\le 0^oC$$

Measurement circuit:



If $R_1 = R_2$

$R_3 = R_t$

2. Thermistor

- Semiconductor devices which behave as **THERMally** sensitive **resISTORS**.
- Mostly **NTC devices** (i.e. they have –ve temp.coeff. of resistance) although **PTC thermistors** do exist

Resistance temperature relationship can be expressed approximately as:

$$R_T = R_{T_o} e^{\beta\left(\frac{1}{T} - \frac{1}{T_o}\right)}$$

Over a small range of temperature,

R_T is the resistance of thermistor at temperature T(K)

R_{T_o} = Resistance of thermistor at reference temperature T_o (K)

T_o is usually 298K (i.e. 25ºC)

β is a material constant that ranges from 3000K to 5000K.

From equation (1) we have,

$$\ln R_T = \ln R_{T_o} + \beta\left(\frac{1}{T} - \frac{1}{T_o}\right)$$

or, $$\frac{1}{T}=\frac{1}{\beta}\ln R_T-\frac{1}{\beta}\ln R_{T_o}+\frac{1}{T_o}$$

or, $$\frac{1}{T}=A+B\ln R_T \qquad (2)$$

where $A=\frac{1}{T_o}-\frac{1}{\beta}\ln R_{T_o}$

and $B=\frac{1}{\beta}$

A better fit for the resistance-temperature characteristic is given by Steinhart-Hart equation as

$$\frac{1}{T}=A_1+B_1\ln R_T+C_1\left(\ln R_T\right)^3 \qquad (3)$$

From equation (1) the sensitivity of the thermistor is obtained as

$$S=\frac{dR_T}{dT}=R_{T_o}e^{\beta\left(\frac{1}{T}-\frac{1}{T_o}\right)}\left[-\frac{\beta}{T^2}\right] \qquad (5)$$

Temperature coefficient, of resistance is

$$\alpha=\frac{\frac{dR_T}{dT}}{R_T}=-\frac{\beta}{T^2} \qquad (6)$$

Considering β = 4000K and T = reference temperature, T_o = 298K, α is obtained as – 0.045/K compared with 0.0039/° for P_T.

Merits of Thermistor

1. Small size (as small a diameter as 0.005″) and hence permits point sensing and rapid response to temperature change.
2. Good sensitivity.
3. Cold junction compensation is not required
4. Absence of contact and lead-resistance problems due to high nominal resistance value.
5. Low cost.

Limitation of Thermistors

1. Non linearity in resistance vs. temperature characteristics.
2. Unsuitable for wide temperature range.
3. Very low excitation current to avoid self heating.

Measuring range:

Thermistors with high nominal resistance (100kΩ - 500kΩ at 25°C) are used for high temperature (150°C to 300°C)
Intermediate-resistance thermistors (2kΩ to 100kΩ at 25°C) are used for intermediate temperature (75 to 150°C).

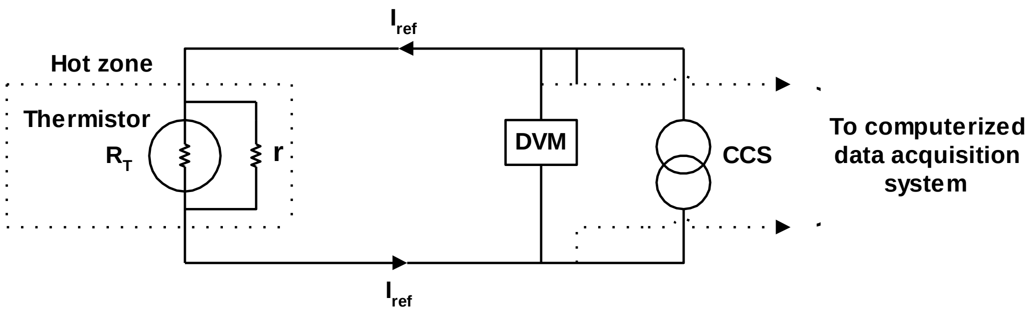
Low-resistance thermistors (100 - 1000Ω at 25°C) are used for low temperature (- 75 to + 75°C).

Measurement Circuitry for Thermistors

The coherent advantage of using thermistor is that since they are available with high nominal resistances, the connecting head resistances do not affect the measurement.

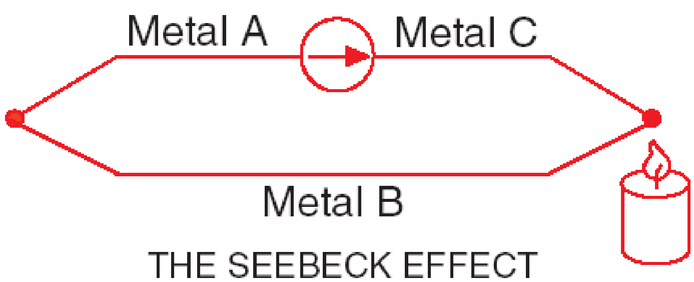
Wheatstone bridge circuits involving null method and direct readout facility can be used for thermistors.

Ohmmeter method of measurement is also widely used for thermistors, and this method four-wire connection is usually not necessary since the problem due to lead resistance are not there.

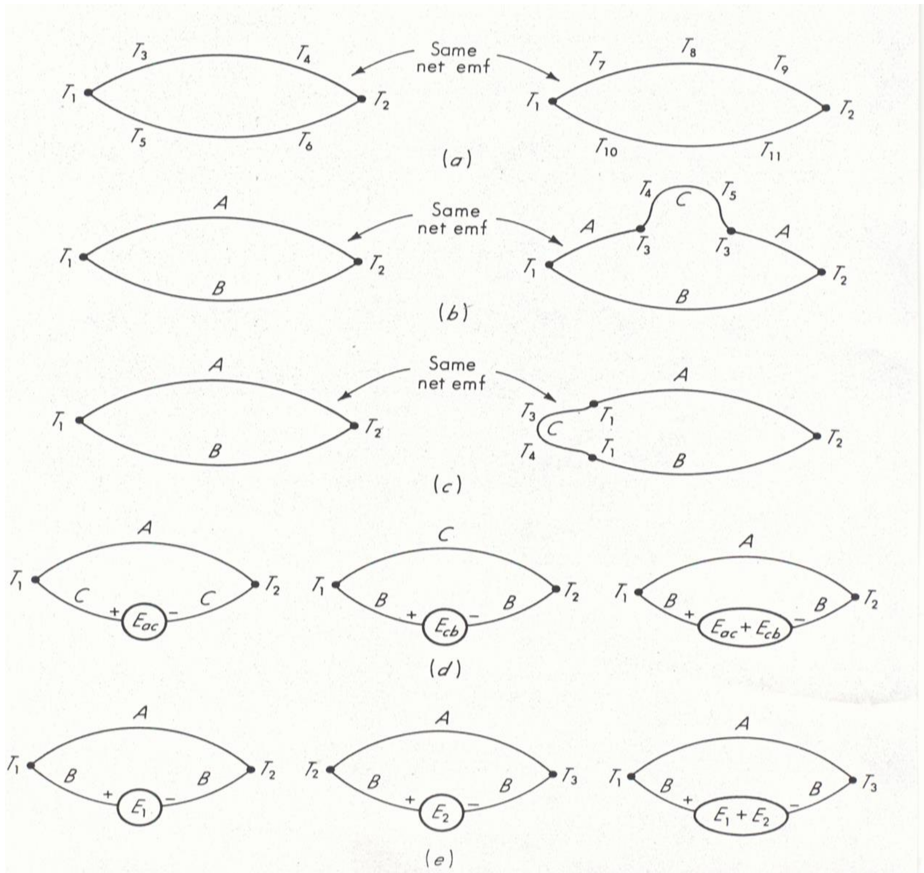


3. Thermocouples

A thermocouple is a device consisting of two different conductors (usually metal alloys) that produce a voltage, proportional to a temperature difference, between the junctions.



Laws of THERMOCOUPLE CIRCUIT

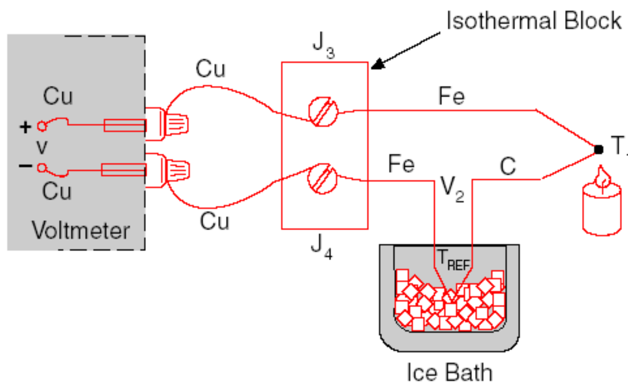


Summary of Laws:

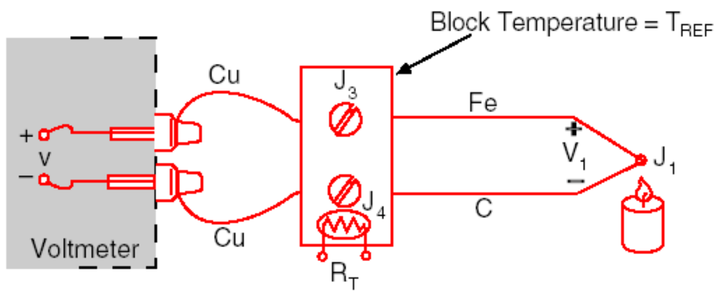
1) The thermal emf of a thermocouple with junctions at T_1 and T_2 is totally unaffected by temperature elsewhere in the circuit if the two metals used are each homogeneous (Fig a).
2) If a third homogeneous metal, C, is inserted into the circuit in either leg, the net emf is unchanged if the junctions to link C are held at the same temperature. This is true regardless of the temperature environment of link C (Fig b).
3) If a metal, C, is inserted at one of the junctions between A and B, the net effect on the emf unchanged, if the junctions AB and AC are held at the same temperature. This is true regardless of the temperature environment along link C (Fig c).
4) If the thermal emf between metals A and C is E_{AC}, and that between metals B and C is E_{CB}, then the thermal emf between metals A and B is $E_{AC} + E_{CB}$ (Fig d).
5) If a thermocouple produces emf E_1 when its junctions are at T_1 and T_2, and produces E_2 with junctions at T_2 and T_3, then it will produce $E_1 + E_2$ when the junctions are at T_1 and T_3 (Fig e) (Law of Intermediate Temperatures).

From: Doebelin, E. O., "Measurement Systems: Application and Design," Third Edition, p 590-591, McGraw-Hill, New York, 1983

Measurement Circuit:



Cold Junction Compensation:



A thermistor, whose resistance R_T is a function of temperature, provides a way to measure the absolute temperature of the reference junction.
Junctions J_3 and J_4 and the thermistor are all assumed to be at the same temperature, due to the design of the isothermal block.

1) Measure R_T to find T_{REF} and convert T_{REF} to its equivalent reference junction voltage, V_{REF} , then

2) Measure V and add V_{REF} to find V_1, and convert V_1 to temperature T_{J1}.

Different types :

	TYPE E	TYPE J	TYPE K	TYPE R	TYPE S	TYPE T
	Nickel-10% Chromium(+) Versus Constantan(-)	Iron(+) Versus Constantan(-)	Nickel-10% Chromium(+) Versus Nickel-5%(-) (Aluminum Silicon)	Platinum-13% Rhodium(+) Versus Platinum(-)	Platinum-10% Rhodium(+) Versus Platinum(-)	Copper(+) Versus Constantan(-)
	-100°C to 1000°C ± 0.5°C	0°C to 760°C ± 0.1°C	0°C to 1370°C ± 0.7°C	0°C to 1000°C ± 0.5°C	0°C to 1750°C ± 1°C	-160°C to 400°C ±0.5°C