Thermistors

PT- 403 INSTUMENTATION
UNIT-I

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Introduction

What is a Thermistor?

The Thermistor is a special type of variable resistive element that changes its physical resistance when exposed to temperature changes. The **Thermistor** is a solid state temperature sensing device which acts a bit like an electrical resistor. Basically it is 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 vary its resistive value in proportion to small changes in the temperature. In other words, as its temperature changes, so does its resistance and hence the name, "Thermistor", a combination of the words THERM-ally sensitive res-ISTOR. The most commonly used oxides are those of **manganese, nickel, cobalt, iron, copper and titanium**. Although the change in resistance due to heat is generally undesirable in standard resistors, this effect is put to a 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.

Thermistors are available in a whole range of types, materials and sizes characterised by their response time and operating temperature. The three most common types are: Bead thermistors, Disk thermistors, and Glass encapsulated thermistors.

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Note: Thermistor is "*A two terminal solid state thermally sensitive transducer, that allows a significant change in its resistive value with respect to change in ambient temperature.*"

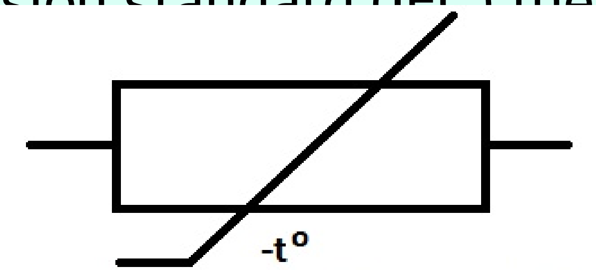
Types of Thermistors

Thermistors can operate in two ways, either by increasing or decreasing their resistive value with changes in temperature. Therefore there are two types of thermistors available: **negative temperature coefficient** (NTC) of resistance and **positive temperature coefficient** (PTC) of resistance.

❖ Negative temperature coefficient (NTC) Thermistor

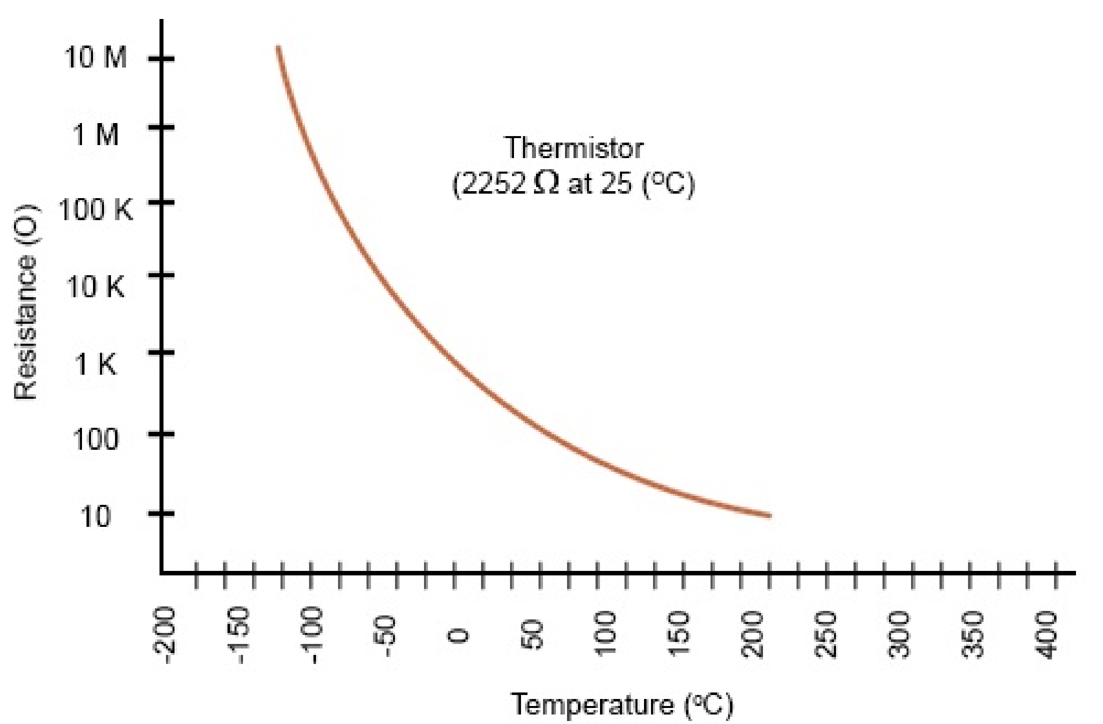
NTC or negative temperature coefficient thermistor is a device whose resistance decreases with increase in temperature. These types of resistor usually exhibit a large, precise and predictable decrease in resistance with increase in temperature.

Unlike other resistors (fixed or variable), these are made of ceramics and polymers, which are composed of metal oxides that are dried and sintered to obtain a desired form factor. In case of NTC thermistor, cobalt, nickel, iron and copper oxides are preferred. According to the international electrotechnical commission standard (IEC) the symbolic for NTC thermistor is:



NTC Thermistor Symbol - IEC Standard

A typical NTC thermistor gives most precise readings in the temperature range of -55°C to 200°C. However some specially designed NTC thermistors are used at absolute zero temperature(-273.15°C) and some can be used above 150°C.The figure below shows the characteristic curve of a NTC thermistor:

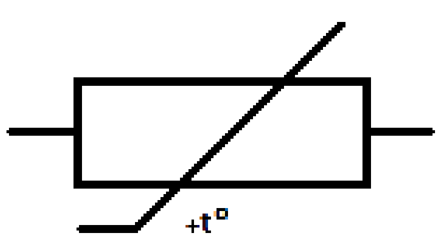


Thermistor Characteristic NTC Curve

- From the figure we can say that they have a steep resistance temperature curve, denoting good temperature sensitivity.
- However due to the nonlinear relationship between resistance and temperature, some approximations are utilized to design practical system.
- Out of all the approximations, the simplest one is:
- $\Delta R = k\Delta T$, where k is the negative temperature coefficient of the Thermistor.

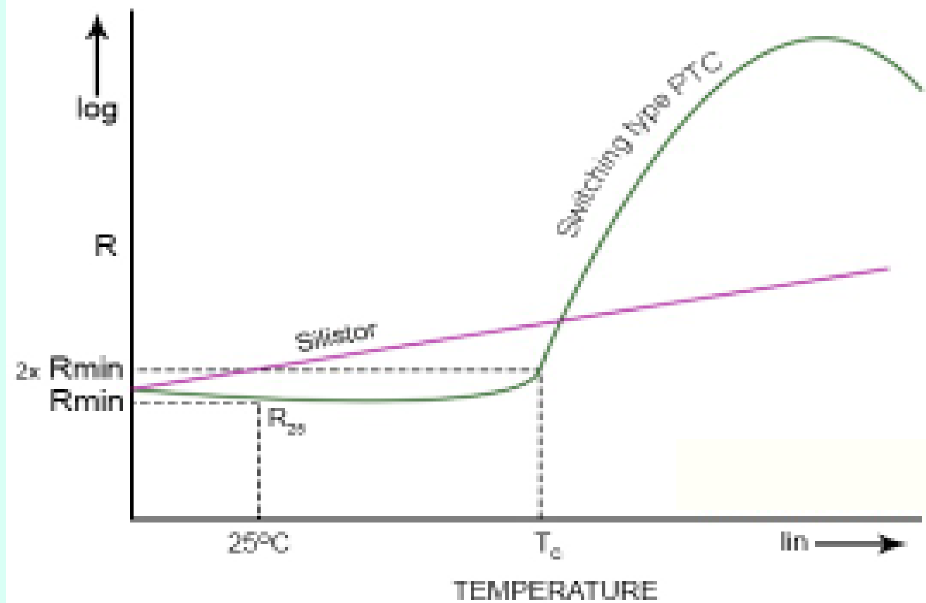
❖ Positive temperature coefficient (PTC) Thermistor

Positive temperature coefficient (PTC) Thermistors are those resistors whose resistance increases with increase in ambient temperature. Silistors are PTC Thermistors that belong to the first group (according to material used and structure). They use silicon as the semiconductor and have linear characteristic. Switching type PTC Thermistors belong to the second category (according to the manufacturing process). This Thermistor has a non linear characteristic curve. As the switching type PTC Thermistor gets heated, initially the resistance starts to decrease, up to a certain critical temperature, after which as the heat is increased, the resistance increases dramatically. The following figure shows the symbol used for PTC Thermi



PTC Thermistor Symbol - IEC Standard

The following figure shows the characteristic curve of a Silistor and a switching type PTC Thermistor



Silistor V/S PTC Thermistor - Characteristic Curve

A silistor PTC has a linear characteristic. This means that this PTC Thermistor is quite sensitive to the change in temperature. Its resistance increases linearly with increase in temperature. The switching type PTC however, is different. It has a nonlinear characteristic curve. We see from the figure that upto a certain temperature, the resistance decreases with increase in temperature much like a NTC Thermistor. As the temperature increases beyond the threshold temperature, the resistance starts to increase dramatically with increase in temperature.

The Resistance and Temperature Relationship in NTC Thermistors

NTC thermistors are characterized by a b parameter equation, which is essentially the Steinhart-Hart equation, a third order resistance-temperature transfer function.

The b-parameter equation is:

$$R_T = R_0 \, exp\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$$

R_T = Resistance at absolute temperature T (K)

R_0 = Resistance at absolute temperature T0(K)

β = Constant depending upon material of the Thermistor

Rearranging the equation we have:

$$\frac{R_T}{R_0} = exp\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$$

Taking natural log on both sides of the equation we get:

$$ln\left(\frac{R_T}{R_0}\right) = \beta\left(\frac{1}{T} - \frac{1}{T_0}\right) \quad Or, \quad \frac{1}{T} = \frac{\beta + T_0 ln\left(\frac{R_T}{R_0}\right)}{\beta T_0} \quad it\ implies\ that \quad T = \frac{\beta T_0}{\beta + T_0 ln\left(\frac{R_T}{R_0}\right)}$$

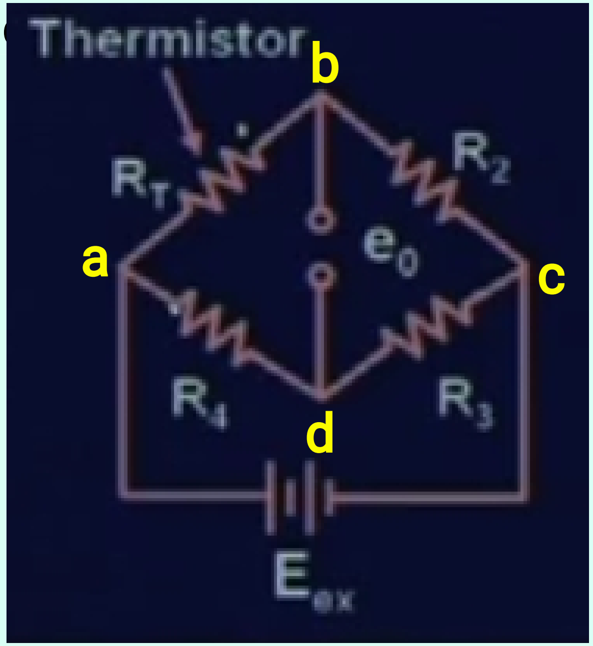
Thus, calculating the value of R_T from the given circuit to which the thermistor is connected the Value of Temperature can be calculated.

The simplest circuits in which NTC thermistors can be used to calculate the temperature of a given body includes:

- Wheatstone bridge
- Potentiostat

❖NTC Thermistor as the active element in a Wheatstone Bridge

Consider the circuit shown in the figure on the extreme right the page



Suppose the circuit is balanced, therefore

$$\frac{R_T}{R_2} = \frac{R_4}{R_3}$$

$$or, \qquad R_T R_3 = R_2 R_4$$

If R_2, R_3 and R_4 are fixed value resistors, then the output voltage (e_o) due to change in resistance (ΔR_T) for change in temperature can be derived as follows:

From the given circuit

$$e_{ab} = \left(\frac{R_T}{R_T + R_2}\right) E_{ex} \quad \text{———} \quad (1)$$

And,

$$e_{ad} = \left[\frac{R_4}{(R_3 + R_4)}\right] E_{ex} \quad \text{———} \quad (2)$$

Continue.........

Now,

$$e_o = e_{bd} = e_{ab} - e_{ad}$$

$\therefore$ Subtracting (2) from (1) we have

$$e_{ab} - e_{ad} = e_o = \left(\frac{R_T}{R_T + R_2} - \frac{R_4}{R_3 + R_4} \right) E_{ex} \quad \text{--- (3)}$$

Now, due to change in temperature (because of attached body whose temperature is to be determined) the resistance

$$R_T \longrightarrow R_T + \Delta R_T = R'_T$$

Continue.........

Substituting $R_T = R_T + \Delta R_T$ in equation (3) we have:

$$e_o = \left[\frac{R_T + \Delta R_T}{R_T + \Delta R_T + R_2} - \frac{R_4}{R_3 + R_4}\right] E_{ex}$$

$$\Rightarrow \frac{e_o}{E_{ex}} = \frac{R_T R_3 + R_T R_4 + \Delta R_T R_3 + \Delta R_T R_4 - R_4 R_T - R_4 \Delta R_T -}{(R_T + \Delta R_T + R_2)(R_3 + R_4)}$$

$$\Rightarrow \frac{e_o}{E_{ex}} = \frac{R_T R_3 + \Delta R_T R_3 - R_2 R_4}{(R_T + \Delta R_T + R_2)(R_3 + R_4)} \quad \text{—— (4)}$$

From the given balanced condition we have

$$R_T R_3 = R_2 R_4$$

Continue.........

From the given balanced condition we have

$$R_T R_3 = R_2 R_4$$

Therefore,

$$\frac{e_0}{E_{ex}} = \frac{\Delta R_T R_3}{(R_T + \Delta R_T + R_2)(R_3 + R_4)}$$

$$\Rightarrow \frac{e_0}{E_{ex}} = \frac{\Delta R_T \not{R_3}}{(R_T + \Delta R_T + R_2)\not{R_3}(1 + R_4/R_3)}$$

$$\Rightarrow \frac{e_0}{E_{ex}} = \frac{\Delta R_T}{(R_T + \Delta R_T + R_2)(1 + R_4/R_3)} \quad \text{— (5)}$$

Continue.........

Rationalising equation ⑤ by R_T we have

$$\frac{e_o}{E_{ex}} = \frac{\Delta R_T / R_T}{\frac{(R_T + \Delta R_T + R_2)}{R_T}\left(1 + R_4/R_3\right)}$$

$$\Rightarrow \frac{e_o}{E_{ex}} = \frac{\Delta R_T / R_T}{\left(1 + \frac{\Delta R_T}{R_T} + \frac{R_2}{R_T}\right)\left(1 + \frac{R_4}{R_3}\right)}$$

If $R_2 = R_3$ and $R_T = R_4$, then

$$\frac{e_o}{E_{ex}} = \frac{\Delta R_T / R_T}{\left(1 + \frac{\Delta R_T}{R_T} + \frac{R_2}{R_T}\right)\left(1 + R_T/R_2\right)}$$

or, $$\frac{e_o}{E_{ex}} = \frac{\Delta R_T / R_T}{\left(1 + \frac{R_T}{R_2} + \frac{\Delta R_T}{R_T} + \frac{\Delta R_T}{R_2} + \frac{R_2}{R_T} + 1\right)}$$

$$\Rightarrow \frac{e_o}{E_{ex}} = \frac{\Delta R_T / R_T}{\left(2 + \frac{R_T}{R_2} + \frac{R_2}{R_T} + \frac{\Delta R_T}{R_T} + \frac{\Delta R_T}{R_2}\right)} \quad \text{—⑥}$$

Continue.........

For thermisters, the terms $\frac{\Delta R_T}{R_T}$ and $\frac{\Delta R_T}{R_2}$ in the denominator are not small with respect to the other terms, therefore cannot be neglected to simplify the solution of the equation for $\Delta R_T / R_T$.

For special case of an equal bridge.

$$R_T = R_2 = R_3 = R_4$$

$\therefore$ Rearranging equation (6) we have

$$\frac{e_0}{E_{ex}} = \frac{\Delta R_T / R_T}{\left(2 + \frac{R_T}{R_2} + \frac{R_2}{R_T} + \frac{\Delta R_T}{R_T} + \frac{\Delta R_T}{R_2}\right)}$$

$$= \frac{\Delta R_T / R_T}{\left(2 + \frac{R_T}{R_T} + \frac{R_2}{R_2} + 2\frac{\Delta R_T}{R_T}\right)}$$

$$\Rightarrow \frac{e_0}{E_{ex}} = \frac{\Delta R_T / R_T}{\left(4 + 2\frac{\Delta R_T}{R_T}\right)} \quad \text{--- (7)}$$

Continue.........

Simplifying equation (7)

$$\frac{4e_0}{E_{ex}} + \frac{2\Delta R_T}{R_T} \times \frac{e_0}{E_{ex}} = \Delta R_T / R_T$$

$$\Rightarrow \frac{\Delta R_T}{R_T} \left(1 - 2\frac{e_0}{E_{ex}}\right) = 4\frac{e_0}{E_{ex}}$$

or, $$\frac{\Delta R_T}{R_T} = \frac{4e_0/E_{ex}}{(1-2e_0/E_{ex})} \quad \text{— (8)}$$

Now $$R'_T = R_T + \Delta R_T$$

$$\Rightarrow R'_T = R_T\left(1 + \frac{\Delta R_T}{R_T}\right) \quad \text{— (9)}$$

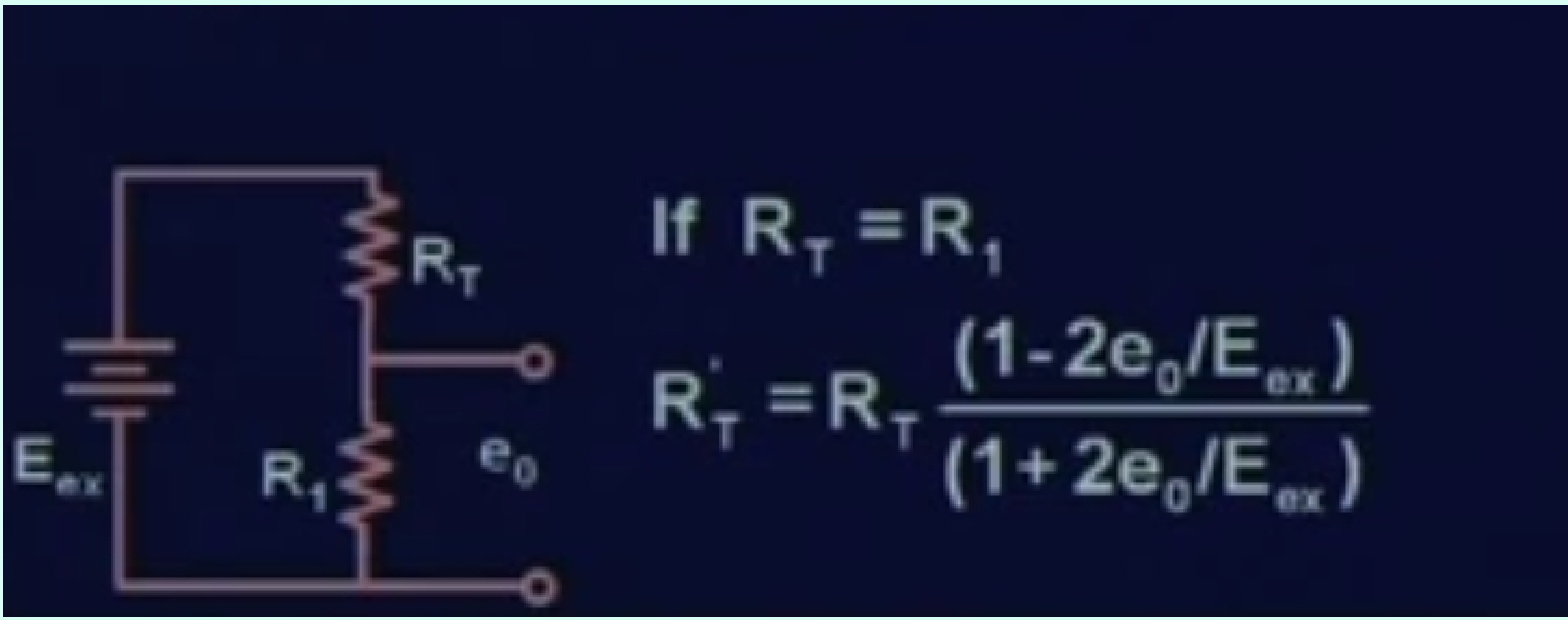
From equations (8) and (9) we get

$$R'_T = R_T\left(\frac{1+2e_0/E_{ex}}{1-2e_0/E_{ex}}\right) \quad \text{— (10)}$$

From equation (10) increase in resistance (R'_T) is calculated ~~as a~~ and is then converted to the temperature using the ~~relation~~ β-parameter equation.

❖NTC Thermistor as the active element in a Potentiometer circuit

- The Thermistor can also be used in the potentiometer circuit as follows:



Thermistors

Advantages

1)Small size and low cost.
2) Fast temperature response.
3) High sensitivity.
4) Suitable for precise temperature measurement and control.
5) Need simple electric circuitry.
6) No need reference junction.

Disadvantages

1)Response is non linear.
2) Not suitable for measurement of high temperature.
3) Required external power source and bridge circuit.
4) Temperature span is limited.

Applications

- ***Applications for negative temperature coefficient thermistors:*** They are used as resistance thermometers in very low-temperature measurements.
- These thermistors are also commonly used in modern digital thermostats.
- NTC thermistors are also used to monitor the temperature of battery packs while charging. As modern batteries such as Li-ion batteries are very sensitive to overcharging, the temperature provides a very good indication of the charging state, and when to terminate the charge cycle.

PTC thermistors can be used as current limiting devices in electronic circuits, where they can be used as an alternative to a fuse.

Another thermistor application is as temperature compensation devices

Thank You