Ministry Of Higher Education and Scientific Research

Salahaddin University - Erbil

College of Engineering

Aviation Engineering Department

Measurements and Instrumentation

Spring semester

Second year

Lecture: 2

Temperature Measurements

Lecturer:

Dr. Salar Saber Kartas

salar.sherwani@su.edu.krd

salar.saber@mail.ru

Erbil 2023

2. Temperature Measurements

2.1. Introduction

We are probably well aware that temperature measurement is very important in all spheres of life. In engineering applications, it is particularly important in process industries, where it is the most commonly measured process variable. It is therefore appropriate for us to devote this first chapter on measurement of individual physical variables to the subject of temperature measurement.

This is a root cause of the fundamental difficulties that exist in establishing an absolute standard for temperature in the form of a relationship between it and other measurable quantities for which a primary standard unit exists. In the absence of such a relationship, it is necessary to establish fixed, reproducible reference points for temperature in the form of freezing and triple points of substances where the transition among solid, liquid, and gaseous states is sharply defined. The International Practical Temperature Scale (IPTS)* uses this philosophy and defines a number of fixed points for reference temperatures. five examples are:

- the triple point of equilibrium hydrogen -259.34°C
- the boiling point of oxygen -182.962°C
- the boiling point of water 100.0°C
- the freezing point of zinc 419.58°C
- the freezing point of silver 961.93°C

2.2.Temperature Scales

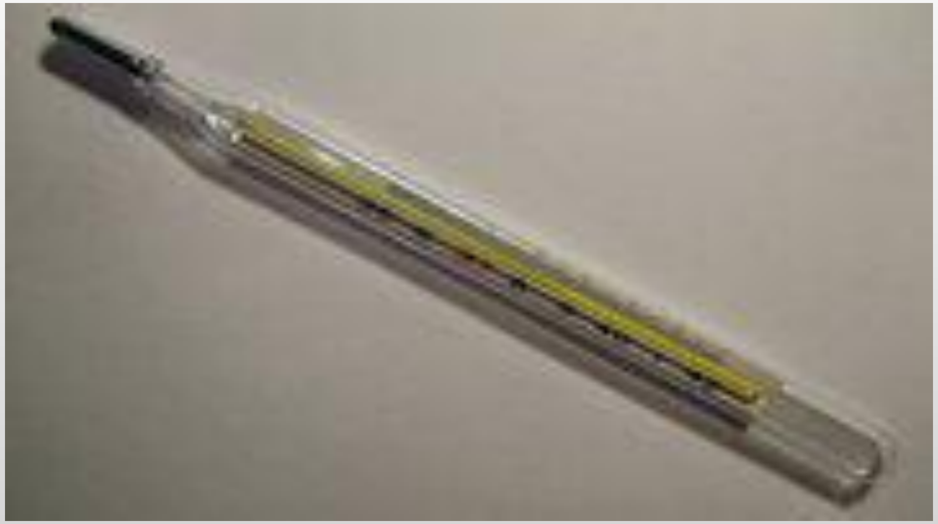
- The hotness or coldness of any material depends upon the molecular activity of the material.
- Kinetic energy is a measure of the activity of the atoms which make up the molecules of any material.
- As Kinetic energy of the material increases, the Temperature of the material increases.
- Therefore, temperature is a measure of the kinetic energy of the material. It has been experimentally determined that the lowest possible temperature is -273.15°C.
- Thermodynamic temperature is indicated by the symbol T and has the unit known as the Kelvin, symbol K.
- The Kelvin temperature scale was chosen so that its zero is at -273.15°C Relation between °C, °F, K:

$$\mathbf{T = T(°C) + 273.15}$$

$$\mathbf{T(°F) = (9/5)\ T(°C) + 32°}$$

2.3.Thermometer

- One of the old-age thermometer is the mercury-in-glass thermometer.
- Its operation was based on the temperature expansion of fluids.
- A glass bulb filled with mercury is connected to a narrow evacuated glass capillary tube.
- As the mercury is warmed, it expands and rises up the capillary tube into a vacuum.
- A mercury-in-glass thermometer is effective in the range -39°C to ~250°C.
- If a thermometer is required for lower temperatures, the alcohol-in-glass thermometer can utilize the same principle in the range -117°C to 78°C.



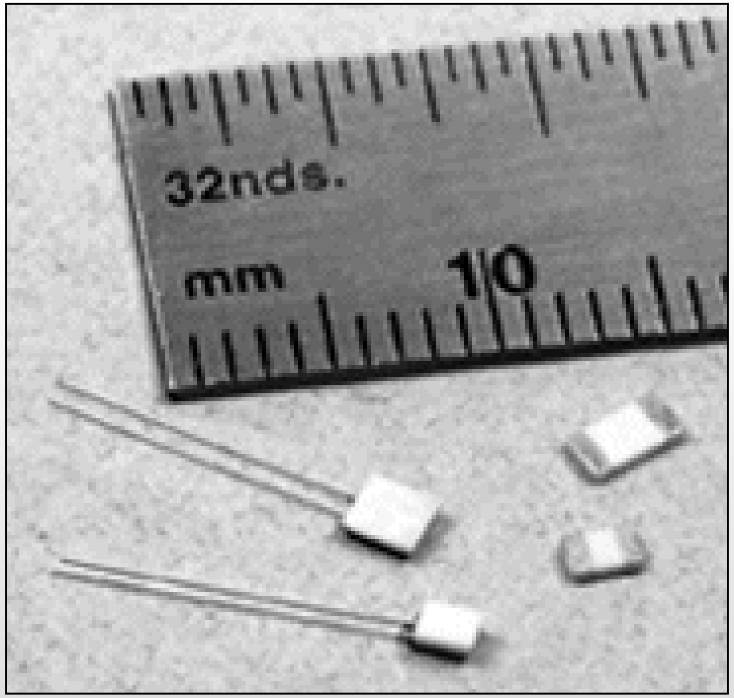
Thermometer

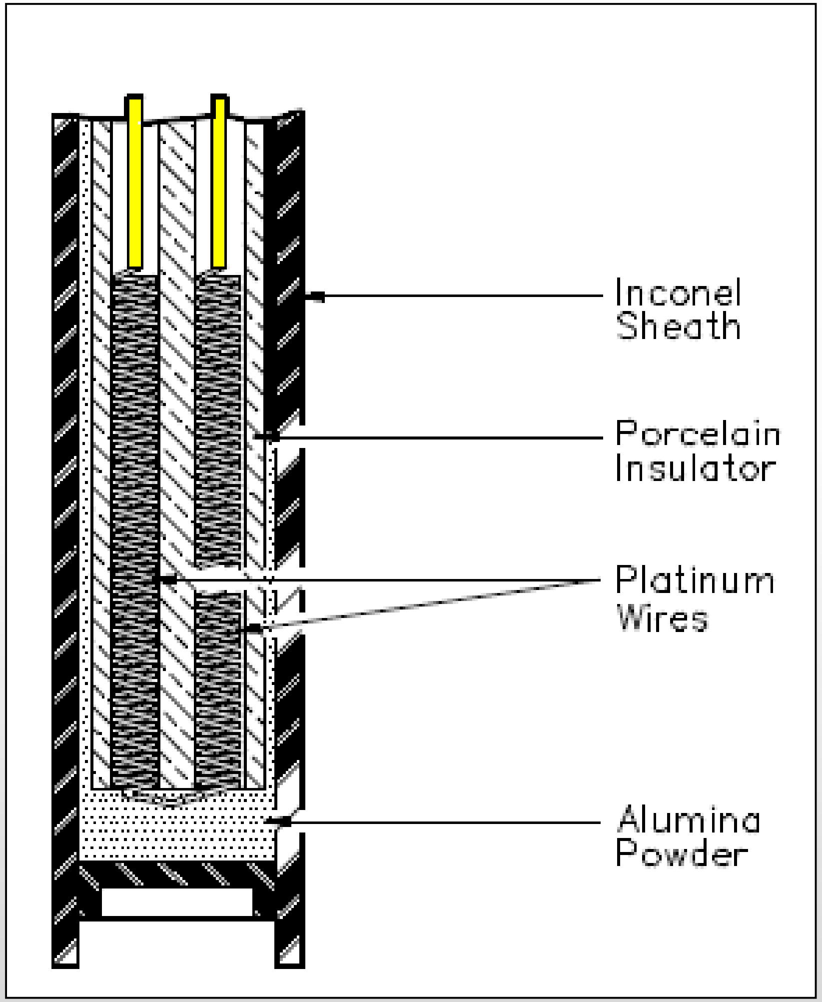
- The thermometers include:
  1) Filled-System Thermometers.
  2) Bimetallic Thermometers.
  3) Thermocouples.
  4) Resistance Temperature Detectors.
  5) Thermistors.
  6) Integrated-Circuit Temperature Sensors.
  7) Radiation Pyrometers.

Resistance Temperature Detector (RTD)

❖ A resistance temperature detector (RTD) is a passive device which measures the change in the electrical resistance of a metal as a function of the temperature.

Resistance Temperature Detector (RTD)





Resistance Temperature Detector (RTD)

- Every type of metal has a different resistance to the flow of electrical current.
- For most metals the change in electrical resistance is directly proportional to its change in temperature and is linear over a range of temperatures, this constant factor called the temperature coefficient of electrical resistance is the basis of resistance temperature detectors.
- The RTD can actually be regarded as a high precision wire wound resistor whose resistance varies with temperature.
- By measuring the resistance of the metal, its temperature can be determined from tables.
- A typical RTD probe contains a coil of very fine metal wire, allowing for a large resistance change without a great space requirement. Usually, platinum RTDs are used as process temperature monitors because of their accuracy and linearity.

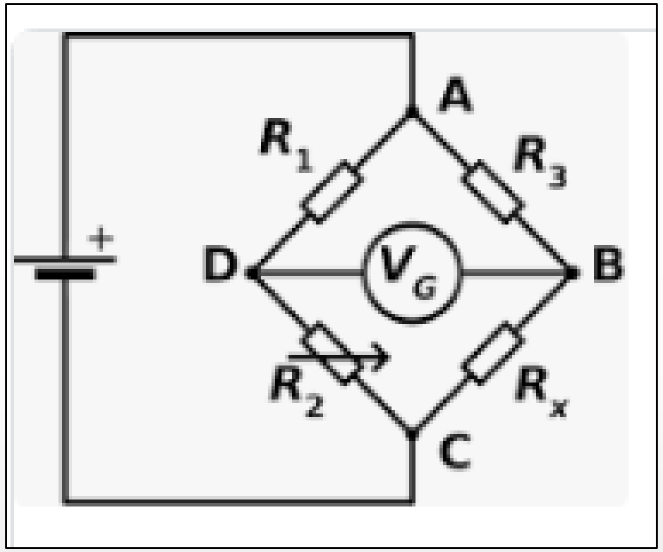
Resistance Temperature Detectors (RTDs)

- Resistance thermometers consist of a sensor element that exhibits a change in resistance with any change in temperature, a signal conditioning circuit that converts the resistance change to an output voltage, and appropriate instrumentation to record and display the output voltage.

- Resistance temperature detectors are simple resistive elements formed of such materials as platinum, nickel, or a nickel-copper alloy.

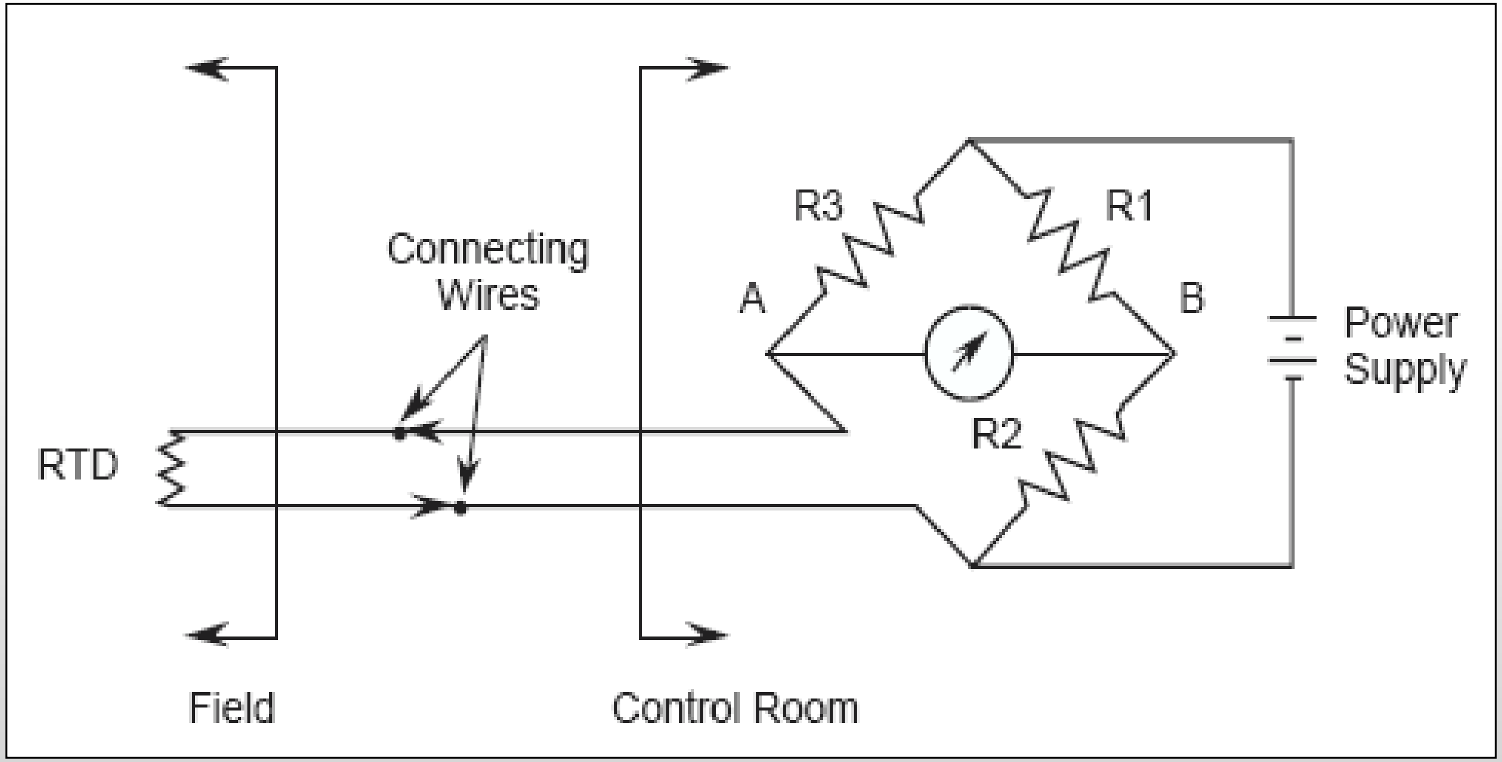
Wheatstone bridge

A Wheatstone bridge is an electrical circuit used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component. The primary benefit of the circuit is its ability to provide extremely accurate measurements.



2-Wire RTD

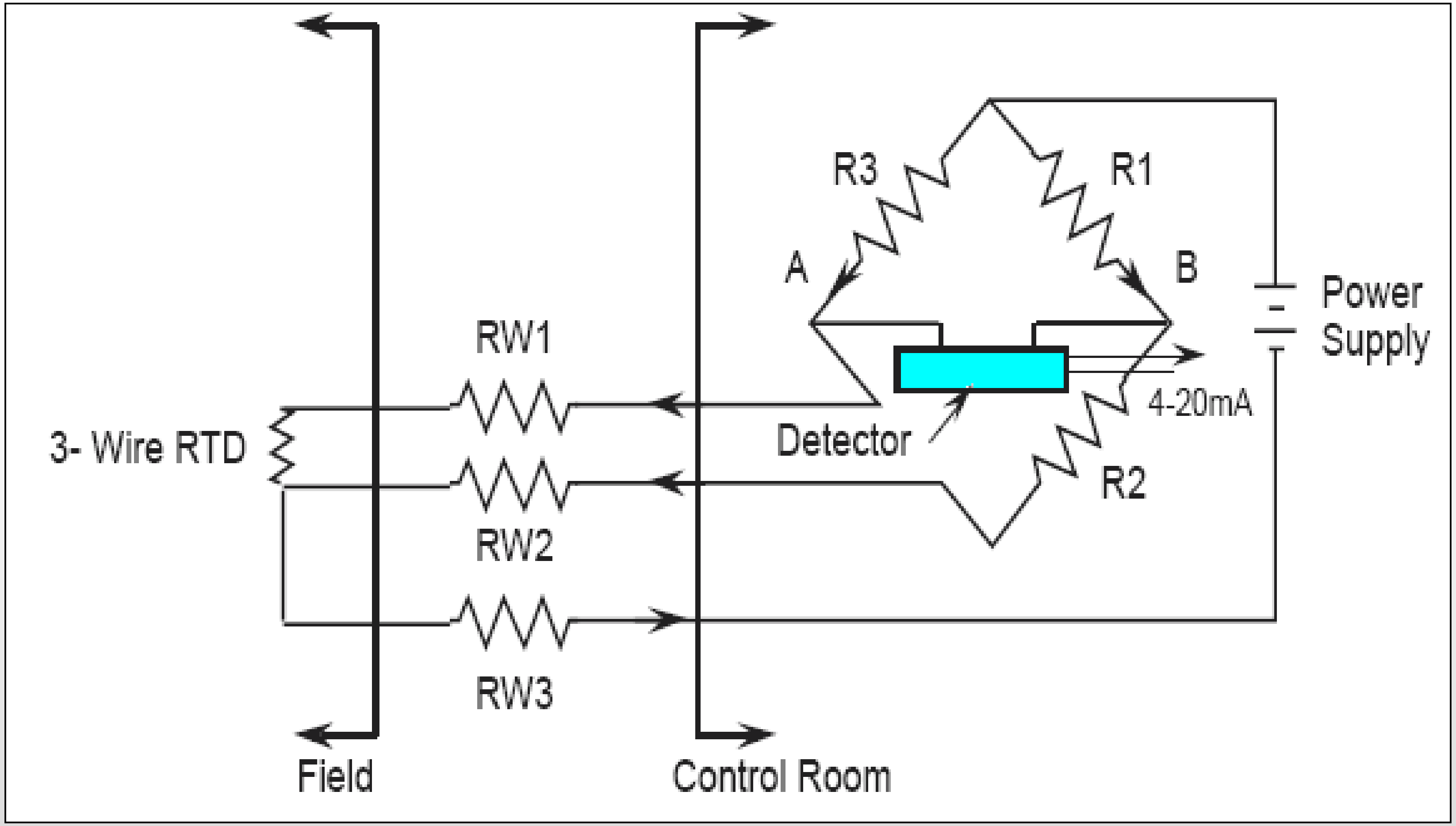
- A temperature transmitter in the form of a Wheatstone bridge is generally used to detect the small variations of resistance of the RTD.



3-Wire RTD

- Since the connecting wires are long, resistance of the wires changes as ambient temperature fluctuates.
- The variations in wire resistance would introduce an error in the transmitter.
- To eliminate this problem, a three-wire RTD is used.
- The connecting wires (w1, w2, w3) are made the same length and therefore the same resistance (Rw1, Rw2, Rw3).
- Since Rw1 = Rw2 = Rw3, the result is that the resistances of the wires cancel and therefore the effect of the connecting wires is eliminated.

3-Wire RTD



R3
R1
A
B
Power
Supply
RW1
4-20mA
3- Wire RTD
Detector
R2
RW2
RW3
Field
Control Room

RTD

- **Advantages:**
  - The response time compared to thermocouples is very fast.
  - Within its range it is more accurate and has higher sensitivity than a thermocouple.
  - In an installation where long leads are required, the RTD does not require special extension cable.
  - Sensors are interchangeable and do not require individual calibration.
- **Disadvantages:**
  - More expensive than thermocouples
  - RTD is not capable of measuring as wide a temperature range as a thermocouple.
  - A power supply failure can cause erroneous readings.
  - All connections must be tight and free of corrosion, which will create errors.

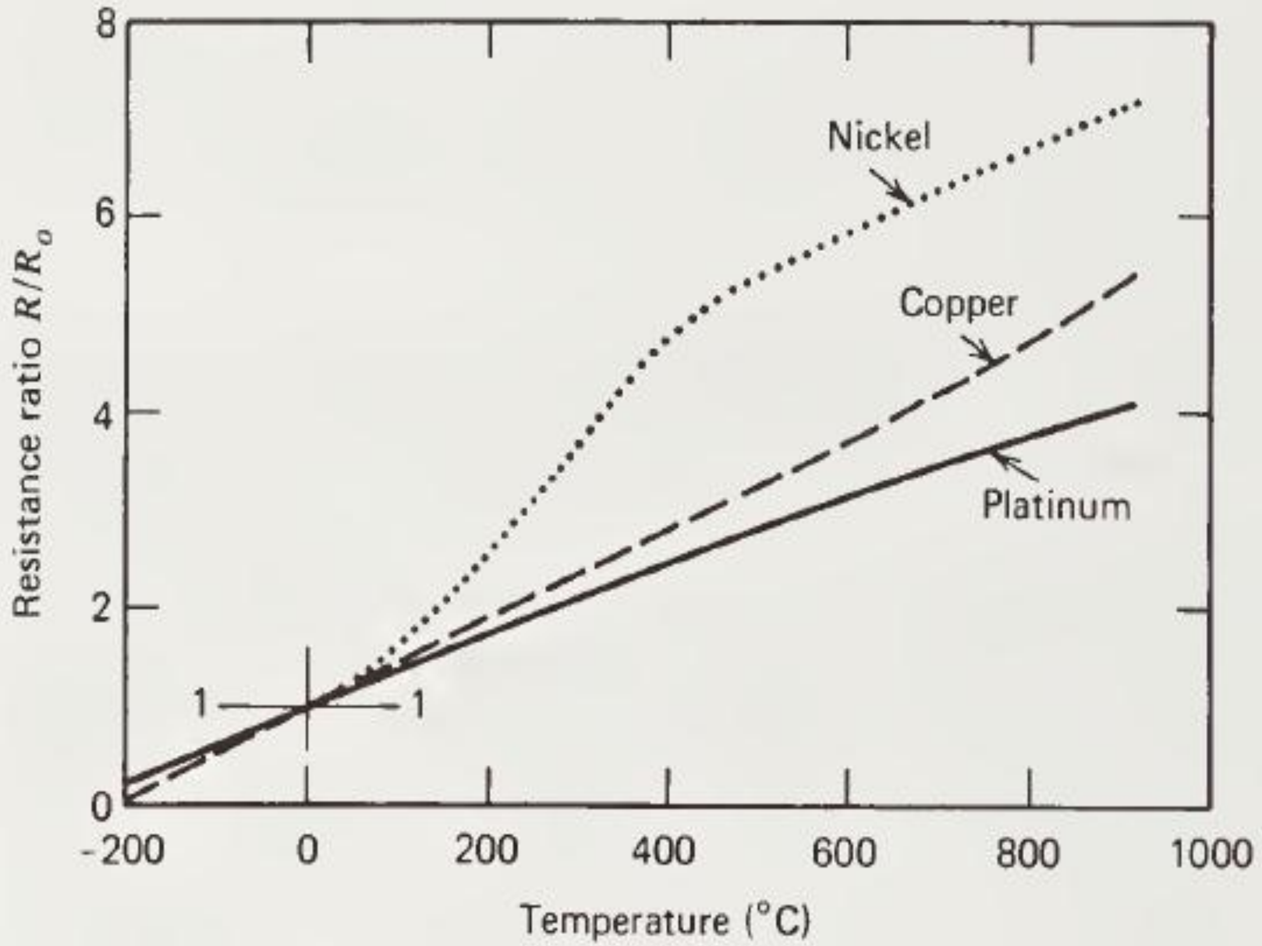


Figure 8.1 Resistance–temperature curves for nickel, copper, and platinum.

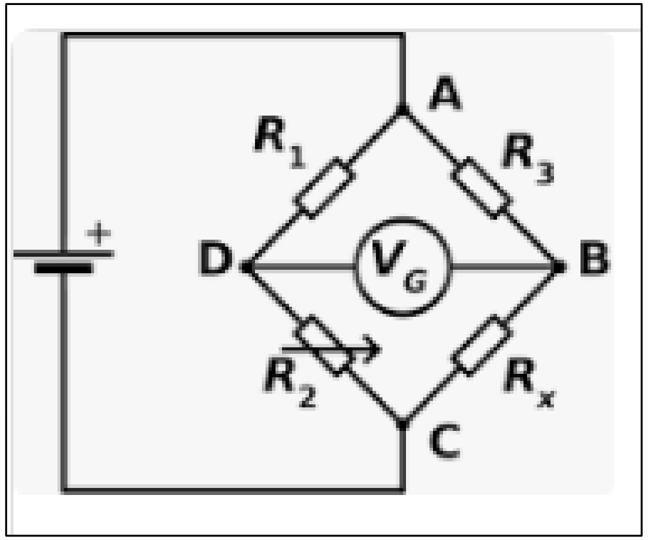
❖ The equations governing the response of RTDs and thermistors to a temperature change yields the second-order relationship:

$$R = R_o(1 + \gamma_1 T + \gamma_2 T^2 + \cdots + \gamma_n T^n)$$

❖ $y_1, y_2, \ldots \ldots . y_n$- are temperature coefficients of resistivity.
❖ R_0- is the resistance of the sensor at a reference temperature
❖ To The reference temperature is usually specified as To= 0 °C

$$\frac{\Delta R}{R_o} = \gamma_1(T - T_o) + \gamma_2(T - T_o)^2$$

❖ The output from a resistance temperature detector (RTD) is a resistance change ΔR/R that can be conveniently monitored with a Wheatstone bridge, as illustrated schematically in Fig. 8.5. The RTD is installed in one arm of the bridge, a decade resistance box is placed in an adjacent arm, and a matched pair of precision resistors are inserted in the remaining arms to complete the bridge.



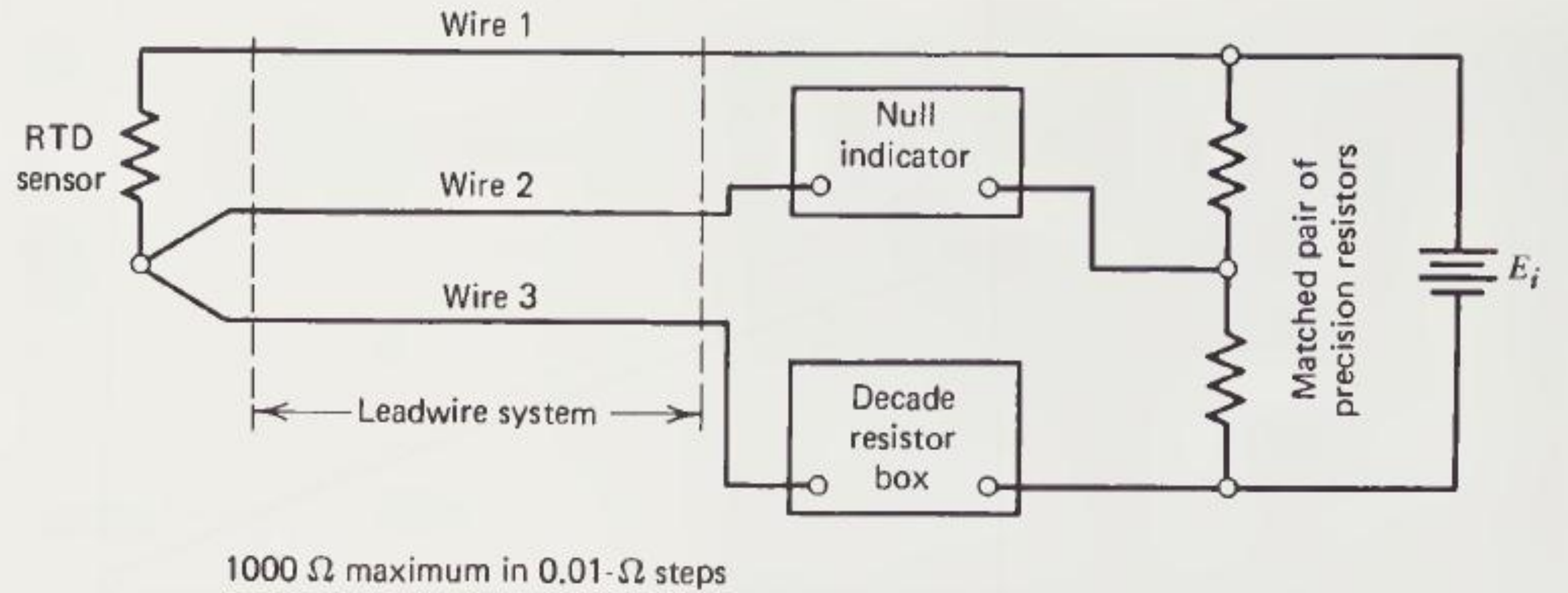
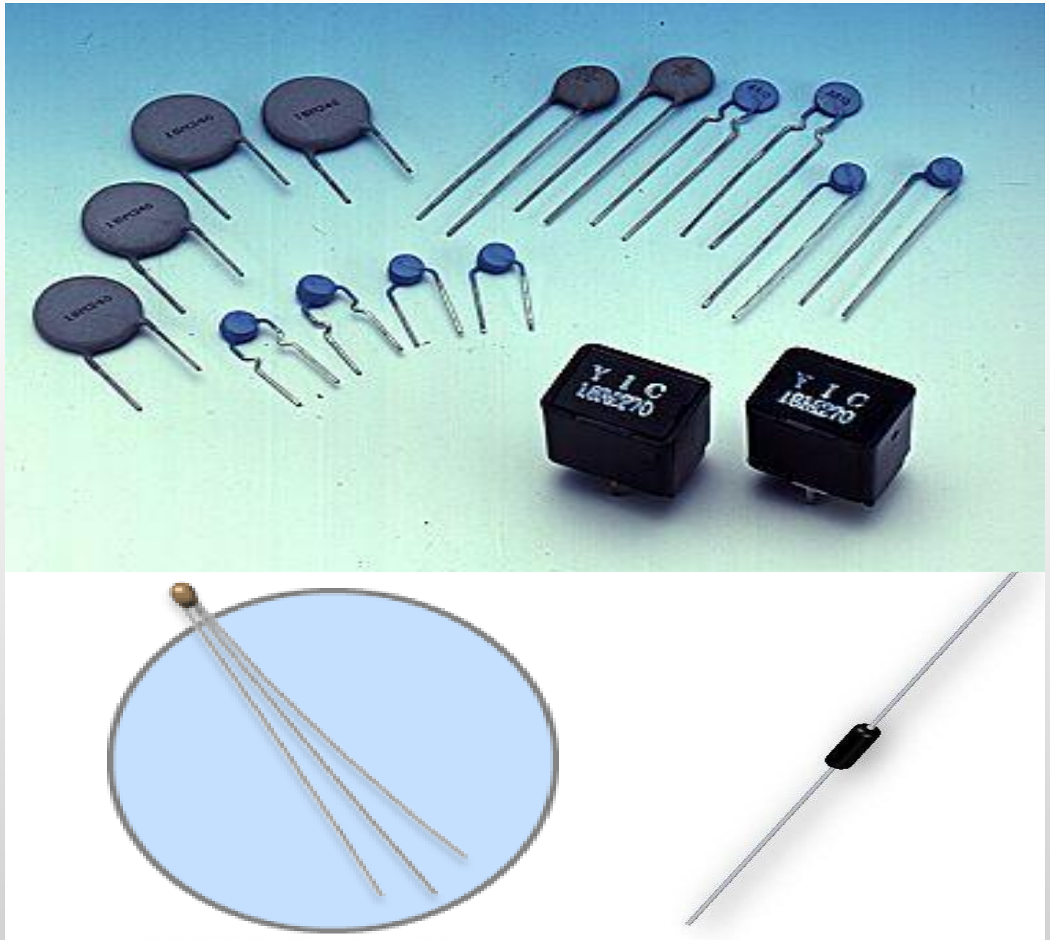
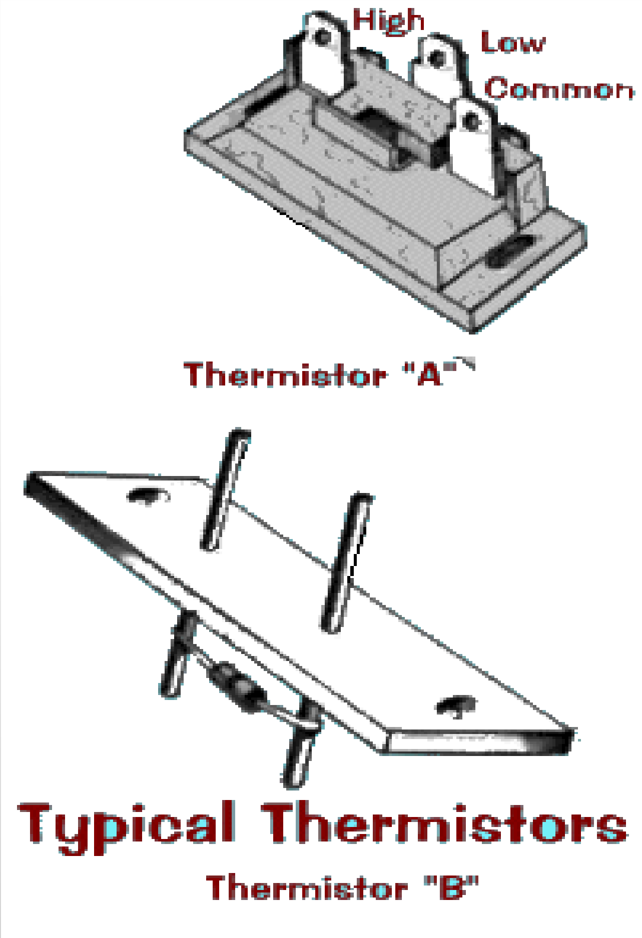


Figure 8.5 Wheatstone-bridge circuit with lead-wire compensation and manual reading of the output from a resistance temperature detector.

2.4.Thermistor

❖ A thermistor is a device designed to measure temperature, and consists of a semiconductor material that, with a small change in temperature, greatly changes its resistance. Typically, thermistors have negative temperature coefficients, meaning their resistance decreases as temperature increases.





Thermistor

- Thermistors are manufactured from beads of semiconductor material.
- Like the RTD, the thermistor is also a temperature-sensitive resistor.
- The typical thermistor has a negative temperature coefficient, this means that with an increase in temperature, the resistance of the thermistor decreases.
- The per degree resistance change in a thermistor is much greater than with an RTD.
- It is also very non-linear and usually used over a very small temperature span.
- They are quite susceptible to permanent decalibration when exposed to high temperatures.

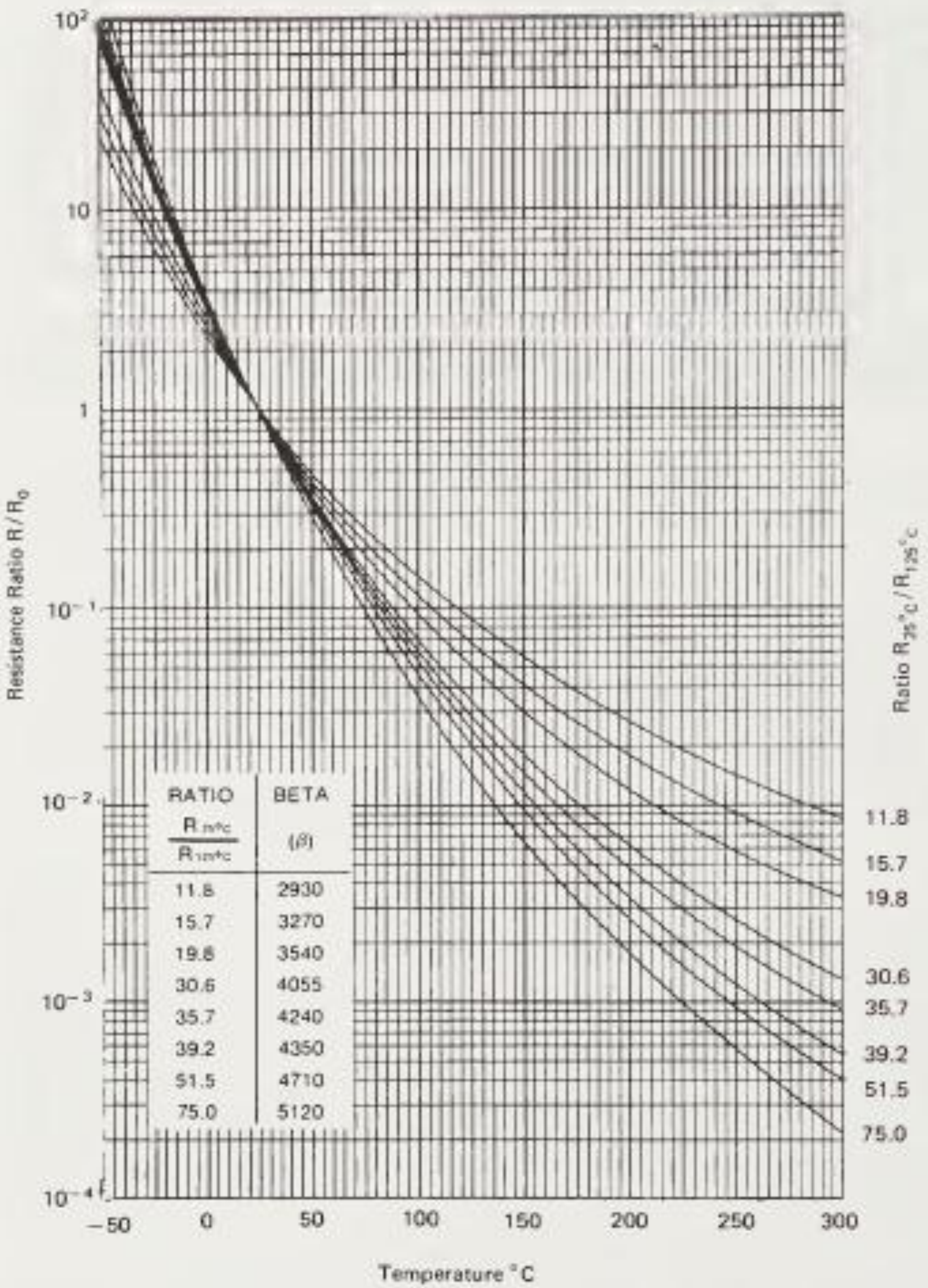
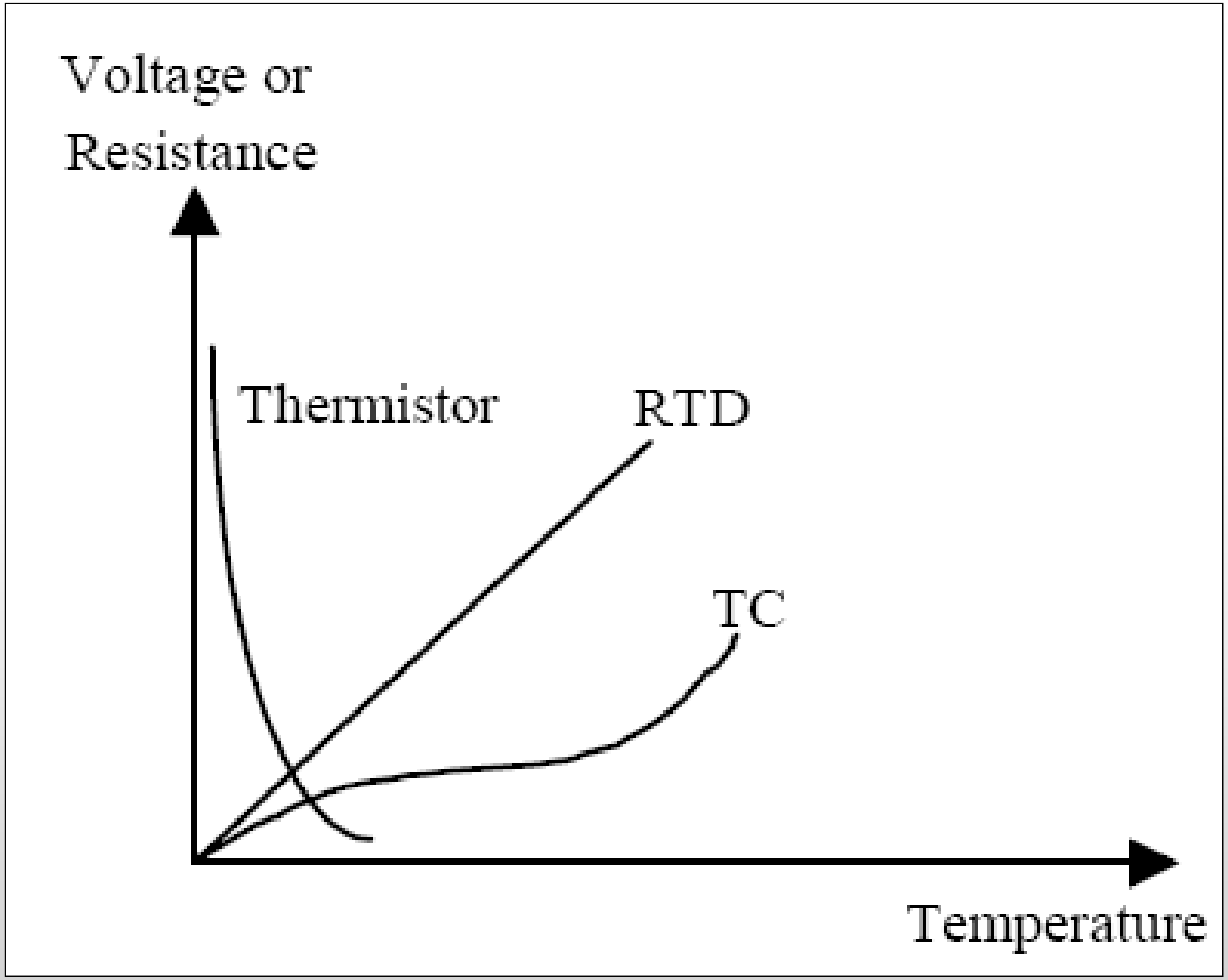


Figure 8.10 Resistance as a function of temperature for different thermistors ($T_0 = 25°C$). (Courtesy of Thermometrics, Inc.)

Thermistor

- **Advantages:**
  - Have high sensitivity.
  - No moving parts.
  - Long service life.
  - Lightweight, compact.
- **Disadvantages:**
  - Very non-linear.
  - Not interchangeable I.e. each sensor needs to be calibrated individually.
  - Quite fragile.

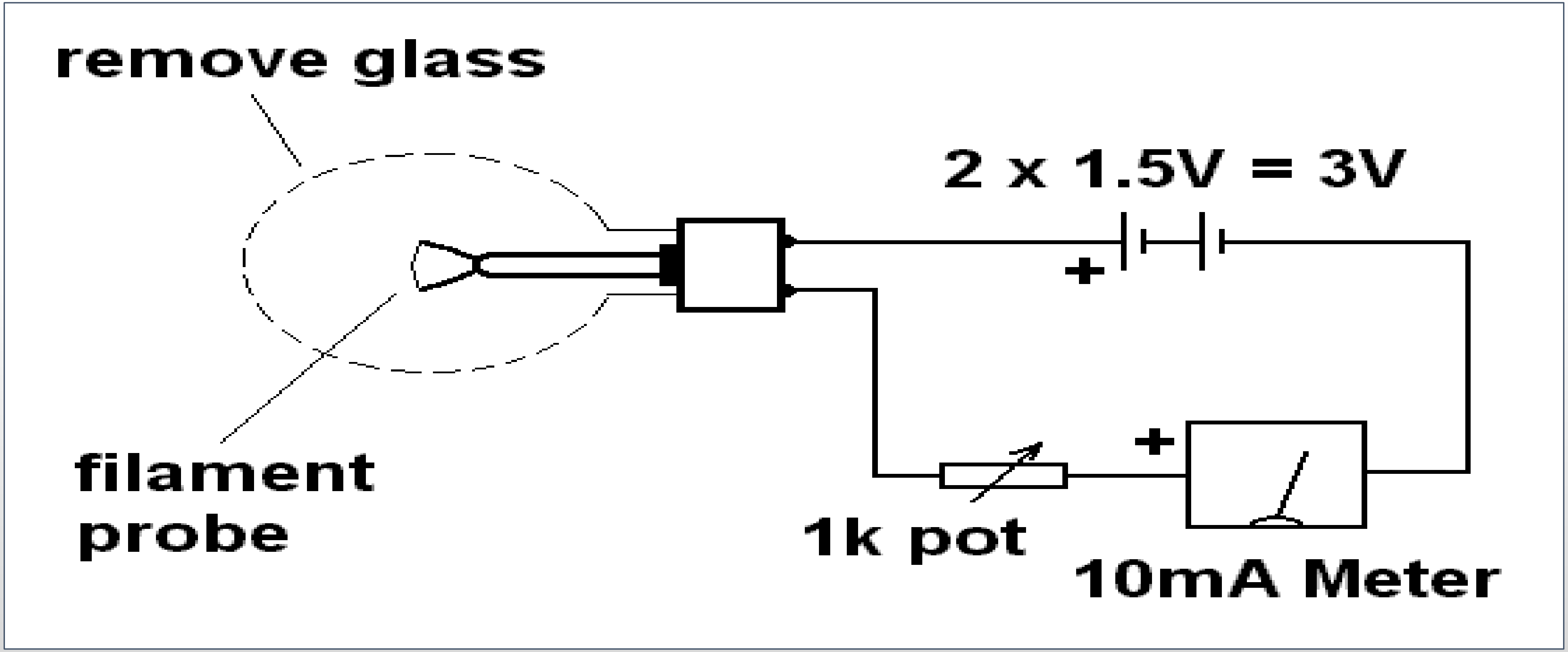
Comparison of T/C, RTD, and Thermistor



High Temperature Light Bulb Thermometer

- A standard household light bulb has a thin filament made of a high melting point metal (probably tungsten: melting point > 3000 ° C).
- When the 240V main electricity passes through the filament of the bulb it heats up and glows so brightly we use it as a lamp.
- The electrical resistance of the filament varies with temperature, in fact its resistance rises as the temperature rises.
- This fact alone makes the current tends to regulate itself when power is applied.

High Temperature Light Bulb Thermometer



❖ Thermistors are temperature-sensitive resistors fabricated from semiconducting materials, such as oxides of nickel, cobalt, or manganese and sulfides of iron, aluminum, or copper. Semiconducting materials, unlike metals, exhibit a decrease in resistance with an increase in temperature. The resistance-temperature relationship for a thermistor can be expressed as.

$$\ln (R/R_o) = \beta(1/T - 1/T_o)$$

$$R = R_o e^{\beta(1/T - 1/T_o)}$$

❖ Where R is the resistance of the thermistor at temperature T. Ro is the resistance of the thermistor at reference temperature To. β is a material constant that ranges from 3000 K to 5000 K. T and To , are absolute temperatures, K.

The sensitivity S of a thermistor is obtained from Eq. (8.4) as

$$S = \frac{\Delta R/R}{\Delta T} = -\frac{\beta}{T^2}$$

Both Wheatstone bridge and potentiometer circuits can be used to determine the resistance changes in a thermistor resulting from a change in temperature.

Use of a thermistor as the active element in a Wheatstone bridge is shown schematically in Fig. 8.12a. If the Wheatstone bridge is initially balanced (RTR3 = R2R4) and if resistors R2, R3, and R4 are fixed-value precision resistors, then the output voltage Δ Eo produced by a temperature-induced change in resistance Δ RT in the thermistor is given by Eq. (8.6) as

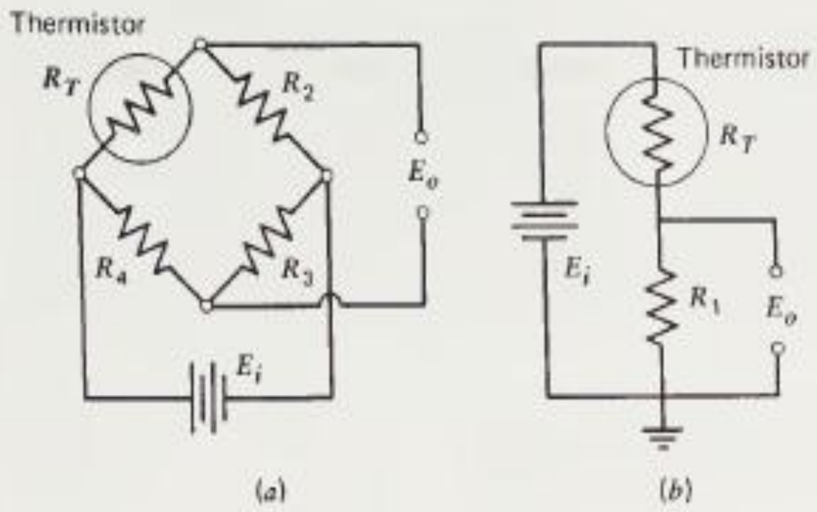


Figure 8.12 Constant-voltage Wheatstone bridge and potentiometer circuits used with thermistors. (*a*) Wheatstone-bridge circuit. (*b*) Potentiometer circuit.

$$\frac{\Delta E_o}{E_i} = \frac{\Delta R_T R_3}{(R_T + \Delta R_T + R_2)(R_3 + R_4)} \quad (8.6)$$

For the common case where R2 = R3. and RT = R4, Eq. (8.6) reduces to

$$\frac{\Delta E_o}{E_i} = \frac{\Delta R_T/R_T}{(1 + \Delta R_T/R_T + R_2/R_T)(1 + R_T/R_2)}$$

$$= \frac{\Delta R_T/R_T}{2 + R_T/R_2 + R_2/R_T + \Delta R_T/R_T + \Delta R_T/R_2} \quad (8.7)$$

For the special case of an equal-arm bridge (RT = R2 = R3 = R4), Eq. (8.7) reduces to a simpler form and the change in thermistor resistance can be expressed in terms of the bridge output voltage ΔE_o as

$$\frac{\Delta R_T}{R_T} = \frac{4\Delta E_o/E_i}{1 - 2\Delta E_o/E_i} \quad (8.8)$$

The thermistor resistance R_T^* at any temperature T is then given by the simple expression

$$R_T^* = R_T + \Delta R_T = R_T(1 + \Delta R_T/R_T) \qquad (8.9)$$

$$R_T^* = R_T \left(\frac{1 + 2\Delta E_o/E_i}{1 - 2\Delta E_o/E_i} \right) \qquad (8.10)$$

The value of obtained from Eq. (8.10) is converted to temperature by using tables that list T as a function of for the specific thermistor being used. This procedure accounts for nonlinearities in both the bridge and the thermistor.

If the constant-voltage supply to the equal-arm Wheatstone bridge (R2, R3, and R4 are fixed-value resistors) is replaced with a constant-current supply, the output voltage ΔEo produced by a temperature-induced change in resistance ΔRT in the thermistor is given by Eq. (8.11) as.

$$\frac{\Delta E_o}{I} = \frac{R_T^2}{4R_T + \Delta R_T} \frac{\Delta R_T}{R_T} \qquad (8.11)$$

Also, since the voltage drop E_T across the thermistor equals IR_T, Eq. (8.11) can be expressed in terms of the voltage drop ET as.

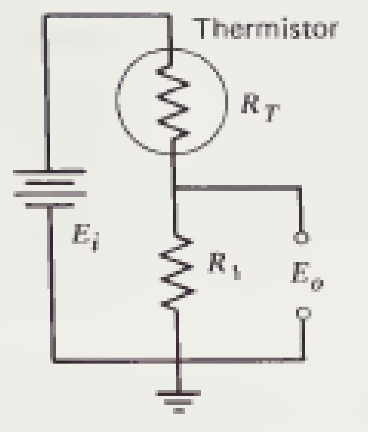
$$\frac{\Delta E_o}{E_T} = \frac{1}{4 + \Delta R_T/R_T} \frac{\Delta R_T}{R_T} \qquad (8.12)$$

$$\frac{\Delta R_T}{R_T} = \frac{4\Delta E_o/E_T}{1 - \Delta E_o/E_T} \qquad (8.13)$$

$$R_T^* = R_T \left(\frac{1 + 3\Delta E_o/E_T}{1 - \Delta E_o/E_T} \right) \qquad (8.14)$$

Potentiometer circuits can also be employed to convert the resistance change ΔR_T of the thermistor to a voltage change ΔE_o. If the thermistor is placed in position R2 of the potentiometer circuit, as shown in Fig. 8.12b, Eq. (8.16) indicates that.

$$\frac{\Delta E_o}{E_i} = -\frac{\dfrac{r}{(1+r)^2}(\Delta R_T/R_T)}{1+\dfrac{r}{1+r}(\Delta R_T/R_T)} = -\frac{\dfrac{r}{1+r}(\Delta R_T/R_T)}{1+r(1+\Delta R_T/R_T)} \tag{8.15}$$



(b)

where $r = \text{RT}/R_1$. Equation (8.15) again shows the presence of nonlinear terms that may be significant. For the special case of $r = 1$, Eq. (8.15) reduces to:

$$\frac{\Delta R_T}{R_T} = -\frac{4\Delta E_o/E_i}{1 + 2\Delta E_o/E_i} \quad (8.16)$$

The resistance of the thermistor R_T^* is obtained by substituting Eq. (8.16) into Eq. (8.9). Thus:

$$R_T^* = R_T\left(\frac{1 - 2\Delta E_o/E_i}{1 + 2\Delta E_o/E_i}\right) \quad (8.17)$$

A simple circuit for determining thermistor resistance R_T^* is shown in Fig. 8.13. This circuit employs a constant-current power supply directly across the thermistor. Since the output voltage E_0 equals IR_T, the voltage change ts. $\Delta E_0 / E_0$ is given by the simple expression:

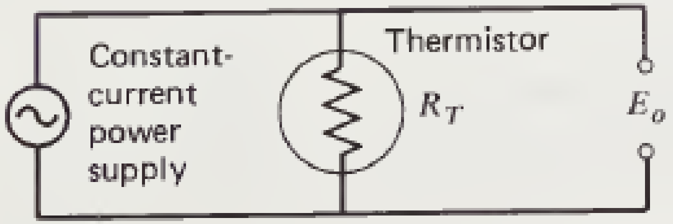


Figure 8.13 Constant-current potentiometer circuit used with thermistors.

$$\frac{\Delta E_o}{E_o} = \frac{\Delta R_T}{R_T} \qquad (8.18)$$

$$R_T^* = R_T(1 + \Delta E_o / E_o) \qquad (8.19)$$

TABLE A.1 Temperature–Resistance Data for a Thermistor

Temperature °C	Resistance	Temperature °C	Resistance	Temperature °C	Resistance
−80	2,210,400	−67	731,700	−54	268,560
−79	2,022,100	−66	675,060	−53	249,600
−78	1,851,100	−65	623,160	−52	232,110
−77	1,695,800	−64	575,610	−51	215,970
−76	1,554,500	−63	531,990	−50	201,030
−75	1,425,900	−62	491,970	−49	187,230
−74	1,308,900	−61	455,220	−48	174,450
−73	1,202,200	−60	421,470	−47	162,660
−72	1,105,000	−59	390,420	−46	151,710
−71	1,016,300	−58	361,890	−45	141,570
−70	935,250	−57	335,610	−44	132,180
−69	861,240	−56	311,400	−43	123,480
−68	793,590	−55	289,110	−42	115,410

TABLE A.1 *(Continued)*

Temperature °C	Resistance	Temperature °C	Resistance	Temperature °C	Resistance
−41	107,910	2	8,850.0	45	1,311.0
−40	100,950	3	8,415.0	46	1,260.0
−39	94,470	4	8,007.0	47	1,212.0
−38	88,440	5	7,617.0	48	1,167.0
−37	82,860	6	7,251.0	49	1,122.9
−36	77,640	7	6,903.0	50	1,080.9
−35	72,810	8	6,576.0	51	1,040.1
−34	68,280	9	6,264.0	52	1,002.0
−33	64,080	10	5,970.0	53	965.10
−32	60,150	11	5,691.0	54	929.70
−31	56,490	12	5,427.0	55	895.80
−30	53,100	13	5,175.0	56	863.40
−29	49,890	14	4,938.0	57	832.20
−28	46,920	15	4,713.0	58	802.50
−27	44,160	16	4,500.0	59	773.70
−26	41,550	17	4,296.0	60	746.40
−25	39,120	18	4,104.0	61	720.00
−24	36,840	19	3,921.0	62	694.80
−23	34,710	20	3,747.0	63	670.50
−22	32,730	21	3,582.0	64	647.10
−21	30,870	22	3,426.0	65	624.90
−20	29,121	23	3,276.0	66	603.30

−20	29,121	23	3,276.0	66	603.30
−19	27,483	24	3,135.0	67	582.60
−18	25,947	25	3,000.0	68	562.80
−17	24,507	26	2,871.9	69	543.90
−16	23,154	27	2,750.1	70	525.60
−15	21,885	28	2,633.1	71	507.90
−14	20,694	29	2,522.1	72	490.80
−13	19,572	30	2,417.1	73	474.60
−12	18,519	31	2,316.9	74	459.00
−11	17,529	32	2,220.9	75	443.70
−10	16,599	33	2,129.1	76	429.30
−9	15,720	34	2,042.1	77	415.20
−8	14,895	35	1,959.0	78	402.00
−7	14,118	36	1,880.1	79	389.10
−6	13,386	37	1,805.1	80	376.50
−5	12,699	38	1,733.1	81	364.50
−4	12,048	39	1,664.1	82	353.10
−3	11,433	40	1,598.1	83	342.00
−2	10,857	41	1,535.1	84	331.20
−1	10,311	42	1,475.1	85	321.00
0	9,795.0	43	1,418.1	86	310.80
1	9,309.0	44	1,362.9	87	301.20

TABLE A.1 *(Continued)*

Temperature °C	Resistance	Temperature °C	Resistance	Temperature °C	Resistance
88	292.11	109	157.50	130	90.279
89	283.20	110	153.09	131	88.041
90	274.59	111	149.01	132	85.869
91	266.31	112	144.90	133	83.751
92	258.30	113	141.00	134	81.609
93	250.59	114	137.19	135	79.710
94	243.09	115	133.50	136	77.790
95	236.01	116	129.99	137	75.900
96	228.99	117	126.51	138	74.079
97	222.30	118	123.21	139	72.309
98	215.79	119	120.00	140	70.581
99	209.61	120	116.79	141	68.910
100	203.49	121	113.79	142	67.290
101	197.70	122	110.91	143	65.700
102	192.09	123	108.00	144	64.170
103	186.60	124	105.18	145	62.661
104	181.29	125	102.51	146	61.209
105	176.19	126	99.930	147	59.799
106	171.30	127	97.410	148	58.431
107	166.50	128	94.950	149	57.099
108	161.91	129	92.580	150	55.791

Question first lecture

1. What is a Thermometer and how does it work?
2. The Thermommeter include?
3. Define Resistance Temperature Detector (RTD)?
4. What is Wheatstone bridge and drawing?
5. What are the difference between 2-Wire RTD and 3-Wire RTD?
6. What is advantage and disadvantage RTD?
7. Define Thermistor?
8. What is advantage and disadvantage Thermistor?