# Sensors and Instrumentation (EEL208)

by

**Dr. Saikat Sahoo**
**Department of Mechatronics**

**Indian Institute of Technology Bhilai**

# Fundamentals of thermal sensors



- ❑ Thermal equilibrium
- ❑ Disturbance in thermal equilibrium – energy exchange
- ❑ Conduction, convection and radiation
- ❑ Minimizing the error
- ❑ Equilibrium and predictive temperature measurement

# Fundamentals of thermal sensors

- Thermal capacity and resistance
- Resistance between the body and sensor ($R_1$) should be as small as possible
- Resistance between the sensor and the environment ($R_2$) should be as large as possible
- Making $R_1$ small
- Making $R_2$ large

# Fundamentals of thermal sensors



- Dynamic case
- Assumption1: R2 is very high (infinite)
- Assumption2: Object temperature does not change after sensor is attached
- Heat transfer

# Resistance temperature detector



- Most accurate temperature sensor
- Governing equation

$$R_t = R_0(1 + \alpha t)$$

- Material used: platinum ($\alpha = 3.94 \times 10^{-3} / \deg C$)
- Purity of platinum can be measure by, $\frac{R_{100}}{R_0} > 1.39$
- Non-linearity of platinum = 0.76% of the full-scale deflection

# Resistance temperature detector

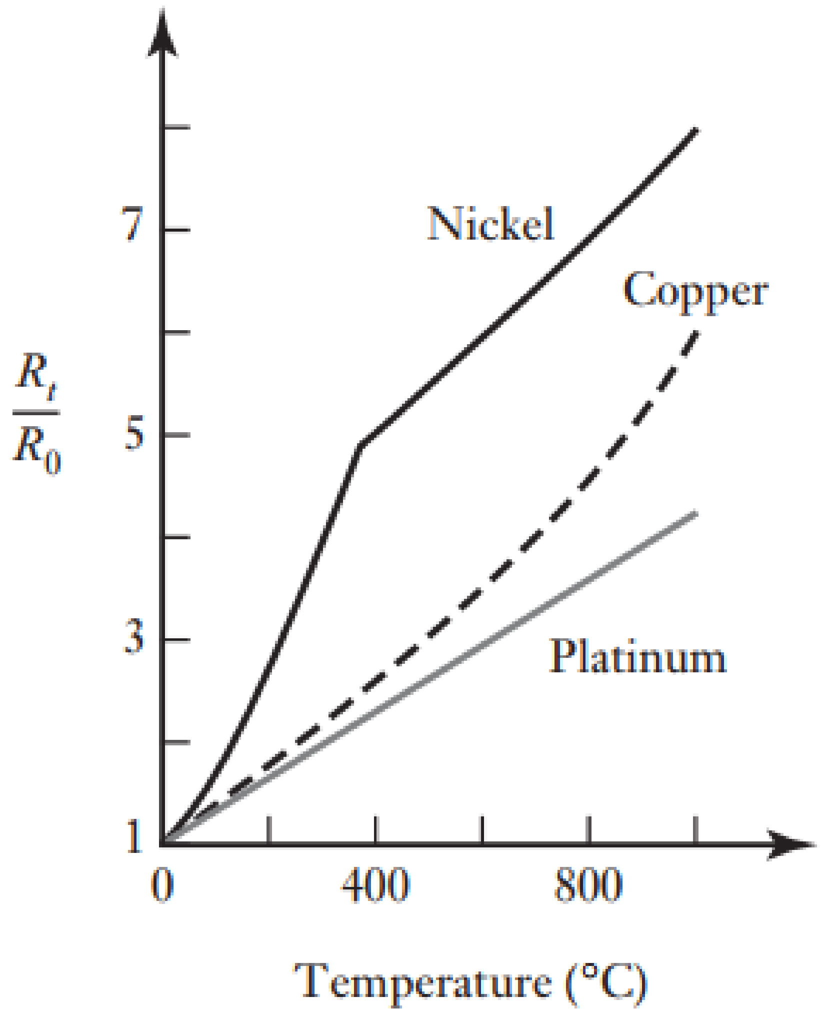


## *Types and range*

| RTD | Range | Remarks |
|---|---|---|
| Platinum | 100 to 650 deg C | Good linearity and chemical inertness |
| Nickel | -180 to 430 deg C | Susceptible to corrosion and oxidation |
| Copper | -200 to 260 deg C | |
| Tungsten | -270 to 1100 deg C | |

# Resistance temperature detector

***Temperature-resistance relationship***



# Resistance temperature detector

## *RTD circuits*

- ❑ Wheatstone bridge
- ❑ Adjustable resistance made of manganin (lowest temperature coefficient of resistance)
- ❑ Issues with simple Wheatstone bridge
  - ➢ Contact resistance
  - ➢ Long connecting wire
  - ➢ Self heating effect

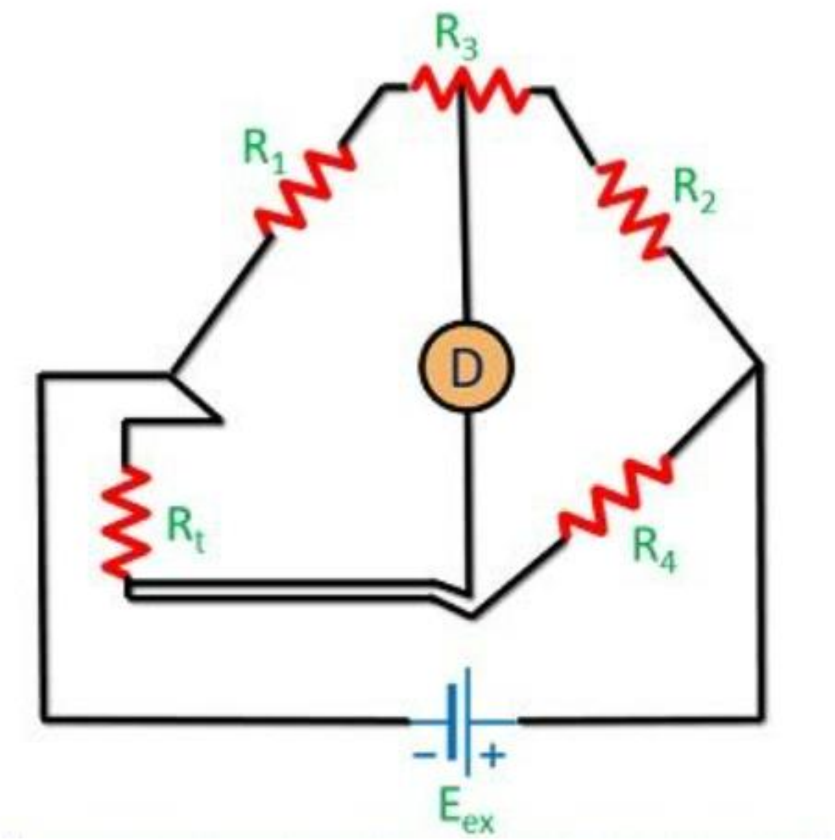
# Resistance temperature detector



## *3-wire method of temperature measurement*

- ❑ Three-wire method of temperature measurement

- ❑ It resolves the contact resistance and lead wire issues




https://electronicscoach.com/resistance-thermometer.html

# Resistance temperature detector

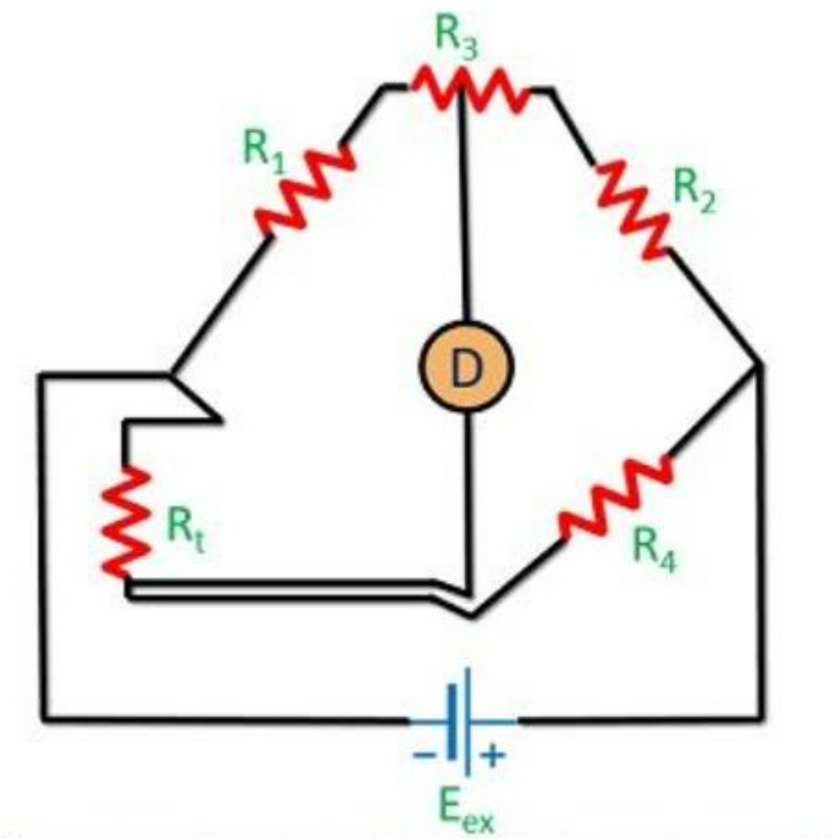


## *3-wire method of temperature measurement (contact resistance compensation)*

$$I_4 R_4 = I_2 [R_2 + (1 - f) R_3]$$

$$I_4 R_t = I_2 (R_1 + f R_3)$$

$$R_t = R_4 \frac{\frac{R_1}{R_3} + f}{\frac{R_2}{R_3} + 1 - f}$$




https://electronicscoach.com/resistance-thermometer.html

# Resistance temperature detector

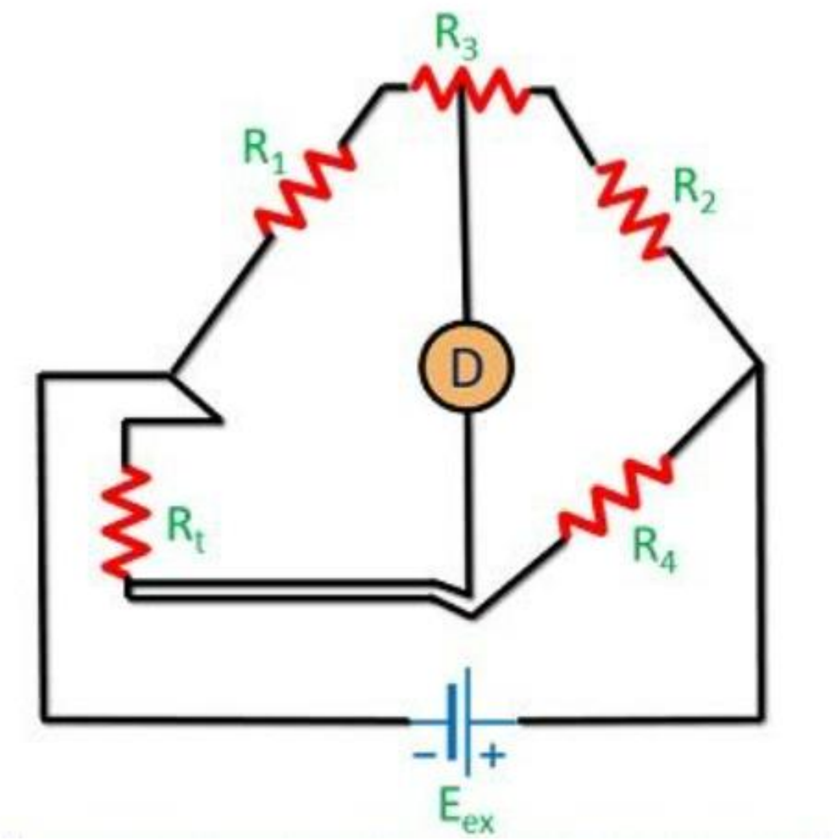


## *3-wire method of temperature measurement (lead wire resistance compensation)*

$$I_4(R_4 + R_L) = I_2\left[R_2 + R_3(1 - f)\right]$$

$$I_4(R_t + R_L) = I_2(R_1 + fR_3)$$

$$\frac{R_t + R_L}{R_4 + R_L} = \frac{\frac{R_1}{R_3} + f}{\frac{R_2}{R_3} + 1 - f}$$



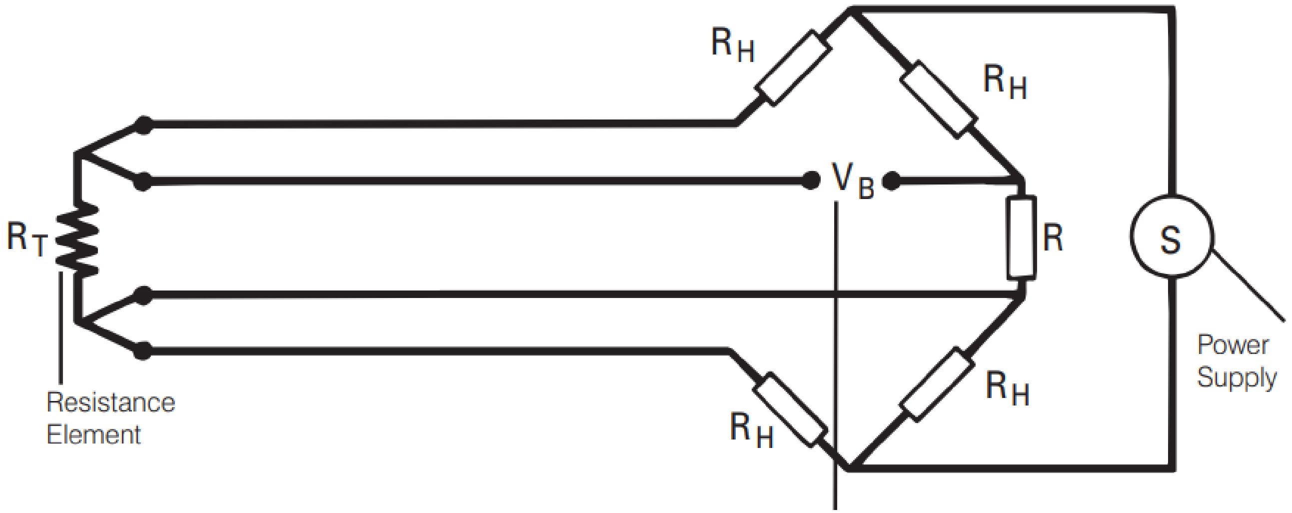

https://electronicscoach.com/resistance-thermometer.html

# Resistance temperature detector



## *4-wire method of temperature measurement or Muller bridge*

- ❑ Three-wire method cannot eliminate the lead resistance issue
- ❑ It completely resolves the lead wire issue and contact resistance issue



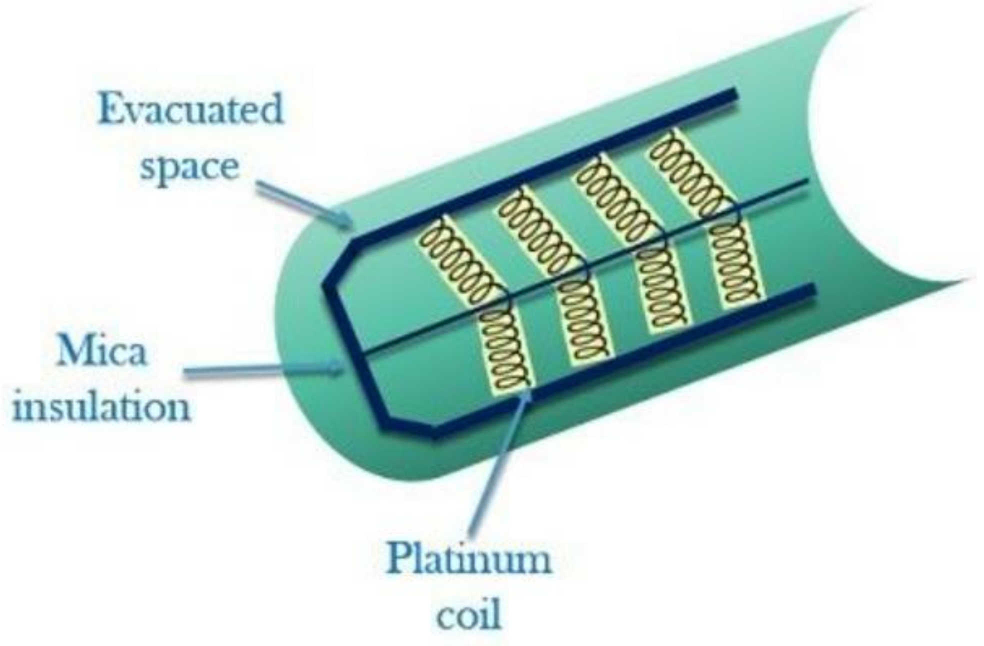

https://www.tc.co.uk/rtd-pt100-information/rtd-bridge-measuring-systems.pdf

# Resistance temperature detector



## *Construction of platinum RTD*

- ❑ Evacuated tube of stainless steel
- ❑ Least strain platinum coil arrangement
- ❑ Mica – better electrical insulation




https://electronicscoach.com/resistance-thermometer.html

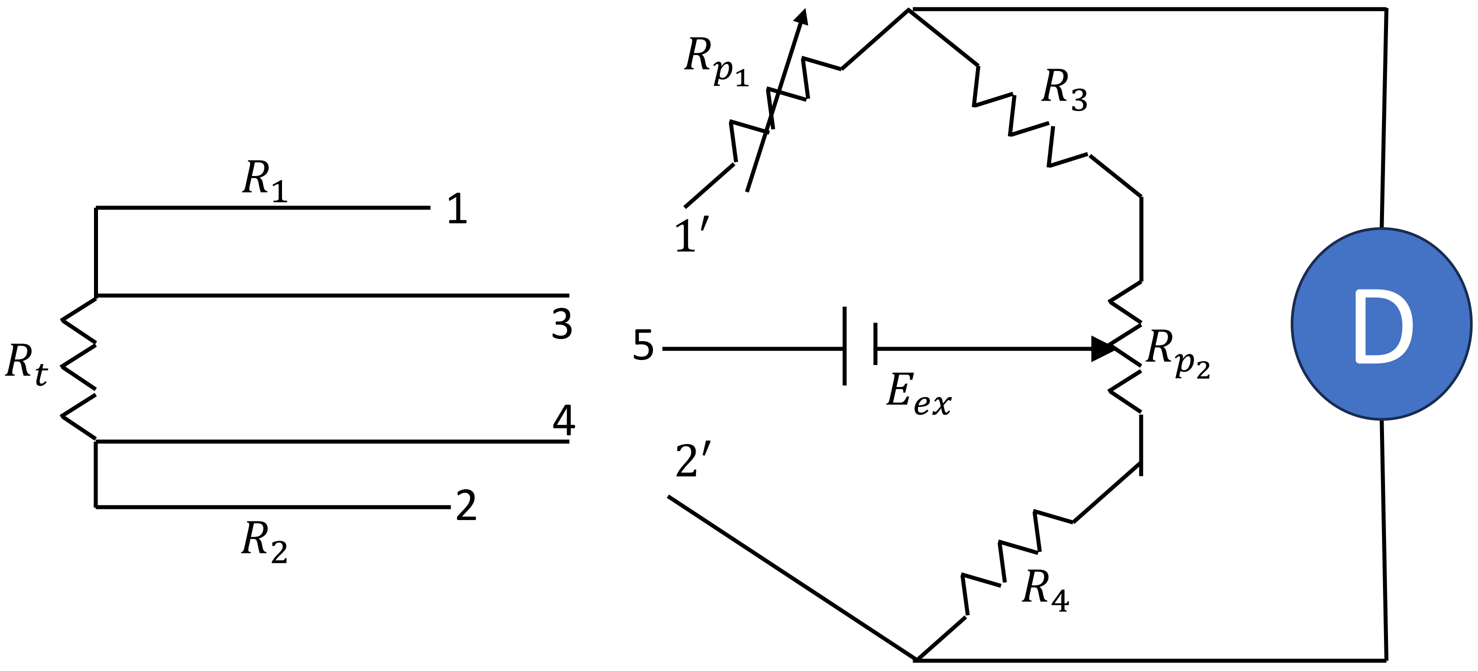
# Resistance temperature detector



## *Muller bridge*

### At position A of the switches

- Point 1 is connected to 2'
- Point 2 is connected to 1'
- Point 4 is connected to 5




At balance

$$R_{P1A} + R_2 = R_t + R_1$$

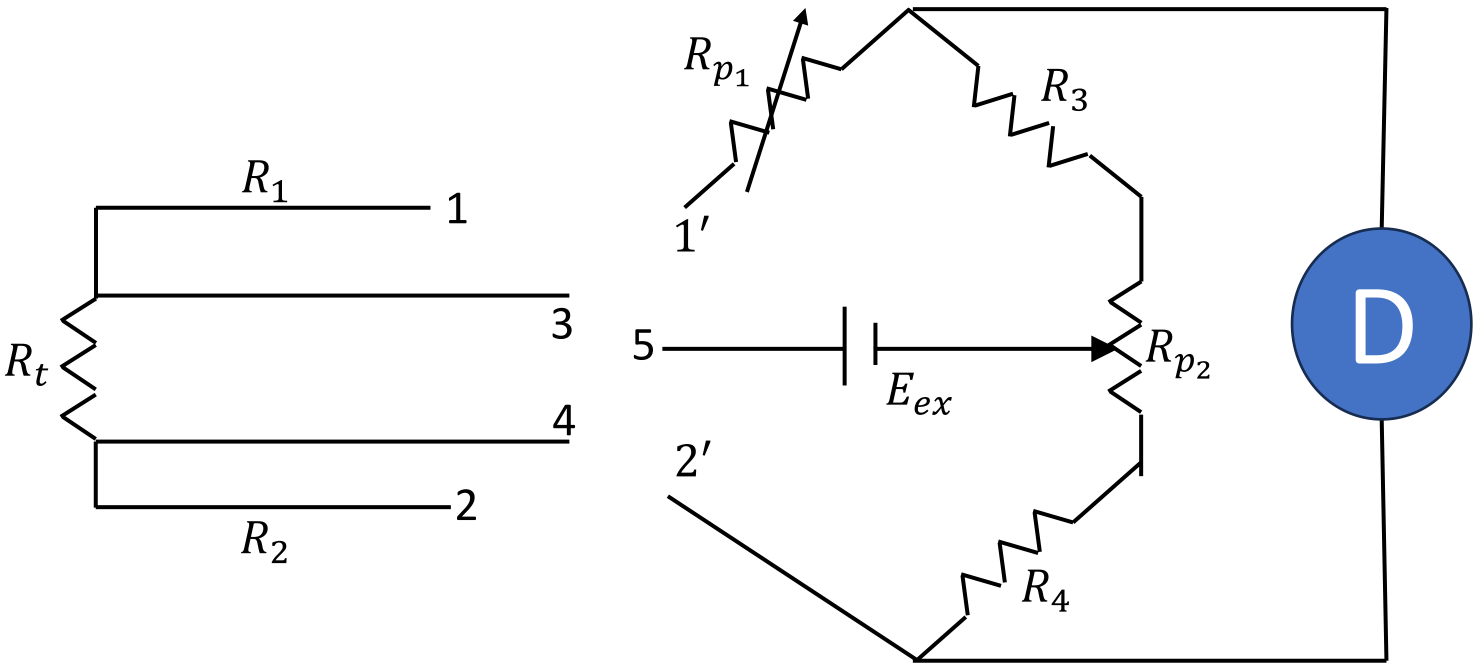
# Resistance temperature detector



## *Muller bridge*

### At position B of the switches

- ❑ Point 1 is connected to 1'
- ❑ Point 2 is connected to 2'
- ❑ Point 3 is connected to 5




At balance

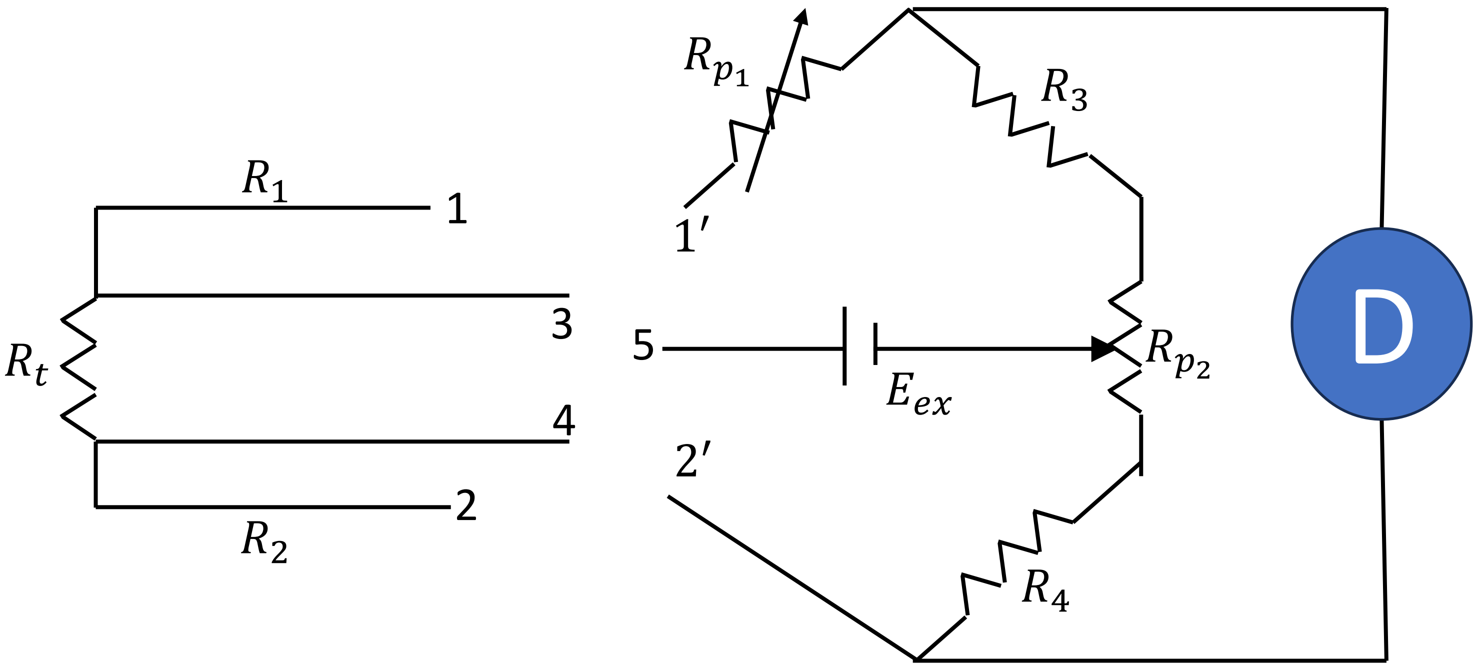
$$R_{P1B} + R_1 = R_t + R_2$$

# Resistance temperature detector

## *Muller bridge*

Adding two equations

$$R_t = \frac{R_{P1A} + R_{P1B}}{2}$$



# Thermistor



## *Introduction*

- Temperature-sensitive resistor
- Resistance change is inversely proportional to temperature
- Semiconductor material: Oxides of nickel, cobalt, or manganese
- Governing equation

$$R_T = R_0 e^{\beta\left(\frac{1}{T}-\frac{1}{T_0}\right)}$$

$\beta$ → Material constant (3000 to 5000 K)

# Thermistor

## *Properties*

Sensitivity of the thermistor

$$\frac{dR}{dT} = R_0 e^{\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)} \cdot \left(-\beta \cdot \frac{1}{T^2}\right)$$

$$\frac{dR}{dT} = R \cdot \left(-\frac{\beta}{T^2}\right)$$

$$S = \frac{\Delta R/R}{\Delta T}$$

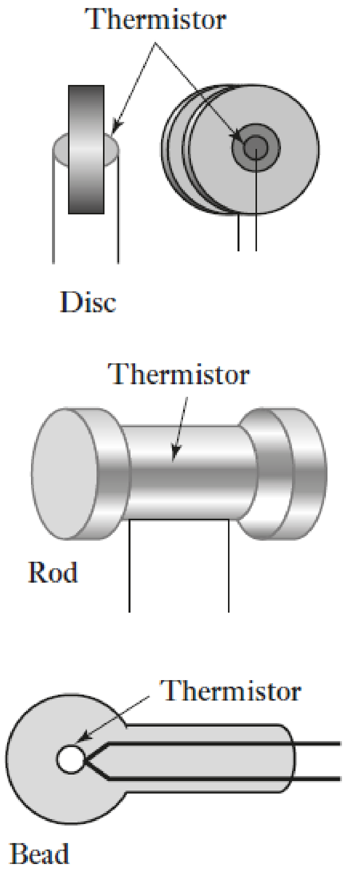
$$S = \frac{1}{R} \cdot R \cdot \left(-\frac{\beta}{T^2}\right)$$

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

# Thermistor

## *Properties*

- ❑ Sensitivity of the thermistor is much higher than platinum RTD
- ❑ Size: 0.125 mm to 1.5 mm
- ❑ Time constant is very small
- ❑ Shape: disk, wafers, flakes and rods
- ❑ Resistance varies from a few **ohm to kilo ohms** even **mega ohms**
- ❑ Minimum resistance should be set carefully




*Bolton 2008*

# Thermistor



## *Signal conditioning circuit*

- ❑ Wheatstone bridge
- ❑ Potentiometer circuit
- ❑ Linearity issue (using parallel resistance)
- ❑ Lead wire issue can be neglected
- ❑ Self-heating error

## *Signal conditioning circuit*

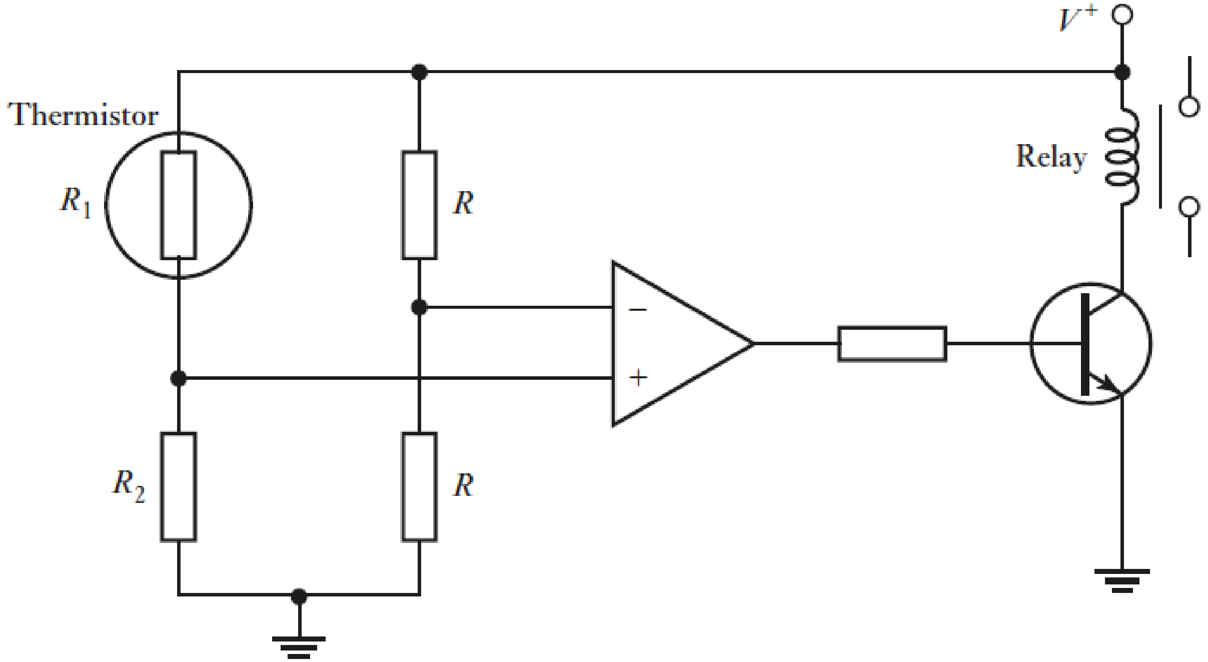
- ❑ Self-heating error

Example: Let $R_T$=5000 Ω is capable of dissipating 1 mW/°C above the ambient temperature. Thus, if the temperature is to be determined with an accuracy of 0.5°C, the power to be dissipated should be limited to less than 0.5 mW.

$$I = \sqrt{(P / R_t)} = 316\ \mu A$$

## *Application*

- ❑ Temperature switch circuit




*Bolton 2008*

# Thermistor



## *Application*

- Wien bridge oscillator
- Power supply/ SMPS

# Thermocouple



## *Introduction*

- Thermocouples working principle
- Three emfs are present in a thermocouple circuit
  - Seebeck effect
  - Peltier effect
  - Thompson effect
- Two laws of thermocouple
  - Law of intermediate metal
  - Law of intermediate temperature
- Why are no two metals used to make a thermocouple?

# Thermocouple

## *Introduction*

- Thermocouples working principle
- Governing equation
- Three emfs are present in a thermocouple circuit
  - Seebeck effect
  - Peltier effect
  - Thompson effect
- Two laws of thermocouple
  - Law of intermediate metal
  - Law of intermediate temperature
- Why are no two metals used to make a thermocouple?

# Thermocouple



## *Characteristics*

- Range: -200 to 2000 deg C
- Linearity: non-linear characteristic
- Sensitivity: 40 $\mu V/°C$
- Stability: inertness (reduction, oxidation, etc)

# Thermocouple



## *K Type thermocouple*

**Positive**: Chromel
**Negative**: Alumel
**Can be represented by**: Eighth-degree polynomial
**Application**: -200°C to 1300°C. The main application is around 700 to 1200 °C
**Voltage swing over range (mV)**: 56.0
**Lead wires**:
•(+): Iron, Copper
•(-): Cu-Ni alloy, Constantan

# Thermocouple



## *T Type thermocouple*

**Positive**: Copper
**Negative**: Constantan
**Can be represented by**: Eighth-degree polynomial
**Application**: -200°C to 350°C. Beyond this temperature, oxidation of copper will occur.
**Voltage swing over range (mV)**: 26.0 (For -184°C to 400°C)
**Lead wires**:

- (+): Cu
- (-): Constantan

# Thermocouple

## *S Type thermocouple*

**Positive**: Platinum / 10% Rhodium
**Negative**: Platinum
**Can be represented by**: Second / Third degree polynomial
**Application**: Main features are its chemical inertness and stability at high temperatures in oxidizing atmospheres. Reducing atmospheres cause rapid deterioration at high temperatures, ranging from 0°C to 1538°C.
**Voltage swing over range (mV)**: 16.0
**Lead wires**: (+): Copper; (-): Copper-Nickel alloy

# Thermocouple

## *R Type thermocouple*

**Positive**: Platinum / 13% Rhodium
**Negative**: Platinum
**Can be represented by**: Second / Third degree polynomial
**Application**:
0°C to 1593°C
**Voltage swing over range (mV)**: 18.7
**Lead wires**:
•(+): Copper
•(-): Copper-Nickel alloy

# Thermocouple



## *B Type thermocouple*

**Positive**: Platinum / 30% Rhodium
**Negative**: Platinum / 6% Rhodium
**Can be represented by**: Eighth degree polynomial
**Application**: 38°C to 1800°C
**Voltage swing over range (mV)**: 13.6
**Lead wires**:
•(+): Copper
•(-): Copper-Nickel alloy

# Thermocouple



## *E Type thermocouple*

**Positive**: Chromel
**Negative**: Constantan
**Can be represented by**: Ninth degree polynomial
**Application**:
0°C to 982°C
**Voltage swing over range (mV)**: 75; Highest sensitivity
**Lead wires**: (+): Iron; (-): Constantan

# Thermocouple

Thermal sensor

| Type | Material | Temperature Range (°C) | Sensitivity (μV/°C) | Accuracy | Key Features | Applications |
|---|---|---|---|---|---|---|
| K | Chromel-Alumel | -200 to 1260 | ~41 | ±2.2°C or ±0.75% | Inexpensive, stable, oxidation resistant. | General-purpose, furnaces, oxidizing atmospheres. |
| J | Iron-Constantan | -40 to 750 | ~52 | ±2.2°C or ±0.75% | Low cost, better in reducing atmospheres, prone to rust. | Industrial, short-term high temperature. |
| T | Copper-Constantan | -200 to 350 | ~43 | ±1.0°C or ±0.75% | Accurate at low temperatures, corrosion resistant. | Cryogenics, food processing, low-temperature research. |

# Thermocouple



| Type | Material | Temperature Range (°C) | Sensitivity (μV/°C) | Accuracy | Key Features | Applications |
|---|---|---|---|---|---|---|
| E | Chromel-Constantan | -200 to 900 | ~68 | ±1.7°C or ±0.5% | High sensitivity, suitable for low-temperature applications. | Laboratory, medical equipment. |
| N | Nicrosil-Nisil | -270 to 1300 | ~39 | ±2.2°C or ±0.75% | Excellent high-temperature stability, resistant to oxidation. | High-temperature furnaces, aerospace. |
| S | Platinum-Rhodium (10%) | 0 to 1450 | ~10 | ±1.5°C or ±0.25% | Highly stable, suitable for long-term use in oxidizing environments. | Laboratory, glass production, metallurgy. |

# Thermocouple



| Type | Material | Temperature Range (°C) | Sensitivity (µV/°C) | Accuracy | Key Features | Applications |
|---|---|---|---|---|---|---|
| **R** | Platinum-Rhodium (13%) | 0 to 1450 | ~10 | ±1.5°C or ±0.25% | Similar to Type S but with higher rhodium content for better stability. | High-accuracy laboratory measurements. |
| **B** | Platinum-Rhodium (30%/6%) | $\boxed{\text{0 to 1700}}$ | ~7 | ±1.5°C or ±0.5% | Extremely stable at high temperatures, limited use below 50°C. | Steel and ceramic industries, very high temperatures. |

# Thermocouple



## *Signal conditioning circuit*

- Cold junction compensation
  - Maintain the cold junction at a constant temperature
  - Or use a thermostatically controlled oven
  - Subtracting the voltage equivalent to the temperature change
    - Junction diode (2.2 mV/deg C)
    - AD 590

## *Signal conditioning circuit*

### Cold junction compensation

| Type | $R_a$ (ohm) |
|---|---|
| J | 52.3 |
| K | 41.2 |
| E | 61.4 |
| T | 40.2 |
| S, R | 5.76 |

# Thermocouple



## *Desirable properties of thermocouple*

- Relatively large thermal emf
- Precision of calibration
- Resistance to corrosion and oxidation
- Inter-changeability

# Thermocouple



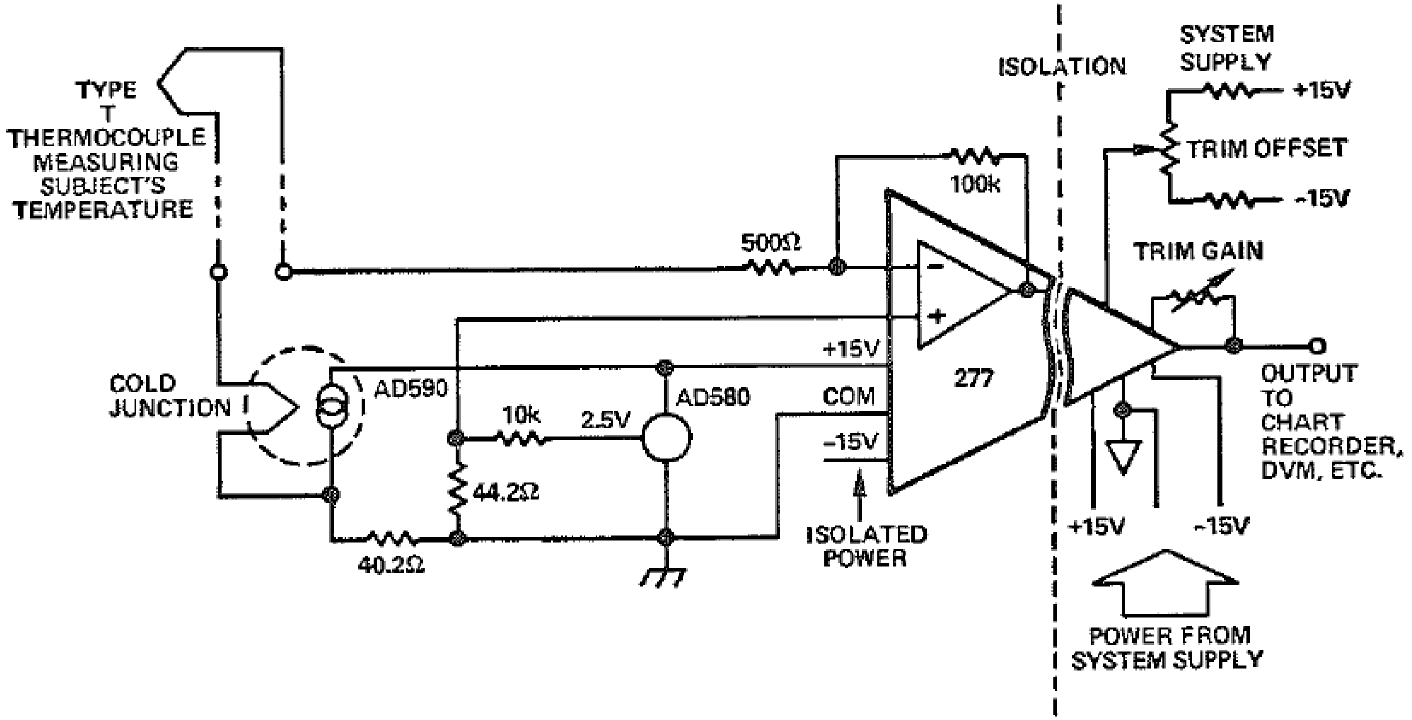
## *Thermopile*

- Amplify the output of the circuit
- Time constant increases

# Thermocouple

## *Application of thermocouple*

- ❑ Isolated thermocouple measurement
  - ➢ Good stability in low temperature
  - ➢ Accuracy



# Thermocouple

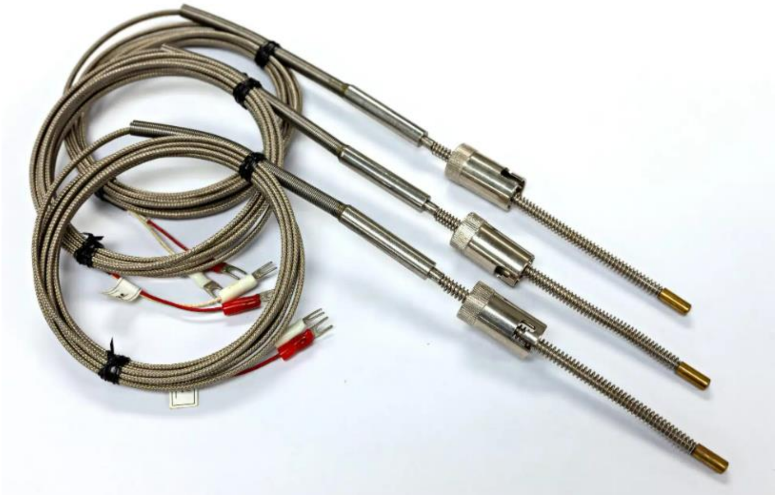


## *Thermocouple to frequency conversion*

- ❑ Reduce signal distortion over a long distances
- ❑ Improve noise immunity
- ❑ Ease of digital processing
- ❑ Voltage to frequency converter (*v to f*) – AD537

# Thermocouple

## *Temperature as a function of voltage readings*



https://www.electronics-cooling.com/2024/03/tech-brief-effect-of-thermocouple-size/

| | B | | E | | J | | K |
|---|---|---|---|---|---|---|---|
| mV | °C | °C/mV | °C | °C/mV | °C | °C/mV | °C |
| −10.000 | — | | — | | — | | — |
| − 5.000 | — | | − 94.4 | 21.70 | − 109.1 | 25.10 | − 153.7 |
| − 2.000 | — | | − 35.3 | 18.40 | − 40.8 | 21.10 | − 53.1 |
| − 1.000 | — | | − 17.3 | 17.60 | − 20.1 | 20.40 | − 25.9 |
| 0.000 | + 42.0 | 4°/μV | 0.0 | 17.06 | 0.0 | 19.84 | 0.0 |
| + 1.000 | 449.6 | 220 | 16.8 | 16.64 | 19.6 | 19.25 | + 25.0 |
| + 2.000 | 634.2 | 160 | 33.2 | 16.21 | 38.9 | 19.08 | + 49.5 |
| + 5.000 | 1018.2 | 109 | 80.3 | 15.19 | 95.1 | 18.43 | + 122.0 |
| +10.000 | 1491.8 | 87 | 153.0 | 14.02 | 186.0 | 18.03 | 246.3 |
| +20.000 | — | | 286.7 | 12.90 | 366.5 | 18.13 | 485.0 |
| +30.000 | — | | 413.2 | 12.47 | 546.3 | 17.57 | 720.8 |
| +40.000 | — | | 537.1 | 12.36 | 713.9 | 15.94 | 967.5 |
| +50.000 | — | | 661.1 | 12.47 | 870.2 | 15.79 | 1232.3 |
| +60.000 | — | | 787.0 | 12.71 | 1035.0 | 16.95 | |
| +70.000 | — | | 915.9 | 13.09 | — | | |

# Thermocouple



***Thermoelectric voltage***

| °C | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Thermoelectric Voltage in Millivolts | | | | | | | | | | | |
| -210 | -8.095 | | | | | | | | | | | -210 |
| -200 | -7.890 | -7.912 | -7.934 | -7.955 | -7.976 | -7.996 | -8.017 | -8.037 | -8.057 | -8.076 | -8.095 | -200 |
| -190 | -7.659 | -7.683 | -7.707 | -7.731 | -7.755 | -7.778 | -7.801 | -7.824 | -7.846 | -7.868 | -7.890 | -190 |
| -180 | -7.403 | -7.429 | -7.456 | -7.482 | -7.508 | -7.534 | -7.559 | -7.585 | -7.610 | -7.634 | -7.659 | -180 |
| -170 | -7.123 | -7.152 | -7.181 | -7.209 | -7.237 | -7.265 | -7.293 | -7.321 | -7.348 | -7.376 | -7.403 | -170 |
| -160 | -6.821 | -6.853 | -6.883 | -6.914 | -6.944 | -6.975 | -7.005 | -7.035 | -7.064 | -7.094 | -7.123 | -160 |
| -150 | -6.500 | -6.533 | -6.566 | -6.598 | -6.631 | -6.663 | -6.695 | -6.727 | -6.759 | -6.790 | -6.821 | -150 |
| -140 | -6.159 | -6.194 | -6.229 | -6.263 | -6.298 | -6.332 | -6.366 | -6.400 | -6.433 | -6.467 | -6.500 | -140 |
| -130 | -5.801 | -5.838 | -5.874 | -5.910 | -5.946 | -5.982 | -6.018 | -6.054 | -6.089 | -6.124 | -6.159 | -130 |
| -120 | -5.426 | -5.465 | -5.503 | -5.541 | -5.578 | -5.616 | -5.653 | -5.690 | -5.727 | -5.764 | -5.801 | -120 |
| -110 | -5.037 | -5.076 | -5.116 | -5.155 | -5.194 | -5.233 | -5.272 | -5.311 | -5.350 | -5.388 | -5.426 | -110 |
| -100 | -4.633 | -4.674 | -4.714 | -4.755 | -4.796 | -4.836 | -4.877 | -4.917 | -4.957 | -4.997 | -5.037 | -100 |
| -90 | -4.215 | -4.257 | -4.300 | -4.342 | -4.384 | -4.425 | -4.467 | -4.509 | -4.550 | -4.591 | -4.633 | -90 |
| -80 | -3.786 | -3.829 | -3.872 | -3.916 | -3.959 | -4.002 | -4.045 | -4.088 | -4.130 | -4.173 | -4.215 | -80 |
| -70 | -3.344 | -3.389 | -3.434 | -3.478 | -3.522 | -3.566 | -3.610 | -3.654 | -3.698 | -3.742 | -3.786 | -70 |
| -60 | -2.893 | -2.938 | -2.984 | -3.029 | -3.075 | -3.120 | -3.165 | -3.210 | -3.255 | -3.300 | -3.344 | -60 |
| -50 | -2.431 | -2.478 | -2.524 | -2.571 | -2.617 | -2.663 | -2.709 | -2.755 | -2.801 | -2.847 | -2.893 | -50 |
| -40 | -1.961 | -2.008 | -2.055 | -2.103 | -2.150 | -2.197 | -2.244 | -2.291 | -2.338 | -2.385 | -2.431 | -40 |
| -30 | -1.482 | -1.530 | -1.578 | -1.626 | -1.674 | -1.722 | -1.770 | -1.818 | -1.865 | -1.913 | -1.961 | -30 |
| -20 | -0.995 | -1.044 | -1.093 | -1.142 | -1.190 | -1.239 | -1.288 | -1.336 | -1.385 | -1.433 | -1.482 | -20 |
| -10 | -0.501 | -0.550 | -0.600 | -0.650 | -0.699 | -0.749 | -0.798 | -0.847 | -0.896 | -0.946 | -0.995 | -10 |
| 0 | 0.000 | -0.050 | -0.101 | -0.151 | -0.201 | -0.251 | -0.301 | -0.351 | -0.401 | -0.451 | -0.501 | 0 |

# Thermocouple



*Thermoelectric voltage*

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.000 | 0.050 | 0.101 | 0.151 | 0.202 | 0.253 | 0.303 | 0.354 | 0.405 | 0.456 | 0.507 | 0 |
| 10 | 0.507 | 0.558 | 0.609 | 0.660 | 0.711 | 0.762 | 0.814 | 0.865 | 0.916 | 0.968 | 1.019 | 10 |
| 20 | 1.019 | 1.071 | 1.122 | 1.174 | 1.226 | 1.277 | 1.329 | 1.381 | 1.433 | 1.485 | 1.537 | 20 |
| 30 | 1.537 | 1.589 | 1.641 | 1.693 | 1.745 | 1.797 | 1.849 | 1.902 | 1.954 | 2.006 | 2.059 | 30 |
| 40 | 2.059 | 2.111 | 2.164 | 2.216 | 2.269 | 2.322 | 2.374 | 2.427 | 2.480 | 2.532 | 2.585 | 40 |
| 50 | 2.585 | 2.638 | 2.691 | 2.744 | 2.797 | 2.850 | 2.903 | 2.956 | 3.009 | 3.062 | 3.116 | 50 |
| 60 | 3.116 | 3.169 | 3.222 | 3.275 | 3.329 | 3.382 | 3.436 | 3.489 | 3.543 | 3.596 | 3.650 | 60 |
| 70 | 3.650 | 3.703 | 3.757 | 3.810 | 3.864 | 3.918 | 3.971 | 4.025 | 4.079 | 4.133 | 4.187 | 70 |
| 80 | 4.187 | 4.240 | 4.294 | 4.348 | 4.402 | 4.456 | 4.510 | 4.564 | 4.618 | 4.672 | 4.726 | 80 |
| 90 | 4.726 | 4.781 | 4.835 | 4.889 | 4.943 | 4.997 | 5.052 | 5.106 | 5.160 | 5.215 | 5.269 | 90 |

# Thermocouple

## *Numerical 1*

*With a cold junction of -14°C an iron-constantan thermocouple produces an emf of 4.82 mV. Calculate the temperature of the hot junction.*

Ans: 78.8 deg C

# Thermocouple



**Type J (Iron-Constantan) Thermocouple Table for 0 C Reference**

| | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 |
|---|---|---|---|---|---|---|---|---|---|---|
| −150 | −6.50 | −6.66 | −6.82 | −6.97 | −7.12 | −7.27 | −7.40 | −7.54 | −7.66 | −7.78 |
| −100 | −4.63 | −4.83 | −5.03 | −5.23 | −5.42 | −5.61 | −5.80 | −5.98 | −6.16 | −6.33 |
| 50 | −2.43 | −2.66 | −2.89 | −3.12 | −3.34 | 3.56 | −3.78 | −4.00 | −4.21 | −4.42 |
| −0 | 0.00 | −0.25 | −0.50 | −0.75 | −1.00 | −1.24 | −1.48 | −1.72 | −1.96 | −2.20 |
| +0 | 0.00 | 0.25 | 0.50 | 0.76 | 1.02 | 1.28 | 1.54 | 1.80 | 2.06 | 2.32 |
| 50 | 2.58 | 2.85 | 3.11 | 3.38 | 3.65 | 3.92 | 4.19 | 4.46 | 4.73 | 5.00 |
| 100 | 5.27 | 5.54 | 5.81 | 6.08 | 6.36 | 6.63 | 6.90 | 7.18 | 7.45 | 7.73 |
| 150 | 8.00 | 8.28 | 8.56 | 8.84 | 9.11 | 9.39 | 9.67 | 9.95 | 10.22 | 10.50 |
| 200 | 10.78 | 11.06 | 11.34 | 11.62 | 11.89 | 12.17 | 12.45 | 12.73 | 13.01 | 13.28 |
| 250 | 13.56 | 13.84 | 14.12 | 14.39 | 14.67 | 14.94 | 15.22 | 15.50 | 15.77 | 16.05 |
| 300 | 16.33 | 16.60 | 16.88 | 17.15 | 17.43 | 17.71 | 17.98 | 18.26 | 18.54 | 18.81 |
| 350 | 19.09 | 19.37 | 19.64 | 19.92 | 20.20 | 20.47 | 20.75 | 21.02 | 21.30 | 21.57 |
| 400 | 21.85 | 22.13 | 22.40 | 22.68 | 22.95 | 23.23 | 23.50 | 23.78 | 24.06 | 24.33 |
| 450 | 24.61 | 24.88 | 25.16 | 25.44 | 25.72 | 25.99 | 26.27 | 26.55 | 26.83 | 27.11 |
| 500 | 27.39 | 27.67 | 27.95 | 28.23 | 28.52 | 28.80 | 29.08 | 29.37 | 29.65 | 29.94 |
| 550 | 30.22 | 30.51 | 30.80 | 31.08 | 31.37 | 31.66 | 31.95 | 32.24 | 32.53 | 32.82 |
| 600 | 33.11 | 33.41 | 33.70 | 33.99 | 34.29 | 34.58 | 34.88 | 35.18 | 35.48 | 35.78 |
| 650 | 36.08 | 36.38 | 36.69 | 36.99 | 37.30 | 37.60 | 37.91 | 38.22 | 38.53 | 38.84 |
| 700 | 39.15 | 39.47 | 39.78 | 40.10 | 40.41 | 40.73 | 41.05 | 41.36 | 41.68 | 42.00 |

https://www.chegg.com/homework-help/questions-and-answers/type-j-iron-constantan-thermocouple-table-0-c-reference-0-5-20-25-30-35-40-45-150-100-50-0-q51120121

# Thermocouple

## *Numerical 2*

*At a temperature of 447°C an iron-constantan thermocouple produces an emf of 8.11 mV. Calculate the temperature of the cold junction.*

0 → 447 = 24.444 mV
X to 447 = 8.11 mV
0 to 300 = 16.327 mV
0 to 301 = 16.383 mV

Ans: 300.1 deg C

# Thermocouple



## *Numerical 3*

The emf of an iron-constantan thermocouple was found to be 44.40 mV with a cold junction of 0°C. If the cold junction changes to 100°C, what emf would the thermocouple produce?

# Thermocouple

## *Numerical 4*

An iron-constantan thermocouple is placed in a known temperature of 400°F. If the thermocouple produces an emf of 10.81 mV, what is the temperature of the cold junction?

# Thermocouple



## *Numerical 5*

Two different thermocouples (A and B) are connected in series. The Seebeck coefficients are: $S_A = 30\,\mu V/°C, \;\; S_B = 50\,\mu V/°C.$

The hot junction is at 500 deg C and the cold junction is at 25 deg C. Calculate the total EMF generated by the system.

Ans: 38 mV

# Thermocouple



## *Numerical 6*

A thermocouple reads an EMF of 15 mV when the hot junction is at 400 deg C. The Seebeck coefficient is 50 μV/deg C. Determine the reference junction temperature.

Ans: 100 deg c

# Thermocouple



## *Numerical 7*

For a non-linear thermocouple, where a = 40 μV/deg C and b = 0.02 μV/deg C. Calculate the EMF when the hot junction is at 300 deg C and the cold junction is at 0 deg C.

Ans: 13.8mV

## *Numerical 8*

A platinum RTD, PT100 measures 100Ω at 0°C and 138.5Ω at 100°C. Calculate temperature when resistance is 110Ω

Ans: 119.25 ohm

# Thermocouple

## *Numerical 9*

For a thermistor, $\beta$=3140 K and the resistance at 27deg C is known to be 1050 . If the thermistor is used for measuring a temperature of 6 deg C, find the resistance of the thermistor.

Ans: 2308.95 ohm

Thank you for your attention!