SENSORS and TRANSDUCERS

Tadeusz Stepinski, Signaler och system

❉ The Thermal Energy Domain

- Physics
  - » Seebeck effect
  - » Peltier effect
  - » Thomson effect
- Thermal effects in semiconductors
- Thermoelectric sensors
- Thermoresistive sensors

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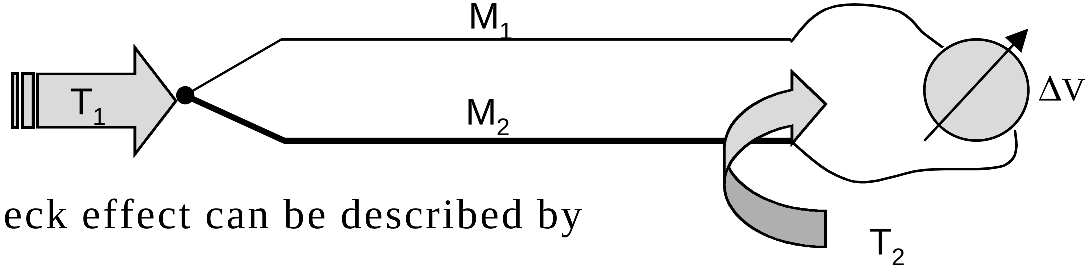
Thermal Energy Domain - Physics

- We are considering thermal transducers that are used for converting thermal information into electrical signals.
- Basic mechanisms relevant for our discussion:
  - Seebeck effect
  - Peltier effect
  - Thomson effect
  - Thermoresistance

Thermal Energy Domain - Physics

- The Seebeck effect

  Generation of electrical voltage due to temperature difference between a weld of two different materials and the other ends of these wires



Seebeck effect can be described by

$$\Delta V = \alpha_S \Delta T$$

where:

α_S ($\mu V K^{-1}$) - Seebeck coefficient

ΔV (V) - voltage difference

ΔT (K) - absolute temperature difference

Thermal Energy Domain - Physics

- Seebeck coefficient describes a bulk effect, determined by the following effects:
  - Temperature difference generates a difference in Fermi level
  - Bandgap distance changes with temperature
  - The gradient of charge carriers changes for *n* and *p* type as a function of temperature
  - Diffusion coefficient is a function of temperature
  - Charge carriers move from the heated side to cold side - thermodiffusion
  - Electric field will be generated due to the transport of charge carriers
- Seebeck effect is used mainly in thermocouples used for temperatures ranging from - 200 to 1600 °C

Thermal Energy Domain - Physics

- Peltier effect

A reverse effect to Seebeck effect, discovered in 1834 by Peltier.

When a current flows through a junction of two different metals heat is dissipated or absorbed towards or from the the environment.

$$Q = -\Pi_{ab} J_{ab}$$

where: Q (J m^{-2}) - dissipated or absorbed heat

Π_{ab} (J C^{-1}) - Peltier coefficient for a junction with materials *a* and *b*

J_{ab} (C m^{-2}) - charge carrier density flowing from *a* to *b*

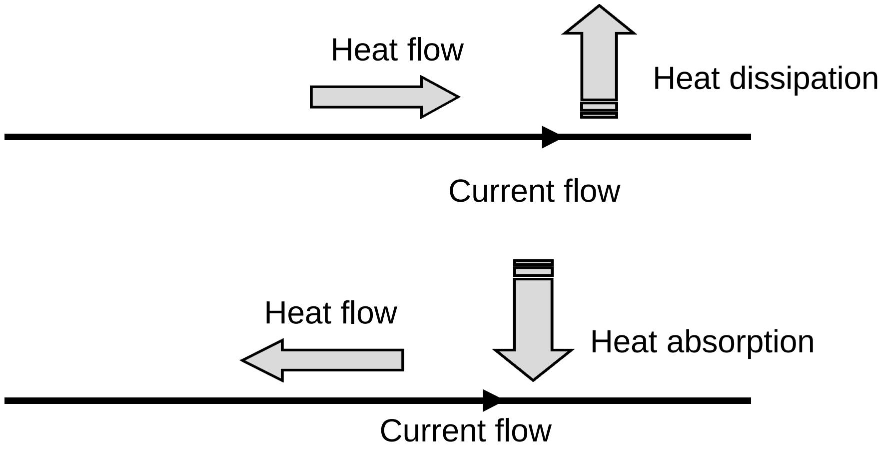
Relationship between Peltier and Seebeck coefficients (under certain conditions)

$$\Pi_{ab} = \alpha_S T$$

Thermal Energy Domain - Physics

- Thomson effect (reversible)

Current flowing in a wire in which temperature gradient is present shows a heat exchange with its environment.



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Thermal Energy Domain - Physics

- Thomson effect

$$Q_{th} = \gamma \cdot J \cdot \Delta T$$

where Q_{th} (W m^{-2}) - heat flaw

γ (VK^{-1}) - Thomson coefficient

J (Am^{-2}) - current density

T (K) - temperature

Kelvin proved the following relationship between Seebeck and Thomson coefficients

$$\gamma = T\frac{\partial \alpha_S}{\partial T}$$

Thermal Energy Domain - Physics

- Thermoresitance

Macroscopic description

$$R(T) = R(0) \cdot (1 + AT + BT^2)$$

where: $R(T)$, $R(0)$ - resistance at temperature T and -273°K, respectively

A, B - temperature coefficients

Term B can be neglected for for most materials

Microscopic description

$$s = n \cdot q \cdot m$$

where: σ (Ω m) - conductivity

n (m^{-3}) - number of charge carriers per unit volume

q ($1.6\ 10^{-19}$ C) - specific charge

μ ($m^2V^{-1}\ s^{-1}$) - electron mobility

Thermal effects in semiconductors

- Thermistor = thermal sensitive resistor

  Thermistors are composed of sintered ceramic semiconductor

  and metal oxides - manganese, cobalt, copper and iron

  Thermistor resistance

$$\rho(T) = \rho(T_0) \cdot \exp\left[-B \cdot (1/T - 1/T_0)\right]$$

where $\rho(T_0)$ - resistivity at $T=T_0$

B - constant (in the range of 4000K)

Most thermistors have negative temperature coefficient (NTC)

$$\alpha = \frac{d\rho}{\rho} = = -\frac{B}{T^2}$$

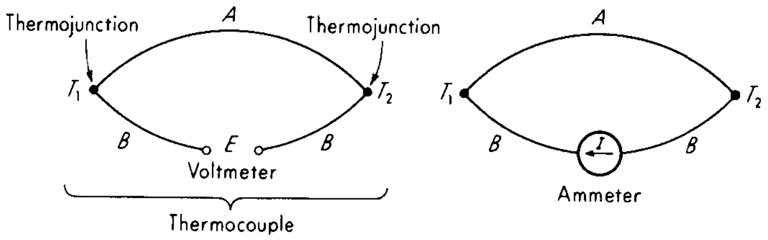
Review of thermal effects

- Thermal physical mechanisms used for transducers

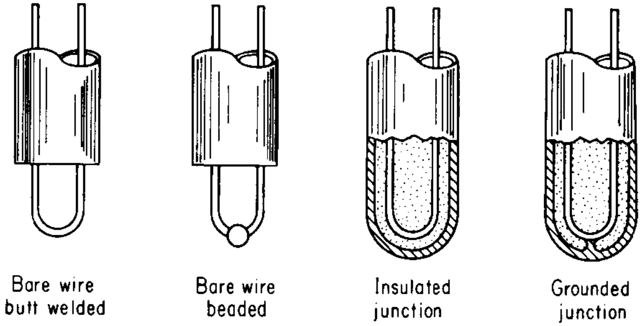
Name of effect	Notation	Macroscopic description
Thermoelectric, Seebec	[th,el,00]	Generation of electrical potential by a joint of two dissimilar conductors
Pyroelectric	[th,el,00]	Change of polarization due to temperature change
Nernst	[th,el,ma]	Generation of electromagnetic field due to temperature gradient
Thermodielectric	[el,el,th]	Change of permitivity of a ferroelectric due to temperature
Thermoconductivity	[el,el,th]	Change of conductivity due to temperature
Thermoluminescence	[th,ra,00]	Emission of radiant energy of certain crystals due to temperature
Curie temperature	[th,ma,00]	Change to paramagnetism of ferromagnetic material at specified temperature
Incadescence	[th,ra,00]	Emission of radiant energy when material is heated
Therochemical	[th,el,00]	Change of structure due to temperature
Electrothermal	[el,th,00]	Generation of heat in a conductor by electric current
Peltier	[el,th, 00]	Generation of temperature difference between two junctions when current passes through them

Thermoelectric sensors

- Thermocouples



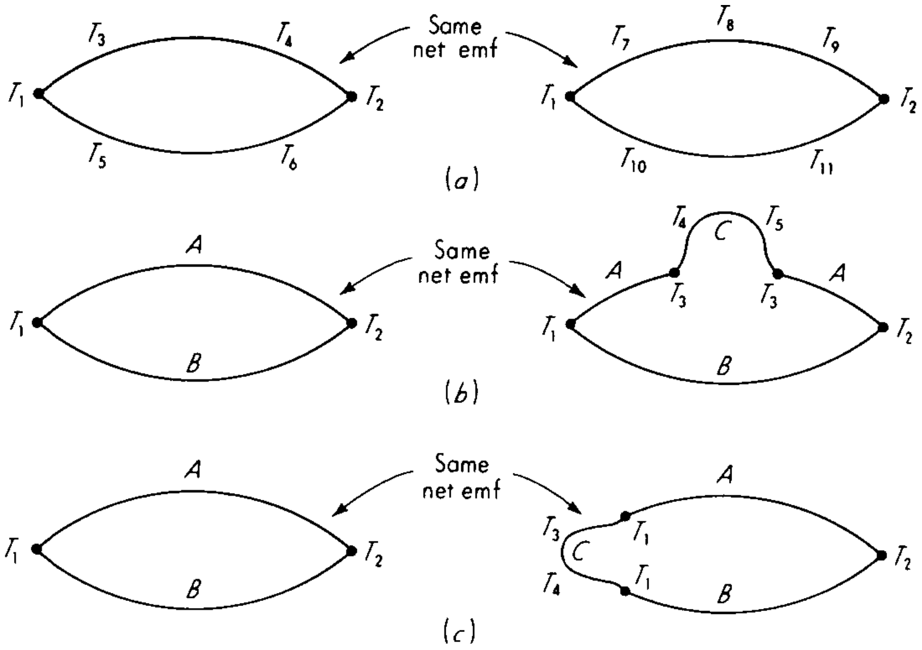
(a)



(b)

Thermoelectric sensors

- Thermocouple laws

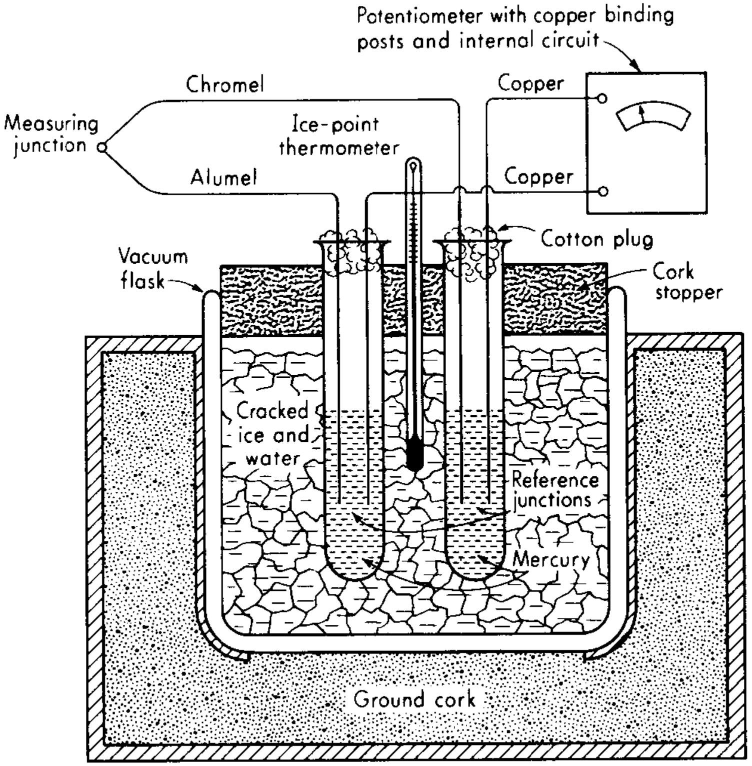


Thermal emf is unaffected by temperature elsewhere in the circuit

A third homogenous metal C does not affect the emf as long as the new junctions have the same temperatures

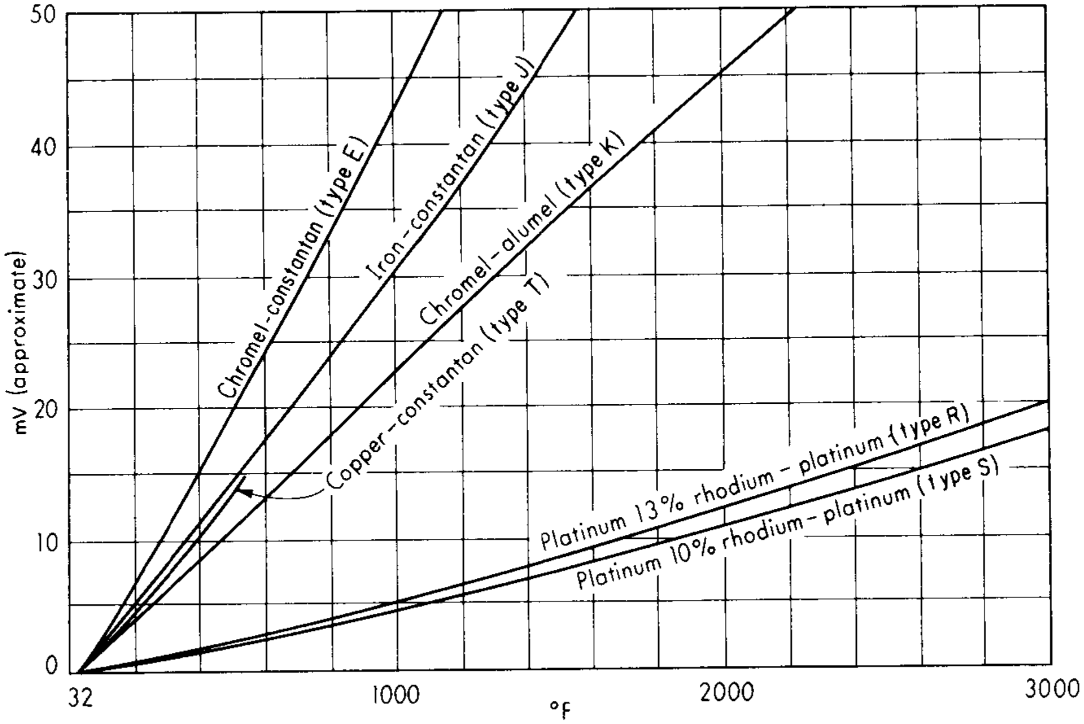
Thermoelectric sensors

- Thermocouples - ice bath for reference junction



Thermoelectric sensors

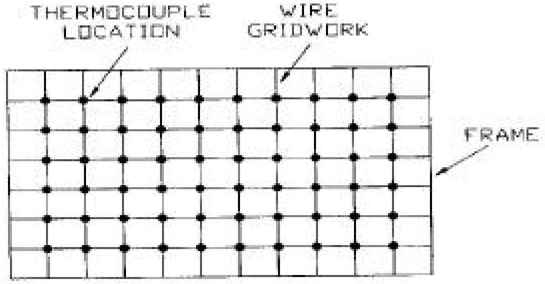
- Thermocouple - mV output versus temperature

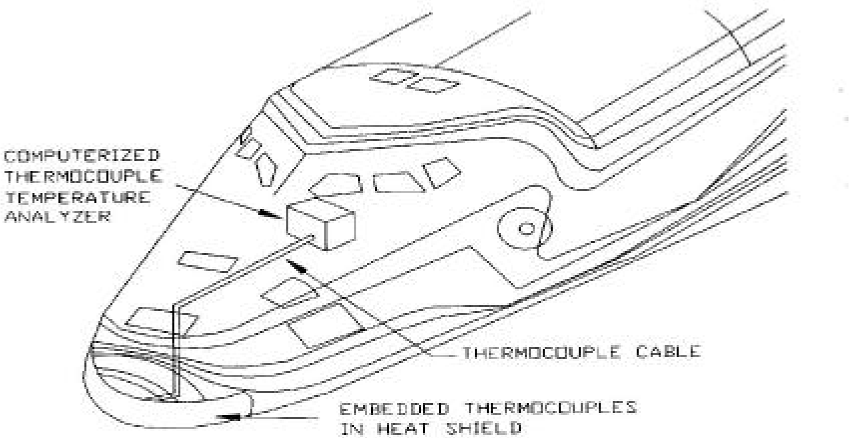


Thermocouple temperature/voltage curves.

Thermoelectric sensors - applications

- Thermocouple grid applied space shuttles frond end

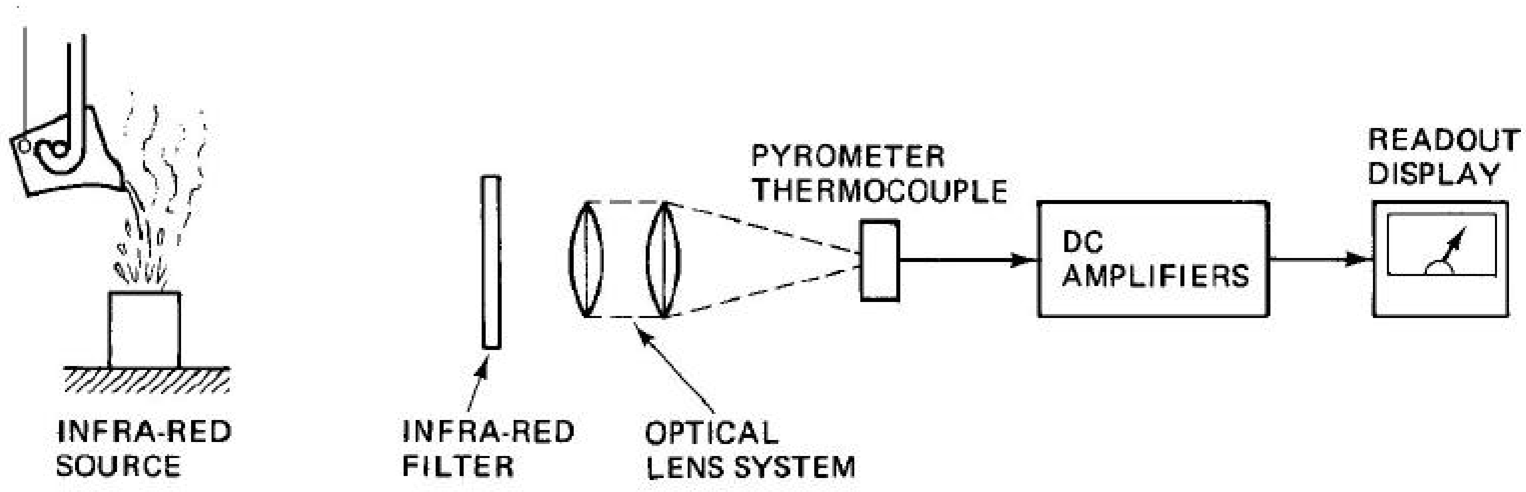




Thermoelectric sensors - applications

- Pyrometer using thermopile circuit

  Thermopile - a circuit arranged of a number of thermocouples in series

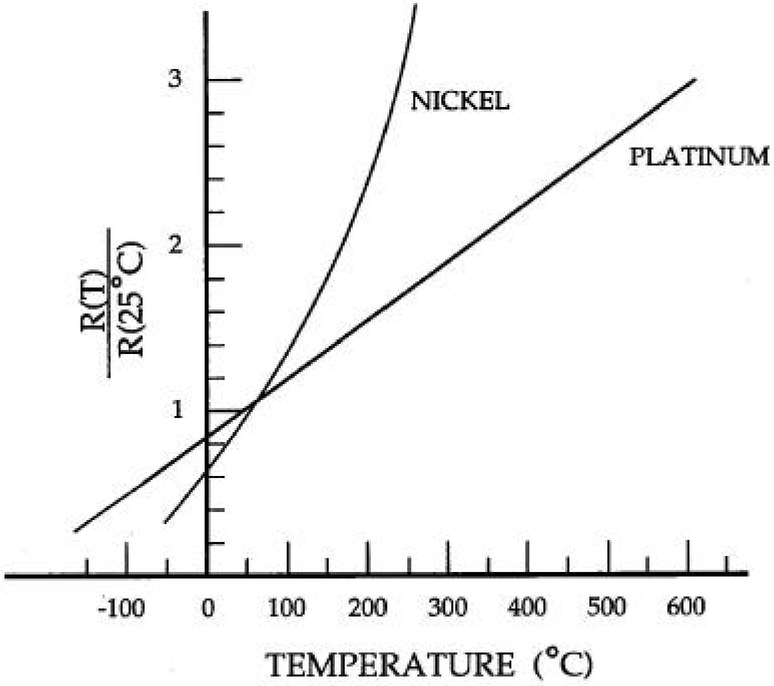


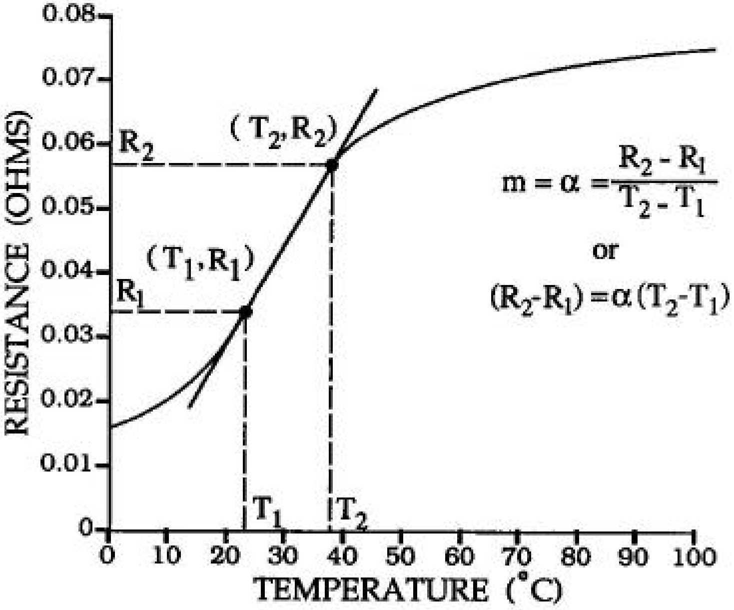
Thermoelectric sensors - applications

- Infrared pyrometer (Omega Eng. Inc.)

Thermoeresistive sensors

- Temperature coefficients of metals





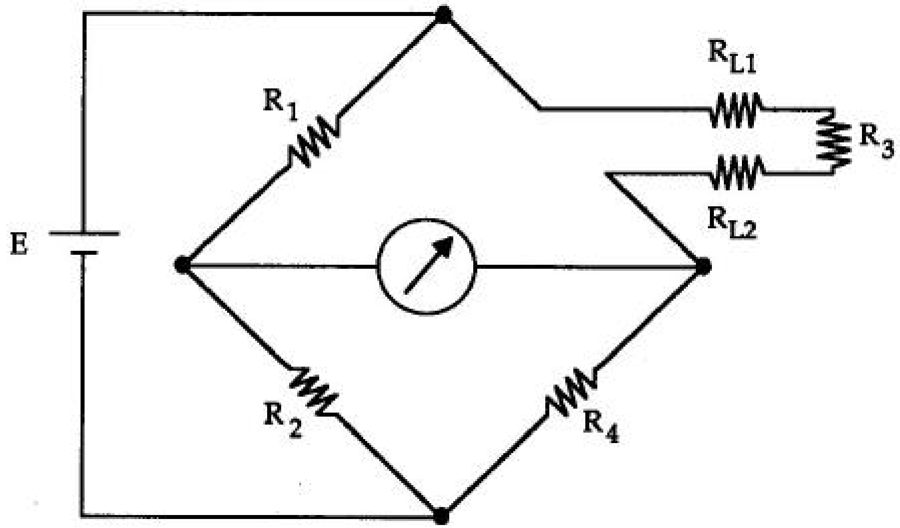
Dc resistance vs temperature for platinum

Thermoeresistive sensors

- RTD signa-conditioning circuits

RTD - resistance temperature detector

- Two-wire uncompensated RTD circuit



For bridge in balance

$$\frac{R_1}{R_2} = \frac{R_{L1} + R_{L2} + R_3}{R_4}$$

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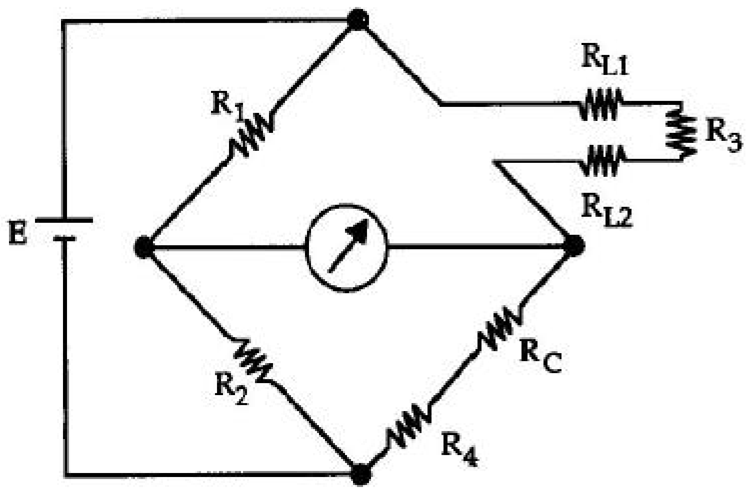
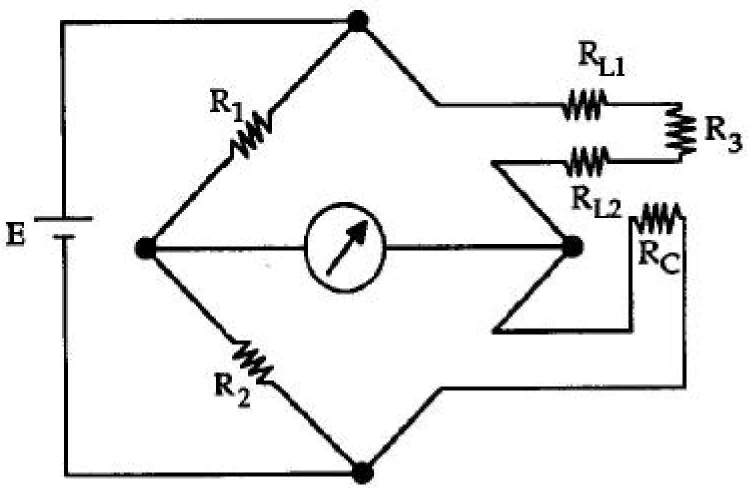
Thermoeresistive sensors

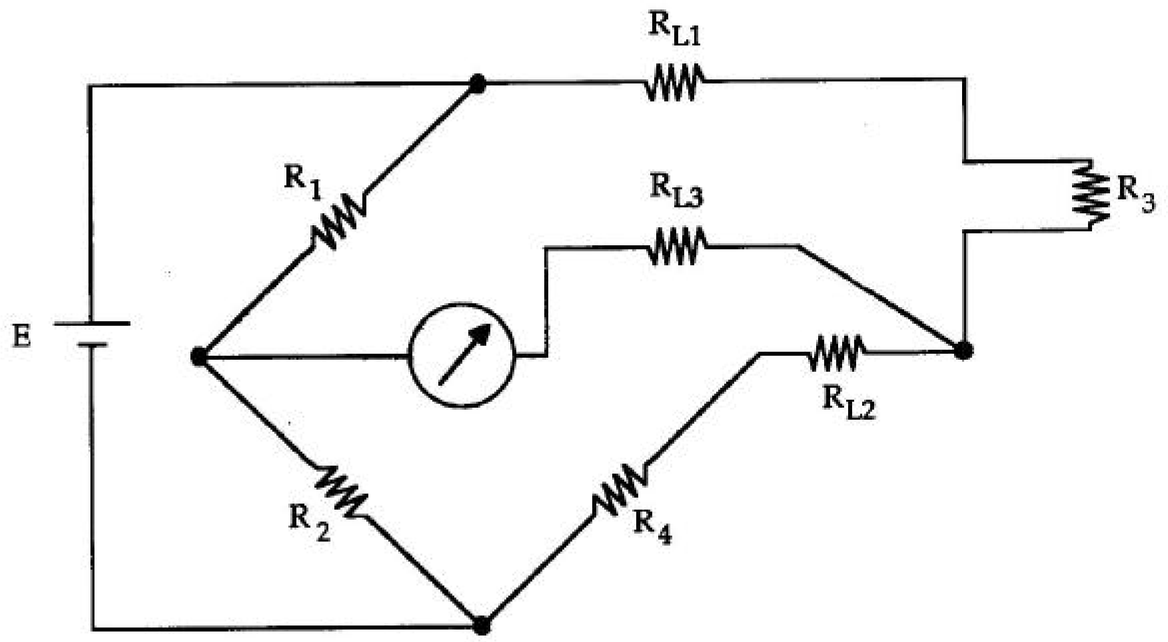
- Two-wire compensated RTD circuit





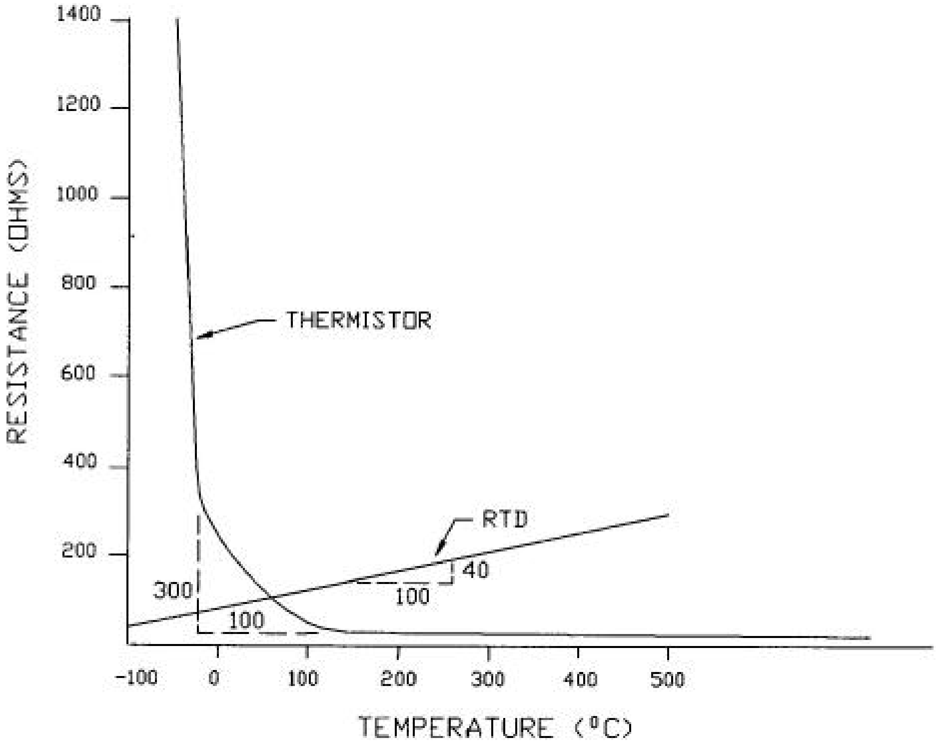
Thermoeresistive sensors

- Three-wire RTD circuit



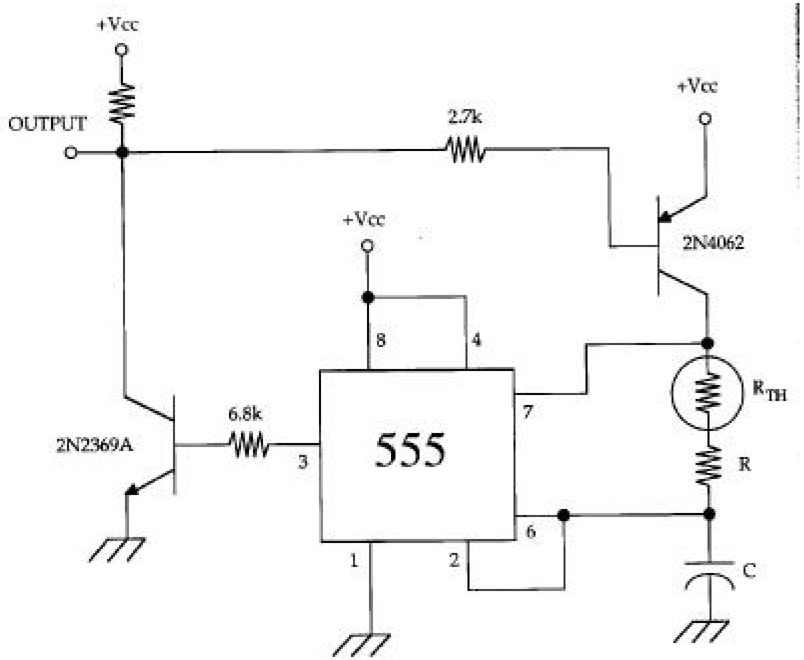
Thermoeresistive sensors

- Thermistor



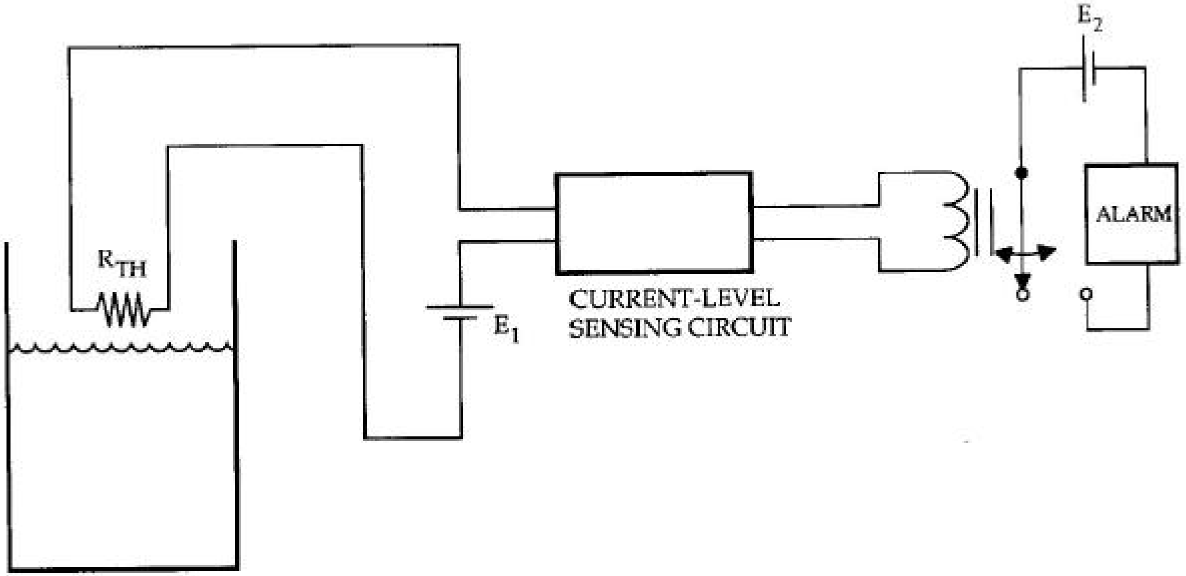
Thermoeresistive sensors - applications

- Temperature - frequency converter



Thermoeresistive sensors - applications

- Thermistor used as level indicating device



Review Questions

- Describe in detail the Peltier, Seebeck and Thomson effects.
- What effects contribute to Seebeck effect?
- What would you think the dc resistance would be for thermocouple? Do you think the resistance would be thousand, hundreds of ohms, or just few ohms?
- What is a thermopile? Where are they used?
- Explain the difference between material having a positive and negative temperature coefficient
- What is the advantage of using a platinum RTD versus one made of nickel? What is the advantage of a nickel RTD?
- Explain the circuit for three-wire RTD and explain its advantages over a standard two-wire uncompensated circuit.