SENSORS and TRANSDUCERS

The Thermal Energy Domain

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

\[ \Delta V = \alpha_S \Delta T \]

where:
- \( \alpha_S (\mu V K^{-1}) \) - Seebeck coefficient
- \( \Delta V (V) \) - voltage difference
- \( \Delta T (K) \) - 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 environment.

\[ Q = -\Pi_{ab} J_{ab} \]

where:

- \( Q \) (J m\(^{-2}\)) - dissipated or absorbed heat
- \( \Pi_{ab} \) (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.
Thermal Energy Domain - Physics

Thomson effect

\[ Q_{th} = \gamma \cdot J \cdot \Delta T \]

where

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

Thermoresistance

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 most materials

Microscopic description

\[ \sigma = n \cdot q \cdot \mu \]

where:

\( \sigma \) (Ω m) - conductivity

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

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

\( \mu \) (m\(^2\)V\(^{-1}\)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

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

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

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Thermoelectric sensors

* Thermocouples

![Diagram of thermocouples](image)
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.](image)
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.)
Thermoereresistive sensors

* Temperature coefficients of metals

Dc resistance vs temperature for platinum
Thermoerisitve sensors

- RTD signal-conditioning circuits
  RTD - resistance temperature detector
- Two-wire uncompensated RTD circuit

For bridge in balance
\[
\frac{R_1}{R_2} = \frac{R_{L1} + R_{L2} + R_3}{R_4}
\]
Thermoerestive sensors

- Two-wire compensated RTD circuit
Thermoerisitve sensors

- Three-wire RTD circuit
Thermoerisistive sensors

- Thermistor
Thermoeresistive sensors - applications

- Temperature - frequency converter
Thermoerisstive 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.