Lecture 11
Temperature Sensing
Temperature Sensing

Q: What are we measuring?
A: Temperature

SI Units: Celcius (° C), Kelvin (K)
British Units: Fahrenheit (° F)

Celcius-Fahrenheit
Approximate Conversion: \( y(° F) = x(° C) \times 2 + 30 \)
Exact Conversion: \( y(° F) = x(° C) \times 1.8 + 32 \)

Celcius-Kelvin
Exact Conversion: \( y(K) = x(° C) + 273.15 \)
## Temperature Sensors

### Resistance Temperature Detector (RTD)
- Honeywell HEL-777-A-T-0 (Platinum RTD)
- Honeywell TD4A (Liquid Temperature RTD)

### Thermistor
- NTCLE100E3 (NTC Thermistor)
- PTCSL03T151DT1E (PTC Thermistor)

### Thermocouple (Thermoelectric)
- Omron E52-CA1DYM6
Applications of Temperature Sensors

Digital Thermometers (Thermistor)

Refrigeration and Food processing (RTD)
Applications of Temperature Sensors

Gas Oven Safety Valve
(Thermocouple)

Oil Refinery
(Thermocouple)
Types of Temperature Sensors

- Resistance Temperature Detector (RTD)
- NTC Thermistor
- Thermocouple
Thin film RTD

- Thin Film RTDs are mainly platinum on Si substrate
- Platinum (Pt-RTD) exhibits a nearly linear temperature-resistance curve
- High stability, repeatability, and accuracy: good for extreme temperature conditions
- Pt-RTD can be used between -50°C and +500°C

Wire-wound RTD

- Wire-wound RTDs contain Platinum wire wound on glass inside ceramic or glass tube
- More expensive than thin film RTDs
- Higher source currents
- Positive Temperature Coefficient: resistance increases with an increase in temperature. Typical PTC = 0.00385 /deg. C
- Typical resistance = 100-300 ohms between -100°C and 400°C

**Resistance vs Temperature Curve**

-200°C to 0°C: \( R_t = R_0[1 + At + Bt^2 + Ct^3(t - 100)] \)

0°C to 630°C: \( R_t = R_0[1 + At + Bt^2] \)

Types of Temperature Sensors

- Resistance Temperature Detector (RTD)
- NTC Thermistor
- Thermocouple
Thermistor

Thermistor = thermal + resistor

- Thermistor changes its resistance with change in temperature
- RTD are usually made from metals, thermistors can be ceramic or polymer based
- RTDs have wide temperature range, thermistors have limited temperature range
- Negative Temperature Coefficient (NTC): resistance decreases with increasing temperature
Thermistor Transfer Function

- **Resistance of thermistor at 25 °C**

- Assume negligible self-heating (negligible rise in its temperature when the current is passing through the thermistor)
Thermistor Model

Basic Equation

\[ \ln S = A_0 + \frac{A_1}{T} + \frac{A_2}{T^2} + \frac{A_3}{T^3} \]

where \( S \)=measured resistance of a thermistor at the unknown temperature \( T \), and \( A_0, A_1, A_2, A_3 \) are constants derived empirically

Simple Model (first order approximation)

\[ \ln S = A + \frac{\beta_m}{T} \Rightarrow S = S_0e^{\beta_m\left(\frac{1}{T} - \frac{1}{T_0}\right)} \Rightarrow T = \left(\frac{1}{T_0} + \frac{\ln \frac{S}{S_o}}{\beta_m}\right)^{-1} \]

where \( \beta_m \)=material characteristic temperature (K), \( T_0 \)=reference temperature (~25 °C), \( S_0 \)=reference resistance

Modified Steinhart-Hart Model (Vishay Spreadsheet)

\[ T = A + B \ln\left(\frac{R}{R_0}\right) + C \ln\left(\frac{R}{R_0}\right)^2 + D \ln\left(\frac{R}{R_0}\right)^3 \]

where

- \( A, B, C, D \)=empirical constants (given)
- \( R_0 \)=reference resistance
- \( R \)=measured resistance
Thermistor Circuit

Wheatstone Bridge with Instrumentation Amplifier

- Match $R_1 = R_2 = R_3 = R = R_0 =$ resistance of thermistor at 25°C

- First figure out $V_{o1}$ in relation to the resistance ratio, $R_4/R$

- Use relation $V_{o2} = G V_{o1}$ (where $G =$ gain of the INA => look up in the datasheet or derive from the measured data) and solve for unknown temperature $T$
Types of Temperature Sensors

- Resistance Temperature Detector (RTD)
- NTC Thermistor
- Thermocouple
Type K (Chromel-Alumel) Thermocouple

Ref: Thermocouple application by Texas Instruments
Thermocouple Sensors

Thermocouple (or Thermoelectric) Sensor

- Thermocouple junction is formed when two dissimilar metals or metal alloys are joined together (often the leads are also made of dissimilar metals).
- Thermocouple junction put in contact with the hot or cold point and the leads are kept at room temperature.
- The temperature gradient is developed along the length of the leads which results in two separate Seebeck EMFs.

Ref: Thermocouple application by Texas Instruments
Thermoelectric (Seebeck) Effect

**Thermoelectric Circuit**

- These can also be two different metals

When one end of the conductor is hotter than the other end, electrons at the hot end are thermally energized and diffuse toward the cooler end.

- **N-type**: Diffusion of electrons creates positive charge at hot end and negative charge (abundance of electrons) at the cool end.

- As a result potential difference or thermocouple EMF is generated.
Seebeck Coefficients

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*: Units are μV/°C; all data provided at a temperature of 0 °C (32 °F)

- Possible wire pairings:
  - Type J(T): Iron(copper) for the positive terminal and constantan for the negative terminal
  - **Most Common is Type K**
  - Type K: Chromel-Alumel
    - Chromel: 90% Ni, 10% Cr
    - Alumel: 95% Ni, 2% Mn, 2% Al and 1% Si

Ref: Thermocouple application by Texas Instruments
Thermocouple: Voltage to Temperature Curves

\[ T_x - T_r = \frac{V_p}{\alpha_p} \]

where, \( T_x \) = unknown temperature, \( T_r \) = reference temperature,

\( V_p \) = thermocouple emf, \( \alpha_p \) = thermocouple sensitivity [\( \mu V/\degree C \)]