ELECTRONIC SYSTEM DESIGN

TEMPERATURE SENSORS

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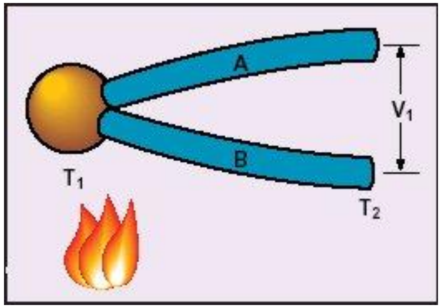
Temperature Sensors

- These sensors translate the temperature into a reference voltage, resistance or current, which is then measured and processed and a numerical temperature value is computed.
- There are four main contact temperature-sensing devices available, divided in three families:
  - Thermocouples (self-generating sensors),
  - Resistance temperature detectors
  - Thermistors (resistive sensors)
  - Temperature-transducing ICs (PN or Semiconductive).

http://sensorwiki.org/doku.php/sensors/temperature

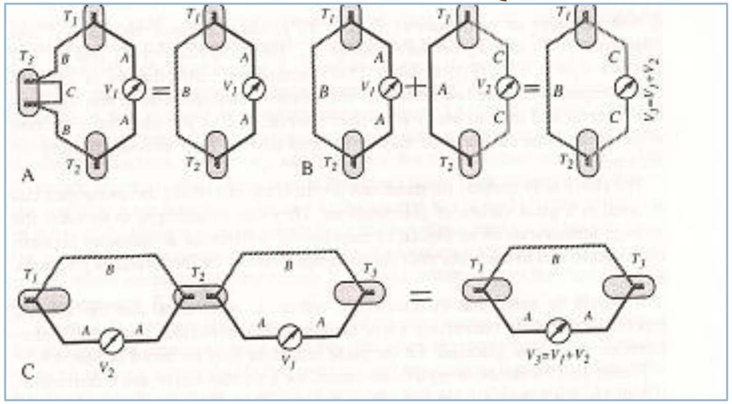
Thermocouples

- Thermocouples are a physically simple sensor, though how they function is more complex
- A thermocouple is comprised of two dissimilar alloys (wires A and B) joined at one end, called the “hot junction” (T1)
  - The other leads are connected to a voltmeter or other input device that measures the voltage (V1) across the “cold junction” (T2).
- The hot junction is the sensing element, and the cold junction is kept at a constant reference temperature.
  - A voltage is produced as the hot junction is heated, which is proportional to the temperature difference between the two junctions
  - This principle, called the thermocouple effect and the electromotive force (EMF) produced when the junctions of dissimilar alloys are maintained at different temperatures is known as the Seebeck EMF



Thermocouple Laws

- Fraden (1997) defines three laws for proper connection of thermoelectric materials :
  - Law No.1 (A) - A thermoelectric current cannot be established in a homogeneous circuit by heat alone. (LAW OF HOMOGENEOUS CIRCUITS)
  - Law No.2 (B) - The algebraic sum of the thermoelectric forces in a circuit composed of any number and combination of dissimilar materials is zero if all junctions are at a uniform temperature. (LAW OF INTERMEDIATE METALS)
  - Law No.3 (C) - If two junctions at temperature T1 and T2 produce Seebeck voltage V2, and temperatures T2 and T3 produce voltage V1, then temperatures T1 and T3 will produce V3 = V1 + V2. (LAW OF INTERMEDIATE TEMPERATURES)

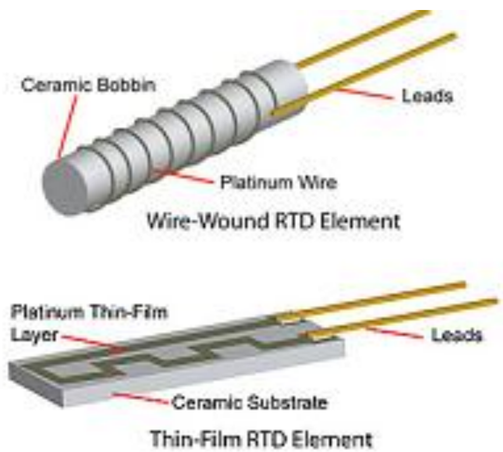


Thermocouples

- The Seebeck EMF produced by a thermocouple is of such small scale that the voltage must be amplified and processed by a specialized thermocouple input module.
- Thermocouples are calibrated with a cold junction temperature of 0°C.
  - However, two problems arise when connecting thermocouples to their input device: firstly, the input terminals, which are constructed with a different type of metal, create their own Seebeck voltage which alters the actual thermocouple voltage; and second, the device has to be recalibrated for an operational cold junction temperature
  - With the advancements in technology over the past few decades, these input modules have been designed to be self-calibrating and self-compensating and are able to be configured for a variety of thermocouple types.

Resistance Temperature Detectors (RTDs)

- Resistivity of metals are highly influenced by temperature
  - RTDs function on the principle that as the sensing element is heated, the resistance of the metal wire increases proportionally
- Two major types of RTDs are available for industrial and commercial use : wire-wound and thin film



Resistance Temperature Detectors (RTDs)

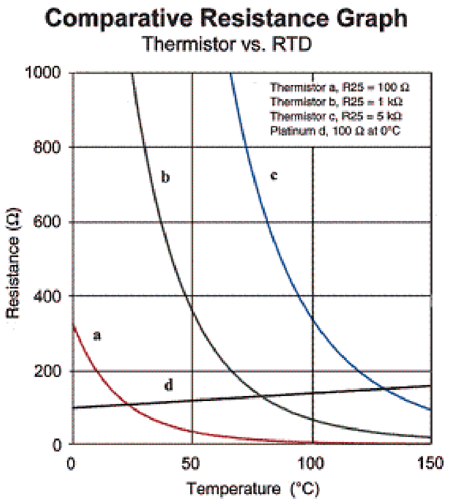
- RTDs are commonly made with copper, nickel, or nickel-iron, but platinum RTDs are the most linear, repeatable, and stable
  - The resistance is almost a linear function of temperature for very pure platinum, which is the primary reason for this metal's pervasiveness in RTDs
- RTDs are calibrated to exhibit a resistance of 100 Ω at 0°C.
  - Their resistance at other temperatures depends on the value of the mean slope of the metal's resistance-temperature plot, known as the *constant alpha*. Alpha is dependent upon the platinum's purity.
- Although RTDs are fairly linear, advanced RTD input devices use software with curve fitting and software processing to increase their accuracy at higher temperatures.

Thermistors

- Thermistors, like RTDs, vary their resistance as the ambient temperature is changed.
  - Unlike RTDs, which use pure metals, the material used in a thermistor is generally a ceramic or polymer.
  - Positive temperature coefficient (PTC) thermistors will show an increase of resistance with increasing temperature
  - Negative temperature coefficient (NTC) thermistors will show a decrease of resistance with increasing of temperature.
- Thermistors typically achieve a higher precision than RTD within a limited temperature range (usually −90 °C to 130 °C).

Thermistors

- Comprised of a metal oxide ceramic semiconductor sensing element, thermistors are notorious for their non-linearity
- Thermistors vary their resistance about -4.4% at 25°C when heated by one degree Celsius
- Since thermistors are resistive devices, in operation an electrical current is passed through the sensor and some of this electricity is converted into heat, which may cause slightly higher than ambient temperature readings
- Thermistors can operate without significant error with long lead wires, because of their high base resistance. Thus they can be installed at long distances, upwards of one hundred meters, from the input module.
- Thermistor resistances are non-standardized and vary from 100 to 1,000,000 Ω at 25°C (Ogden, 2000).



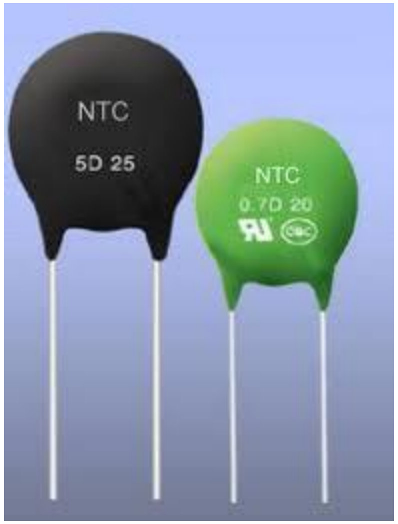
Temperature Transducer ICs

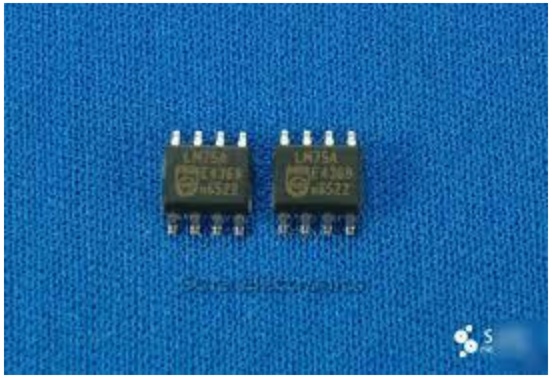
- Semiconductor diodes have temperature-sensitive voltage vs. current characteristics.
  - When two identical transistors are operated at a constant ratio of collector current densities, the difference in base-emitter voltages is directly proportional to the absolute temperature.
- The use of IC temperature sensors is limited to applications where the temperature is within a –55° to 150°C range.
  - The measurement range of IC temperature sensors may be small compared to that of thermocouples and RTDs, but they have several advantages: they are small, accurate, and inexpensive
- Temperature sensing ICs are available either in analog form, which output a voltage or current which is proportional to the temperature, or digital, which communicate temperature over a digital communication line, such as one-wire PWM, two-wire I2C, or a multiple wire SPI connection

Comparison of Temperature Sensors

Characteristic	Platinum RTD	Thermistor	Thermocouple	Temperature IC
Active Material	Platinum Wire	Metal Oxide Ceramic	Two Dissimilar Metals	Silicon Transistors
Changing Parameter	Resistance	Resistance	Voltage	Voltage or Current
Temperature Range	-200°C to 500°C	-40°C to 260°C	-270°C to 1750°C	-55°C to 150°C
Sensitivity	2 mv/°C	40 mV/°C	0.05 mV/°C	~1 mv/°C or ~1 uA/°C
Accuracy	-45 to 100°C: ±0.5°C; 100 to 500°C: ±1.5°C; 500 to 1200°C: ±3°C	-45 to 100°C: ±0.5°C; degrades rapidly over 100°C	0 to 275°C: ±1.5 °C to ±4°C; 275 to 1260°C: ±0.5 to ±0.75%	±2 °C
Linearity	Excellent	Logarithmic, Poor	Moderate	Excellent
Response Time	2-5 s	1-2 s	2-5 s	
Stability	Excellent	Moderate	Poor	Excellent
Base Value	100 Ω to 2 kΩ	1 kΩ to 1 MΩ	< 10 mV	Various
Noise Susceptibility	Low	Low	High	High
Drift	+/- 0.01% for 5 years	+/- 0.2 to 0.5°F per year	1 to 2°F per year	0.1°C per month
Special Requirements	Lead Compensation	Linearization	Reference Junction	None
Device Cost	$60 - $215	$10 - $350	$20 - $235	$5 - $50
Relative System Cost	Moderate	Low to Moderate	Moderate	Low

Practical Shape





Assignment

- Implement a temperature sensing circuit that produces a voltage proportional to the temperature at a particular point.