Thermistors

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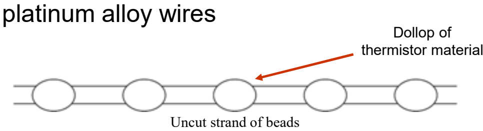
Thermistors

- A thermistor is a thermally sensitive semiconductor whose resistance varies with temperature
- Semiconductor materials: Typically oxides of
  - Manganese
  - Cobalt
  - Iron
  - Nickel
  - Copper
  - Uranium
- Typically have a large negative temperature coefficient (NTC)
  - Resistance decreases with increasing temperature
- Resistance function is non-linear
- Static sensitivity is much larger than for RTDs

How are thermistors made?

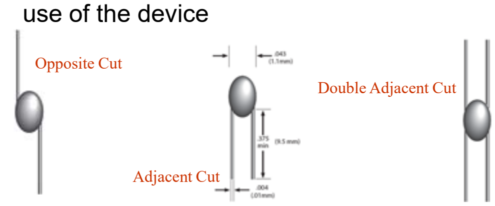
- A dollop of slurry made of mixed metal oxides and a suitable binder is dropped onto platinum alloy wires



- Surface tension forms an ellipsoidal shape
- The metals are heated to form an electrical contact with the wires

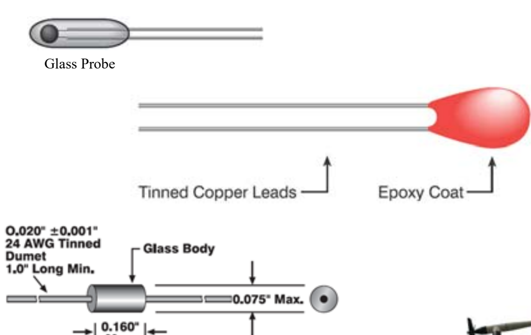
Cut the wires to shape

- The wires are cut to shape depending on the use of the device



- The thermistor is usually coated with glass and/or another protective covering to seal the thermistor and provide some strain relief

Thermistor Coatings



Thermistor Transfer Equation

- There are several possible transfer equations for different thermistors
- In all cases, the resistance of a thermistor is a function of the absolute temperature

Steinhart-Hart Equation

- Studies have shown that a good relationship for a thermistor exists between $\ln(R_T)$ and a polynomial of 1/T

$$\ln(R_T) = b_0 + \frac{b_1}{T} + \frac{b_2}{T^2} + \ldots$$

  - R_T = Resistance at T (in K)

- This is one version of the Steinhart-Hart equation
- Requires many calibration coefficients

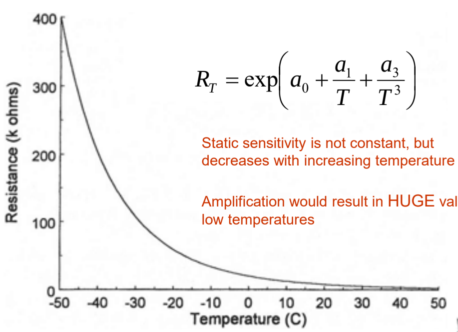
Steinhart-Hart Equation

- Empirical tests have shown that only three terms are required for accurate measurements:

$$R_T = \exp\left(a_0 + \frac{a_1}{T} + \frac{a_3}{T^3}\right)$$

- Very nonlinear
- Nonlinearities can be corrected with analog conditioning circuits such as bridge circuits or by using microprocessors

Thermistor Transfer Equation

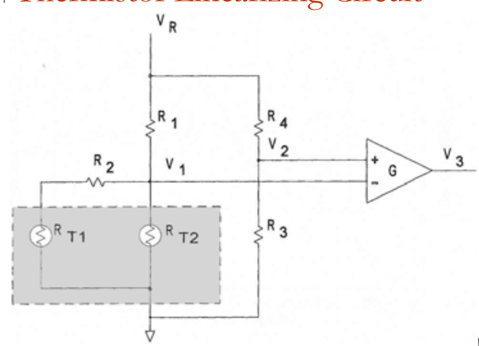


$$R_T = \exp\left(a_0 + \frac{a_1}{T} + \frac{a_3}{T^3}\right)$$

Static sensitivity is not constant, but decreases with increasing temperature

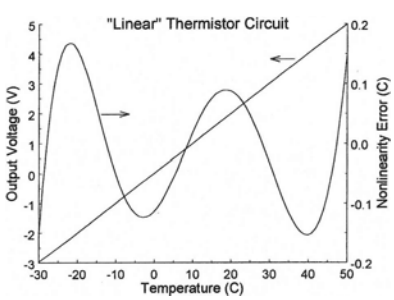
Amplification would result in HUGE values for low temperatures

Thermistor Linearizing Circuit



An almost linear circuit with two thermistors

Thermistor Linearizing Circuit



The voltage output (left) and residual nonlinearity (right) from the linearizing circuit with properties given in your textbook (p. 75)

Thermistor Advantages

- High resistance (1 kΩ to 100 kΩ)
  - Eliminates problems with resistance in lead wires
- Highly non-linear R_T vs. T relationships
  - Mostly negative temperature coefficients (NTC) from metal oxides, but positive temperature coefficient (PTC) models are available from barium and strontium titanate mixtures
  - Can be linearized

- Small physical size
  - Fast response time
  - Not as small as thermocouples

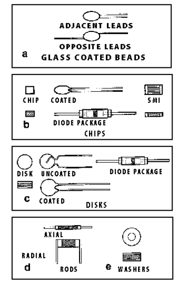
Thermistor Advantages

- Lower cost than RTDs
  - Easy to manufacture in bulk
- Wide temperature range
- Very high sensitivity and resolution
  - Up to 1000 times more sensitive than RTDs
- Can withstand shock and vibration
- Accurate

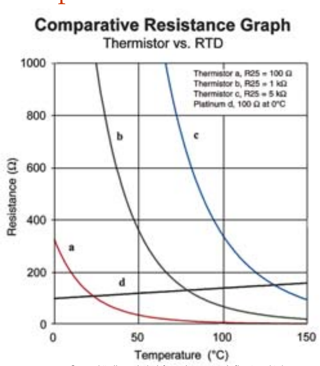
Image source: http://www.advindsys.com/Products/Thermistors.htm

Thermistor Disadvantages

- The nonlinear response requires extra circuitry
- Limited range of linear response with this additional circuitry
- Narrow "linear" operating range for a single sensor
- The glass can break if mishandled
- Requires an excitation current
- High resistance leads to self-heating errors (more so than RTDs)
- Less stable than RTDs



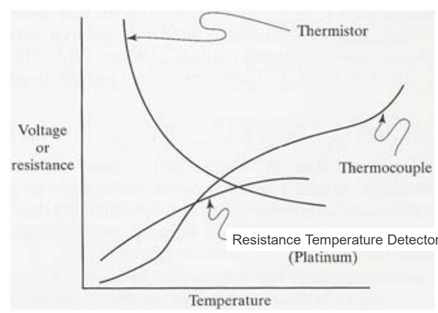
Comparison of Resistance Thermometers



Source: http://www.designinfo.com/cornerstone/ref/negtemp.html

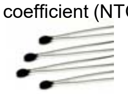
$$SS = \frac{dR_T}{dT}$$

Comparison of Resistance Thermometers



Resistance Thermometers: A Summary

- The electrical resistance of various materials changes in a reproducible way when subjected to temperature variations.
- An RTD (resistance temperature detector) is a precision temperature-sensing device that utilizes metal conductors (typically a fine platinum wire winding or a thin metallic layer applied to a substrate) and has a positive coefficient of resistance. That is, as T increases, resistance increases almost linearly. These are called positive temperature coefficient devices (PTC).
- Thermistors are made from semiconductor materials that have a large negative coefficient of resistance. That is, as T increases, resistance decreases. These are called negative temperature coefficient (NTC) thermistors.



Other types of temperature sensors:

Capacitive Sensors

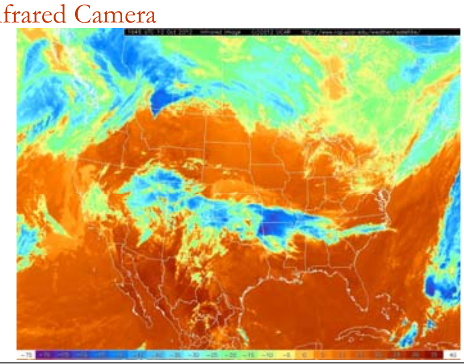
$$C = \frac{K\varepsilon_0 A}{d}$$

- Once we fix A and d, the only variable that can change is the dielectric constant, K, which changes with temperature

Other types of temperature sensors:
Integrated Circuit (IC) Thermometer

- Used in automotive applications and cheap weather sensors
- Sensor and signal conditioning circuits all located on a single integrated circuit
- Accuracy is ~0.5°C
- Low cost

Other types of temperature sensors:
Infrared Camera



Other types of temperature sensors:
Infrared Thermocouple

- Receives heat energy from object and converts to electrical potential
- Unpowered
- Low cost
- Non-invasive
- Fast response time

Sensor Choice

- How do we decide which type of sensor to use?
- Usually depends on your application
  - Cost
  - Size
  - Additional circuitry
  - Accuracy
  - Response time
- We can also make a decision by determining which sensor requires the least amount of gain

Figure of Merit

- Assuming <u>all other things are equal</u>, look at the gain:
  - Figure of merit = $(log_{10}(G))^{-1}$
  - We want the smallest gain possible
    - High gain amplifier amplifies noise <u>and</u> the signal and is more expensive

Sensor	Gain	Merit
Thermocouple	2456	0.29
Resistance (RTD)	93	0.51
Linear thermistor	14.7	0.86

In this example, the thermistor is the best bet, but this may not be the case for your application!