Lecture 4: Thermocouple and Infrared Thermometry

0. Review

1. Thermocouple

2. Infrared Thermometer

- Reading: pdf's on website
  1. Thermocouple
  2. Thermal sensing
  3. TA Thermometry

- Today: HW1 due
  Quiz next Tue (1/21) ← HW1 material
- Lab1 report due next Fri (1/25)
  (see course website for template)
- PreLab2 due next lab session
- HW2 due next Thu (Jan 24)

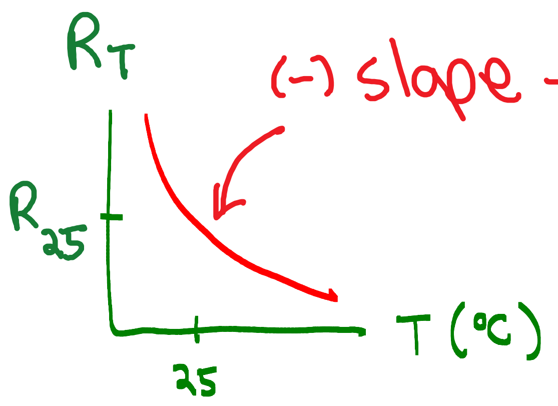
0. Review

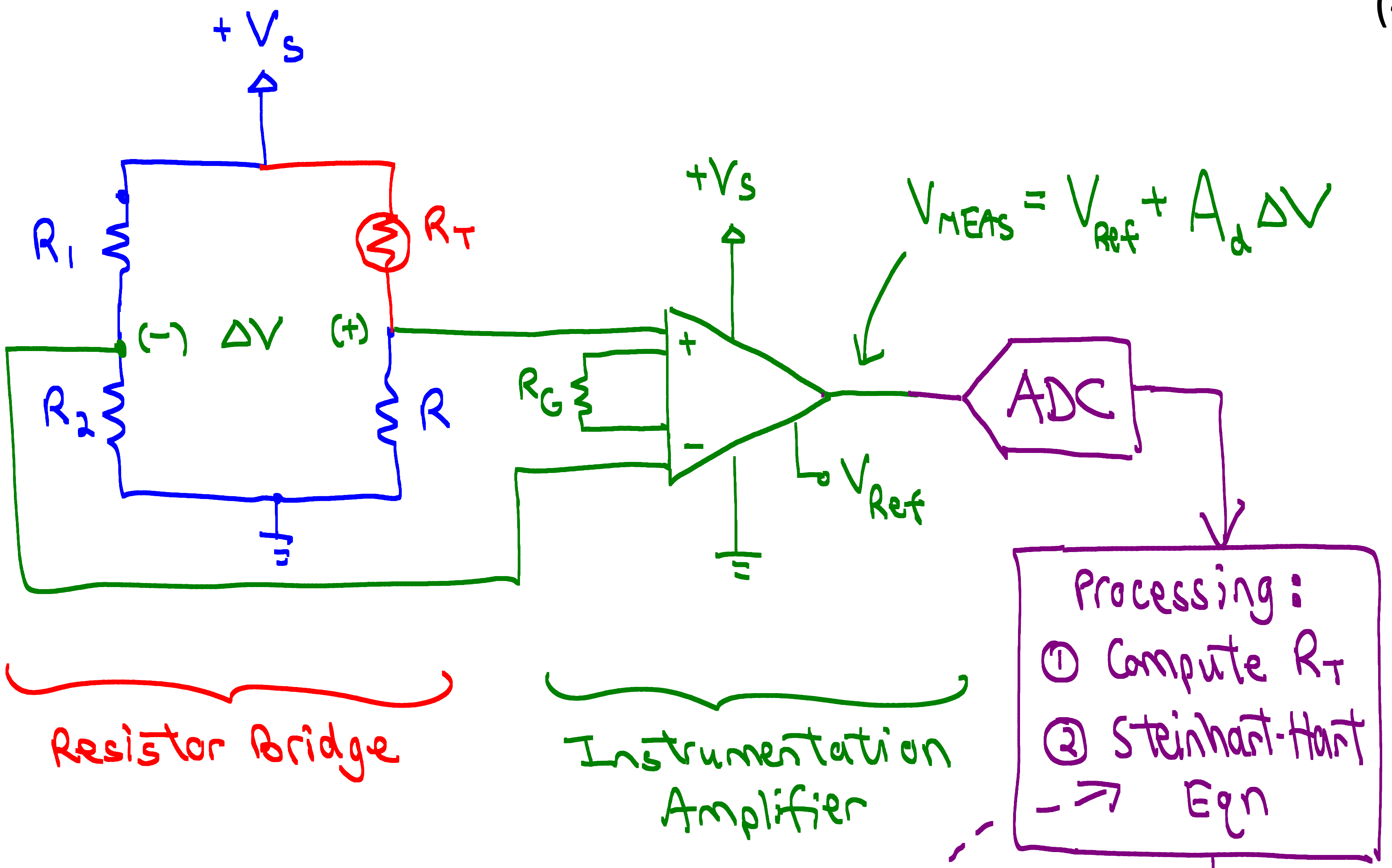
- **Thermistor**

$$\frac{\partial R_T}{\partial T} = \alpha R_T$$

Negative TempCo (NTC)

(-) slope





Sensitivity:

$$\Delta T_{MIN} = \frac{\Delta V_{MIN}}{\partial V_{MEAS}/\partial T}$$

Larger of V_{noise} vs. ΔV_{ADC}

$$T = \frac{1}{A + B\ln\frac{R_T}{R_{25}} + C\left(\ln\frac{R_T}{R_{25}}\right)^2 + D\left(\ln\frac{R_T}{R_{25}}\right)^3}$$

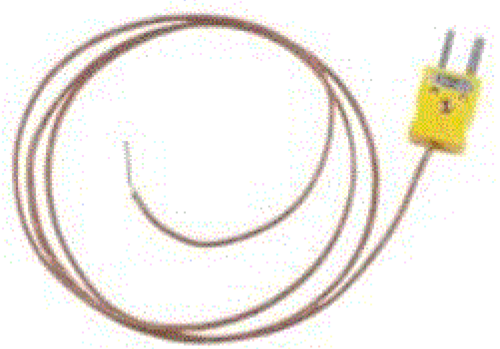
deg K

Temperature

1. Thermocouple

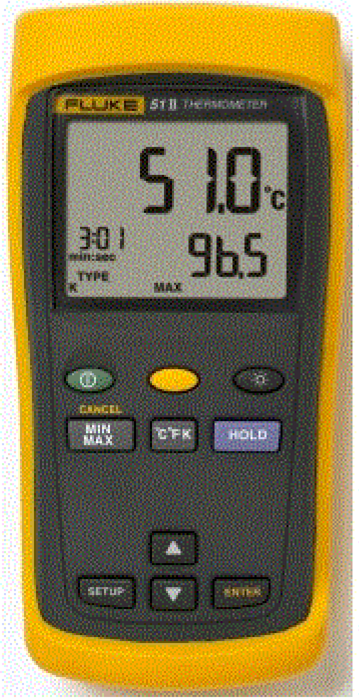
- More robust than thermistors
- Very wide temperature range ($\gtrsim 1000°C$!)
- Not as accurate as thermistors

community.craftsman.com



tecpel.com

Temperature is measured at the probe tip.



www.fluke.com

Probe plugs into this readout module

A. Seebeck Voltage

When two ends of a metal wire are at <u>different</u> temp, a small voltage exists!

$$\Delta V = V_A - V_B = S \times (T_A - T_B)$$

Seebeck coefficient

Copper: $S = +6.5\ \mu V/^\circ C$

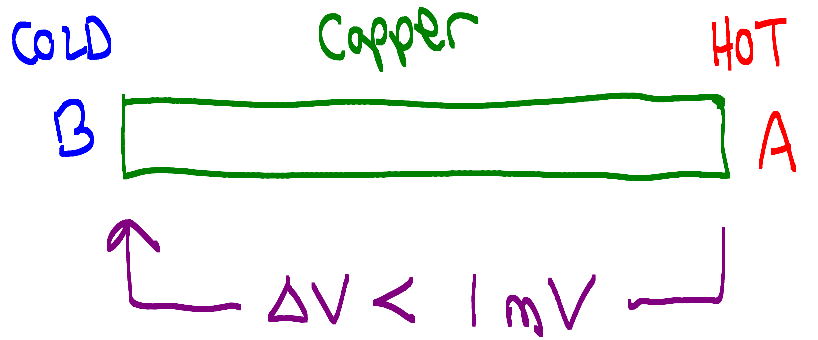
Constantan: $S = -35\ \mu V/^\circ C$

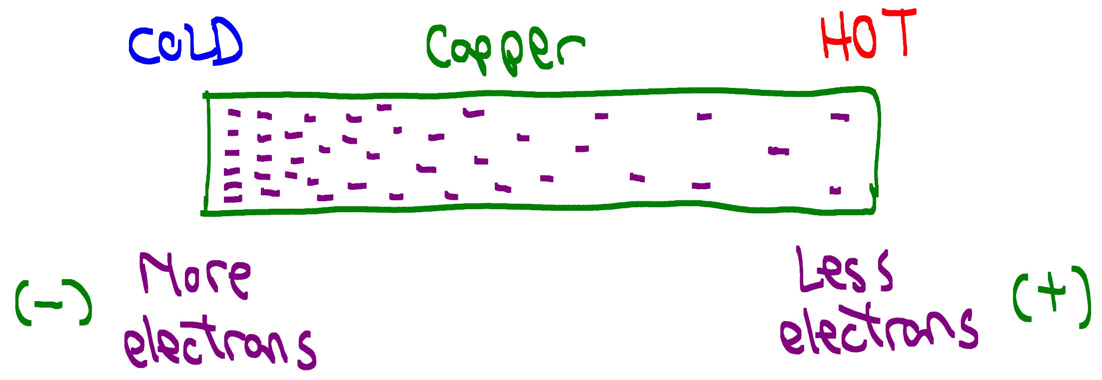
Why different sign?

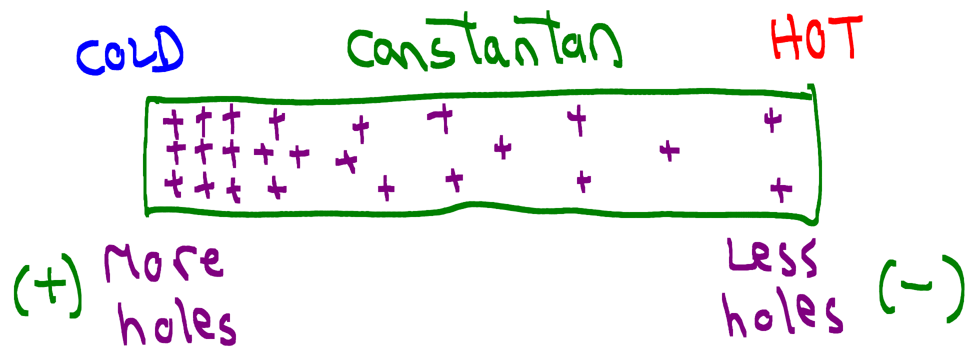
Cu: Diffusion by <u>electrons</u>

Ni/Cu: Diffusion by "holes"

Ex:

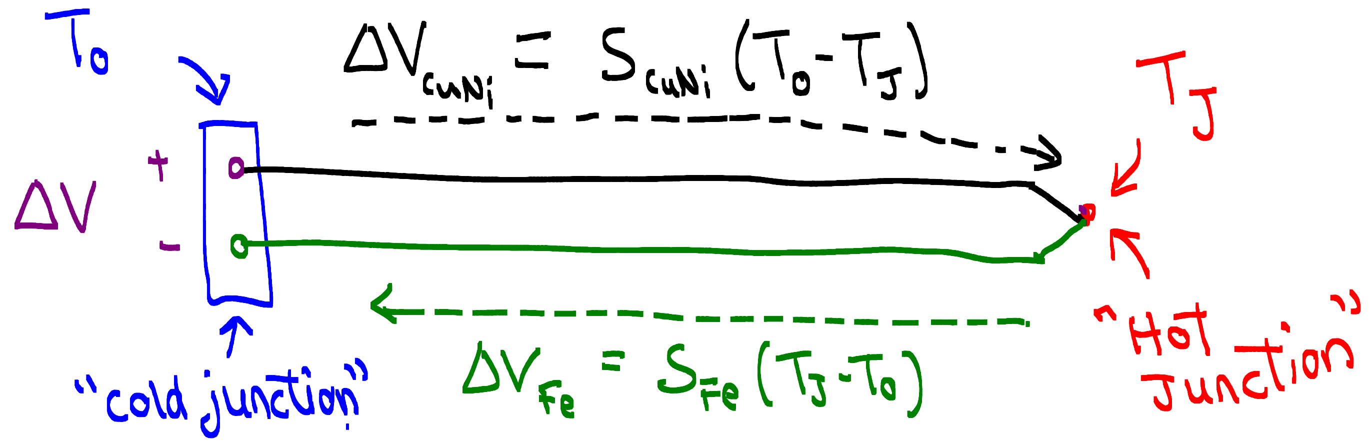






B. Thermocouple Junction

- A more useful configuration uses two wires of dissimilar metals
- Example: Iron-Constantan (Type J)



$$\Delta V = \Delta V_{CuNi} + \Delta V_{Fe} = S_{CuNi}(T_0 - T_J) + S_{Fe} \times (T_J - T_0)$$

$$= \underbrace{(S_{Fe} - S_{CuNi})}_{\Delta S} \times (T_J - T_0)$$

Type	Metal Pair	ΔS ($\mu V/°C$) ← At $T = 0°C$
E	Constantan-Chromel	62
J	Constantan-Iron	51
K	Alumel-Chromel	40
T	Constantan-copper	40

Chromel = Chromium/Nickel alloy

Constantan = Copper/Nickel alloy

Alumel = Aluminum/Nickel alloy

- Example: $T_0 = 20°C$, $T_J = 40°C \rightarrow \Delta T = 20°C$

$$\Rightarrow \Delta V = \left(51 \frac{\mu V}{°C}\right)(20°C) = 1020\,\mu V = \underline{\underline{1.02\,mV}}$$

Depends on temp difference

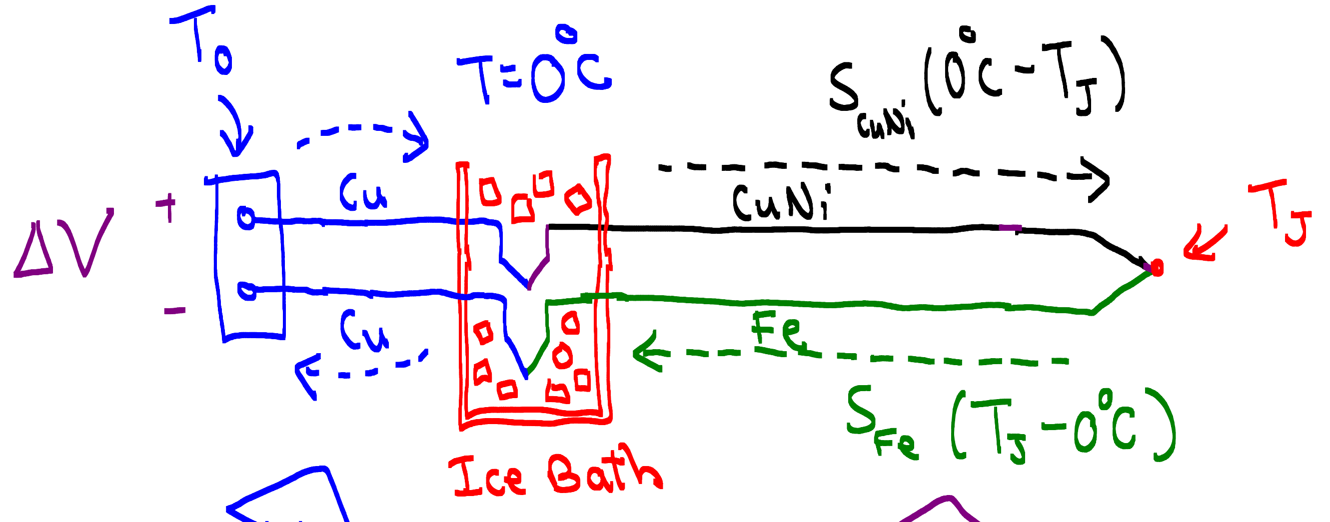
c. Ice Point Reference

How to get temperature T_J?

$$\Delta V = \Delta S * (T_J - T_0)$$

$$\Rightarrow T_J = \frac{\Delta V}{\Delta S} + \boxed{T_0}$$ ← Need to measure this as well :(

- Old fashioned solution was to include an ice point reference



Two Cu wires connect ice point to cold junction T_0

Both CuNi and Fe wires are connected to 0°C and T_J

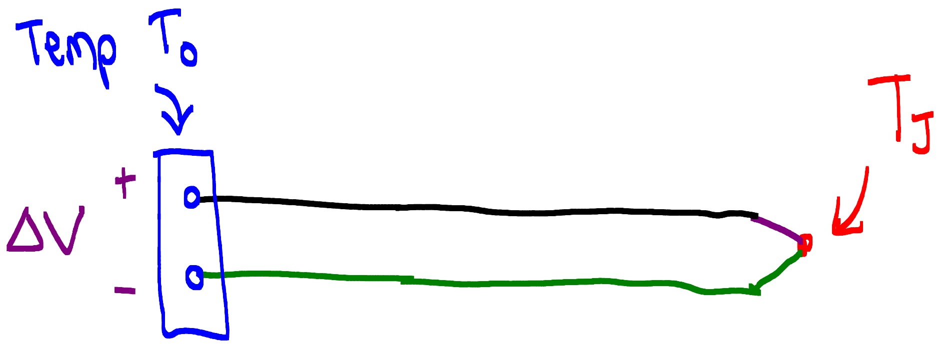
$$\Rightarrow \Delta V = \cancel{S_{Cu}(T_0 - 0°C)} + S_{CuNi}(0°C - T_J) + S_{Fe}(T_J - 0°C) + \cancel{S_{Cu}(0°C - T_0)}$$

$$= (S_{Fe} - S_{CuNi}) * T_J = \Delta S * T_J$$ ← No dependence on T_0! :)

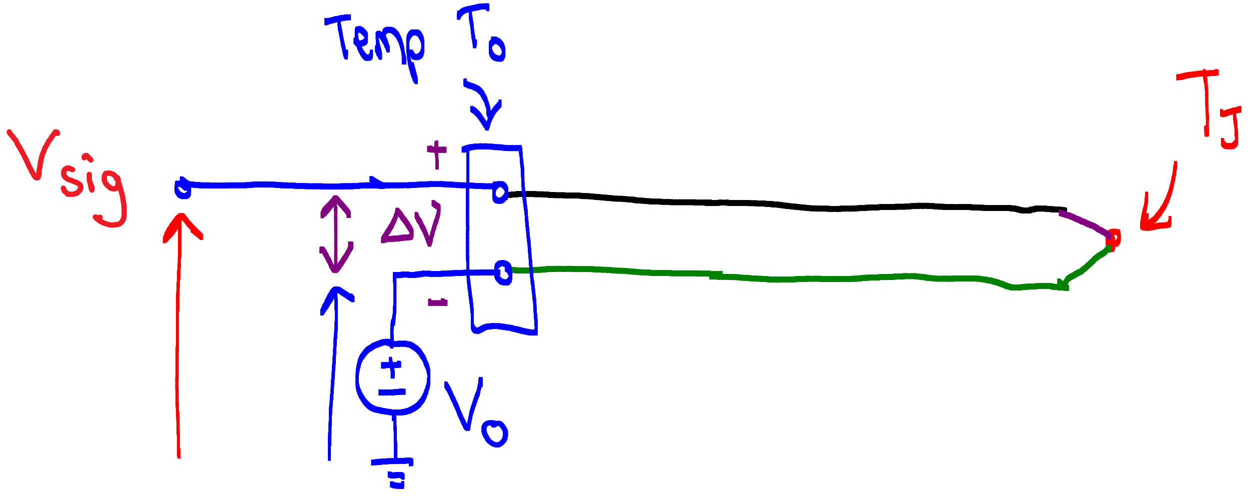
BUT, ice bath is not practical...

D. Cold Junction Compensation (CJC)

Q: How to replace the ice bath with a circuit?



VS.



$$\Delta V = \Delta S(T_J - T_0)$$

? ← :(

$$V_{sig} = V_0 + \Delta V$$

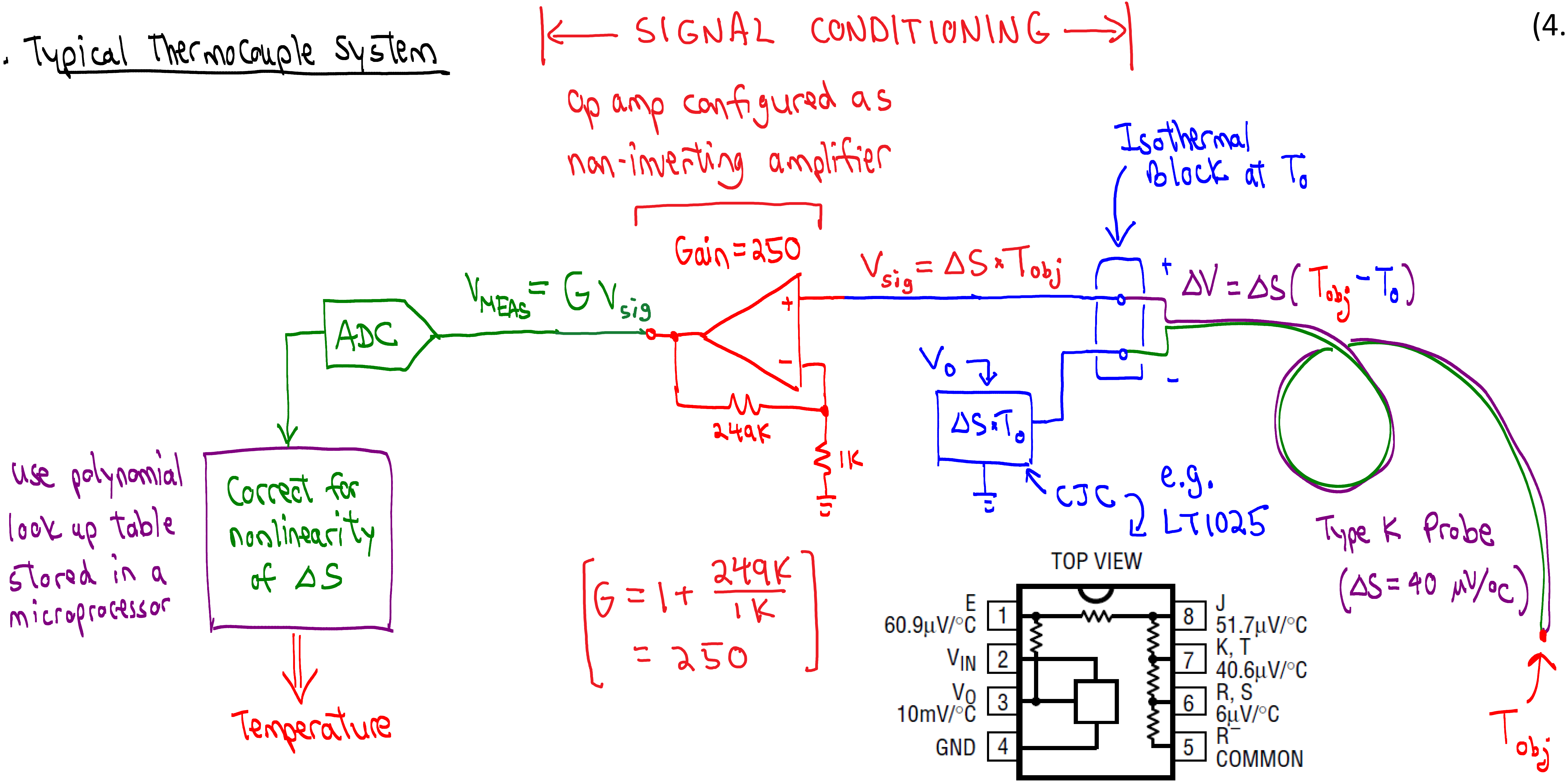
$$= \underbrace{V_0}_{\Delta S \cdot T_0} + \Delta S(T_J - T_0) = \Delta S \cdot T_J \quad :)$$

☆ $V_0 = \Delta S \cdot T_0$ is produced by a chip that measures T_0 (e.g. with thermistor)

Ex: LT1025 chip from Linear Technology

(4.6)

E. Typical Thermocouple System



2. Infrared Thermometry

- Thermistors and thermocouples require physical contact with the object
- Non-contact methods detect <u>infrared emission</u> from the object

depends on the object temperature! ⇐ Due to blackbody radiation

Examples:

① Ear Thermometer

② Temporal Artery Thermometer ↵ Ellis Hospital

③ Industrial thermometer

Google Images

①

②

www.exergen.com

③

www.fluke.com

A. Infrared Basics

- Wavelength: Broadly speaking, IR can have $0.8\,\mu m < \lambda < 1000\,\mu m$

- **Blackbody Radiation**

→ An object at thermal equilibrium radiates energy.

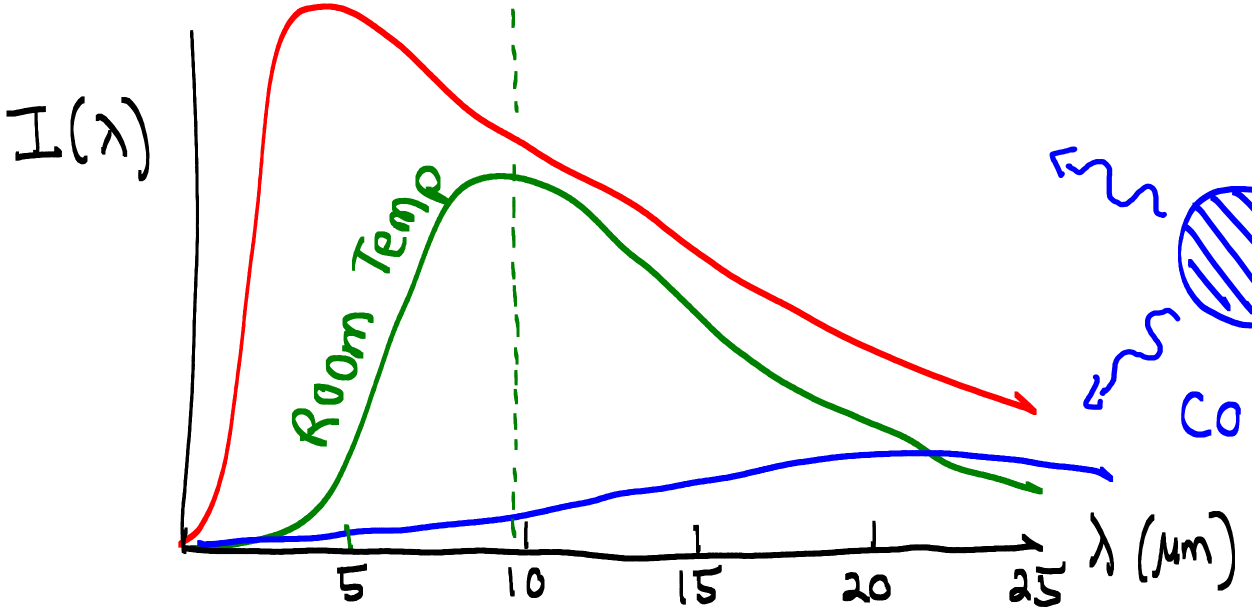
⇒ At room temperature, peak wavelength ~ 10 μm

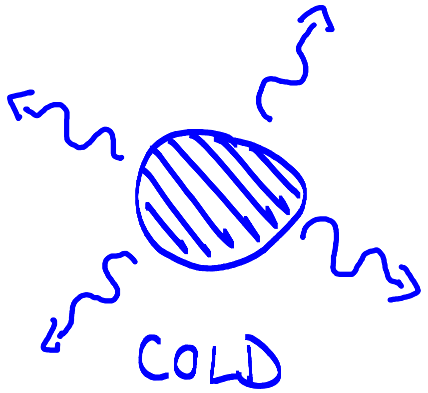
⇒ Radiated power density (W/cm²) over all wavelengths is:

$$\frac{P}{A} = \sigma \varepsilon T_{obj}^4$$

σ: Stefan-Boltzmann constant $\left(5.67 \times 10^{-8} \frac{W}{m^2 K^4}\right)$

ε: emissivity $(0 < \varepsilon < 1)$





B. System Diagram

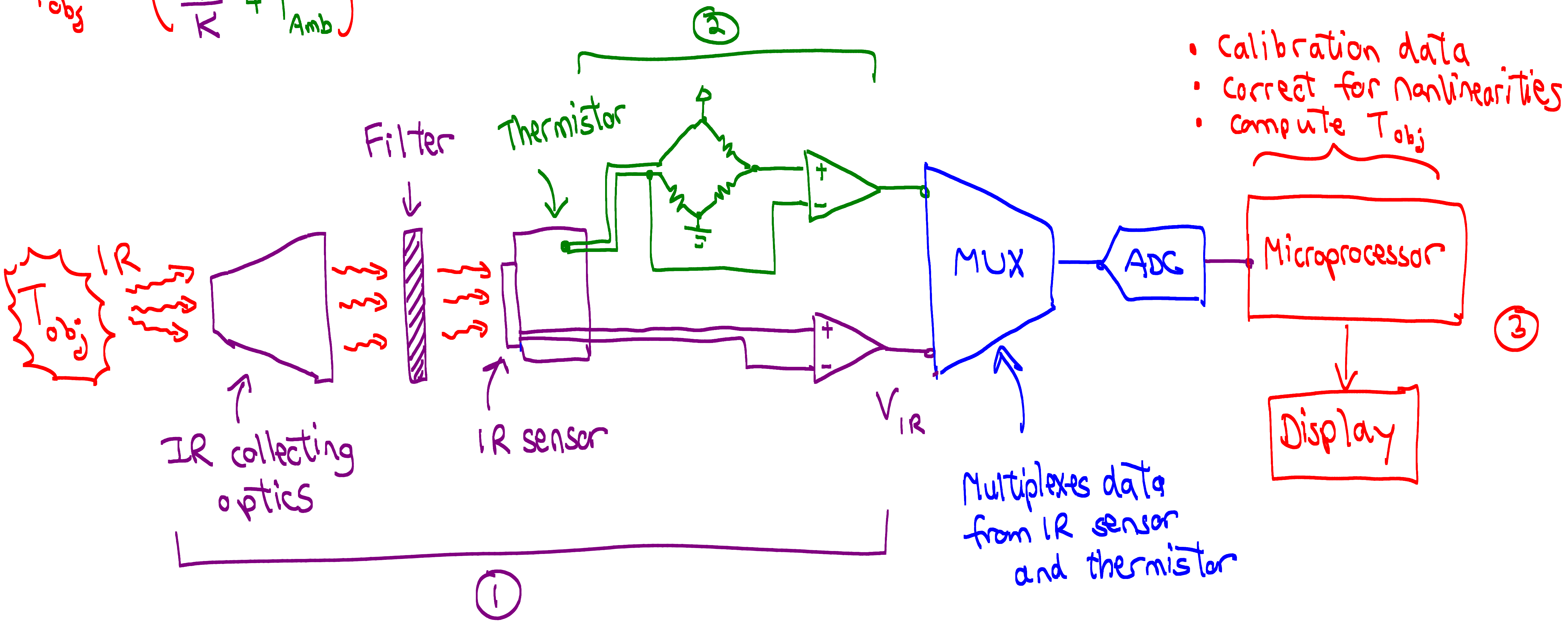
① Detect IR emitted from object: $V_{IR} = K * \left[T_{Object}^4 - T_{Ambient}^4 \right]$

Signal is really due to difference in temperature!

Depends on detector, optics, amplifier gain, etc

② Measure ambient temperature T_{Amb}

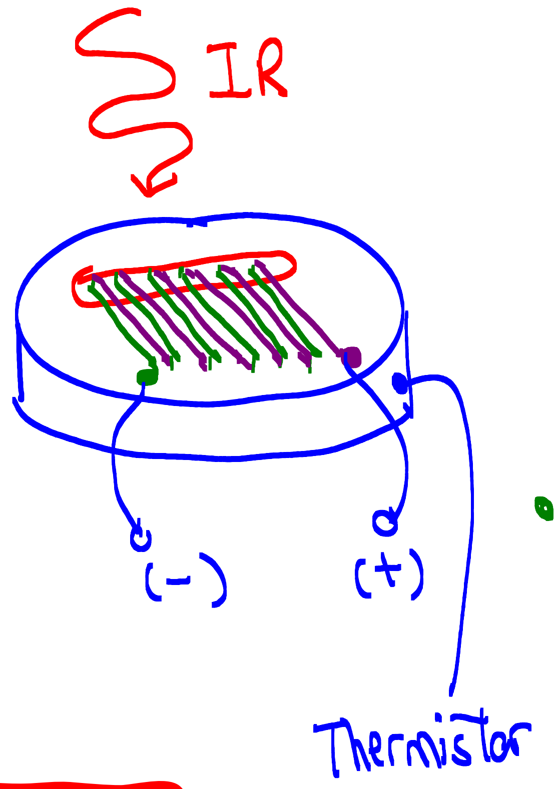
③ $T_{obj} = \left(\frac{V_{IR}}{K} + T_{Amb} \right)^{1/4}$



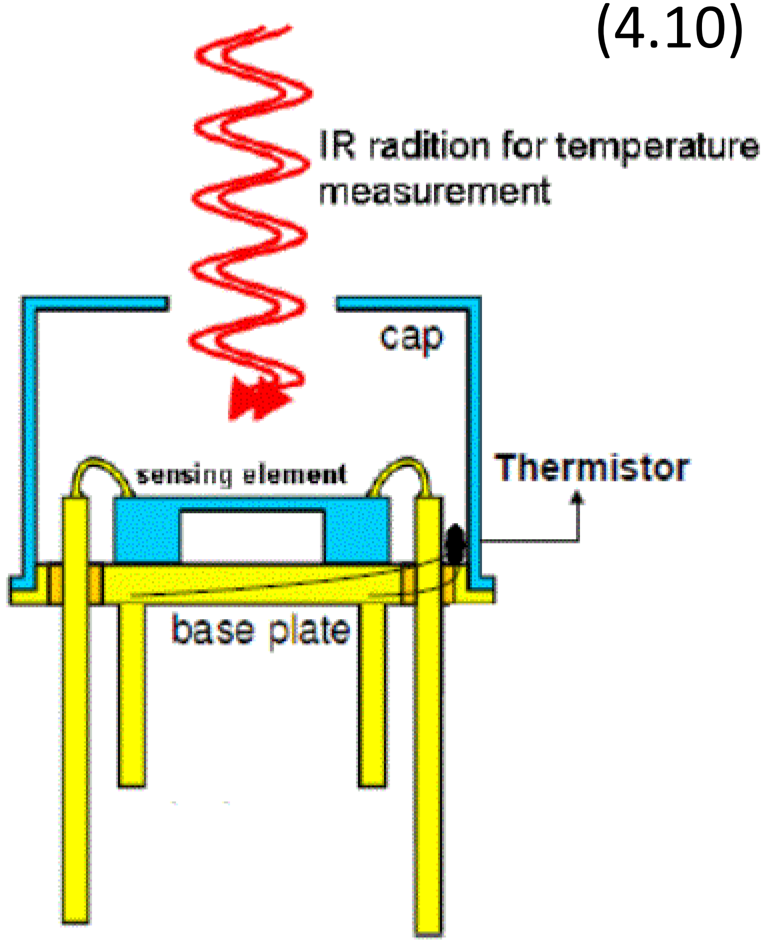
C. Thermopile Detector

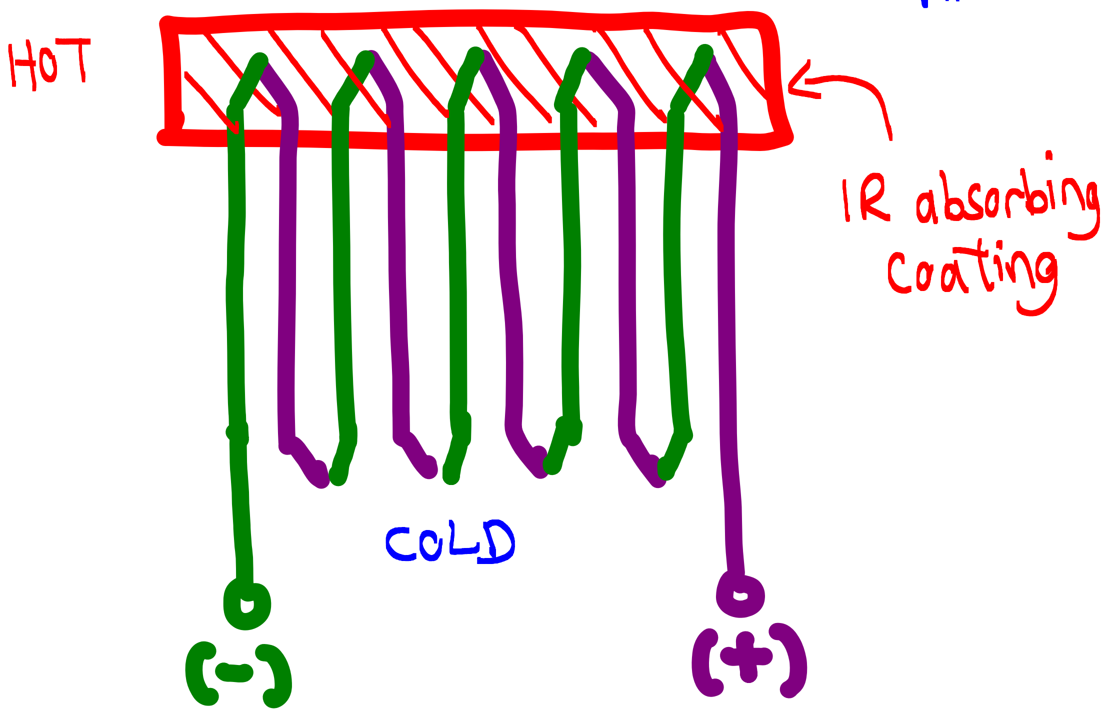
- Bunch of tiny thermocouples connected in series.

⇒ Voltages from each mini thermocouple add together to produce large output!

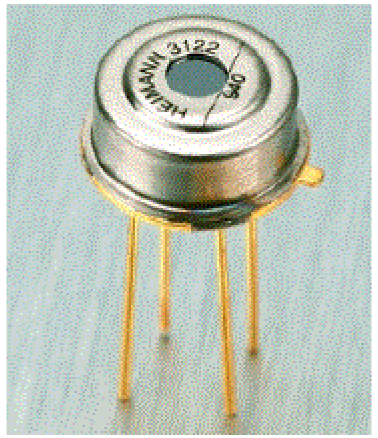


- Built-in thermistor to measure $T_{Ambient}$





Made by silicon micromachining.



www.excelitas.com

D. Temporal Artery (TA) Thermometry

- Easy to use and fast

① Brush the forehead

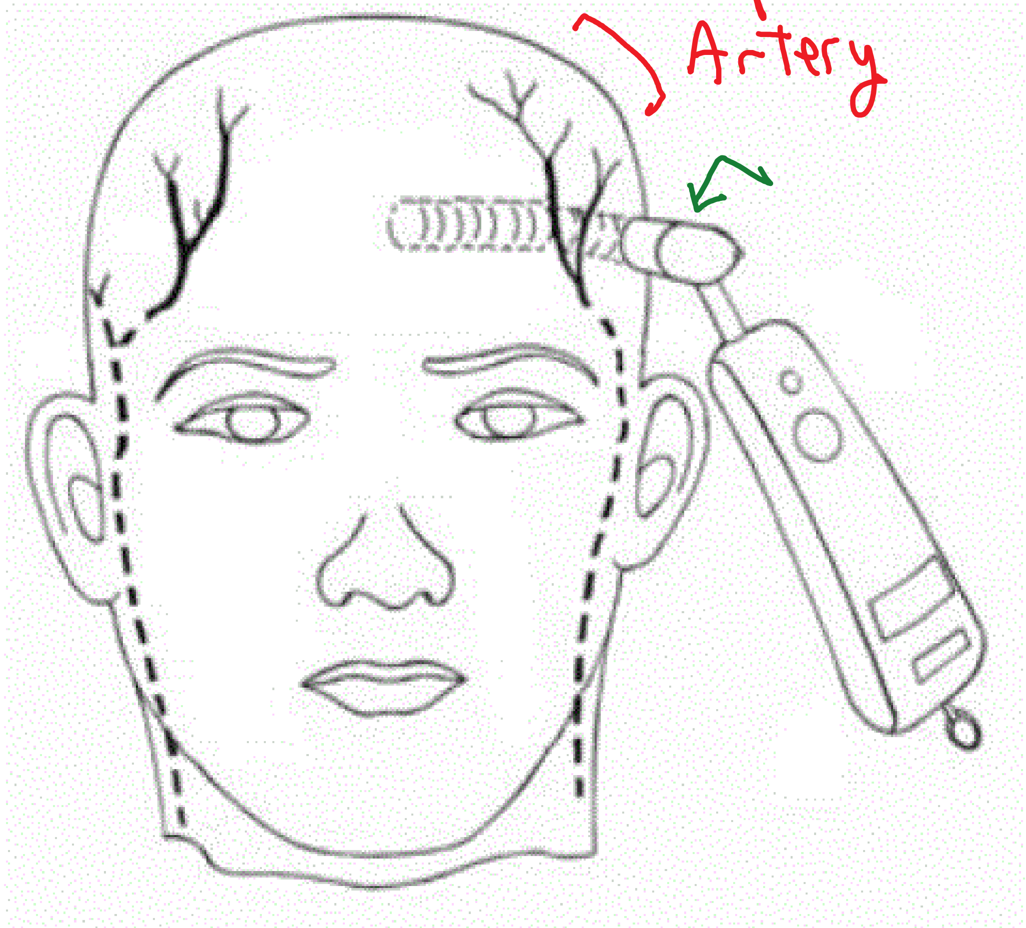
② IR Thermometer acquires ~1000 readings during forehead scan

- Measures temperature at skin surface
- Determines the "hot spot" where the temporal artery is located

③ Computes and displays temperature of blood flowing in temporal artery (underneath skin)

www.exergen.com

Temporal Artery



TA thermometer scanning across the superficial temporal artery

IR enters here!