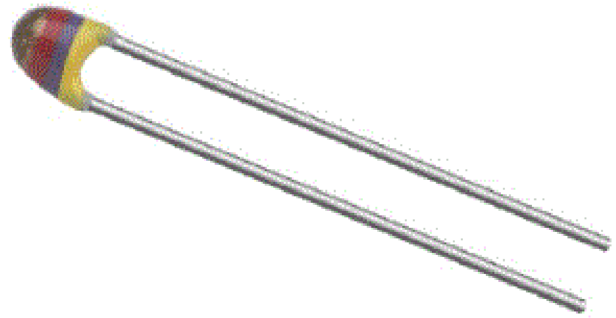
Lecture 3 : Thermistor



0. Review

1. Thermistor

2. Signal Conditioning + Processing

3. Temperature Sensitivity

- Hw 1 due Thu (Jan 16)

  Quiz next Tue (Jan 21) ← HW1 material

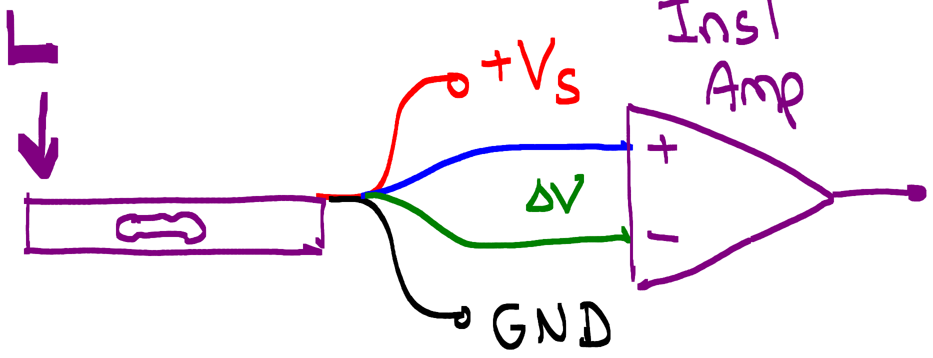
- PreLab 1 due at lab session

- Reading: Thermistor tutorial (pdf)

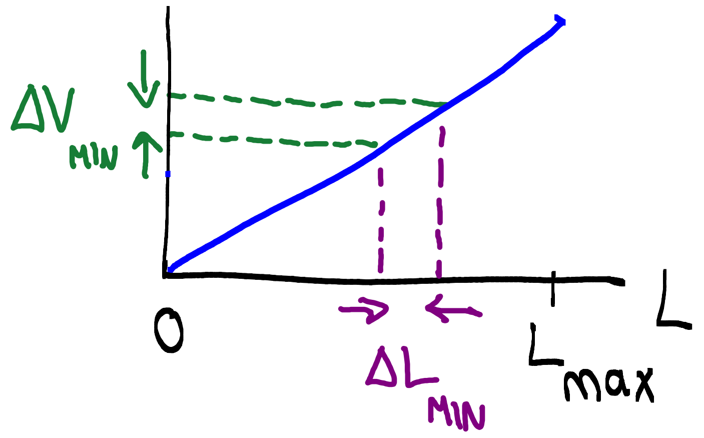
- PreLab 2 due next lab session

0. Review

① Load cells:



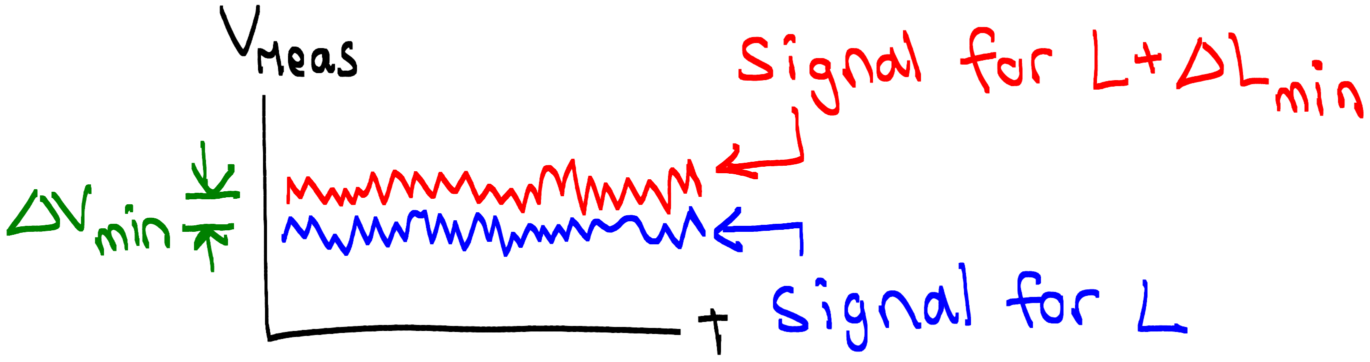
$$V_{MEAS} = A_d \cdot \overbrace{V_s \cdot RO \cdot \frac{L}{L_{Rated}}}^{\Delta V}$$



② Sensitivity:

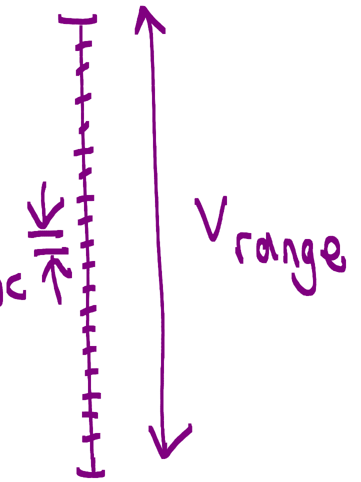
$$\Delta L_{MIN} = \frac{\Delta V_{MIN}}{\partial V_{MEAS}/\partial L}$$

ΔV_{MIN} ← Larger $\begin{cases} V_{n,rms} \\ \Delta V_{ADC} \end{cases}$

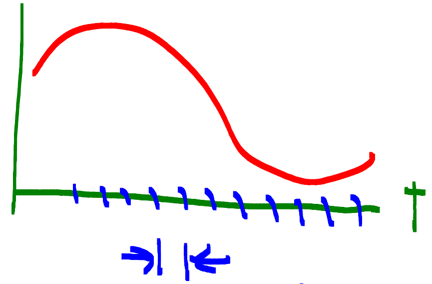


③ Analog-to-Digital Conversion

Vertical Resolution: $\left.\frac{V_{range}}{2^n - 1}\right\} \Delta V_{ADC}$



Sampling Interval:



$\Delta t = 1/f_s$

1. Thermistor

A. Temperature Intro

Q: Why measure temperature?

① In medicine, external body temperature is an important indicator of health

→ Low temp (shock)

→ High temp (fever)

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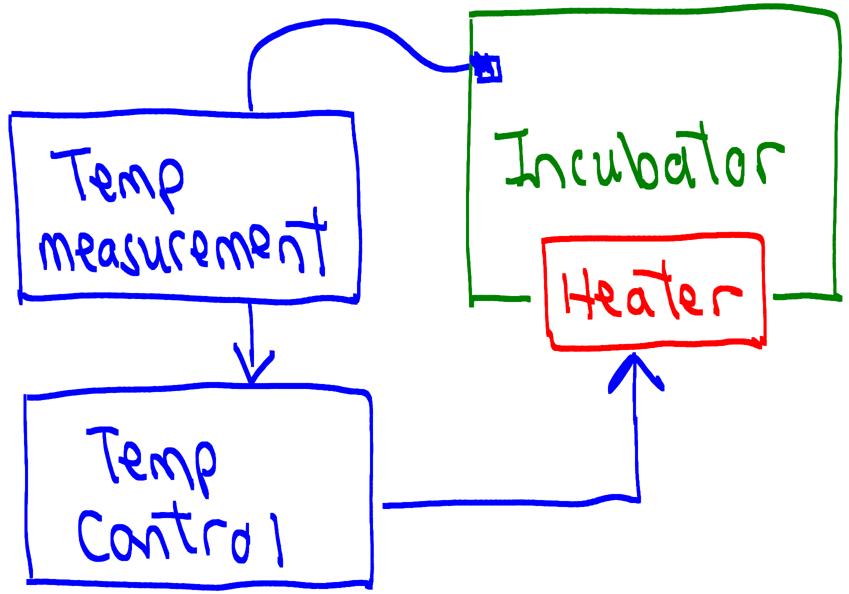
② Many biomedical experiments require temperature control

→ Egg incubator

→ chemical reactions

→ simulate human body conditions



B. Thermistor Basics (THERMally sensitive resISTOR)

- Similar concept to strain gauge, except:

  ① R_T strongly depends on temperature

  ② R_T has negative temp dependence

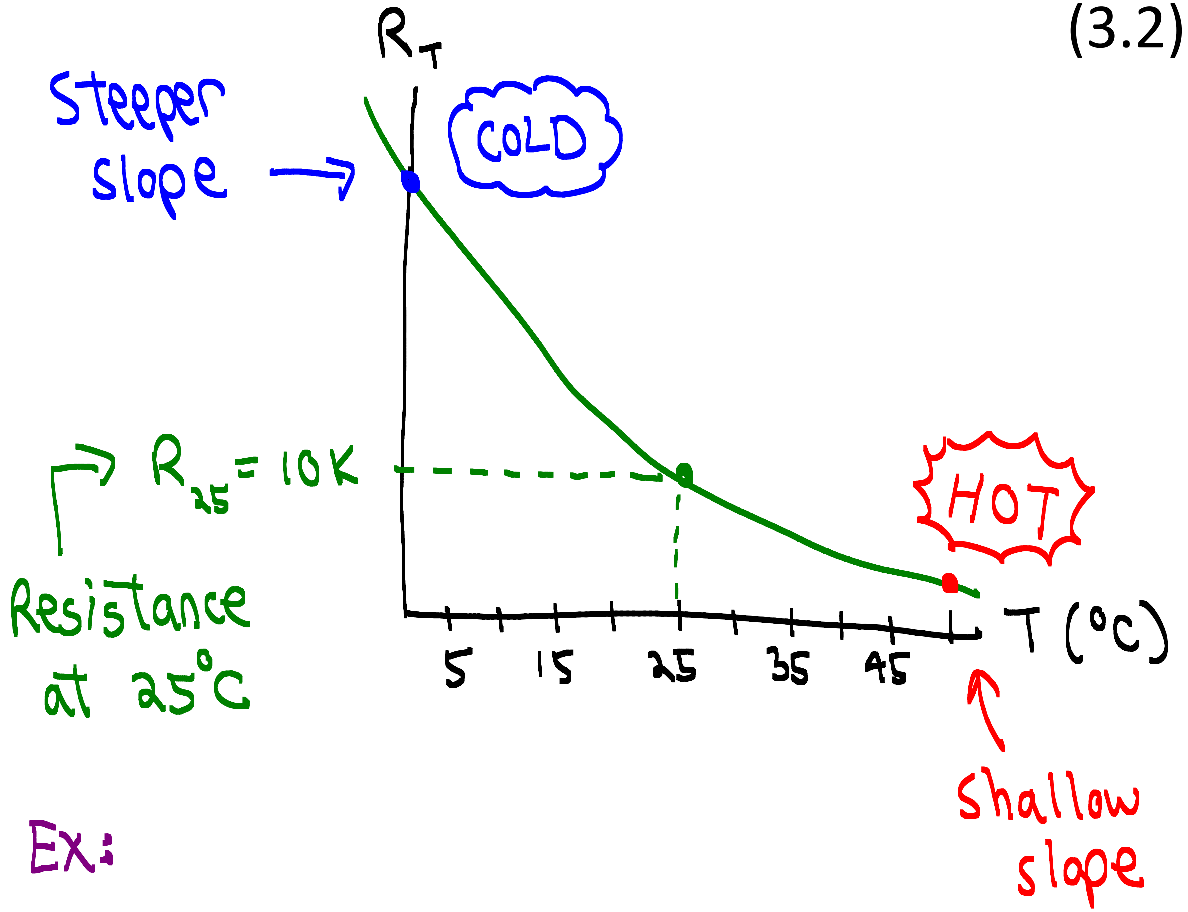
  ③ R_T has nonlinear temp dependence

  ④ Material is a ceramic semiconductor (e.g. manganese oxide)

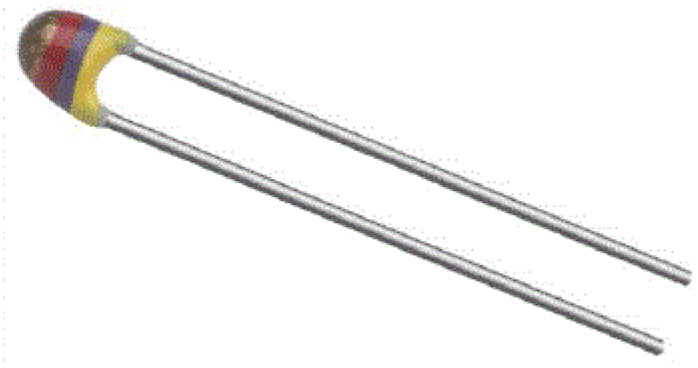
- Lots of resistance values (R_{25} = 10, 15, …, 1K, 2.2K, … 100K)

- Temperature range is typically ~ −50 to 200°C

- Common shapes: Bead, Disc, Chip



Ex:



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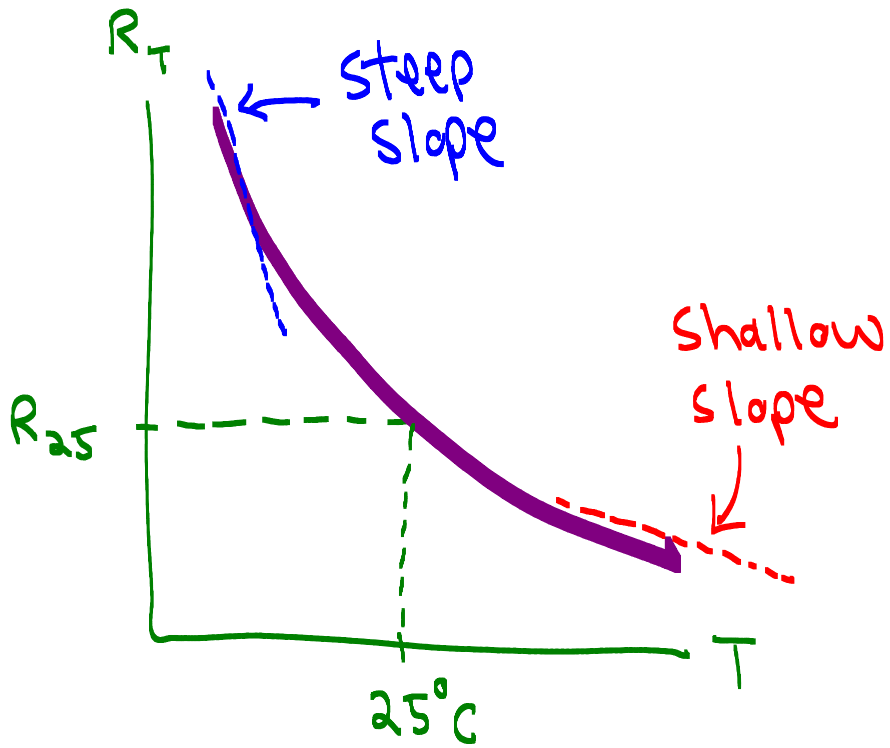
C. Negative Temp Coefficient (NTC)

$$\text{Slope} = \frac{\partial R_T}{\partial T} = \boxed{\alpha} R_T$$

Tempco



* α depends on temperature!

Ex: 10K thermistor

T	R_T	α	Slope = αR_T
10°C	19.87 kΩ	−4.79 %/°C	$(-.0479\ \frac{1}{°C})(19.87\,k\Omega) = -0.95\ k\Omega/°C$
40°C	5.33 kΩ	−4.02 %/°C	$(-.0402\ \frac{1}{°C})(5.33\,k\Omega) = -0.21\ k\Omega/°C$

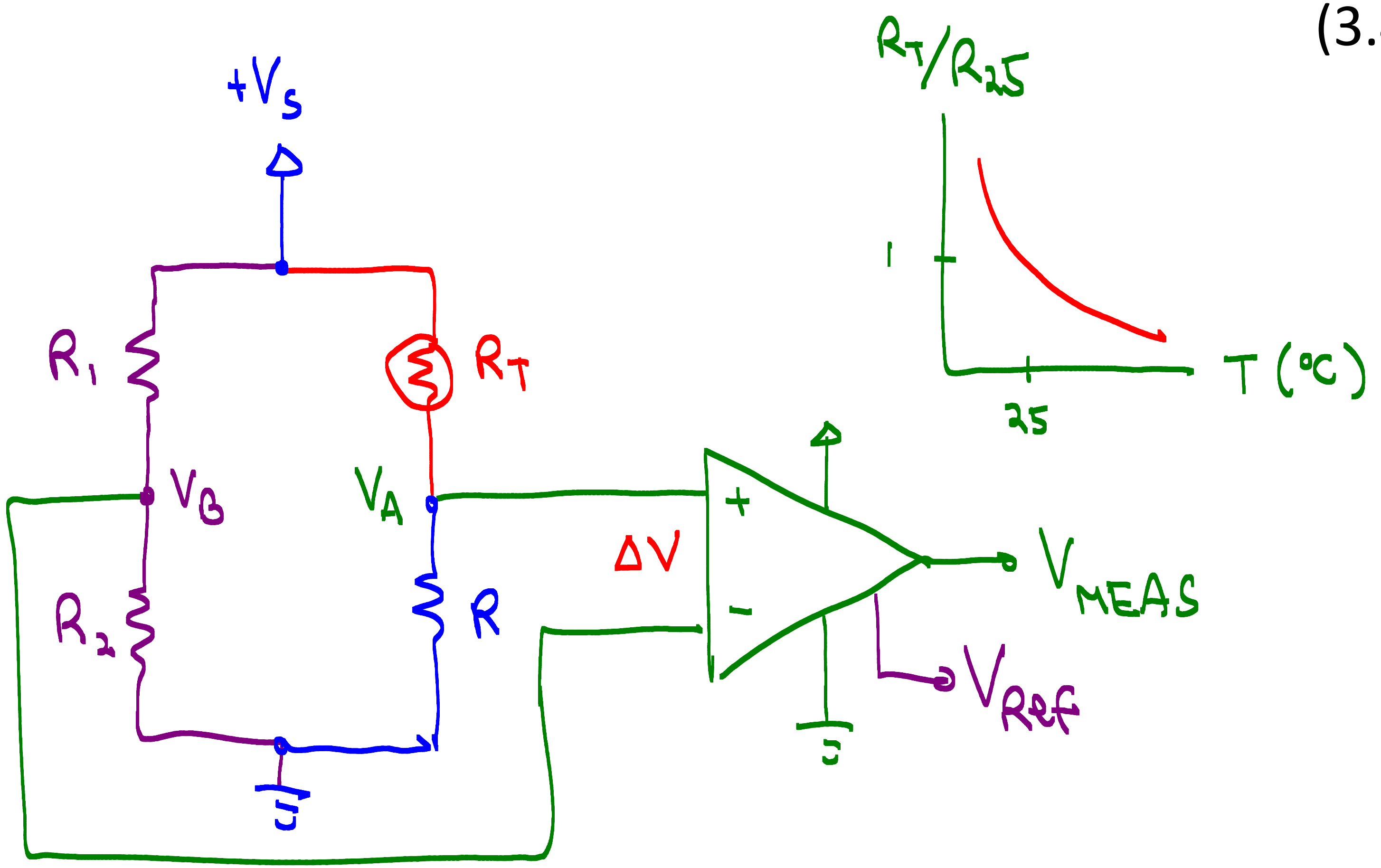
2. Signal conditioning + processing

A. Signal Conditioning

Use a quarter bridge + inst amp.

$$V_{MEAS} = \underbrace{V_{REF}}_{\text{Reference voltage}} + A_d \underbrace{\Delta V}_{\text{From bridge}}$$

Reference voltage: Acts like a "default" value (when $\Delta V = 0$, then $V_{Meas} = V_{Ref}$)



- As temp ↑, then R_T ↓, so V_A ↑ ⇒ $\Delta V > 0$ ⇨ V_{MEAS} increases
- As temp ↓, then R_T ↑, so V_A ↓ ⇒ $\Delta V < 0$ ⇨ V_{MEAS} decreases

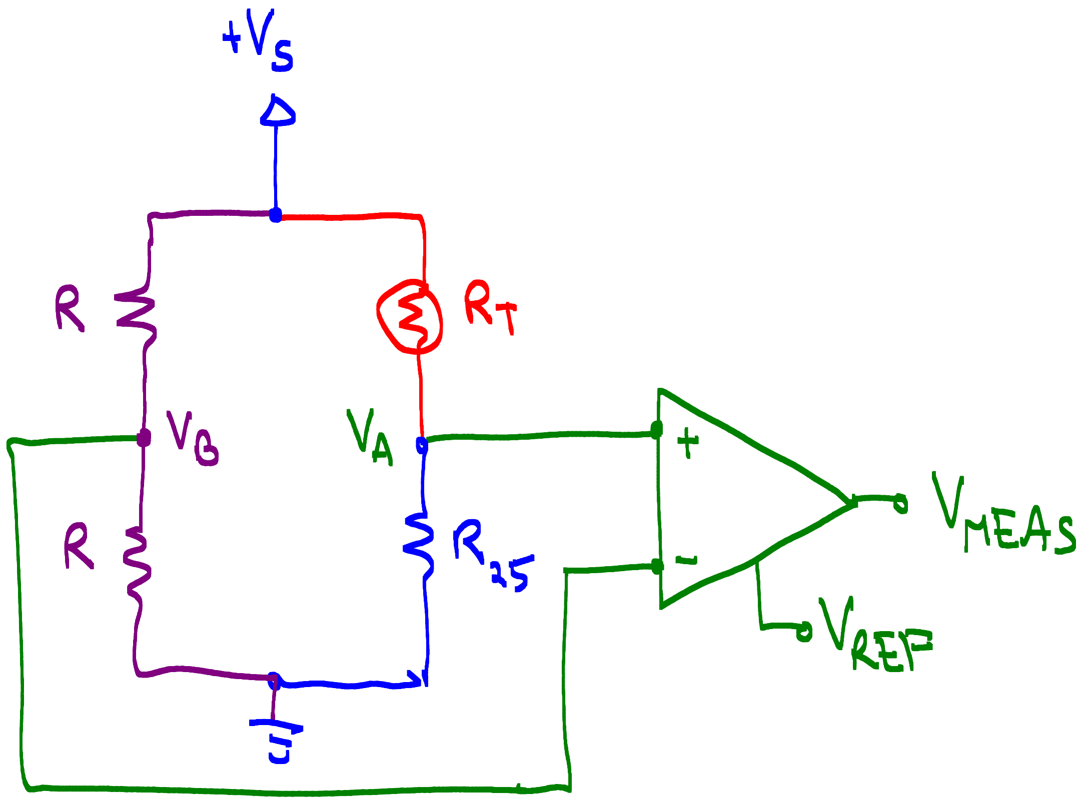
What is the measured signal?

Ex: Left side of bridge has R

Right side has R_{25}

$$V_{MEAS} = V_{REF} + A_d \boxed{[V_A - V_B]}$$

PreLab 2 Problem: $\Delta V = V_s\left(\frac{R_{25}}{R_T + R_{25}} - \frac{1}{2}\right)$



$$\boxed{V_{MEAS} = V_{REF} + A_d V_s\left(\frac{R_{25}}{R_T + R_{25}} - \frac{1}{2}\right)}$$

Varies with temp

Only valid for this example!

Ex: $R_{25} = 10K$ $\quad R_T = 18K$ $\quad V_s = 5V$

$A_d = 3$ $\quad V_{REF} = 2.5V$

$$V_{MEAS} = 2.5 + 3 \cdot 5\left(\frac{10K}{18K + 10K} - \frac{1}{2}\right)$$

$$= \underline{\underline{0.36V}}$$

B. Signal Processing

Q: How to convert V_{MEAS} to a temperature value?

Step 1: Convert V_{MEAS} to R_T

use $\Delta V = \dfrac{V_{MEAS} - V_{REF}}{A_d} = V_S \left[\dfrac{R_{25}}{R_T + R_{25}} - \dfrac{1}{2} \right]$

Only for previous example

Solve for R_T

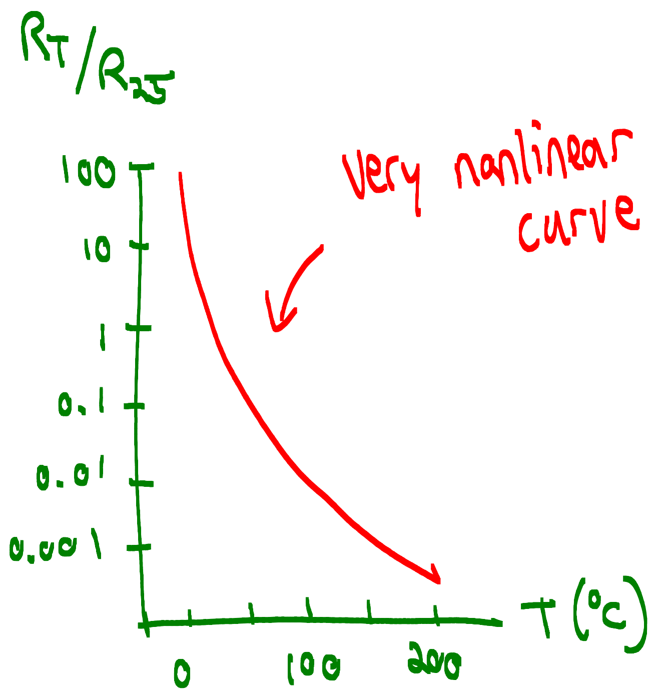
Step 2: Convert R_T to temperature

Use the "Extended Steinhart-Hart Equation"

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

Very accurate over a ~100°C temp range

Best done with a microprocessor or computer.



Ex: $A = 3.354016 \times 10^{-3}$

$B = 2.569850 \times 10^{-4}$

$C = 2.620131 \times 10^{-5}$

$D = 6.383091 \times 10^{-6}$

C. Self-Heating

At $T = 25°C$, $R_T = R_{25}$ (e.g. 10K).

However, R_T dissipates power.

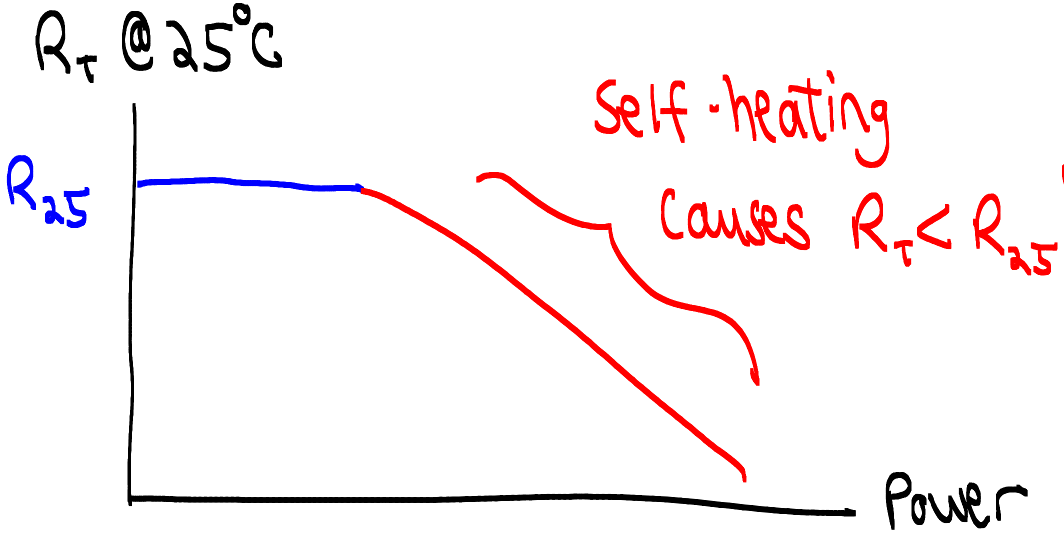
→ $P = I^2 R$ } Heat causes thermistor to get slightly warm

⟹ Resistance is lower

Q: How to compute self-heating?

$$\Delta T = \frac{[\text{Power dissipation in thermistor}]}{[\text{Dissipation Factor}]}$$

mW/°C

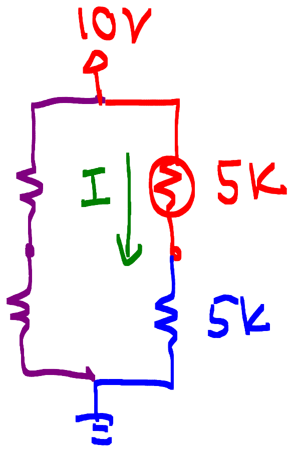


Self-heating causes $R_T < R_{25}$!

Ex: $\delta = 5\ mW/°C$

$R_T = R = 5K$

$V_s = 10V$



→ $P = IV = \frac{10V}{5K+5K} \cdot 5V$

$= 5\ mW$

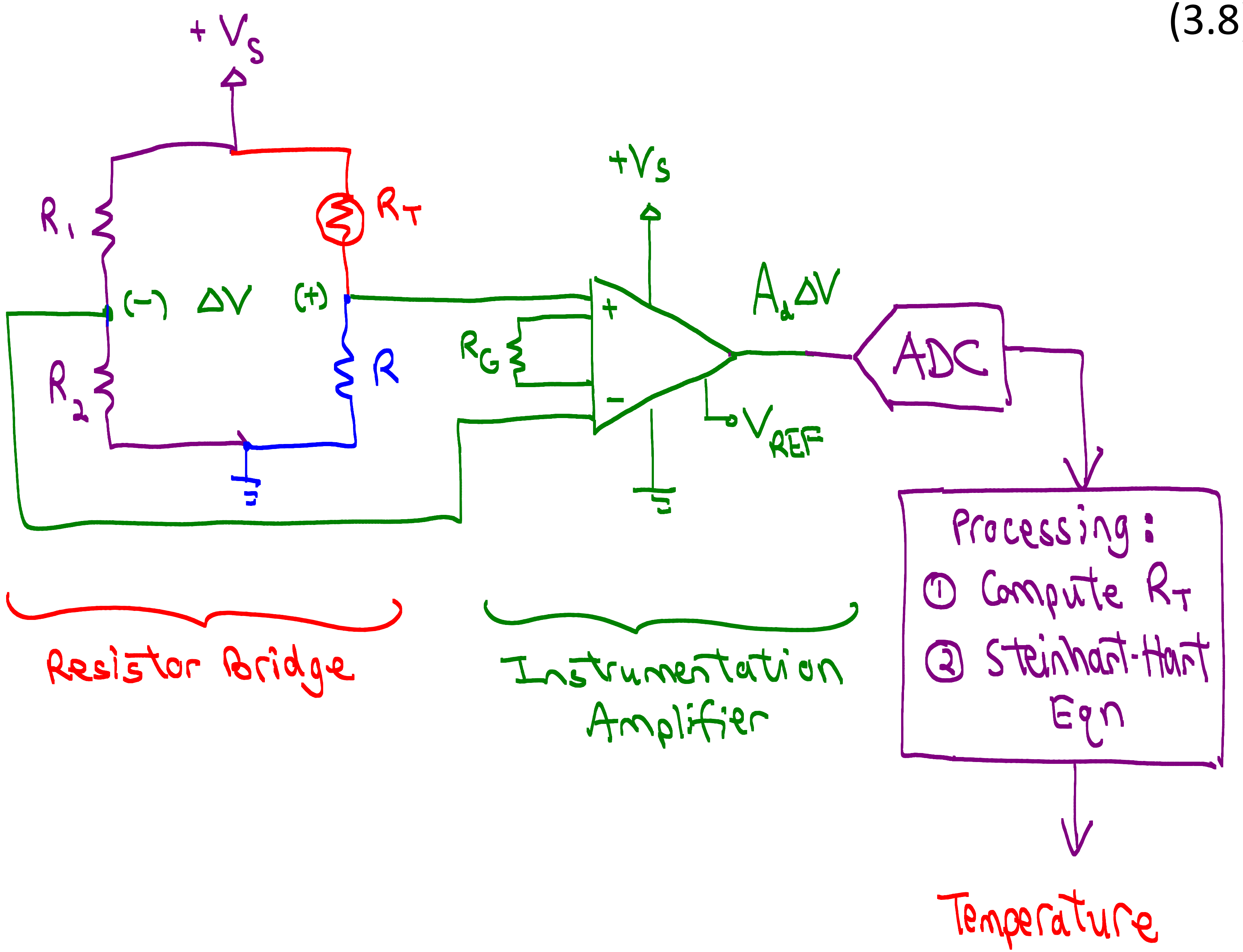
→ $\Delta T = \frac{P}{\delta} = 5\ mW / (5\ mW/°C) = 1\ °C$ NOT good (want $< 0.1\ °C$)

D. Overall System

- Signal conditioning is similar to strain gauge.
  - → Resistor bridge (Quarter bridge)
  - → Instrumentation Amplifier

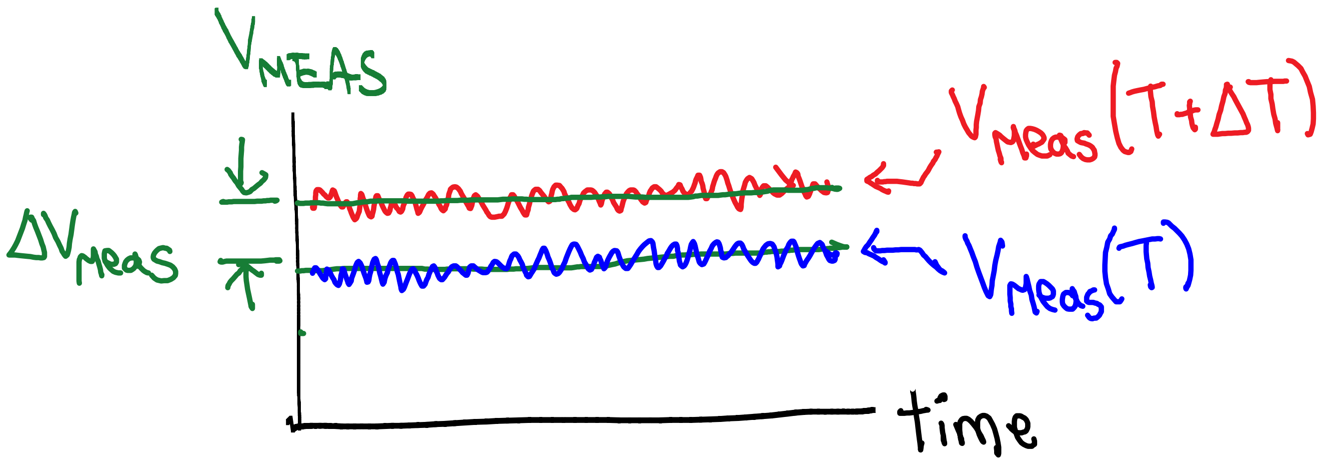
- Processing must convert recorded voltage to R_T, then compute temperature.

- Sensitivity can be $\Delta T_{min} \sim 0.01^\circ C$!



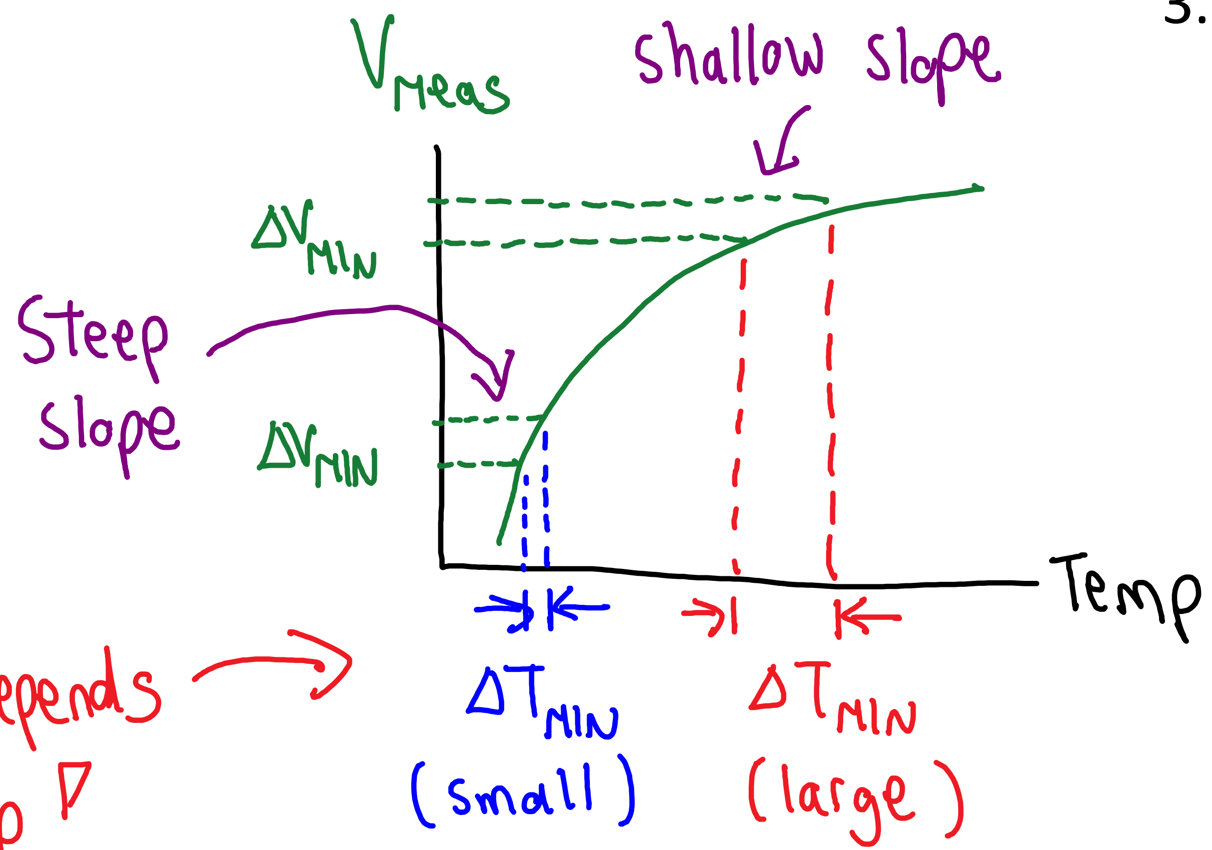
3. Temperature Sensitivity

ΔT_{MIN} = smallest detectable change in temp



$$\Delta V_{meas} = V_{meas}(T+\Delta T) - V_{meas}(T)$$

$$\approx \frac{\partial V_{meas}}{\partial T}\Delta T$$



ΔT_{MIN} depends on temp!

☆ ΔT_{MIN} produces smallest detectable ΔV_{meas}!

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

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

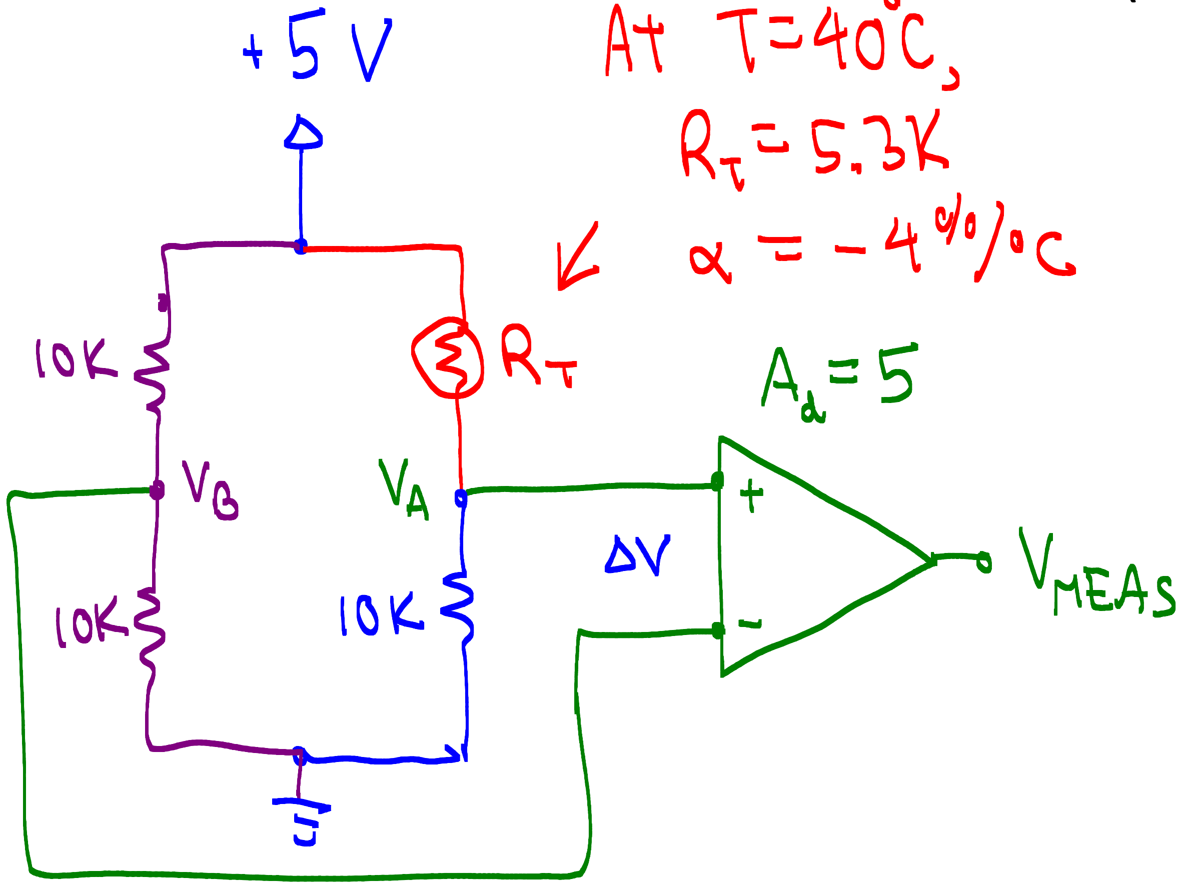
Larger of $V_{N,rms}$ vs. ΔV_{ADC}

slope

- Example: If $\Delta V_{MIN} = 10\,mV$, what is ΔT_{MIN}?

$$\star \quad \Delta T_{MIN} = \frac{\Delta V_{MIN}}{\dfrac{\partial V_{MEAS}}{\partial T}} \leftarrow ?$$

At $T = 40^\circ C$,
$R_T = 5.3K$
$\alpha = -4\,\%/^\circ C$



① Need expression for V_{MEAS}

$$V_{MEAS} = \underset{\substack{\uparrow \\ \text{constant}}}{V_{REF}} + A_d \cdot V_s \cdot \underbrace{\left[\frac{10K}{R_T + 10K} - \frac{1}{2} \right]}_{\Delta V}$$

where is T? ☹

② use Chain rule:

$$\frac{\partial V_{MEAS}}{\partial T} = \frac{\partial V_{MEAS}}{\partial R_T} \frac{\partial R_T}{\partial T} = \left[-A_d V_s \frac{10K}{(R_T + 10K)^2} \right] \left[\alpha R_T \right]$$

using $\dfrac{\partial R_T}{\partial T} = \alpha R_T$

SO, $\frac{\partial V_{MEAS}}{\partial T} = \left[-5 \cdot 5V \frac{10K}{(5.3K + 10K)^2} \right] \left[-0.04\ \%/_{^\circ C} \cdot 5.3K \right] = 0.226\ V/_{^\circ C}$

use ≥3 decimal places!

③ Finally,

$$\Delta T_{MIN} = \frac{\Delta V_{MIN}}{\frac{\partial V_{MEAS}}{\partial T}} = \frac{.010V}{.226\ V/^\circ C} = \boxed{.044^\circ C}$$

Only at 40°C! ΔT_{MIN} is NOT identical at other temp!

NOTE: Suppose at $T = 25^\circ C \rightarrow R_T = 10K$ and $\alpha = -4.3\%$

$$\Rightarrow \frac{\partial V_{MEAS}}{\partial T} = \left[-5 \cdot 5V \cdot \frac{10K}{(10K + 10K)^2} \right] \left[-.043\ \%/_{^\circ C} \cdot 10K \right] = 0.269\ V/^\circ C$$

$$\Rightarrow \Delta T_{MIN} = \frac{.010V}{.269\ V/^\circ C} = \boxed{0.037^\circ C}$$

← slightly better sensitivity than @ 40°C