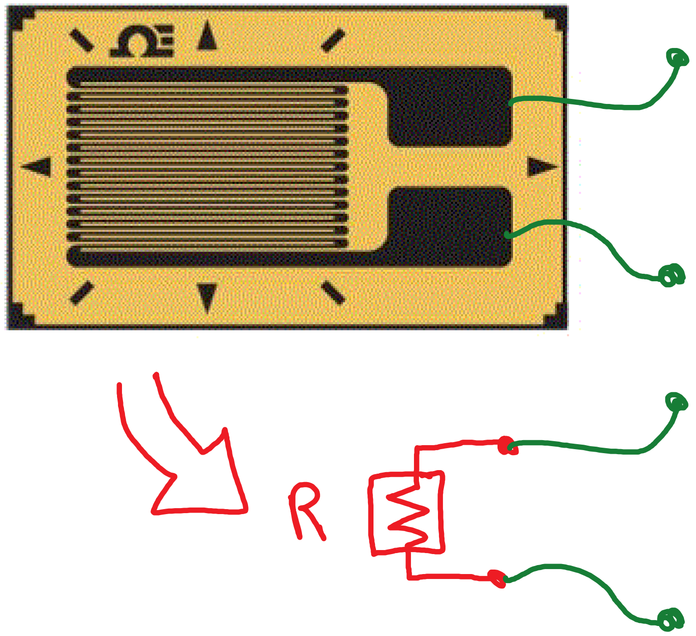
Lecture 2: Load Cells

0. Review
1. Load Cells
2. ADC Basics
3. Sensitivity

- Course website: minerva.union.edu/bumat
- Reading: Load cell tutorial (pdf)
  ADC tutorial (pdf)
- PreLab 1 due at lab session (Jan 14/16)
- HW1 due next Thu (Jan 16)
  Quiz (Jan 21)
  HW1 material

0. Review

Strain Gauge:



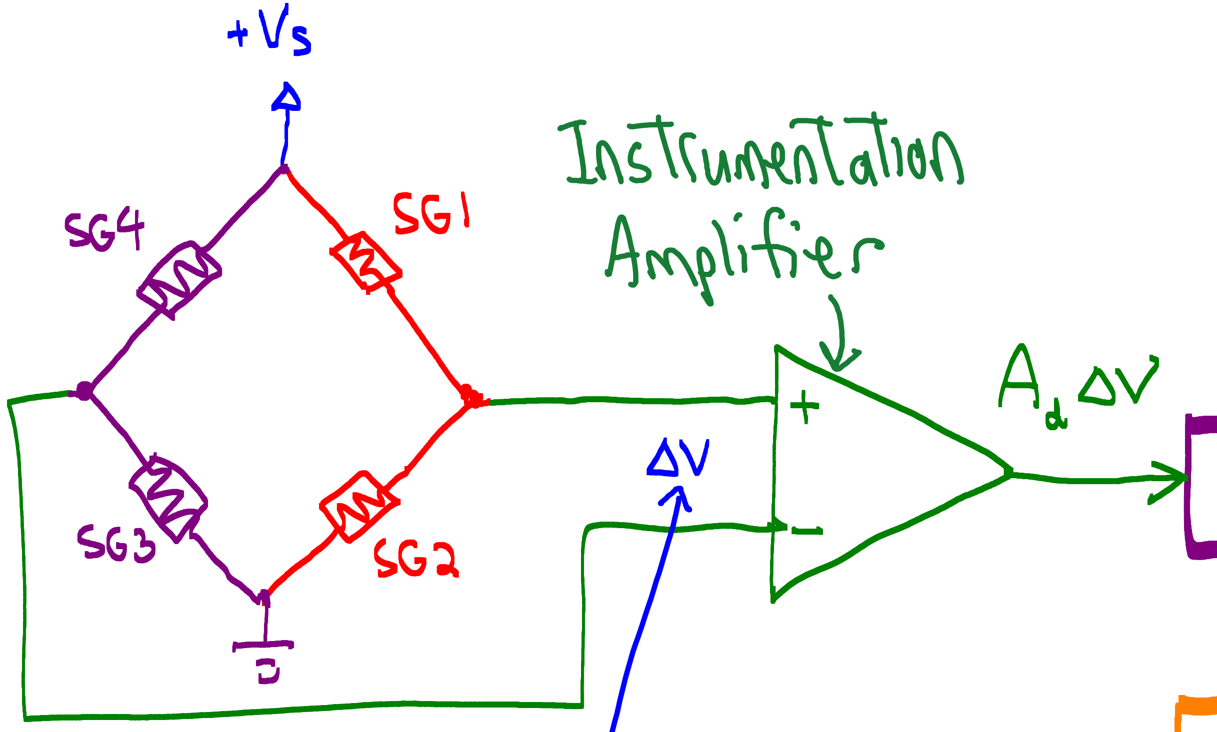
Gauge Factor

- $\frac{\Delta R}{R} = G \cdot \varepsilon$ ← Strain

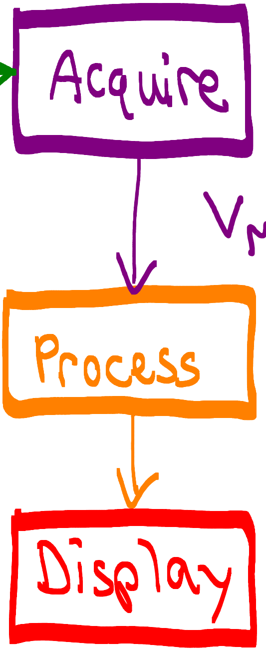
$$= \left[1 + 2\mu + \left(\frac{\Delta\rho/\rho}{\Delta L/L}\right)\right] \times \frac{\Delta L}{L}$$

Dimensional

Piezoresistive



$$\underbrace{V_s \frac{\Delta R}{R} = V_s G \varepsilon}_{\text{Only for full bridge!}}$$



$$V_{Meas} = A_d \overbrace{V_s G \varepsilon}^{\Delta V}$$

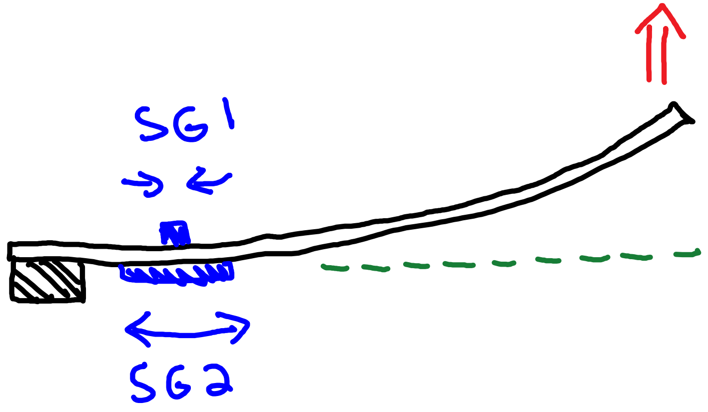
$$\varepsilon = \left[\frac{1}{A_d V_s G}\right] \cdot V_{Meas}$$

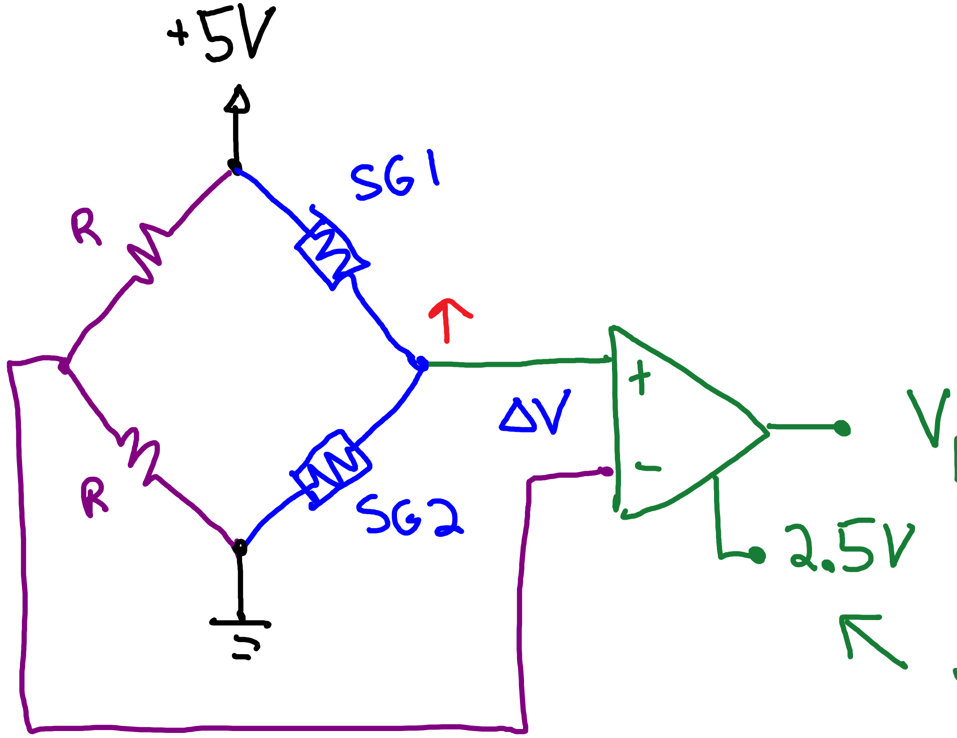
★ Slightly different eqn's for $\frac{1}{2}$ and $\frac{1}{4}$ bridge!

• Demo of cantilever with ½ bridge:

(2.0b)

(+) Deflection

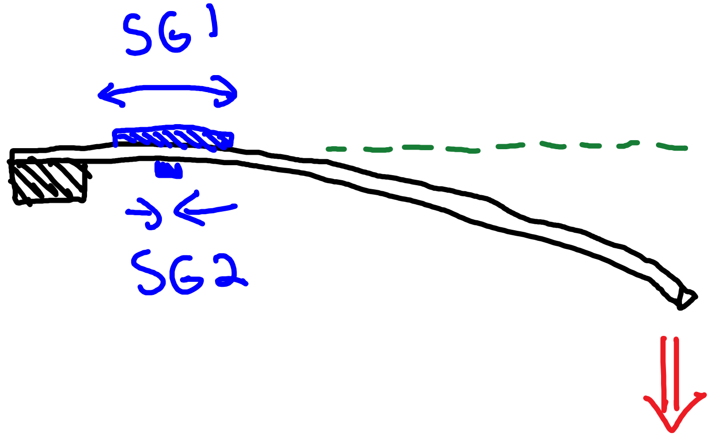


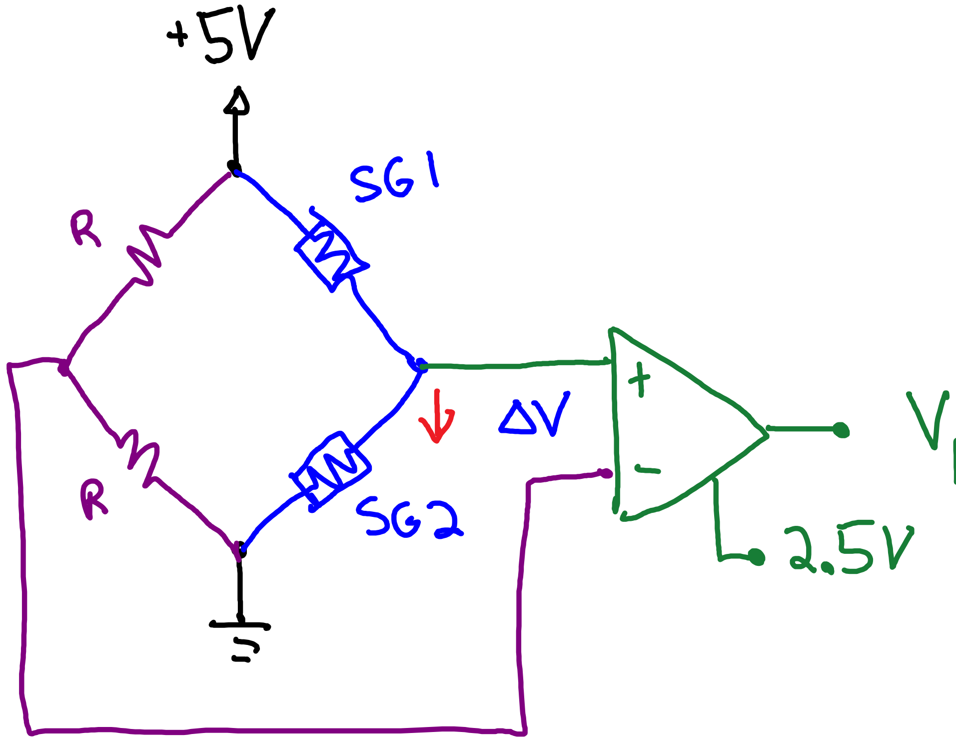


$V_{meas} = 2.5 + \boxed{A_d \Delta V}$ ⇑

"Reference voltage" (i.e. baseline)

(−) Deflection



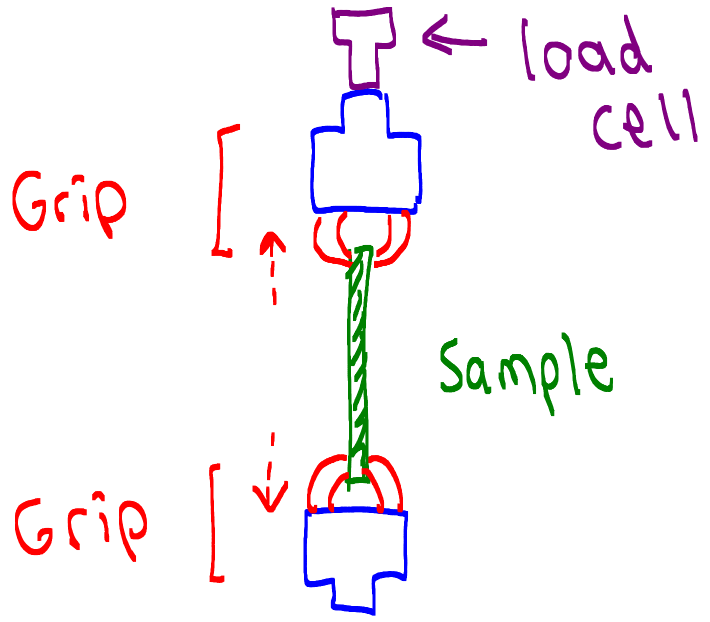


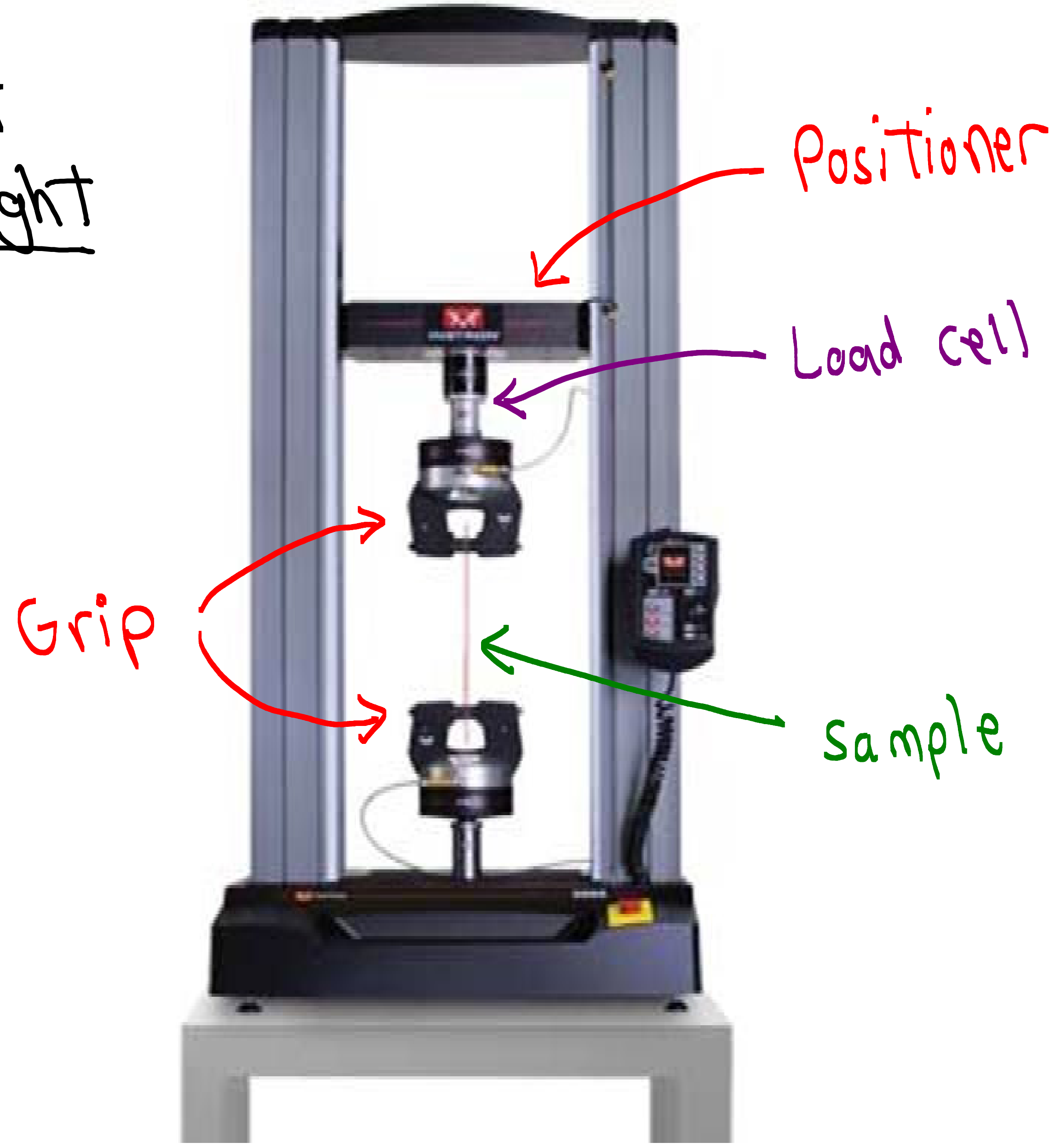
$V_{meas} = 2.5 + \boxed{A_d \Delta V}$ ⇓

1. Load Cells

- In many applications, you want to measure <u>force</u> or <u>weight</u> rather than strain.

Ex: "Instron" mechanical testing system.





www.instron.com

Ex: Digital weighing scale

www.ohaus.com

(2.2)

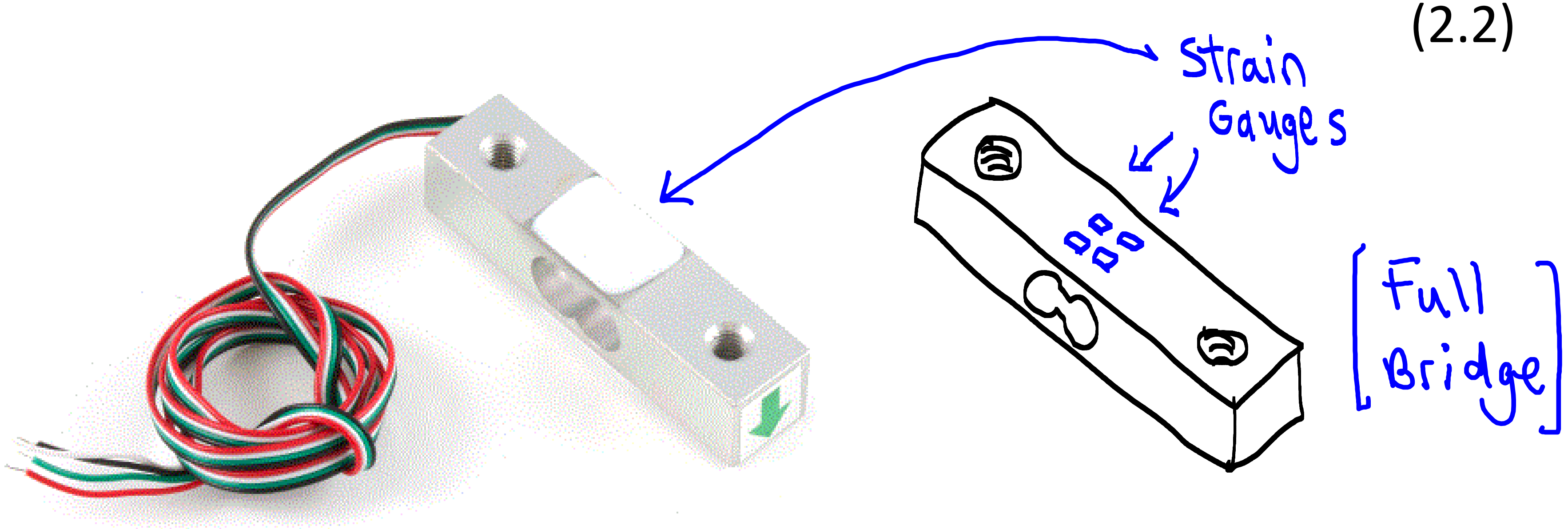
A load cell is basically a metal structure with strain gauges

① Load deforms the metal structure

② Structure affects strain gauges

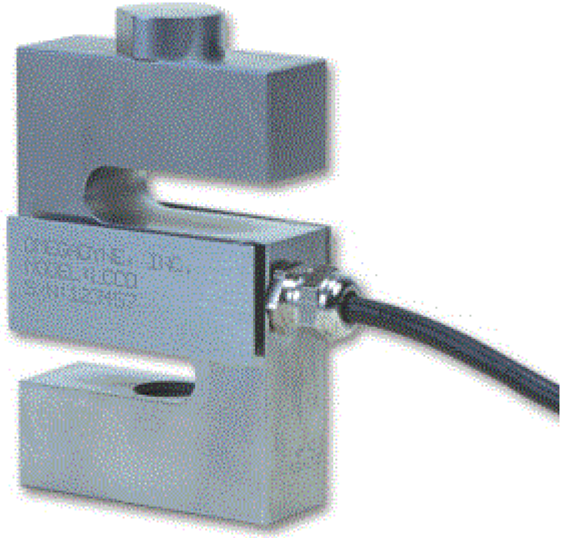
③ output voltage is proportional to force.

Many different shapes + sizes...

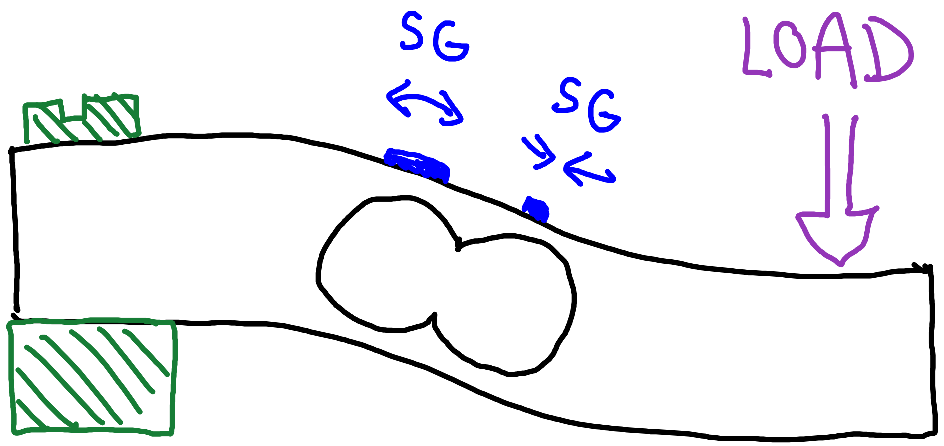


Phidgets.com

Instron



www.omega.com

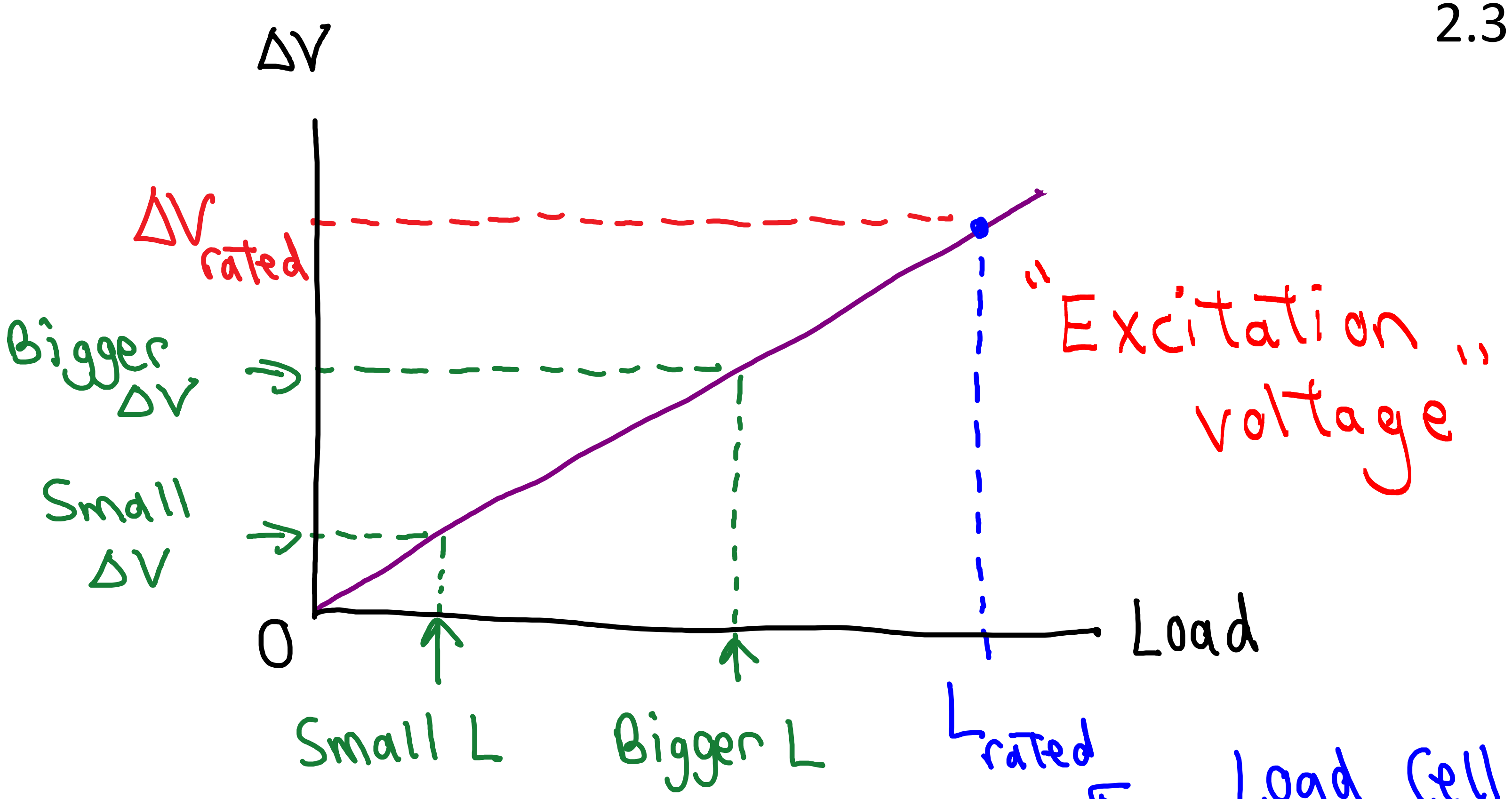


- Output voltage of load cell:

ΔV is linearly proportional to load.

$$\Delta V = \boxed{\text{Slope}} \times L = \frac{\Delta V_{rated}}{L_{rated}} \times L \quad (1)$$

?



Load Cell is tested with "Rated Load"

Recall that ΔV from a bridge circuit depends on V_s!

e.g. $\Delta V = V_s \dfrac{\Delta R}{R}$ (2)

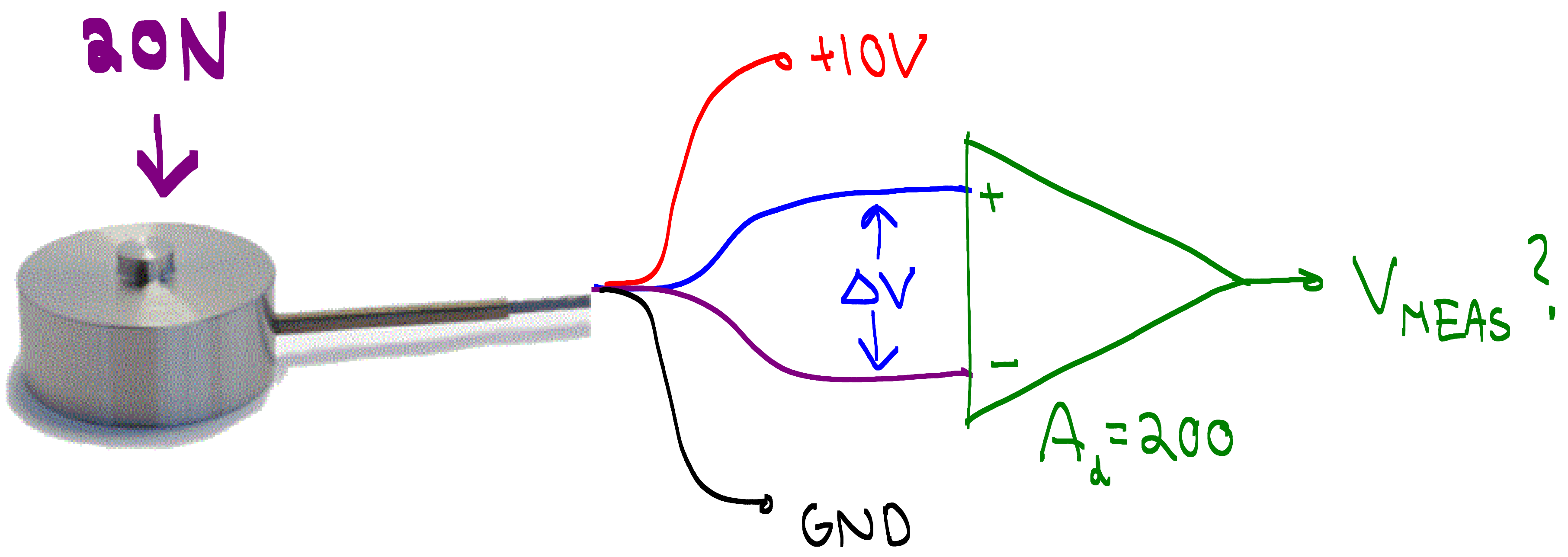
Re-write (1) to look like (2):

"Excitation Voltage"

"Rated output $\left(\frac{mV}{V}\right)$"

$$\rightarrow \Delta V = V_s \times \left[\frac{\Delta V_{rated}}{V_s}\right] \times \frac{L}{L_{rated}} = \boxed{V_s \times RO \times \frac{L}{L_{rated}}}$$

Example:



Rated output = 2 mV/V

Rated load = 100N

Start with:

$$V_{MEAS} = A_d \, \Delta V$$

$$= A_d \, V_s \cdot RO \cdot \frac{L}{L_{rated}} = 200 \times \underbrace{10V \times \frac{2mV}{V} \times \frac{20N}{100N}}_{4mV} = \boxed{800\,mV}$$

OR $$200 \times \underbrace{10V \times \frac{.002V}{V} \times \frac{20N}{100N}}_{.004V} = \boxed{0.8V}$$

2. ADC Basics

- Most measurement systems rely on <u>digital</u> data acquisition
- ADC (Analog-to-Digital Converter) is like a voltage "ruler"

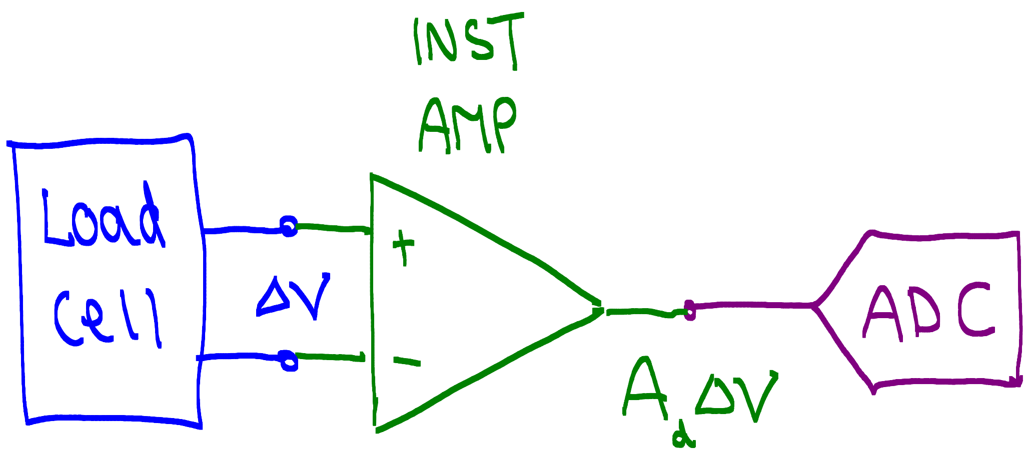
Ⓐ Vertical

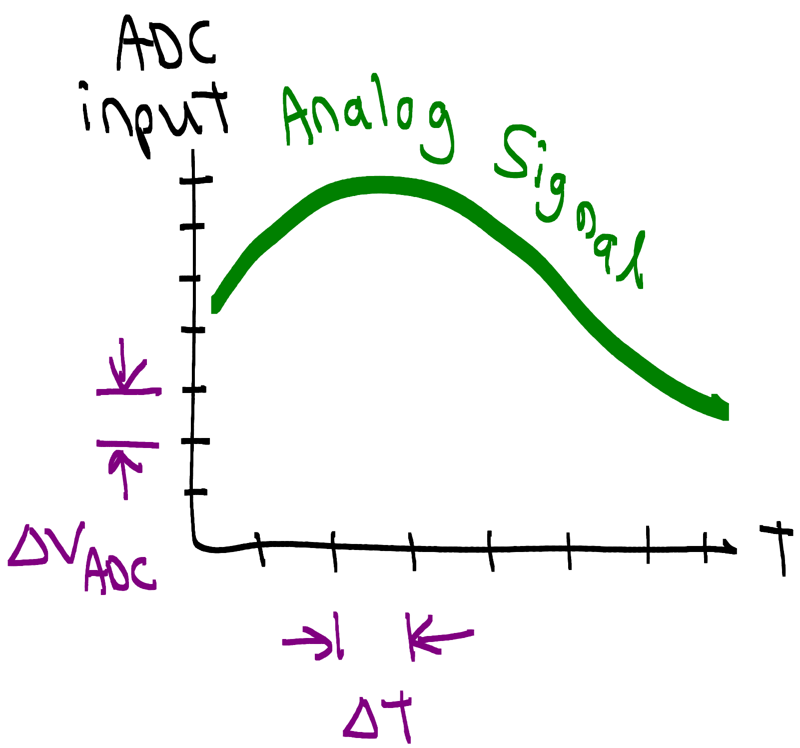
→ Continuous amplitude must be quantized

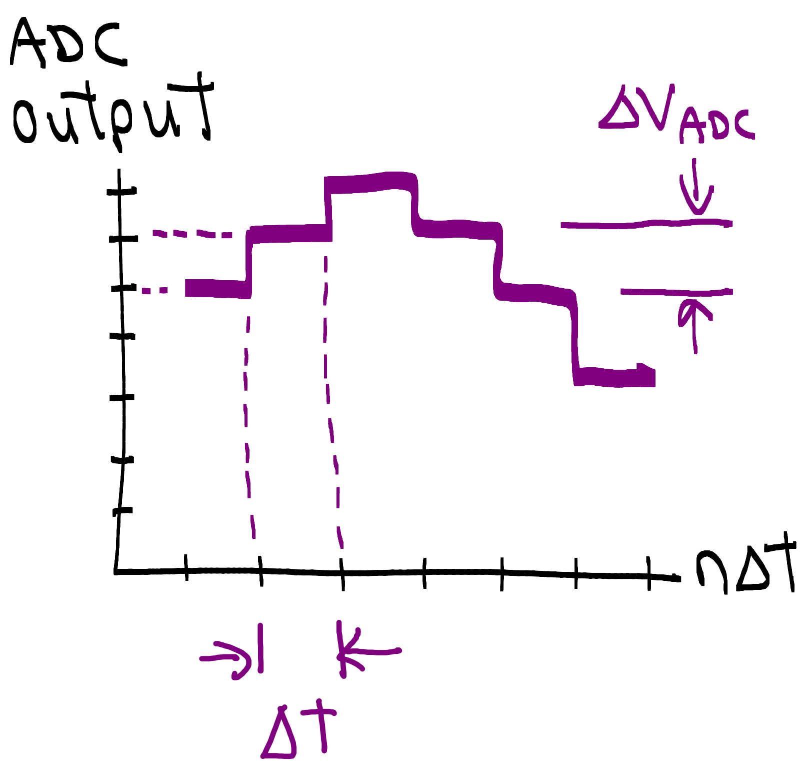
Ⓑ Horizontal

→ Samples are acquired at regular time intervals

Ex:



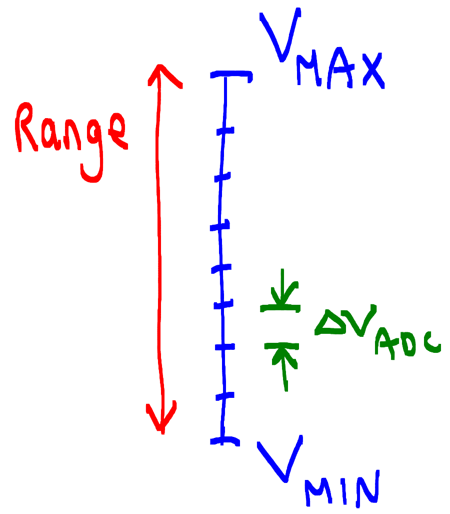




A. Vertical Resolution

- The # of bits of an ADC determines the number of quantization levels.

  ↗ # of tick marks



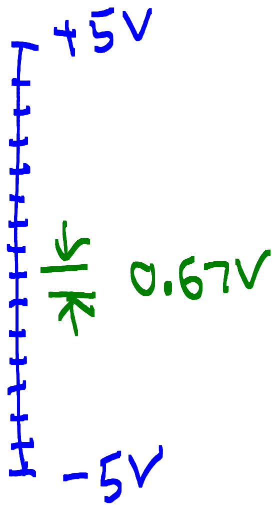
- The smallest voltage difference that can be recorded is:

$$\boxed{\Delta V_{ADC} = \frac{V_{MAX} - V_{MIN}}{2^n - 1}}$$

Example:

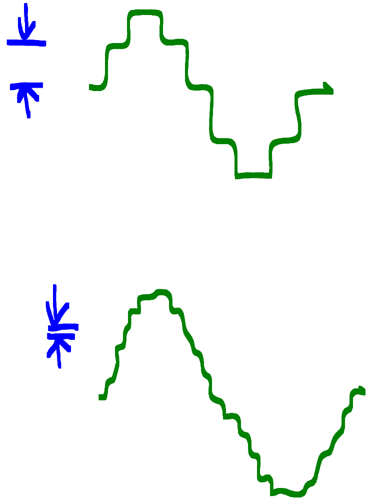
4-bit ADC operates from -5 to +5 V

$$\Rightarrow \Delta V_{ADC} = \frac{10V}{16-1} = 0.67V$$



Number of bits: n	Number of quantization levels: 2^n
8	256
10	1024
12	4096
14	16384
16	65536

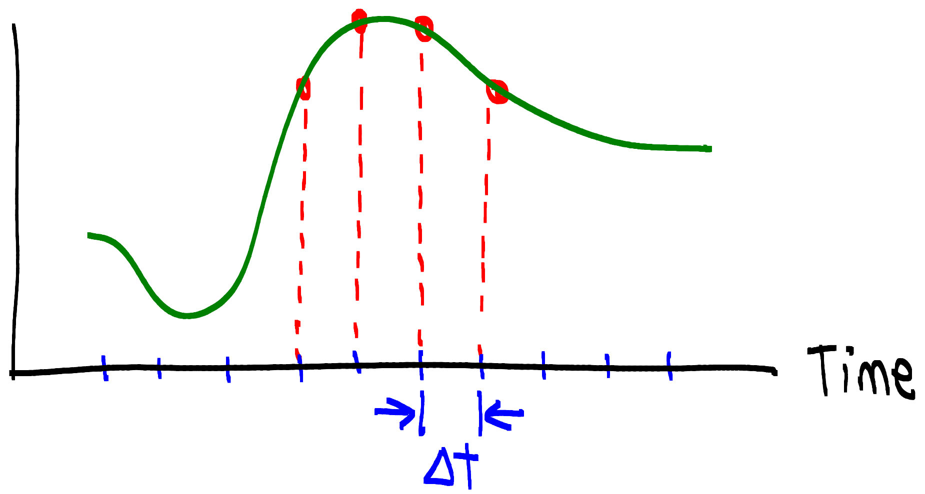
⇓ Better resolution



B. Sampling Rate

- Sampling Rate = # of acquired samples per second

Ex: $f_s = 44\ kS/sec = 44{,}000$ samples/sec



- Sampling Interval = Time between consecutive samples

$$\boxed{\Delta t = 1/f_s}$$

Ex: If $f_s = 44\ kHz$,

$$\Delta t = \frac{1}{44\,kHz} = \frac{1}{44 \times 10^3\ Hz}$$

$$= 2.27 \times 10^{-5}\ s = \underline{\underline{22.7\ \mu s}}$$

NOTE: Usually, there is a trade off between resolution (# bits) and max speed (sampling rate)

# bits	Typical f_s
8	1 GS/sec ← oscilloscope
10	100 MS/sec
12	10 MS/sec
14	100 kS/sec

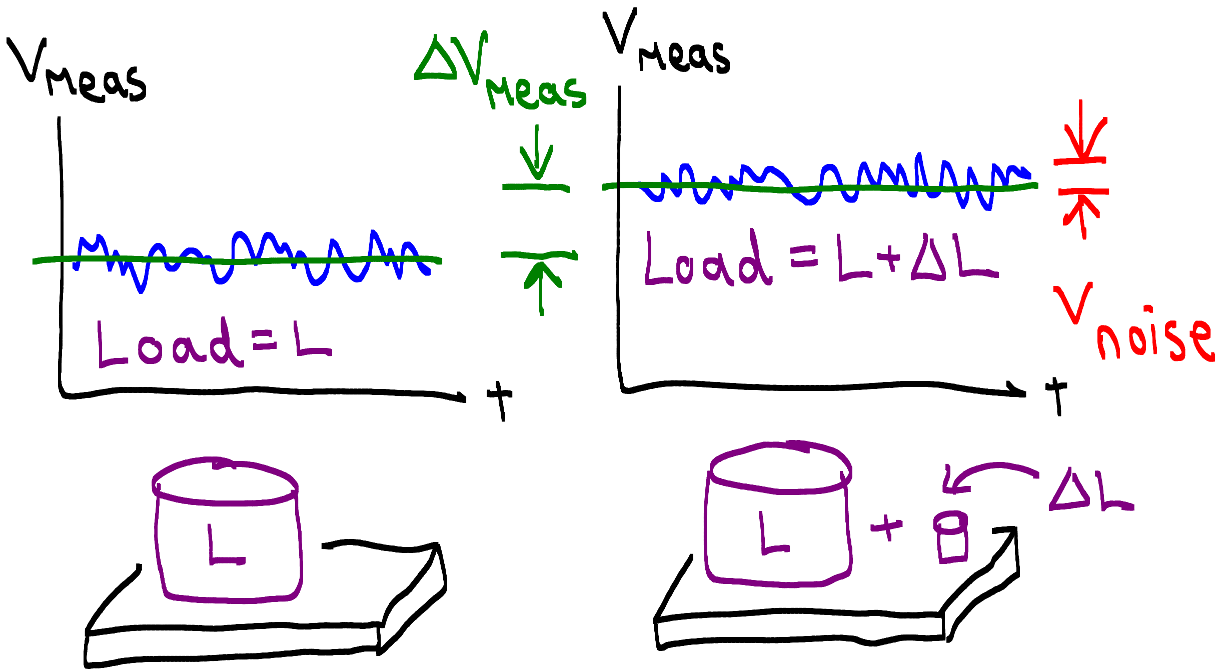
3. Sensitivity

Q: what is the smallest measurable change in load ΔL_{MIN}?

This is called SENSITIVITY.

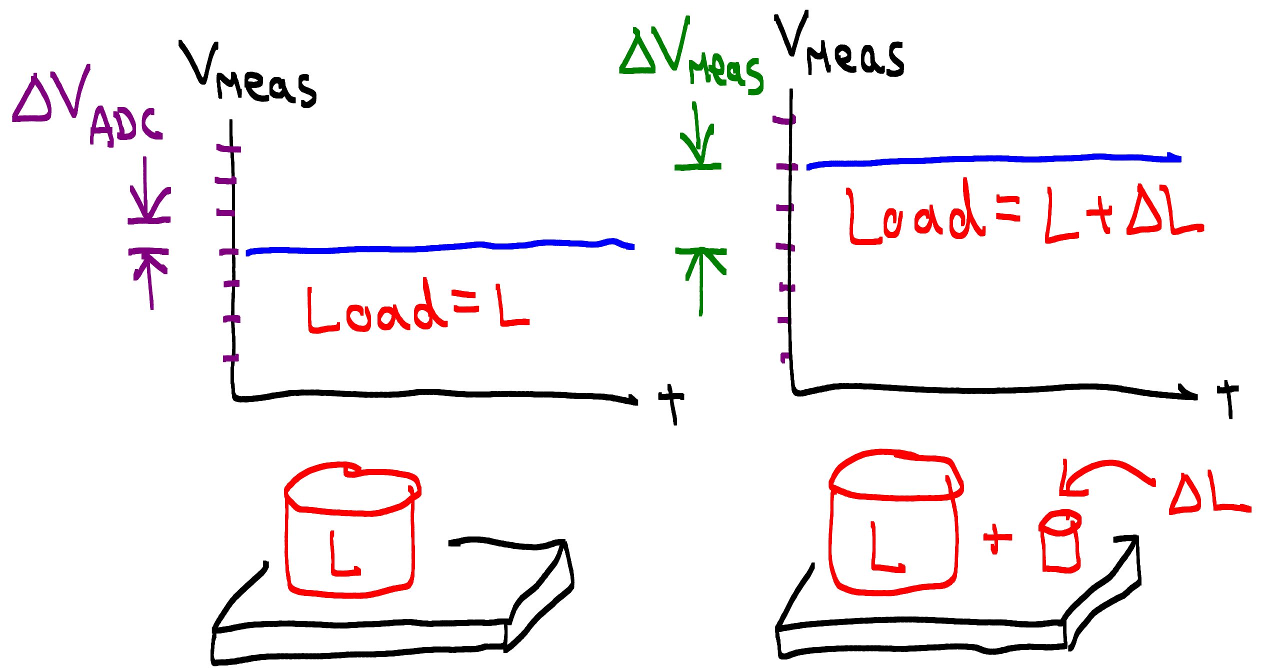
Two main factors...

① Measurement noise



★ Can detect a signal change if $\Delta V_{Meas} > V_{noise}$

② Vertical Resolution



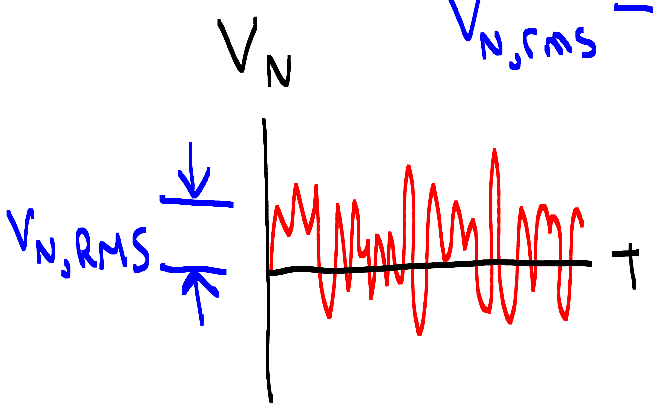
★ Can detect a signal change if $\Delta V_{Meas} > \Delta V_{ADC}$

- Let ΔV_{MIN} be the minimum detectable voltage change

☆ ΔV_{MIN} is the LARGER of $V_{N,rms}$ vs. ΔV_{ADC}

Noise amplitude is often specified as RMS (root mean square)

$$V_{N,rms} = \sqrt{\frac{1}{T}\int_0^T (V_N - \bar{V}_N)^2\, dt}$$



Similar to std deviation

- We can detect a signal change if $\Delta V_{Meas} = V_{Meas}(L+\Delta L) - V_{Meas}(L) > \Delta V_{MIN}$

- Let ΔL_{MIN} correspond to $\Delta V_{Meas} = \Delta V_{MIN}$

$$\underbrace{V_{Meas}(L+\Delta L_{MIN}) - V_{Meas}(L)}_{\frac{\partial V_{Meas}}{\partial L}\Delta L_{MIN}} = \Delta V_{MIN}$$

Minimum detectable load $\Rightarrow$ $\boxed{\Delta L_{MIN} = \dfrac{\Delta V_{MIN}}{\frac{\partial V_{Meas}}{\partial L}}}$

Example Load Cell:

$$RO = 1.5\,\text{mV/V} \;@\; 5\,\text{kg}, \quad V_s = 10\,\text{V}$$

$$A_d = 500, \quad V_{N,rms} = 10\,\text{mV}, \quad \Delta V_{ADC} = 5\,\text{mV}$$

- Start with: $V_{Meas} = A_d \Delta V = A_d V_s \cdot RO \cdot \frac{L}{L_{Rated}}$

- Compute Derivative: $\frac{\partial V_{Meas}}{\partial L} = A_d V_s \cdot RO \cdot \frac{1}{L_{Rated}}$

Since $V_{n,rms} > \Delta V_{ADC}$

$$\Rightarrow \Delta L_{NW} = \frac{10\,\text{mV}}{500 \times 10\text{V} \cdot \frac{1.5\,\text{mV}}{\text{V}} \cdot \frac{1}{5\,\text{kg}}}$$

$$= 6.7 \times 10^{-3}\,\text{kg} = \underline{\underline{6.7\,\text{g}}}$$

D. Proper amplifier gain

- Naturally, we want to measure a signal with the finest possible resolution.

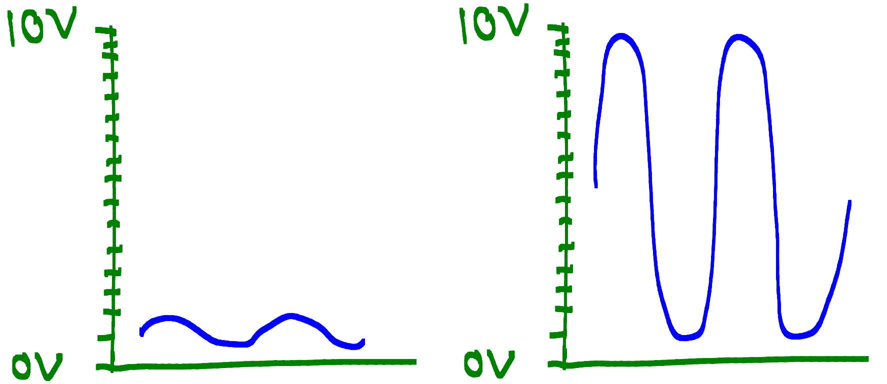
→ Max signal amplitude should span most of the ADC's voltage range!

⇒ If adjustable gain is not possible, then we must wisely choose the proper gain!

① Need to estimate max sensor signal

② Need to know ADC specs

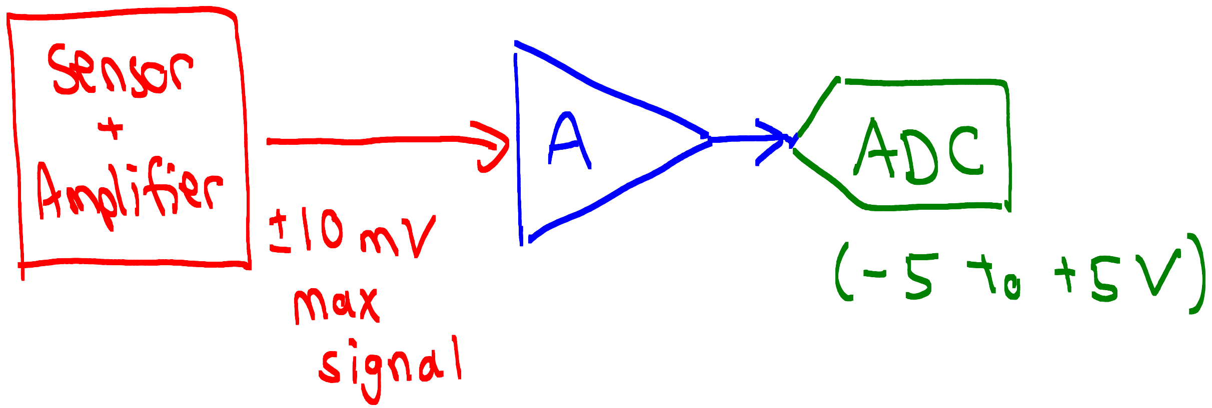
Ex:



Poor match :(

Good match :)

Ex:



Want $A \cdot (.010V) \leq 5V$

$$A \leq \underline{\underline{500}}$$