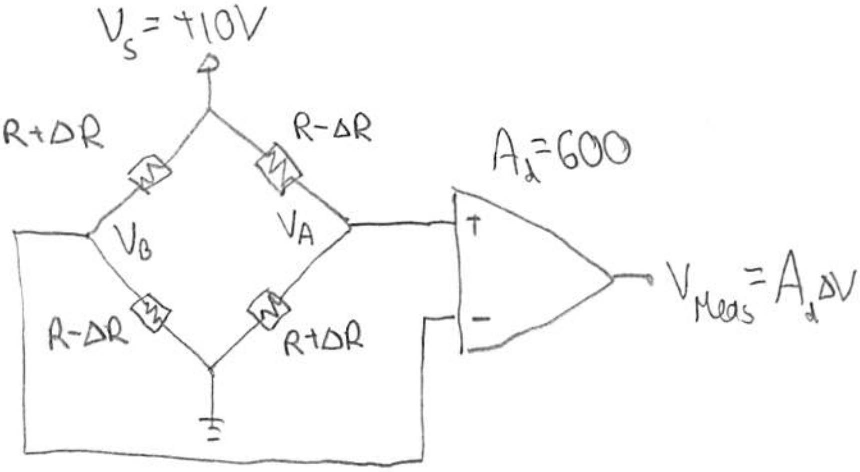
BME/ECE 386
HW1 Solns

Total = 100 pts



① (+5)

$$V_A = \frac{V_s}{(R-\Delta R)+(R+\Delta R)}(R+\Delta R)$$

$$= V_s \frac{R+\Delta R}{2R} = \frac{V_s}{2} + \frac{V_s}{2}\left[\frac{\Delta R}{R}\right]$$

$$\uparrow G\varepsilon$$

$$V_A = \frac{V_s}{2} + \frac{V_s}{2} G\varepsilon = \frac{10}{2} + \frac{10}{2}(2.1)(350 \times 10^{-6}) = \boxed{5.003675V}$$

$$V_B = \frac{V_s}{(R-\Delta R)+(R+\Delta R)}(R-\Delta R) = \frac{V_s}{2} - \frac{V_s}{2} G\varepsilon$$

$$= \frac{10}{2} - \frac{10}{2}(2.1)(350 \times 10^{-6}) = \boxed{4.996325V}$$

② (+5)

$$\Delta V = V_A - V_B = 5.003675 - 4.996325 = \boxed{.00735V}$$

$$V_{Meas} = A_d \Delta V = 600 \cdot .00735V = \boxed{4.41V}$$

③ (+5)

$$V_{Meas} = A_d V_s G\varepsilon \rightarrow \varepsilon = \frac{V_{Meas}}{A_d V_s G} = \frac{-2V}{600(10V)(2.1)}$$

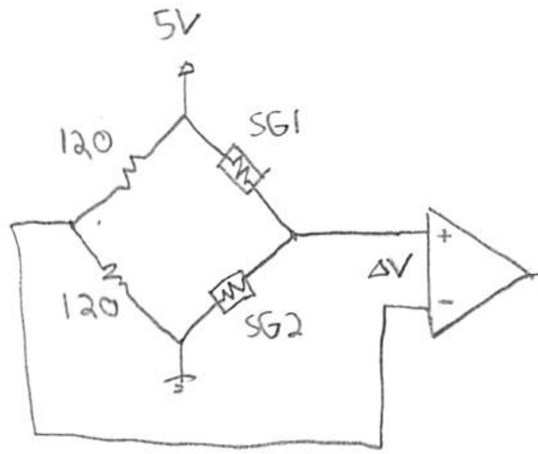
$$= -1.587 \times 10^{-4}$$

$$= -158.7 \times 10^{-6}$$

$$= \boxed{-158.7 \ \mu strain}$$

4 Half-bridge

+3



$V_{MEAS} = A_d \Delta V$

5

+10

+5V

0V

-5V

Max (+) signal $\leftarrow$ want $V_{MEAS} = A_d \Delta V_{MAX} < 5V$

For ½ bridge!

$$\Delta V_{MAX} = \frac{V_s}{2}\left(\frac{\Delta R}{R}\right)_{max} = \frac{V_s}{2} G \varepsilon_{MAX}$$

$$= \frac{5V}{2}(2.1)(600 \times 10^{-6})$$

$$= 3.15 \times 10^{-3}\, V$$

So, $A_d < \dfrac{5V}{3.15 \times 10^{-3}\, V} = 1587.3$

$\rightarrow$ Choose $\boxed{A_d = 1000}$

6 Want $\Delta V_{ADC} < \frac{1}{2} V_{n,rms} \rightarrow \dfrac{10V}{2^n - 1} < \frac{1}{2}(.002V) \Rightarrow 2^n > 10001$

+10

Method 1:

$2^{10} = 1024$ ✗

$2^{12} = 4096$ ✗

$2^{14} = 16384$ ✓

Choose $\boxed{n = 14}$

Method 2: $\log(2^n) > \log(10001)$

$$n > \frac{\log(10001)}{\log(2)} = 13.3$$

Choose $\boxed{n = 14}$

(7) +10

$$\Delta\varepsilon_{MIN} = \frac{\Delta V_{MIN}}{\frac{\partial V_{MEAS}}{\partial \varepsilon}}$$

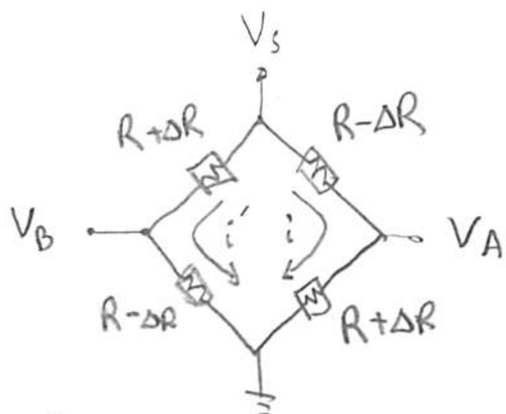
since $\Delta V_{ADC} < V_{N,rms}$, we know that $\Delta V_{MIN} = 2\,mV$

$$V_{MEAS} = A_d \frac{V_s}{2} G \varepsilon$$ For ½ bridge!

$$\frac{\partial V_{MEAS}}{\partial \varepsilon} = A_d \frac{V_s}{2} G$$

$$\Rightarrow \Delta\varepsilon_{MIN} = \frac{.002V}{1000 \times \frac{5V}{2} \times 2.1} = 3.81 \times 10^{-7} = \boxed{0.381 \times 10^{-6} = 0.38 \text{ microstrain}}$$

(8) Full Bridge: +12



$$V_A = i \times (R+\Delta R)$$

$$= \frac{V_s}{R - \cancel{\Delta R} + R + \cancel{\Delta R}} (R+\Delta R)$$

$$= \frac{V_s}{2R}(R+\Delta R) = \frac{V_s}{2} + V_s \frac{\Delta R}{2R}$$

$$V_B = i' \times (R - \Delta R)$$

$$= \frac{V_s}{R + \cancel{\Delta R} + R - \cancel{\Delta R}} (R - \Delta R)$$

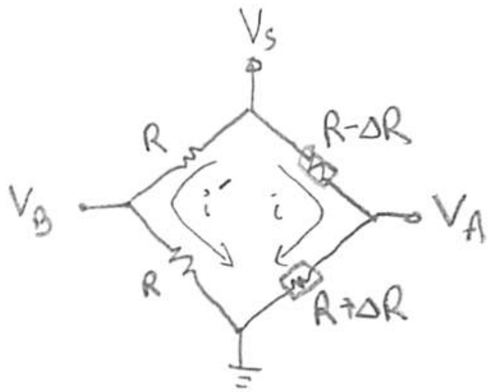
$$= \frac{V_s}{2R}(R - \Delta R) = \frac{V_s}{2} - V_s \frac{\Delta R}{2R}$$

$$\Delta V = V_A - V_B$$

$$= \cancel{\frac{V_s}{2}} + V_s \frac{\Delta R}{2R} - \left(\cancel{\frac{V_s}{2}} - V_s \frac{\Delta R}{2R}\right)$$

$$\boxed{\Delta V = V_s \frac{\Delta R}{R}}$$

Half-Bridge



$$V_A = i(R+\Delta R)$$

$$= \frac{V_s}{R-\cancel{\Delta R}+R+\cancel{\Delta R}}(R+\Delta R)$$

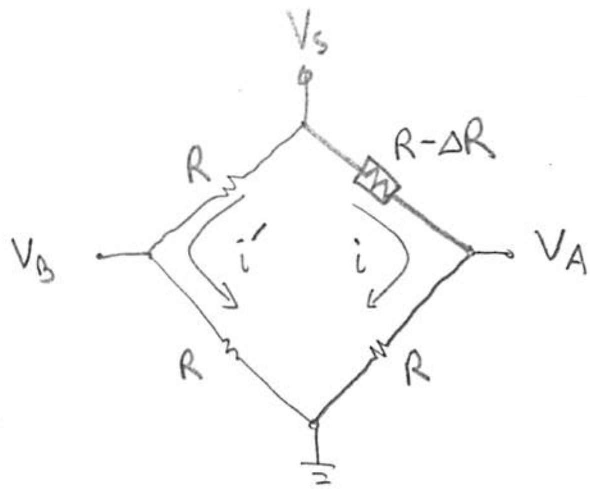
$$= \frac{V_s}{2} + V_s\frac{\Delta R}{2R}$$

$$V_B = i'R = \frac{V_s}{2R}R = \frac{V_s}{2}$$

$$\Delta V = V_A - V_B$$

$$= \left(\cancel{\frac{V_s}{2}} + \frac{V_s}{2}\frac{\Delta R}{R}\right) - \cancel{\frac{V_s}{2}} = \boxed{V_s\frac{\Delta R}{2R}}$$

Quarter Bridge



$$V_A = iR$$

$$= \frac{V_s}{R-\Delta R+R}\cdot R$$

$$= \frac{V_s}{2R\left(1-\frac{\Delta R}{2R}\right)}\cdot R = \frac{V_s}{2}\,\frac{1}{1-\frac{\Delta R}{2R}}$$

$$\approx \frac{V_s}{2}\left(1+\frac{\Delta R}{2R}\right) = \frac{V_s}{2} + V_s\frac{\Delta R}{4R}$$

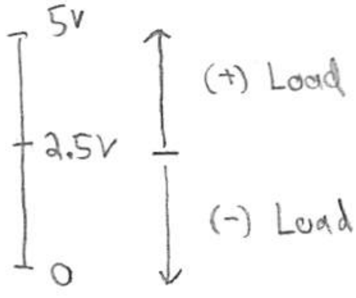
$$V_B = i'R = \frac{V_s}{2R}R = \frac{V_s}{2} \implies \Delta V = V_A - V_B = \left(\cancel{\frac{V_s}{2}} + V_s\frac{\Delta R}{4R}\right) - \cancel{\frac{V_s}{2}}$$

$$= \boxed{V_s\frac{\Delta R}{4R}}$$

☆ NOTE: The approximation $\frac{1}{1+x} \sim 1-x$ (for $x \ll 1$) is very useful! It is simply a 1st order Taylor Series expansion of $\frac{1}{1+x}$ about $x=0$.

(9) +10

ADC:



want

$$V_{MEAS} = 2.5 + A_d \Delta V < 5V$$

$$\Delta V_{MAX} = 1.5\frac{mV}{V} \times 5V \times \frac{3kN}{5kN}$$

$$= 4.5 mV$$

so, $2.5 + A_d \times .0045V < 5V$

$$A_d < \frac{5 - 2.5V}{.0045V} = 555.6 \rightarrow \boxed{\text{Choose } A_d = 500}$$

(10) +10

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

- ΔV_{MIN} is larger of ΔV_{ADC} and $V_{n,rms}$

$$\frac{5V}{2^{12}-1} = \underbrace{1.22 mV}_{\text{This is } \Delta V_{MIN}}$$

$0.5 mV$

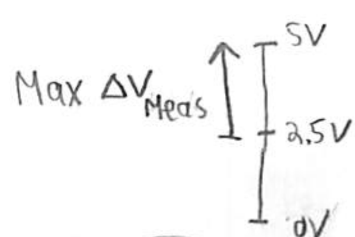
- $$\frac{\partial V_{MEAS}}{\partial L} = A_d \, RO \, V_s \frac{1}{L_{rated}}$$

$$= 500 \left(1.5\frac{mV}{V}\right)(5V)\frac{1}{5000N}$$

$$= 0.75 \frac{mV}{N}$$

$$\Rightarrow \Delta L_{MIN} = \frac{1.22 mV}{0.75 mV/N}$$

$$= \boxed{1.63 N}$$



(11) $$DR = 20\log_{10}\frac{\text{Max }\Delta V_{Meas}}{\Delta V_{MIN}} = 20\log_{10}\frac{2.5V}{.00122V} = \boxed{66.2 \, dB}$$ +5

(12) Design requirements are Max Load = 1 kg, Sensitivity = 1 g] Must make sure BOTH are satisfied!

+15

- Many ways to solve this problem. One reasonable way is to compute the max V_{MEAS} (corresponding to L = 1 kg) and ΔL_{MIN} for all 4 combinations.

Want $$\text{Max } V_{MEAS} = 5 + A_d \, RO \, V_s \frac{1\text{ kg}}{L_{rated}} < 10V$$ ← Limited by ADC for this problem

Want $$\Delta L_{MIN} = \frac{\Delta V_{MIN}}{\frac{\partial V_{MEAS}}{\partial L}} = \frac{\Delta V_{MIN}}{A_d \, RO \, V_s} L_{rated} < 1g$$

↑ OK if ΔL_{MIN} is smaller than desired

$$\Delta V_{ADC} = \frac{10V}{2^{14}-1} = .6\text{ mV}$$

- LC #1, Amp #1

$$\text{Max } V_{MEAS} = 5 + 200(.008)10 \frac{1\text{kg}}{10\text{kg}} = 6.6V \checkmark$$

$$\left.\begin{array}{l} V_n = 2mV \leftarrow \Delta V_{MIN} \\ \Delta V_{ADC} = .6mV \end{array}\right\} \Delta L_{MIN} = \frac{2\text{ mV}}{200\left(\frac{8mV}{V}\right)10V} \times 10^4 g$$

$$= 1.25g \; X \; (\text{Too big})$$

- LC #1, Amp #2

$$\text{Max } V_{Meas} = 5 + 500\left(.008 \tfrac{V}{V}\right)10V \frac{1\text{kg}}{10\text{kg}} = 9V \checkmark$$

$$\left.\begin{array}{l} V_n = 5mV \leftarrow \Delta V_{MIN} \\ \Delta V_{ADC} = .6mV \end{array}\right\} \Delta L_{MIN} = \frac{5mV}{500\left(\frac{8mV}{V}\right)10V} \times 10^4 g = 1.25g \; X$$

• LC#2
Amp#1

$$\text{Max } V_{meas} = 5 + 200\left(.0025\tfrac{V}{V}\right)10V\,\frac{1\,kg}{2\,kg} = 7.5V \checkmark$$

$$\Delta L_{MIN} = \frac{2\,mV}{200\left(2.5\,\frac{mV}{V}\right)10V} \times 2000g = 0.8g \checkmark$$

• LC#2
Amp#2

$$\text{Max } V_{meas} = 5 + 500\left(.0025\tfrac{V}{V}\right)10V\,\frac{1\,kg}{2\,kg} = 11.25V \times \left(\text{too big}\right)$$

$$\Delta L_{MIN} = \frac{5\,mV}{500\left(2.5\,\frac{mV}{V}\right)10V}\,2000g = 0.8g \checkmark$$

WINNER is $\boxed{\text{LC\#2, Amp\#1}}$

NOTE: Another approach to this problem is to compute L_{max} and ΔL_{MIN} for each combo.

$$\text{Max } V_{MEAS} = 10V = 5 + A_d\, RO\, V_s\,\frac{L_{MAX}}{L_{Rated}}$$

$$\Rightarrow \text{ we want } L_{Max} = \frac{5V}{A_d \cdot RO \cdot V_s}\,L_{Rated} \geq 1\,kg \,!$$

$$\text{we also want } \Delta L_{MIN} = \frac{\Delta V_{MIN}}{A_d \cdot RO \cdot V_s}\,L_{Rated} \leq 1g \,!$$

	L_{max}	ΔL_{MIN}
• LC1 Amp1	$\frac{5}{200(.008)(10)}(10kg) = 3.13\,kg$ ✓	$\frac{.002}{200(.008)10} \times 10^4 = 1.25g$ X
• LC1 Amp2	$\frac{5}{500(.008)10}\,10kg = 1.25\,kg$ ✓	$\frac{.005}{500(.008)10} \times 10^4 = 1.25g$ X
• LC2 Amp1	$\frac{5}{200(.0025)10}\,2kg = 2.0\,kg$ ✓	$\frac{.002}{200(.0025)10} \times 2000g = 0.8g$ ✓
• LC2 Amp2	$\frac{5}{500(.0025)10}\,2kg = 0.8\,kg$ X	$\frac{.002}{500(.0025)10} \times 2000g = 0.8g$ ✓

$\boxed{\text{WINNER is LC2, Amp1}}$