HW 1 – Strain Measurement
(12 problems for 100 pts)

STRAIN GAUGE BASICS

In class, we discussed a strain measurement system using a full-bridge (see page 1.7 of lecture notes). Suppose we use 350 ohm constantan strain gauges, an excitation voltage V_S = 10V, and an instrumentation amplifier with a differential gain A_d = 600. Assume that $V_{MEAS} = A_d\Delta V$, which means zero strain produces V_{MEAS} = 0V.

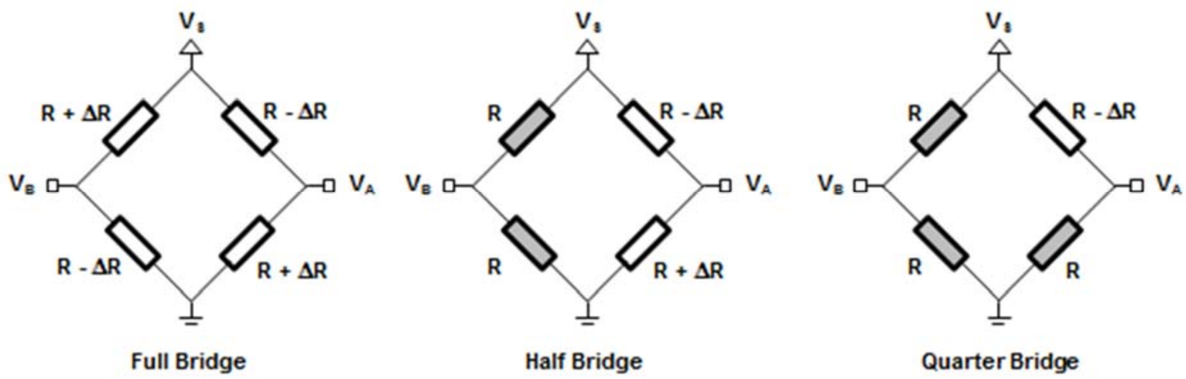
- PROBLEM 1: Suppose the applied strain is ε = +350 μstrain. Compute the values of V_A and V_B (see page 1.7 of lecture notes) out to six decimal places (e.g. 3.123456V).
- PROBLEM 2: Compute the bridge voltage ΔV and measured voltage V_{MEAS}.
- PROBLEM 3: Suppose V_{MEAS} = -2V. What is the applied strain? Express your answer in μstrain.

MORE STRAIN GAUGES

Consider a strain measurement system, where the maximum expected strain is $|\varepsilon_{MAX}|$ = 600x10^{-6}. You decide to use a half-bridge configuration using 120 ohm strain gauges made of constantan (gauge factor = 2.1) and 120 ohm 1% resistors. The supply voltage is V_S = +5 V. Your ADC operates from -5V to +5V, so you can assume that zero strain produces a measured voltage of 0V.

- PROBLEM 4: Sketch the circuit diagram for the signal conditioning electronics (e.g. bridge and amplifier). You can simply label the strain gauges as SG1 and SG2.
- PROBLEM 5: Suppose you have a choice of instrumentation amplifier gain = 10, 20, 50, 100, 200, 500, 1000, 2000, or 5000. Which is the best value? Show all work.
- PROBLEM 6: Suppose the noise voltage of your measurement system is V_{NOISE} = 2 mV_{RMS}. In order to get the best performance out of your system, your ADC vertical resolution should be less than HALF the noise voltage (e.g. $\Delta V_{ADC} \leq 0.5V_{NOISE}$). You must choose between an ADC with 8, 10, 12, 14, or 16 bits. Which is the best value? Show all work. Hint: You should get 14 bits.
- PROBLEM 7: Given the value of V_{NOISE}, compute the strain sensitivity of your system. Express your answer in units of 10^{-6}. Show all work. Hint: You should get 0.38 microstrain.
- PROBLEM 8: In class, we discussed how a full bridge, half bridge, and quarter bridge produce $\Delta v = V_S\Delta R/R$, $0.5V_S\Delta R/R$, and $0.25V_S\Delta R/R$, respectively. Derive these three results based on the circuit schematics shown below. Show all work!

  Hint: For the quarter bridge, you can use the linear approximation: $\frac{1}{1-\frac{\Delta R}{2R}} \approx 1 + \frac{\Delta R}{2R}$. This approximation is valid if ΔR/2R << 1, which is typically the case for strain gauges.



LOAD CELL

Consider a load cell measurement system. The load cell has a rated output of 1.5 mV/V @ 5 kN. The supply voltage is V_S = +5V. Your ADC operates from 0 to +5V with 12 bits. Assume that V_{REF} = 2.5V, meaning that zero load produces a measured voltage of 2.5V.

- PROBLEM 9: Suppose you have a choice of instrumentation amplifier gain = 10, 20, 50, 100, 200, 500, 1000, 2000, or 5000. Assuming you want the maximum measured load to be 3 kN, what is the best amplifier gain? Show all work.

- PROBLEM 10: Suppose the noise voltage of your measurement system is V_{NOISE} = 0.5 mV_{RMS}. Compute the load sensitivity of your system. Show all work. Hint: You should get ΔL_{MIN} near 1.6 N.

- PROBLEM 11: Dynamic range (DR) is defined as the ratio between the largest and smallest measurable voltage signal. This ratio is usually expressed in decibels, where DR = $20\log_{10}(\Delta V_{MAX}/\Delta V_{MIN})$. For example, $\Delta V_{MAX}/\Delta V_{MIN}$ = 100 translates to DR = 40 dB. Compute the DR of the load cell measurement system in this problem. Hint #1: Keep in mind that ΔV_{MAX} is really the largest voltage swing away from V_{REF}. Hint #2: DR should be around 66 dB.

ANOTHER LOAD CELL

You want to measure a maximum load of 1 kg with a sensitivity of 1g. The supply voltage is V_S = +10V. Your ADC operates from 0 to +10V with 14 bits. Assume that zero load produces a measured voltage of 5V (half-way between 0 and +10V).

You have two load cells available. Load cell #1 has a rated output of 8 mV/V at 10 kg, while load cell #2 has a rated output of 2.5 mV/V at 2 kg. You also have two amplifiers available. Amplifier #1 has a gain of 200 with an output noise voltage of 2 mV_{RMS}, while amplifier #2 has a gain of 500 with a noise voltage of 5 mV_{RMS}.

- PROBLEM 12: There are four possible combinations of load cell and amplifier. What is the best combination of load cell and amplifier gain that satisfies the design requirements? You must also show why the other three combinations are no good. Show all work.

  Hint #1: Make sure your system satisfies BOTH design specifications (max load and sensitivity).

  Hint #2: You should find that the "winning" combination is: Load cell #2 and Amplifier #1. (End of HW1)