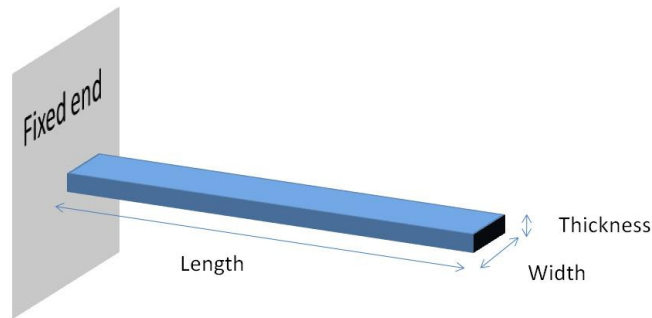


1. Strain Gauge Load Sensor

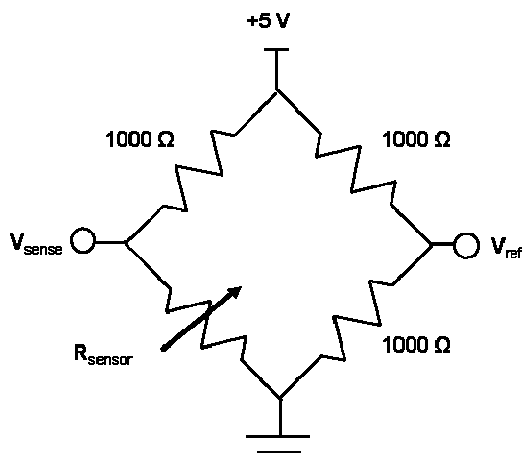
Your lab partner is setting up an apparatus to measure strains. She has a strain gauge with a gauge factor of 3 and a nominal (strain-free) resistance of $1\text{k}\Omega$. The strain gauge is mounted on the top of a rectangular aluminum bar with dimensions of 10 cm long x 2 cm thick x 4 cm wide.



Your partner connects this strain gauge to a simple Wheatstone bridge consisting of $1\text{k}\Omega$ resistors. The bar is fixed at one end and free at the other. Loads are placed at the free end of the beam. (Please use a modulus of elasticity (E) of 73.1 GPa)

Q: What is the resistance of the strain gauge when an added load of 1 kg is applied to the end of the beam?

Q: The Wheatstone bridge is biased with a 5V V_{in} . What is the voltage difference between the sense and reference terminals of the bridge?



2. Thermometer Noise Calculation

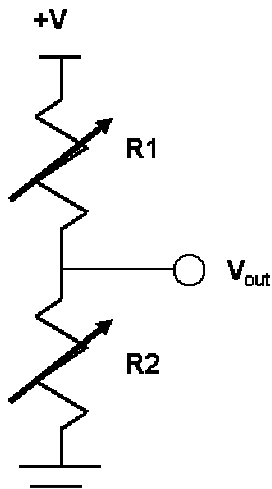
The LM35 thermometer has noise spectral density that is less than $10 \frac{\mu V}{\sqrt{Hz}}$ from 0.1 Hz to 100 kHz

Q: If you connected the output of this sensor to a band pass filter with a low frequency cutoff at 0.1 Hz and a high frequency cutoff at 100 Hz, and made sure that there were no temperature changes, what would the amplitude of the RMS noise be?

Q: If the filter cutoff frequency were changed to 1 Hz, what would the RMS noise amplitude be?

3. Output non-linearity for a force sensor

A cantilever beam has a pair of strain gauges mounted on the top and bottom of the beam, so that bending of the beam causes one to increase in resistance and the other to decrease in resistance. In equation form, $R_1 = R_0 \left(1 + \frac{F}{\beta} \right)$ and $R_2 = R_0 \left(1 - \frac{F}{\beta} \right)$, where $R_0 = 1000\Omega$, $\beta = 1000N$, F is the applied force in Newtons, and R_1 and R_2 are the resistance values of the sensors. These are wired together as a voltage divider as shown below. If the bias voltage is 5V, what is the output voltage as a function of load force, F ? Using the Taylor series expansion (as in other homework problems), estimate the size of the quadratic error term relative to the linear term.



4. Suppose your thermostat used a small (1 mm x 1 mm x 1 mm) thermistor to measure air temperature. This thermistor has a heat capacity of $10^{-3} J/K$ and a thermal conductivity to the air of $2 \times 10^{-4} W/K$. Now, suppose you placed a desk lamp 10 cm away from the thermostat, and assume that the bulb in the lamp emits 100W of power. (Since the power oscillates at 60Hz, the power output of the lamp really looks like

$P = 100 + 100 \cos(2\pi 60t)$ where P is power {Watts}. Also assume that the thermistor absorbs all IR and optical radiation that it intercepts.

- a) What effect does the lamp have on the thermostat temperature (quantitatively, I want an equation and number answer)?
- b) The thermistor has a nominal resistance of 1000 ohms, and is measured with a current of 0.2 mA. How much effect does our measurement current have on the measured temperature?
- c) What can you do to minimize these effects?

5. A “Smart” clothes drying machine operates by detecting the weight of the clothes. A standard “load of clothing” has a weight of >10 kg when wet and <5 kg when dry. The dryer has a weight of 50 kg when empty.

The weight sensor is constructed with a strain gauge placed in one of the 4 “feet” of the clothes dryer. In this position, it detects exactly 1/4 of the weight of the machine plus the clothes. It consists of a structure that has a pre-assembly length of 1 cm, and a stiffness of 1,000,000 N/m. A metal film strain gauge with a nominal resistance of 1 k Ω and a gage factor of 2.5 is attached to this structure so that the weight of the washing machine causes tensile strain in the strain gauge that is the same magnitude as the strain in the feet.

- a) If the unloaded length of the “foot” is 1 cm, what is the length when the entire machine is assembled and mounted upright on the ground? What is the resistance of the strain gauge in this situation?
- b) After adding a load of wet clothing, what is the possible range of resistance values?
- c) When the clothes are dry, what is the possible range of resistance values?
- d) The Laundry Room environment can have large temperature variations – leading to resistance variations as large as 4%. Is this a problem for this application? If so, what can be done in the design of a circuit to reduce or eliminate the effect of temperature on the sensor output?