# MAS.836
# PROBLEM SET THREE

**FSR, Strain Gauge, and Piezo Circuits:**
The purpose of this problem set is to familiarize yourself with the most common forms of pressure and force measurement. The circuits you develop herein will be directly applicable to other sensors, as these sensors cover the majority of the source impedances you will encounter. Piezo sensors are high-impedance and very capacitive, FSRs are resistive, with a wide range of resistance, and strain gauges are extremely low impedance sources.

**Force Sensitive Resistors:** FSRs are a fairly inexpensive and easy to implement method of measuring an applied force. They vary with time, temperature, and loading conditions, which make them inaccurate and unrepeatable, but for prototyping an idea quickly, they are a good solution.

**Strain Gauges:** Strain gauges can be less expensive than FSRs, but they also need to be mounted to some mechanical device which will convert an applied force to a strain. This, along with requiring complicated conditioning electronics, makes them more difficult to work with, although they are many orders of magnitude more accurate and repeatable. A strain gauge's sensitivity with the applied strain is called the gauge factor (Se). The gauge factor will determine the change in resistance with applied strain according to the following formula:

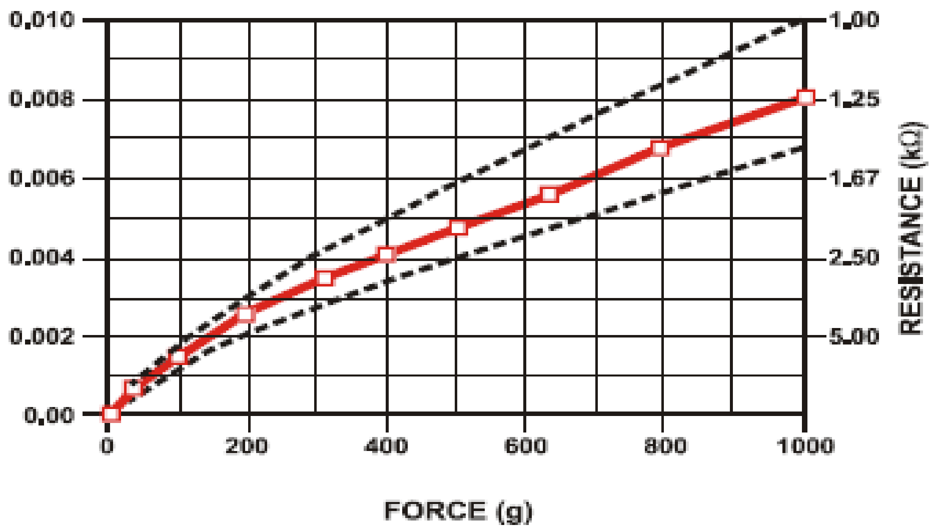
$$\mathbf{Rs = Ro \times (1 + Se \times e),}$$

where Rs is the resistance with applied strain, Ro is the initial resistance, and e is the applied strain.

**Piezo Films:** The most common form of piezoelectric sensors is a PVDF film, as they are inexpensive to make, and can be easily applied to many different surfaces. Just as with the strain gauges, the piezo film needs to be applied to some other material which will translate the applied force into a strain in the piezo film. The piezo film will then produce a voltage proportional to this applied strain. The voltage produced will be a function of the direction the strain is in, the Young's Modulus of the material, the dielectric constant of the material, the piezoelectric coefficients, and the geometry of the piezo film. A detailed explanation of these relations can be found in the MSI literature linked off the class website. Pay close attention to pages 3, 15 - 19, and 27 - 29.

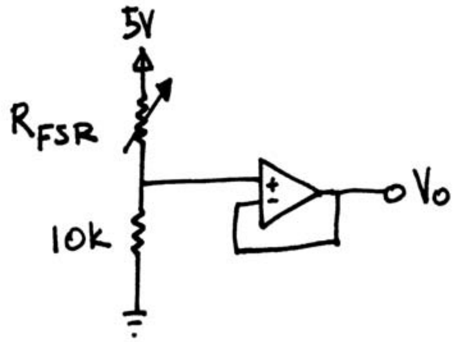
Piezo films have many advantages in terms of ease of use, cost, and longevity, but they are not capable of maintaining a DC signal, as they have internal leakage which will drain off the charge induced by the applied strain. Furthermore, they have a high source impedance, making them susceptible to pick-up noise. This is further complicated by the fact that they exhibit responses to both light and heat, so good bandpass amplifiers should be used with piezo films.

**Problem One:**
The following graph is the force versus resistance curve of the Interlink FSRs which are included in your lab kit. The righthand axis is in kilohms, and the lefthand axis is in units of conductance (in this case, decisiemens). Note that the righthand scale is not linear, as the FSR travels through many decades of resistance over the 1kg force range.

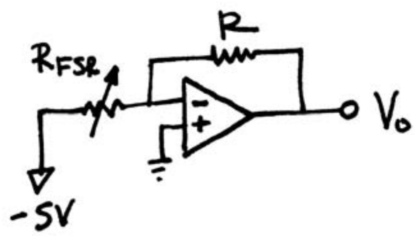





1. Using the above force versus resistance relationship, please plot Vo versus force for the following circuit.

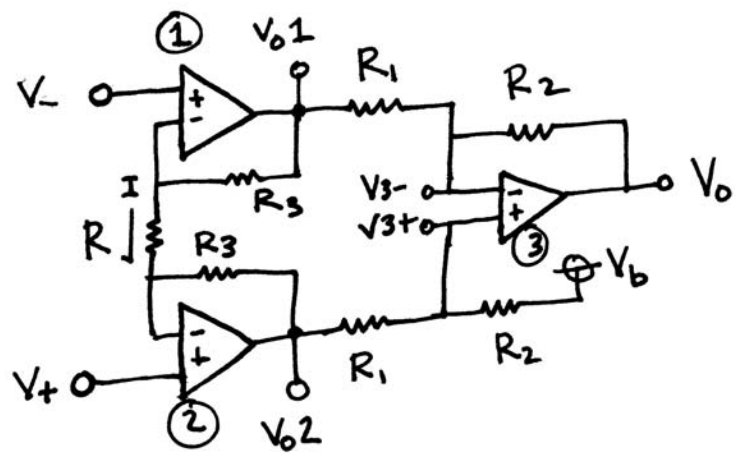



2. For the following circuit, if we want Vo to go from 0V to 5V as the applied force goes from 0kg to 1kg, what value should R be?



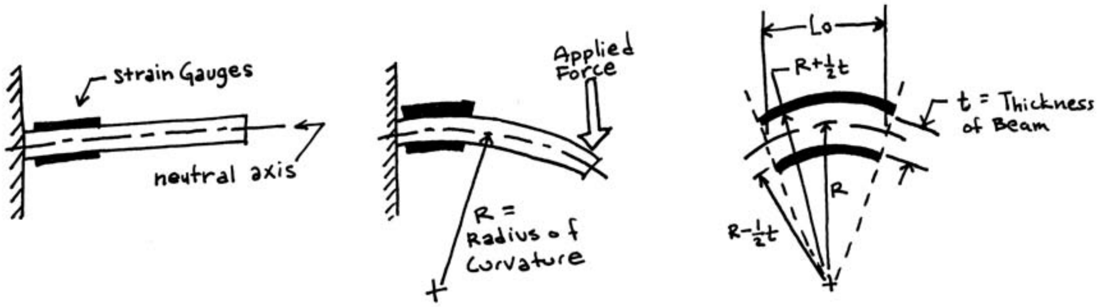
3. For the value of R chosen in (2), please plot, overlayed on your graph from (1), Vo versus force for the circuit shown in (2).
4. Under what conditions would you use the first circuit rather than the second?

**Problem Two:**
The circuit below is a standard 3 op-amp differential amplifier. It has the advantages over a single op-amp differential amplifier of having a much higher input impedance, and having its gain settable by a single resistor valuable. Please answer the questions below to analyze the functioning of this amplifier.




1. What are the voltages at the inverting terminals of op-amps 1 and 2?
2. What is the current (I) flowing through R in terms of V+ and V-?
3. What is the current flowing through both R3's?
4. What is the voltage difference between Vo1 and Vo2 in terms of I, R, and R3?
5. Substitute your result from (2) into (4) to find a relation for the difference between Vo1 and Vo2 in terms of R, R3, V+, and V-.
6. What is V3- in terms of Vo1, Vo, R1, and R2?
7. What is V3+ in terms of Vo2, Vb, R1, and R2?
8. Since V3+ equals V3-, find a relation for Vo in terms of Vo1, Vo2, Vb, R1, and R2.
9. Substitute your result from (5) into (8) to get the transfer function of this circuit.
10. Which is the single resistor you would vary to set the gain?
11. How would you bias this amplifier?

**Problem Three:**
Strain gauges are inexpensive and accurate tools for measuring force and displacement. Since the level of displacement they measure is so small, they are more often used as force sensors. By attaching the strain gauge to a flexible member of a known geometry, the displacement to force characteristics can be derived. The simplest form of a flexible member is the cantilever beam, and is shown below.




The applied force bends the beam, and creates a radius of curvature which decreases with this force, such that it is infinite (for a flat beam) at zero force. The neutral axis is the line about which the beam bends. All of the material above the neutral axis expands, and all the material below the neutral axis compresses, whilst the neutral axis stays the same length. Strain gauges are generally extremely thin, such that we can neglect their thickness in relation to the beam thickness (t). This allows us to assume that the strain induced in the strain gauge is exactly equal to that of the exterior surfaces of the beam. For some section of length L0, this strain (e) is merely the change in length, L1 - L0, divided by the original length, or e = (L1 - L0) / L0, where L1 is the length at the surface, and L0 is the length of the neutral axis.

For this problem, assume we have a strain gauge applied to both the top and bottom of a cantilever beam, as shown above, and that the strain gauge is thin compared to the beam thickness. Furthermore, it is given that the beam thickness is 1mm, and the minimum radius of curvature that will be seen will be 20cm. The strain gauges have an initial resistance of 200Ω, and a gauge factor of 2.

1. What is the peak strain (e) of the inner and outer strain gauges?
2. What is the resistance of the strain gauges under maximal load?
3. Utilizing the strain gauges, design a Wheatstone bridge which is temperature compensated (assume both strain gauges are always at the same temperature).
4. What is the differential voltage, for a 5V excitation voltage, across your Wheatstone bridge for both the unloaded and maximally loaded cases?
5. Design a bridge amplifier running off a single 5V rail that will give a reading of 0V for no applied force, and 5V for the maximum applied force with your Wheatstone bridge above.

**Problem Four:**

For this problem, assume we are using the same cantilever beam setup as in Problem Three, but this time we are using piezo PVDF films rather than strain gauges to sense the applied force. The geometry and maximal deflection of the beam shall be the same. The piezo films are 30µm thick, and 0.7cm wide by 0.7cm long. The 1-axis is along the length of the beam, and the 3-axis is perpendicular to the surface of the film. Use the values given in the MSI Piezo Guide linked off the class website to answer the following.

1. What is the capacitance across each of the piezo films?

2. What is the maximum voltage produced by each of the piezo films?
3. Design a circuit with two resistors and a single op-amp running off a 5V rail which will buffer the piezo signal, roll off frequencies below 100Hz, have a gain of 1, and have its output centered at 2.5V.
4. Add two diodes and resistor to your above circuit to clamp the input voltage and protect the amplifier.

MAS.836 Sensor Technologies for Interactive Environments
Spring 2011