MAS.836 Sensor Technologies for Interactive Environments
Lab 4: Force-Sensitive Resistors and Piezo Films

The purpose of this lab assignment is to familiarize yourself with the implementation of force-sensitive resistors and piezo films, and the associated amplifiers and signal-conditioning electronics. Both of these sensors have specific amplifier requirements due to their nonlinearities and high impedance. The force-sensitive resistor can be particularly difficult as it has a non-linear response to the applied force.

You will construct your circuit from the parts included in your lab kit, in addition to any necessary resistors, capacitors, and diodes from the Responsive Environments stock area.

In all the opamp circuits here you will use your 5V power supplies that you built in Lab 2, so the negative and positive supply rails of the opamp will be 0 V and 5 V, respectively.

- Your **lab report** detailing your designs and answering the questions will be due in class.
- Your **functioning circuits** should be demoed to a TA for grading by 7 PM on the due date.

Please be careful with the sensors in your kit. The crimped leads on both sensors can be fragile, and the FSR can be damaged by shear forces. When applying force to the FSR, be sure to press down on the sensor element and not diagonally, as the shear force can separate the layers of the sensor.

1 FSR Amplifier Design

Before beginning your amplifier design, familiarize yourself with the force-sensitive resistor integration guide [1]. You will use the information in this guide to select initial gain values for your amplifier.

The FSR included in your kit is one of the smallest ones made. They can be custom-ordered in any size that a design requires, but for prototypes and small runs where it is not cost-effective to have sensors custom-manufactured, there are a small variety of standard sizes to choose from.

FSRs are generally not very accurate, repeatable, or robust, and are mildly expensive at around $6 per sensor. But, they make up for this with ease-of-use, and are still inexpensive and small compared to some other force sensing elements such as load cells.

1.1 Voltage-Divider FSR Circuit

To start investigating the behavior of your FSR, **build a simple voltage divider using the FSR as one of your level-setting resistors**. Observe the behavior of the divider as you press on the sensor. **Where is it most sensitive?**

1.2 Linearizing the FSR

Note that the force-resistance characteristics of the FSR are not linear as a function of the force applied. In many applications, you will be interested in having a linear voltage response to the applied force. The integration guide describes several circuits for linearizing the response of an FSR sensor (pay attention to the force-voltage curves). You are welcome to use any method of your choosing, but keep in mind that the entire lab assignment must be completed with your single quad op amp package.

Design an FSR amplifier that gives an approximately linear 0 V to 5 V output for a linear input of 0 to 1 kgf applied to the FSR. Since you will not have a method for measuring the input force, estimate the force that you are applying with the knowledge that 1 kgf is approximately the force produced by a finger being pressed down relatively hard. You may find the questions below to be useful hints in designing this circuit.

1.3 Lighting an LED

To demonstrate the output voltage increasing with increasing forces, design your circuit so that an LED becomes brighter as the force increases. The brightness of an LED is approximately proportional to the current that passes through it. If an LED has a resistor in series with it, and the voltage drop across the LED is small compared to the total voltage applied, the current will be proportional to the applied voltage, as the resistor will approximate a linear voltage-to-current source. Therefore, for the purposes of this lab, merely placing a resistor and LED at the output of your circuit will suffice.

A reasonable maximum current to run through an LED is 20mA (though your op amp may have trouble sourcing this much current.) The LEDs given in the kit can produce a significant amount of light at less than 5mA. Differences in brightness will also be most apparent for small currents through the LED.

Demonstrate this circuit (with LED and also using the oscilloscope or multimeter) to one of the TAs. Also include your final schematic in your lab report.

Questions

1. What is the resistance across your FSR with the maximal force ($\approx$ 1 kgf) applied? With no force?
2. What is the output voltage for your linearizing stage when:
   $R_{FSR} \ll R_G$
   $R_{FSR} = R_G$
   $R_{FSR} \gg R_G$
3. What do the answers to the previous question say about your choice for R_G?
4. What gain and bias do you need to apply after your linearizing stage to achieve full-range (0 V–5 V) output?
5. What is the maximum voltage the TLV2374 can reach if it is at room temperature, sourcing 20 mA, and running from a single 5 V supply?

2 Piezo Film Amplifer Design

The PVDF piezo film included in your lab kit is an inexpensive ($2-3) means of measuring vibration, and comes in a relatively small package. The film itself is 28 μm thick [2]. It is not as small, repeatable, or accurate as a MEMS accelerometer, but it is a fraction of the cost. This makes it a good candidate for picking up general motion where accuracy is not a concern.

In this section we'll build a simple wind/breath sensor that we could hook up to a micro-controller.

2.1 Building the buffer

The piezo film requires a buffer amplifier to ensure that its high source impedance does not degrade its output. For this reason, the opamp in your kit has been selected to have an extremely low input bias current (on the order of 1 pA).

We'll start by building a buffer so we can examine the output of the piezo sensor without worrying about the effects of the oscilloscope leads. **Build a buffer and test it with the signal generator first, looking at the output on your scope.** Note that for our wind sensor we only care about the total amplitude of the signal.

Now hook up your piezo sensor to the input of the buffer. You'll want to add a large resistor to ground from the sensor's output because the piezo element itself doesn't provide a DC path to ground, so any accumulated charge can show up as a DC offset.

Turn your buffer into a non-inverting amplifier to scale the piezo signal so that it is close to 5 V when you blow hard.

2.2 Tracking Wind Speed

In this part of the lab assignment, you will use your piezo film to design a simple wind speed detector. Air moving across the sensor will cause the film to vibrate. Your circuit should produce a clean analog voltage signal proportional to the wind speed, varying from 0 volts under no wind, and 5 volts with maximum wind speed. This should be a clean and stable signal that one could sample with the ADC on a microcontroller without noise. This means you'll want your output signal to follow the peaks (the envelope) of your raw signal, and not oscillate at the resonant frequency. Hint: there's a diode involved.

2.3 Triggering on Wind

Having a continuous wind sensor is useful, but you also might want a binary signal for whether the is or isn't wind. Add a digital signal that goes high (5 V) when the wind speed goes above a preset threshold, and is low (0 V) when the wind speed is below the threshold. This should be a clean digital pulse that could be used to wake up a microcontroller to start sampling when conditions are windy enough. Set the threshold so that your trigger turns on with a light blow, and attach an LED as in the first section.

Place the piezo film vertically in your breadboard, and blow on it to generate the vibration.

How might you modify your circuit to give clean triggering even when the wind signal is near the threshold? **Implement this modification in your detector circuit**

BONUS: Design and implement a filter stage to isolate the resonant frequency of the piezo element to improve your circuit's immunity to other vibrations.

Demonstrate your final circuit for the TA, and include your final schematic in your lab report.

Questions

1. What is the effect of running an unbiased AC signal into our single-supply buffer? How does this affect our ability to measure the amplitude of the signal?
2. What is the amplitude and dominant frequency of the buffered piezo signal when you blow hard on it?
3. What do the transients look like when you tap your breadboard? (use the oscilloscope's "single" triggering mode to capture them).

References

[1] Interlink Electronics, *Force Sensing Resistor Integration Guide.*
`https://www.sparkfun.com/datasheets/Sensors/Pressure/fsrguide.pdf`
Also available in the Stellar materials page.

[2] *MSI Piezo Film Sensor Datasheet.*
`https://www.sparkfun.com/datasheets/Sensors/Flex/MSI-techman.pdf`