Lab 1

ECE 167

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Checked off by **Arturo Gamboa-Gonzalez**
at **2:57PM April 14, 2022**

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April 15, 2022

1 Overview

The goal of this lab was to create a musical instrument that would output sound when the piezoelectric sensor was tapped, at a tone depending on the flex sensor output. This was done in parts. The speaker was already setup to output provided frequencies in the last lab. This lab simply required adding the flex sensor, and the piezoelectric sensor as controls. We also were supposed to familiarize ourselves with low-pass and high-pass filters by picking different capacitor and resistance values, and mapping out the frequency generation output with our oscilloscopes.

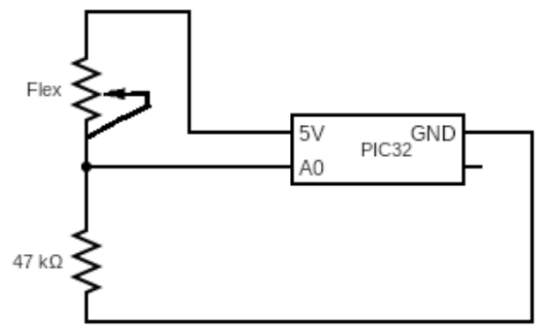
Parts Required:

- Flex Sensor
- Piezoelectric Sensor
- Speaker
- Amplifier Board
- 1μF Capacitor
- $1M\Omega$, 220Ω and $47K\Omega$ Resistors
- chipKIT32
- Jumper wires

2 Lab Methods

2.1 Flex Sensor

The first section of the lab just involved setting up the flex sensor. I started off by hooking up the flex sensor using the schematic given. I implemented the following:

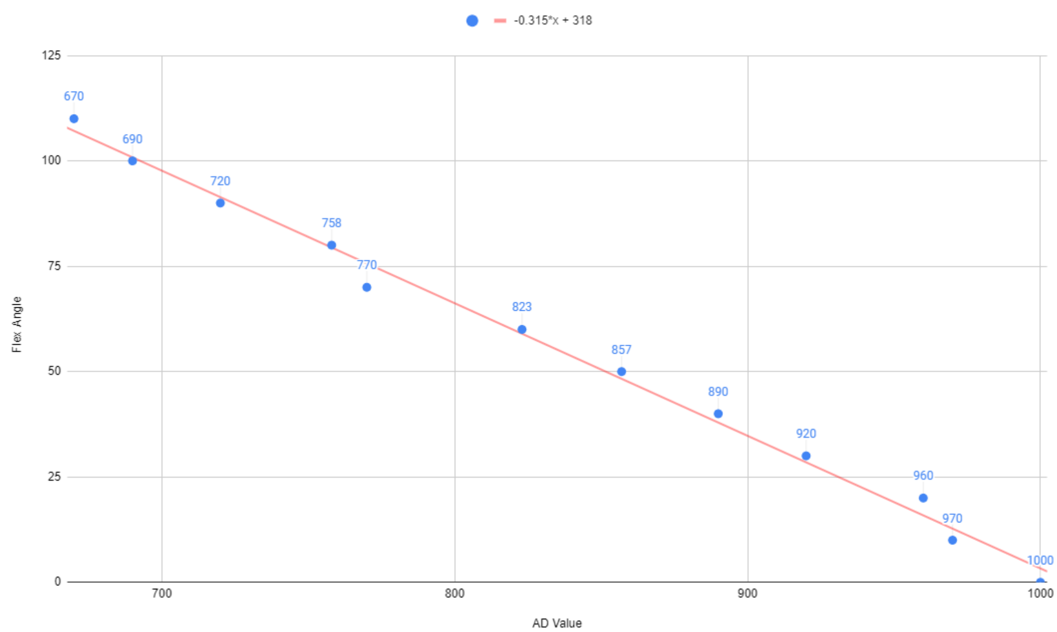


(a) Wiring schematic of the flex sensor hooking up to the microcontroller

The A0 pin was then set as the pin to read from using the ADC library. This value was set to display on the OLED, real time in order to get an idea of what kind of values would come out of the flex sensor. The flex sensor's range seemed to be **700 - 1023**. Tones are generated on a scale from **0 - 1000**. In order to adapt the scales, I used the following code:

```
toneValue = flexValue - minFlexValue;
toneValue *= flexScalar;
toneValue /= 100;
```

The number was divided by 100 in order to avoid the use of float values. $minFlexValue$ was found experimentally as 630 for my flex sensor. The $flexScalar$ was calculated as $flexScalar = \frac{100{,}000}{1023 - minFlexValue}$. We were tasked with also adapting the flex sensor value to an angle of bend. This was done by measuring flex values at every 10°s and writing down this value. The following graph was made:

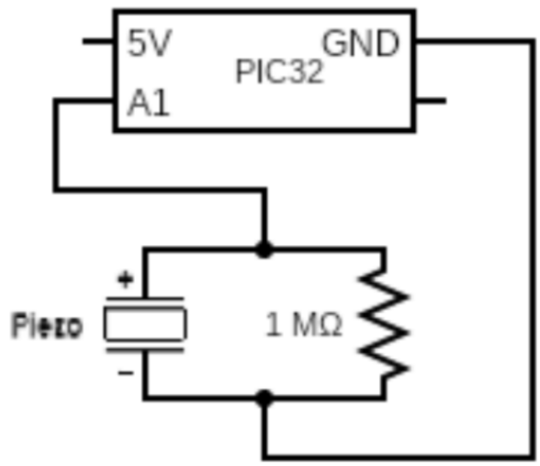


(b) Graph of the theoretical fake band-pass

The line of best fit for the points was determined to be $y = \frac{-1}{3}x + 318$. This equation was implemented in the program to display the flex angle on the screen. Notice the angle values only go up to 110°. This is because anymore was risking damage to the flex sensor.

2.2 Piezoelectric Sensor

This lab also required setting up the piezoelectric sensor to detect it being tapped and respond with tone generation. The piezoelectric sensor was first and foremost, hooked up to the board. This was done using the following wiring diagram:



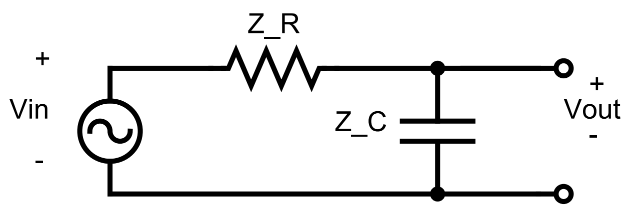
(c) Wiring schematic of the piezoelectric sensor hooking up to the microcontroller

The pin, A1 was then added to the list of pins read with the ADC library, and the value of the pin was set to display on the OLED. This was to get a feel for how big of a value would be considered a tap. This value was then decided to be $piezo > 350$. Whenever the value was >350, a flag was set high meaning that a tap was registered. A timer was set up which would set this flag low after one second. Every time the piezo value was >350, the timer was also reset. While the flag was high, the tone generation would be on.

2.3 Simple Analog Filtering Analysis

Low-Pass Filter

With this section, we were first tasked with solving for the transfer function of the single pole low pass filter. We then needed to pick capacitor and resistor values and use that to plot the theoretical magnitude vs. frequency curve. I started out by analyzing the following model:

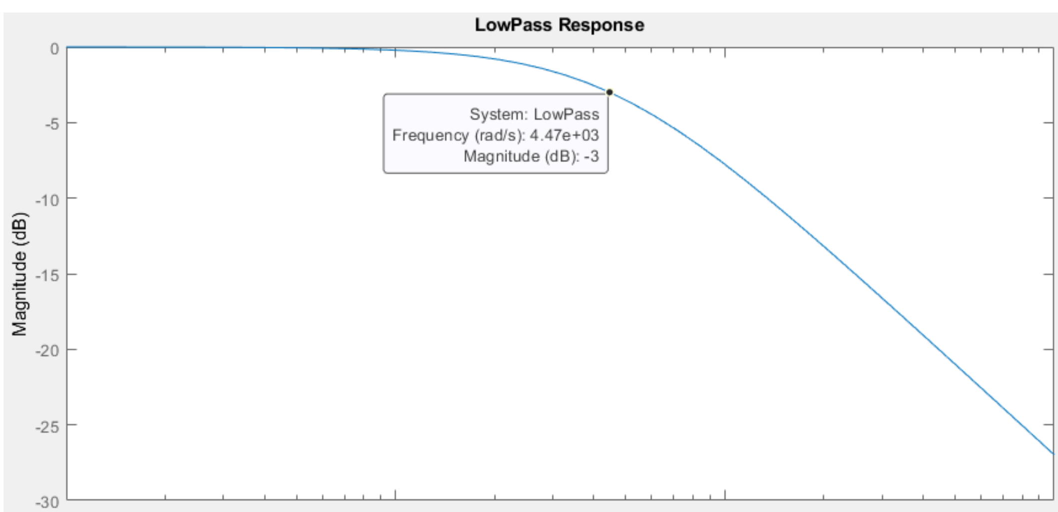


(d) Wiring schematic of a low-pass filter

A transfer function $H = \frac{V_{out}}{V_{in}}$. Looking at this circuit, we can use KVL to observe that, $V_{out} = Z_C$ and $V_{in} = Z_R + Z_C$. We know from the impedance formulas that the impedance values $Z_R = R$ and $Z_C = \frac{1}{j\omega C}$. Plugging this in:

$$H = \frac{V_{out}}{V_{in}} \longrightarrow \frac{\frac{1}{j\omega C}}{R+\frac{1}{j\omega C}} \longrightarrow \frac{1}{1+j\omega RC}$$

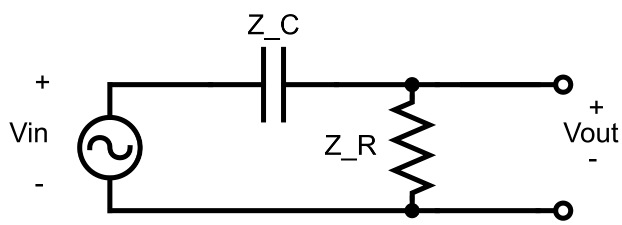
With the Laplace transform taken, the transfer function becomes $H(s) = \frac{1}{1+sRC}$. Using the same values from my previous low-pass filter; a 223Ω resistor and $1\mu F$ capacitor gave a cut-off frequency of 4460 rad/s or $711Hz$. Plugging these values into Matlab gave the following Bode plot.



(e) Bode graph of the theoretical frequency response

High-Pass Filter

Following the same procedure as the low-pass filter, we were then tasked with solving for the transfer function of a high=pass filter. The theoretical values were again plotted out. I started with the following circuit schematic:

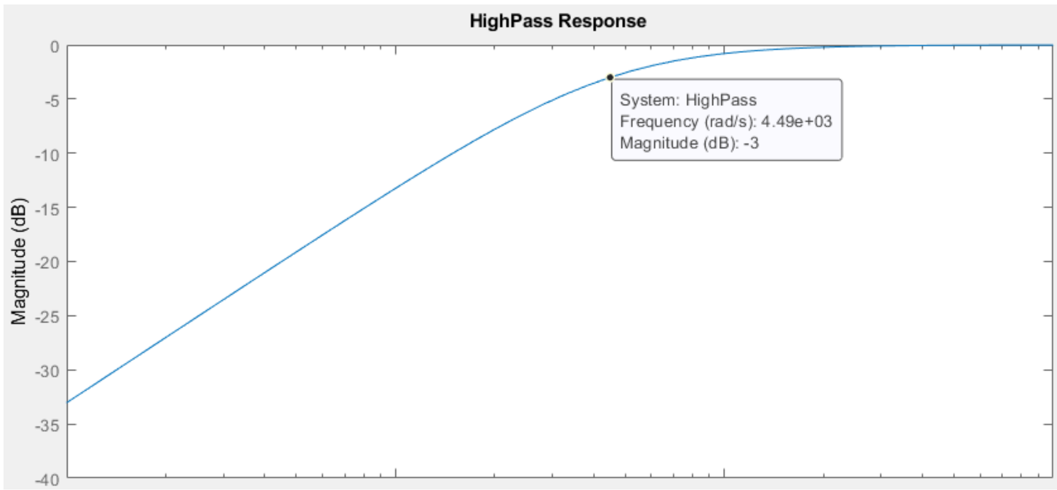


(f) Wiring schematic of a high-pass filter

Knowing again that transfer function $H = \frac{V_{out}}{V_{in}}$, $Z_R = R$ and $Z_C = \frac{1}{j\omega C}$ we use KVL to determine the high-pass transfer function. We can use KVL to observe that, $V_{out} = Z_R$ and V_{in} remains unchanged as $V_{in} = Z_R + Z_C$. Plugging this in:

$$H = \frac{V_{out}}{V_{in}} \longrightarrow \frac{Z_R}{Z_R + Z_C} \longrightarrow \frac{R}{R + \frac{1}{j\omega C}}$$

With the Laplace transform taken, the transfer function becomes $H(s) = \frac{R}{R+sC}$. Using the same values from my low-pass filter; a 223Ω resistor and $1\mu F$ capacitor gave a cut-off frequency of 4490 rad/s or $715Hz$. Plugging these values into Matlab gave the following Bode plot.

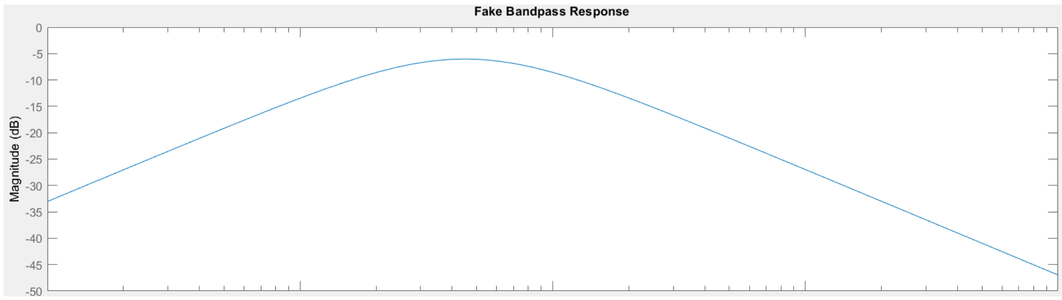


(g) Bode graph of the theoretical frequency response

Band-Pass Filter

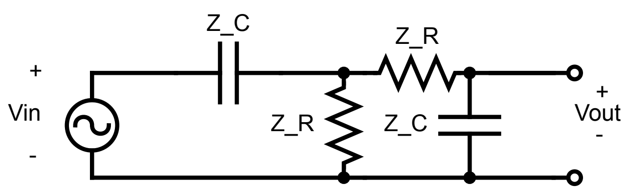
We were tasked with the same as before. Deriving the transfer function of the band-pass filter and then plotting the theoretical magnitude vs. frequency response. The band-pass transfer function was now find by multiplying the low-pass and high-pass transfer functions analytically. We needed to assume the V_{out} of the first filter equaled the V_{in} of the second. The actual transfer function was then found using KCL with the band-pass filter schematic. We were finally asked to derive the transfer function of the Sallen-key band-pass filter and determine how it varied from the passive one, if it was possible to set Q and ωn independently, and plot the frequency vs. magnitude theoretical response with the same R and C values.

This time starting out by multiplying the low-pass and high-pass transfer functions together gives us $H(s) = \frac{sRC}{(sRC+1)^2}$ with the following Bode:



(h) Bode graph of the theoretical fake band-pass

After this, the actual band-pass transfer function was found by observing the following given circuit:

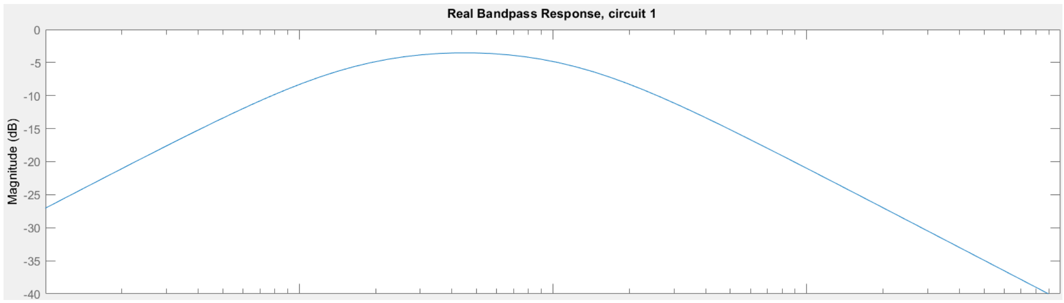


(i) Wiring schematic of a band-pass filter

Observing with KVL, we can see:

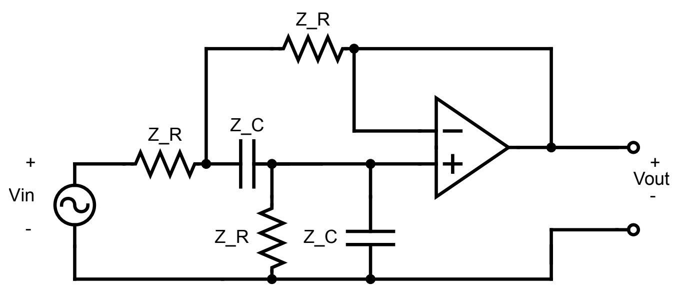
$$H = \frac{V_{out}}{V_{in}} \longrightarrow \frac{Z_C//2Z_R}{Z_C+Z_R//(Z_R+Z_C)} \longrightarrow \frac{\frac{1}{\frac{1}{Z_C}+\frac{1}{2Z_R}}}{Z_C+\frac{1}{\frac{1}{Z_R}+\frac{1}{Z_R+Z_C}}} \longrightarrow \frac{\frac{1}{\frac{1}{\frac{1}{sC}}+\frac{1}{2R}}}{\frac{1}{sC}+\frac{1}{\frac{1}{R}+\frac{1}{R+\frac{1}{sC}}}} \longrightarrow \frac{2RCs}{s^2C^2R^2+3CRs+1}$$

This resulted in the following Bode:



(j) Bode graph of the theoretical band-pass, circuit 1

We were then tasked to do the same with the Salen-key band-pass filter. This transfer function was found by observing the following given circuit:

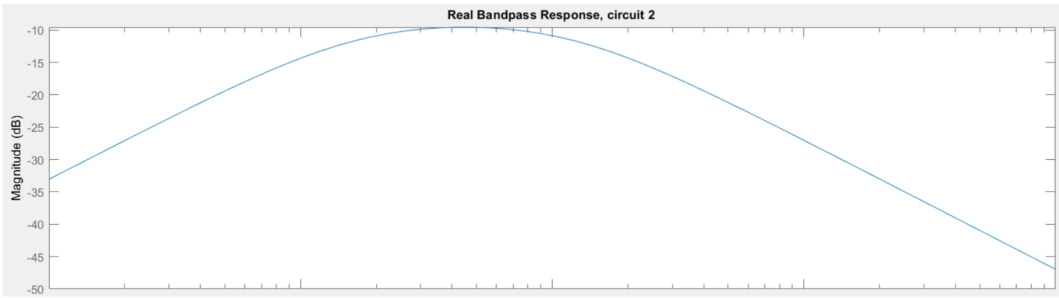


(k) Wiring schematic of a Salen-key band-pass filter

For this one, the derivation was as follows

$$H = \frac{V_{out}}{V_{in}} \longrightarrow \frac{Z_C//Z_R}{Z_R+Z_C+(Z_R//Z_C)} \longrightarrow \frac{\frac{1}{\frac{1}{\frac{1}{sC}}+\frac{1}{R}}}{R+\frac{1}{sC}+\frac{1}{\frac{1}{R}+\frac{1}{R+\frac{1}{\frac{1}{sC}}}}} \longrightarrow \frac{RCs}{s^2C^2R^2+3CRs+1}$$

This gave the following Bode:

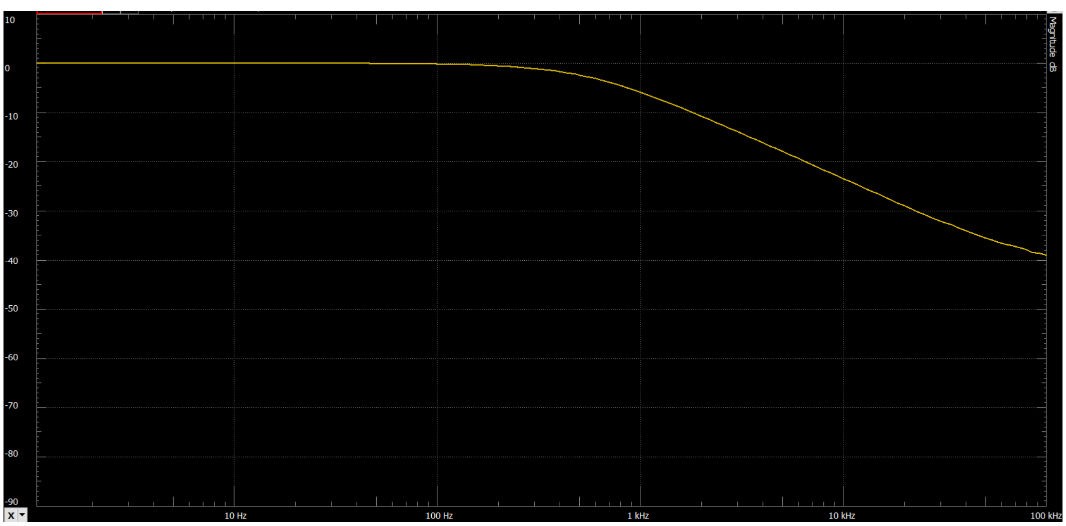


(l) Bode graph of the theoretical band-pass, circuit 2

2.4 Experimental Validation of Analog Filtering

Low-Pass Filter

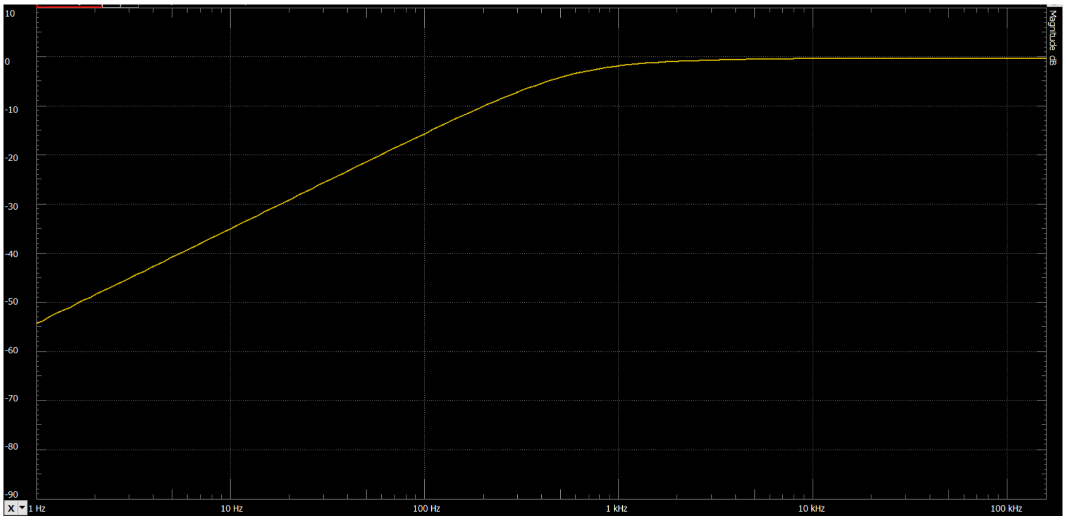
Building the the single pole low pass filter with the same resistor and capacitor values I used in the calculations, I got the following graph:



(m) Bode graph of the actual low-pass

High-Pass Filter

Building the the single pole low pass filter with the same resistor and capacitor values I used in the calculations, I got the following:



(n) Bode graph of the actual high-pass

3 Conclusion

The final implementation of this lab involves being able to tap on the piezoelectric sensor and have a tone play. The frequency of this tone must be proportional to the angle of flex in the flex sensor. The angle of flex in the flex sensor must also be displayed on the OLED screen. This required functions for converting flex values both into the angle of flex, and into frequency of tone to generate. The flex sensor also required a smoothing function to smooth out how rapidly the value would jump around. Corner frequencies and magnitude vs frequency graphs were also required to be calculated and observed for low-pass, high-pass, and band-pass filters. The programming section of this lab was easy. The sudden review in filter design, transfer function derivation, and build/testing took 75% of the time for this lab.
Est. Hours: 13