ECE167 Sensing and Sensor Technology

Lab1

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Checkoff TA: Eric -1/16/25 ~ 4:15PM

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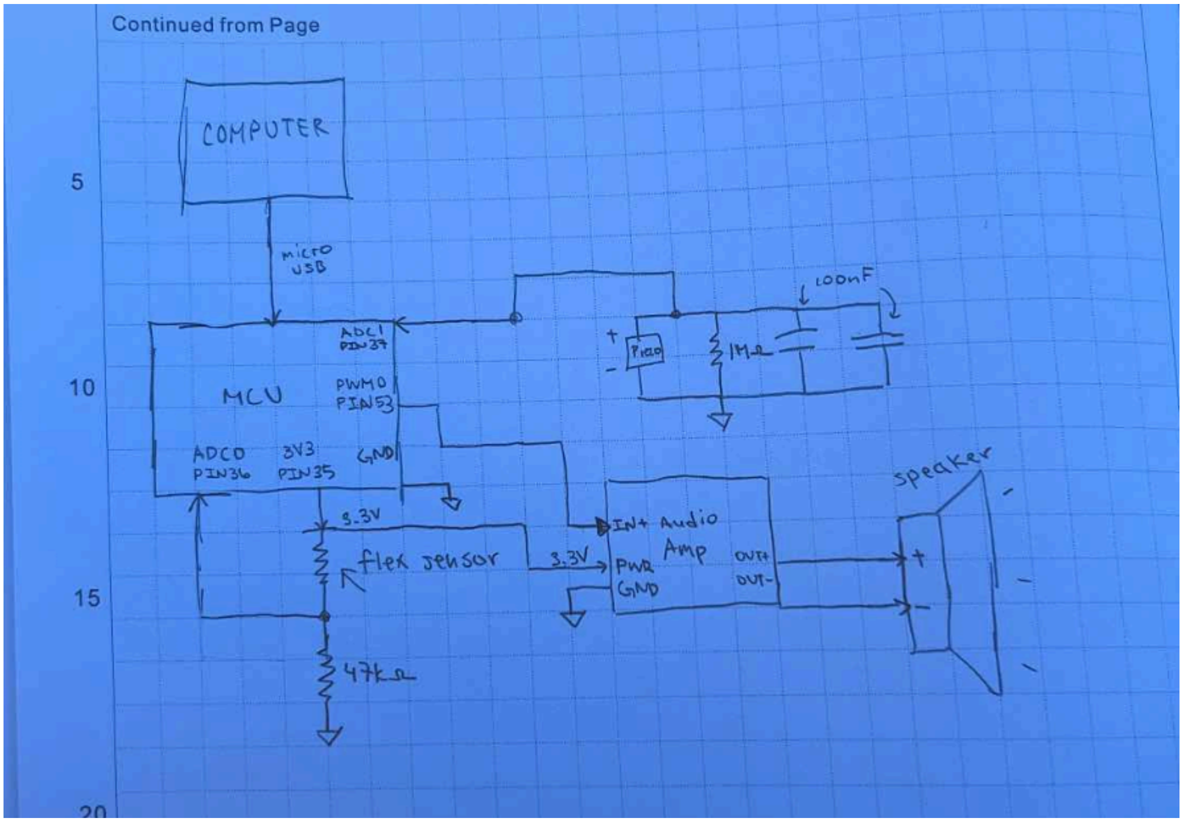
1. Project Introduction

In Lab1, the task was to set up a simple instrument using a flex sensor and a piezo sensor. Tapping the piezo will play a sound, and bending the flex sensor will change the tone. Note that if the piezo is being tapped continuously it plays the same sound continuously. In order to use the flex sensor, measurements of the bend degree and its resistance is taken to see the behavior of the sensor. This flex sensor changes resistance, which is not measurable by the microcontroller. Therefore, a simple voltage divider is needed to see the resistance change in terms of voltage. The piezo sensor by itself produces a massive voltage spike, which will damage the microcontroller input pins, as seen on the oscilloscope. Snubbing is required by setting up a simple circuit noted in the lab document.

Lastly a simple bandpass filter is designed and implemented, which will be tested and see its results on the oscilloscope. This requires one low pass and one high pass filter, each with its transfer function and cutoff frequency calculated. Combining the two together will result in a bandpass filter, but a simple op-amp buffer will be implemented between the high and low pass filter. The math for combining the two filters together can be done in two different ways, one by convolution, and the other by nodal analysis. These will result in slightly different bandpass filter transfer function at the end, as no real circuit in the world is represented perfectly by circuit theory. Bode plots are included to show the filter behavior.

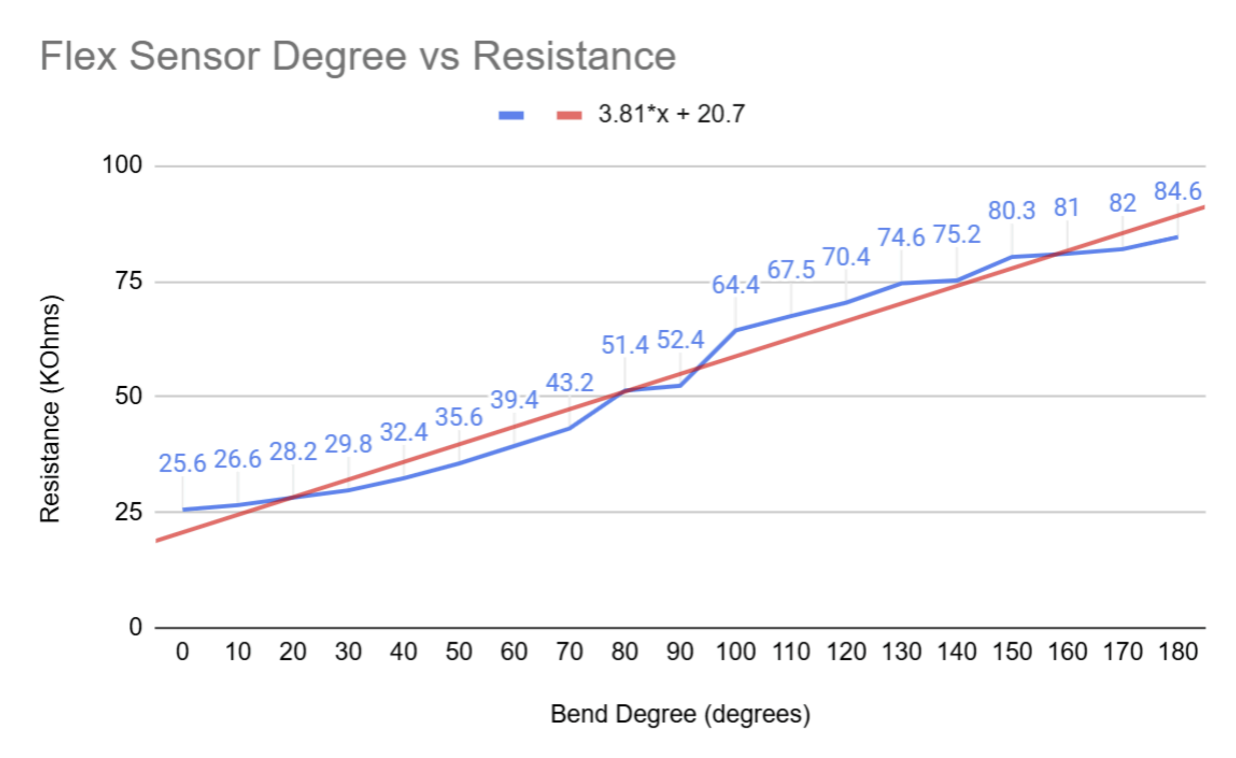
2. System Block Diagram

The overall system diagram for the simple instrument will be included here, the filter diagram will be with all the filter documentation under hardware components.



3. Hardware Components

Hardware for this lab will include the audio amplifier and speaker from Lab0. Additionally, a piezo sensor and flex sensor will be used. The flex sensor does not produce a linear resistance change with respect to the bend degree. The following data show its linearization in a trendline.



The piezo sensor produces high voltage spikes by itself, the following data shows the voltage spikes on the oscilloscope as well as average voltage spike. Last row contains the average of each column. This voltage is way above the STM32 input pin!

Pk-Pk (V)	Max (V)	Min (V)
30	27	-4
26	23	-4
68	49	-20

66	43	-24
56	53	-4
109	81	-28
26	25	-2
50	47	-4
54	47	-8
52	49	-4
74	65	-10
40	37	-4
68	49	-20
58	25	-34
62	57	-6
55.93333333	45.13333333	-11.73333333

As seen on the oscilloscope, the voltage spike from the piezo sensor.

Below is all the math and diagrams for the bandpass filter.

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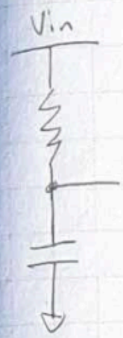


$$V_{out} = V_{in}\frac{\frac{1}{sC}}{\frac{1}{sC}+R} \qquad W_0 = \frac{1}{RC}$$

$$\frac{V_{out}}{V_{in}} = \frac{\frac{1}{sC}}{\frac{1}{sC}+R} = \frac{1}{1+RCs} \longrightarrow \frac{\frac{1}{RC}}{s+\frac{1}{RC}}$$

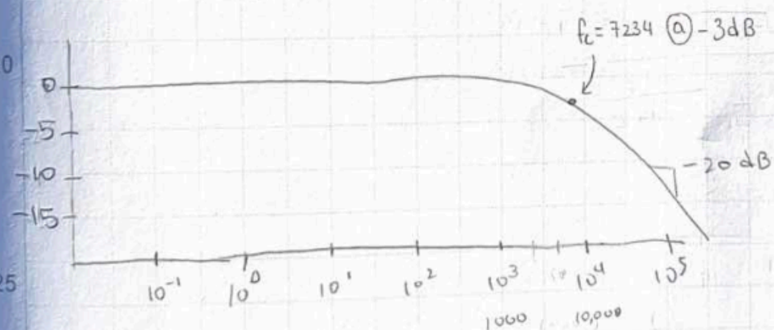
$$f_c = \frac{1}{2\pi RC}$$

$R = 1k\Omega$

$C = 22nF$

$$f_c = \frac{1}{2\pi(1k\Omega)(22nF)} = 7234Hz$$

$$H(s) = \frac{1}{1+(1k\Omega)(22nF)s} = \frac{1}{1+0.00022s}$$



Bode Plot

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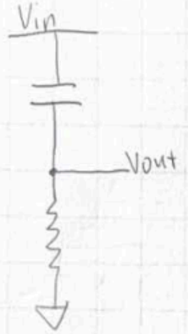


$$f_c = \frac{1}{2\pi RC}$$

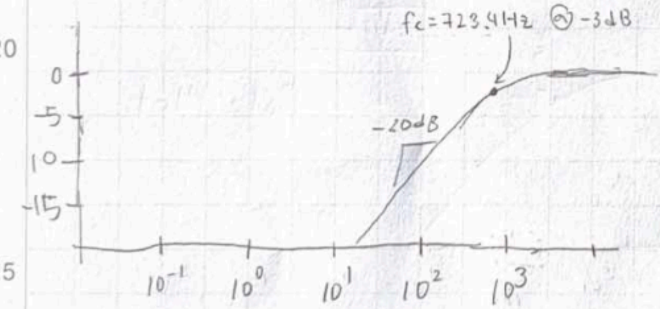
$R = 10k\Omega$
$C = 22nF$

$$f_c = \frac{1}{2\pi(10k\Omega)(22nF)} = 723.4\,Hz$$

$$V_{out} = V_{in}\frac{R}{\frac{1}{sC} + R}$$

$$\frac{V_{out}}{V_{in}} = \frac{R}{\frac{1}{sC}+R} = \frac{sRC}{1+sRC} = \frac{s}{s+\frac{1}{RC}}$$

$$H(s) = \frac{s}{s + \frac{1}{(10k\Omega)(22nF)}} = \frac{s}{s+\frac{1}{0.0022}}$$



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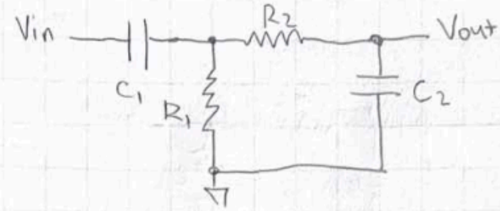
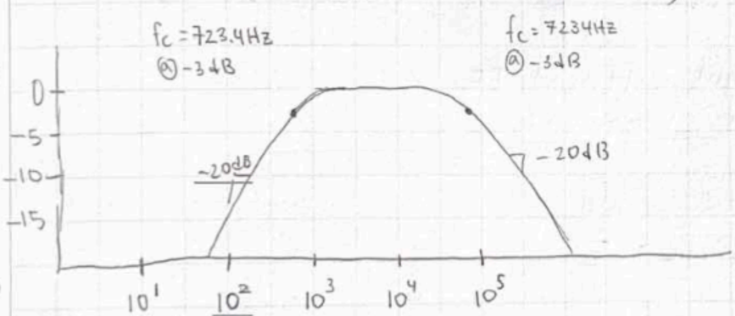


$$H(s)_{HPF} = \frac{s}{s + \frac{1}{0.0022}}$$

$$H(s)_{LPF} = \frac{1}{1 + 0.00022s}$$

$$H(s)_{BPF} = H(s)_{HPF} \cdot H(s)_{LPF}$$

$$H(s)_{BPF} = \left(\frac{s}{s + \frac{1}{0.0022}}\right)\left(\frac{1}{1 + 0.00022s}\right) = \frac{s}{(s+454.55)(1+0.00022s)}$$



$Q = \frac{1}{2\delta}$ $\qquad H(s)_{BPF} = \frac{4545.45s}{s^2 + 500s + \underbrace{2.066\times10^6}_{\omega_n^2}}$

ω_n

$s^2 + 2\delta\omega_n s + \omega_n^2$ $\qquad \omega_n = \sqrt{2.066\times10^6}$

$Q = \frac{1}{2(0.174)} = 2.87$ $\qquad \omega_n = 1437.36\ Hz$

$2\delta(1437.36)s = 500s$

$\delta = 0.174$

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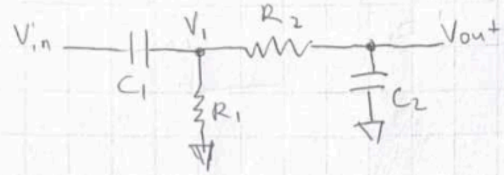

KCL:

V_1:

$$\frac{V_{in}-V_1}{\frac{1}{sC_1}} + \frac{0-V_1}{R_1} + \frac{V_{out}-V_1}{R_2} = 0$$

$$(V_{in}-V_1)\,sC_1 + \frac{-V_1}{R_1} + \frac{V_{out}-V_1}{R_2} = 0$$

V_{out}:

$$\frac{V_1-V_{out}}{R_2} + \frac{0-V_{out}}{\frac{1}{sC_2}} = 0$$

$$\rightarrow (1+sR_2C_2)V_{out} = V_1$$

KCL result in a slight different TF then using previous method.

If we assume all RC value are the same, Then $H(s)_{BPF} = \frac{1}{2}$

This means the HPF and the LPF cancel each other out, resulting in only the -3dB point. That why if we take $s^2+2\zeta\omega_n+\underbrace{\omega_n^2}$

$$\omega_n^2 = 2$$

$$\omega_n = \sqrt{2} \quad \text{aka } -3dB$$

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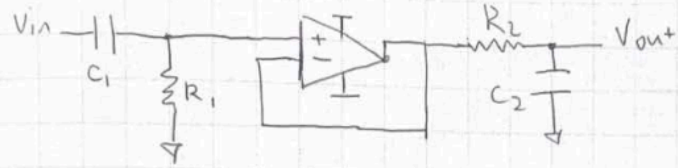
Buffered BPF



4. Software Components

Software components include reading the ADC value, moving average filter, and setting the PWM like the previous lab.

But in addition, the flex sensor requires software linear regression to achieve a linear tone on the speaker. This requires some math and conversion, the ADC reads 0-4095, which needs to be converted to voltages.

$$voltages = \frac{ADC}{4095} \times 3.3v$$

A voltage to resistance of the flex sensor is needed, where V_{in} and R_2 is 3.3V and 47KΩ. V_{out} is the convert voltage read from the ADC from the previous conversion.

$$R_{flex} = R2\frac{Vin - Vout}{Vout}$$

Lastly, by using the linear regression line from google sheets earlier, we can arrive at the last conversion from flex sensor resistance to bend degree.

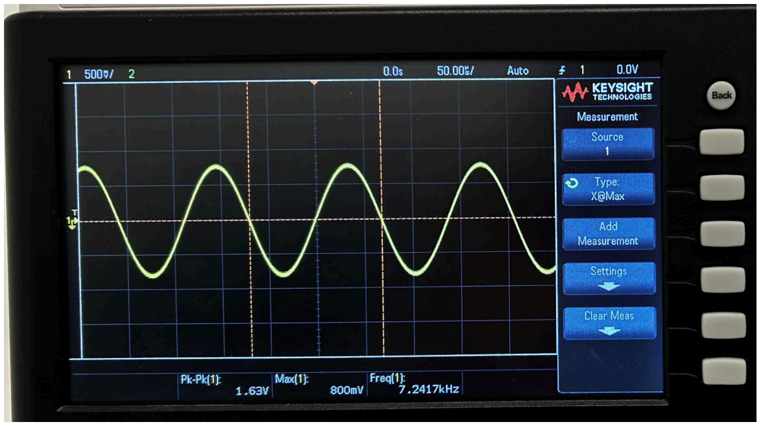
For the rest of the speaker control software is very similar to the previous lab, with an additional while loop to have a delay on the speaker. When tapping piezo, the sound will play for a short delay and stop. This while loop counts down, when count is 0, the delay or time is up. If another piezo tap is received, then the count resets.

5. Testing and Result

For the data collection for the sensors, I took about 10-15 pieces of data for each sensor. This resulted in my linear regression model for flex sensor and the max output voltage average for the piezo sensor. This is important as the max input voltage for the ADC pins on the microcontroller is 3.3V, anything higher would result in frying the pin. With the linear regression, the model was quite accurate and produced a nice tone with different bend degrees.

As for the bandpass filter, the actual result is quite close to the theoretical, but obvious real circuits never match theory. Below are the low pass filter results on the oscilloscope. The first picture shows an input signal, of pk-pk of 1V, at 3KHz. The low pass filter has a cutoff frequency of 7234 Hz, as seen in the hardware section. At 3000 Hz, the signal is not attenuated at all.

At 7234 Hz, we can see the signal is attenuated to 800mV, by theory it should be at 707mV, as it is at the -3dB cutoff frequency, but 800 is quite close.

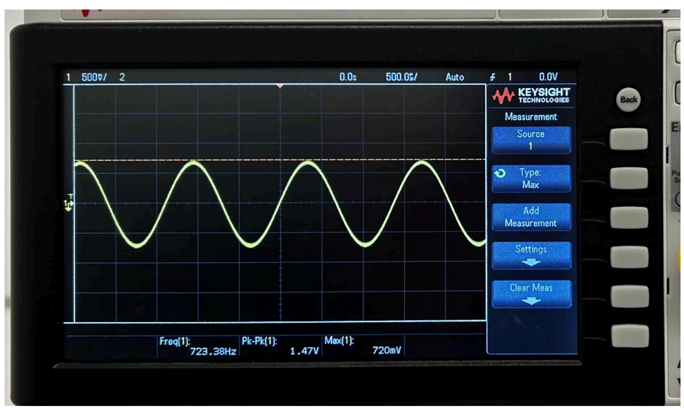


For the high pass filter, the cutoff frequency is 723 Hz, below are the oscilloscope data. At 100 Hz, the signal is not attenuated at all.

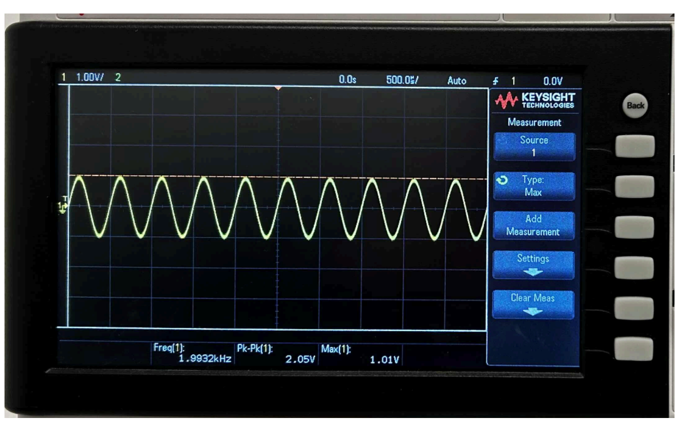
Then at 724 Hz, again at the -3dB point, the signal is attenuated to 800mV, not quite the theory, but close enough.

By combining the two filters together we can build a bandpass filter where signals between 723 Hz and 7234 Hz are not attenuated. Anything outside these ranges should be attenuated. Here at 200 Hz, the high pass filter knocks it down.

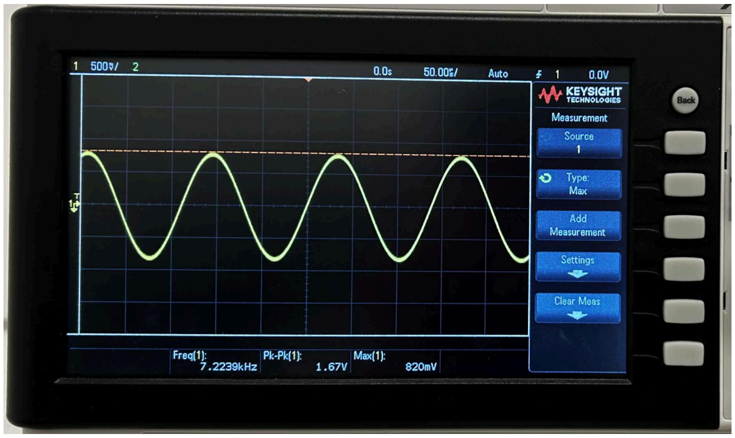
At 723 Hz, we see the attenuation at 720mV better result than previous.



At 2 Khz, inside our bandpass section, we see no attenuation to our signal.



At 7234 Hz, we see our low pass filter attenuation at 820mV, similar to our result of the low pass by itself.



This concludes the successful bandpass filter, although never exact to our theory, it is quite close. If we use 800mV and compare it to the theory of 707mV, we get about 13% of error margin.

6. Conclusion

Lab1 is not too difficult, but more time consuming than the previous lab. Took me a couple days at the lab to gather data, and build the required circuits. The flex sensor can be linearized through the regression model, producing a more consistent change when bending the flex sensor. I also think that when using the ADC pins, make sure to ground them as well (pin 42), it was causing trouble for me when it was not properly grounded. When building the bandpass, make sure to use the ground from the power supply when powering the op-amp. Circuits will never be exact to its theoretical calculations, but it will come close.