6.131 Final Project Report

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1 Background and Motivation

A theremin is a musical instrument that uses a unique blend of power electronics, signal processing, and mechanical design to make a one-of-a-kind instrument that is played without touching it. The theremin was invented in 1920 and has been eye-catching ever since. Using capacitive sensing, a theremin uses the palm of your hand as the other plate of a capacitor using an antenna. This small change in capacitance changes an oscillation frequency in the instrument to provide a large range of notes.

I wanted to make a theremin as a final project because it has the ability to show a depth of understanding in power electronics through audio and because I like projects with sound in them.

2 Overview and Schematics

This project uses a hand as a capacitor to modulate an oscillating circuit that is used to control a half-bridge "totem pole" to create varying frequencies of notes. The Vdd in the totem pole comes from a simulated 5V battery which is boosted to 12V using a boost converter. Together this system creates an instrument that lowers the oscillation frequency of note as your hand comes closer to the antenna.

There are four modules in this project and each one is important to the system's functionality. The first module is primarily standard theremin oscillation circuitry. This includes the oscillation that is manipulated using your hand. The second module is a boost converter with feedback to drive a 5V voltage source to a stable 12V source. This is meant to simulate having a battery as an input with varying input voltage as the voltage decreases. The third module takes the frequency produced by module 1 and puts it through delay circuitry to modulate a half-bridge configuration. The fourth module is the half-bridge circuit which then is filtered to an AC signal and sent to a speaker.

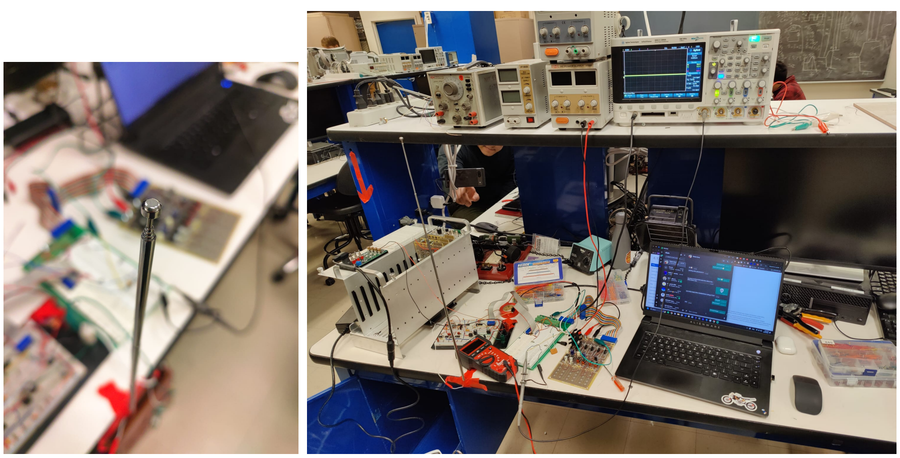


Figure 1: Antenna and project workbench

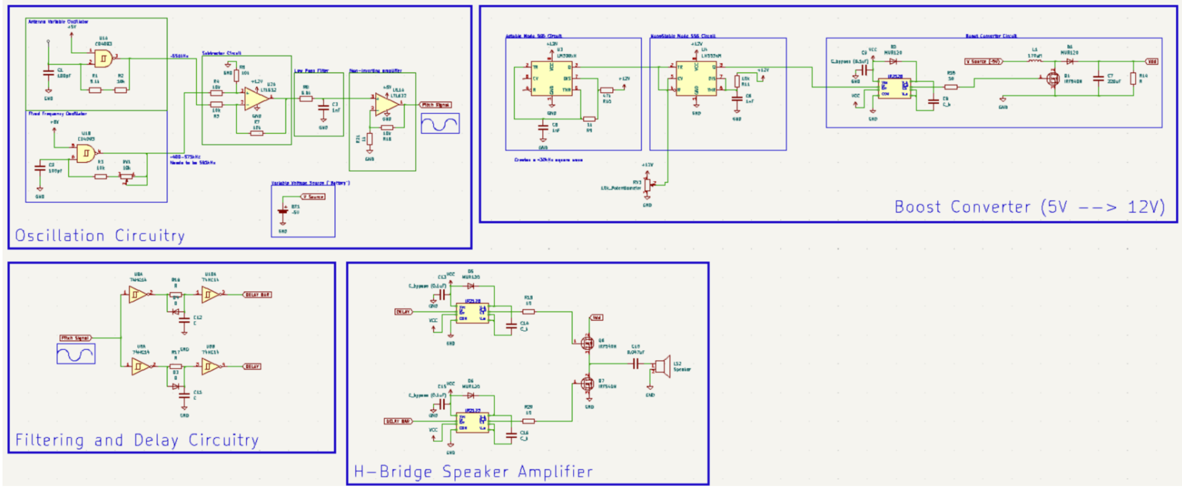


Figure 2: Complete schematics of my project

3 Module 1

Module 1 starts with two oscillator circuits. These circuits are built on a principle used throughout the class which is using a resistor, capacitor, and inverter to create a square wave with a duty cycle of 0.5. Both oscillators are about 550kHz with one being fixed and the other being variable. The variable oscillator uses a hand as a 5pF capacitor and varies the frequency by about 5kHz. The fixed oscillator has a potentiometer that can vary the fixed frequency.

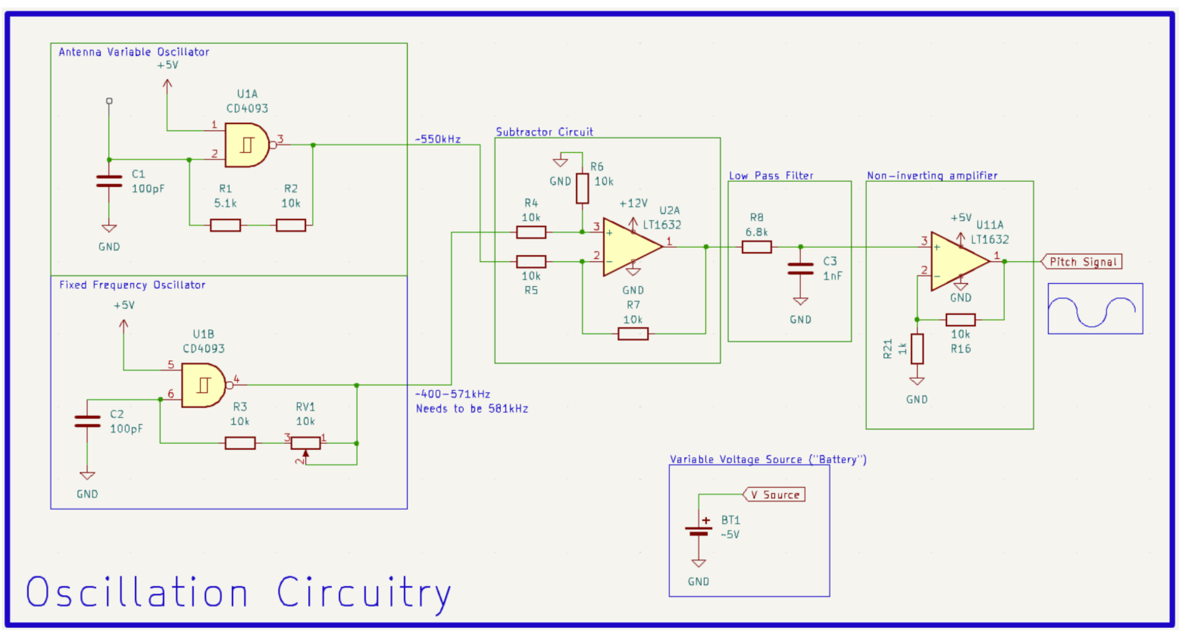


Figure 3: Module 1 oscillation circuitry

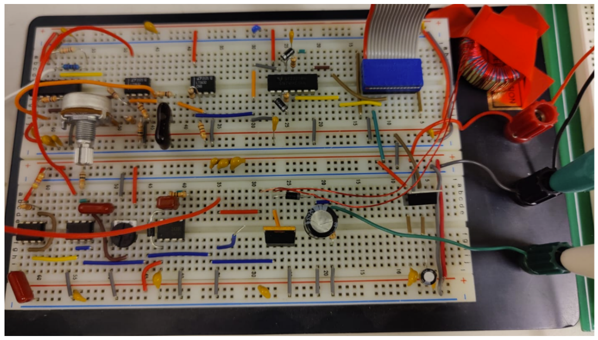


Figure 4: Prototyping board containing module 1

The purpose of these two oscillators is to subtract the fixed frequency from the variable frequency to provide a lower frequency that is audible to the human ear. After the subtraction process, it gets put through a low pass filter to remove high-frequency noise from the resulting subtraction. This new lower frequency wavelength is of smaller voltage, so after being subtracted and filtered, it goes through a non-alternating amplifier circuit using an LT1632 Op-amp. By using the non-inverting amplifier at 5V and a high amplification factor, it hits the threshold of the op-amp and creates a semi-square wave.

Shown below in Figures 5 and 6, are the two oscillators while my hand is not very close to the antenna.

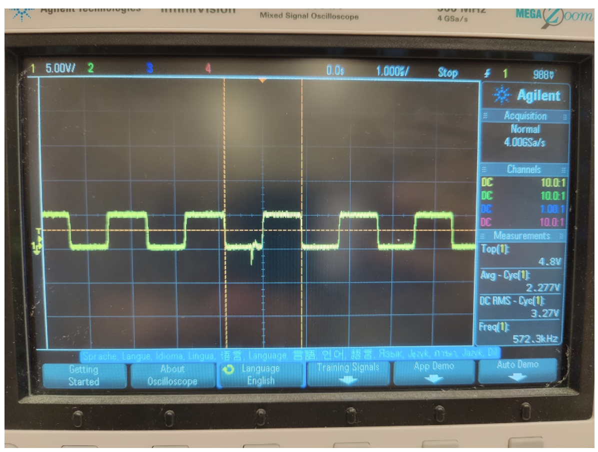


Figure 5: Oscilloscope shot of the variable oscillator

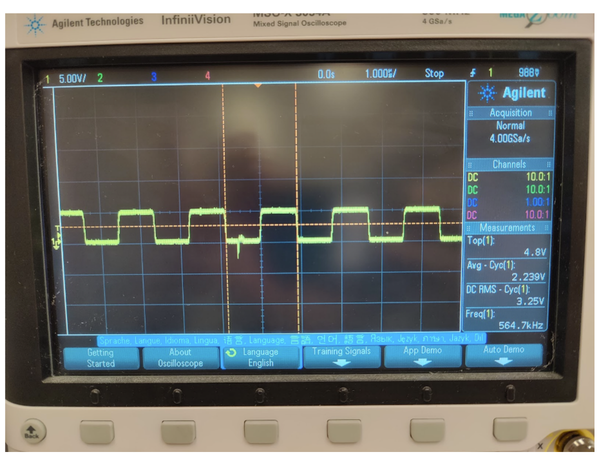


Figure 6: Oscilloscope shot of the fixed oscillator

After going through the LM1632 Op Amp for frequency subtraction, they are reduced to a low-frequency signal with high-frequency noise as shown in Figure 7.

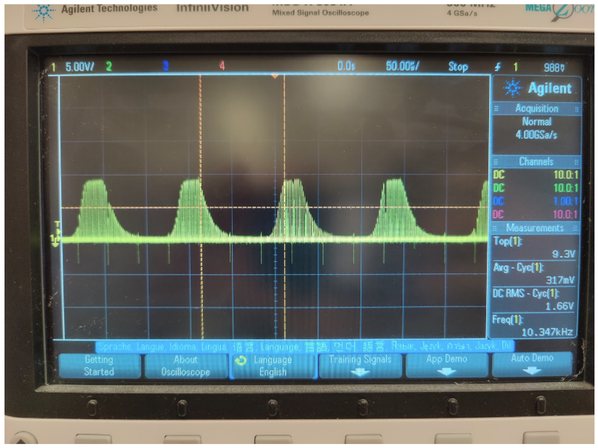


Figure 7: Post subtraction waveform

They then go through a low pass filter to reduce the high-frequency noise and result in a much smoother waveform (Figure 9). This low pass filter uses a 6.8k resistor and a 1nF capacitor producing a -3db cutoff frequency of 1326Hz. A bode plot of this low-pass filter is shown in Figure 8.

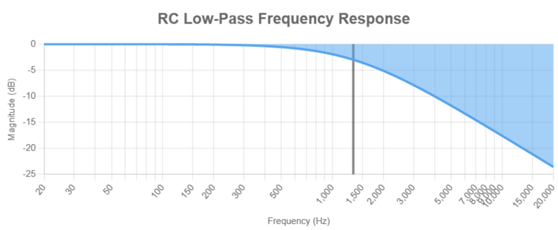


Figure 8: Low pass bode plot with cutoff frequency around 1300Hz

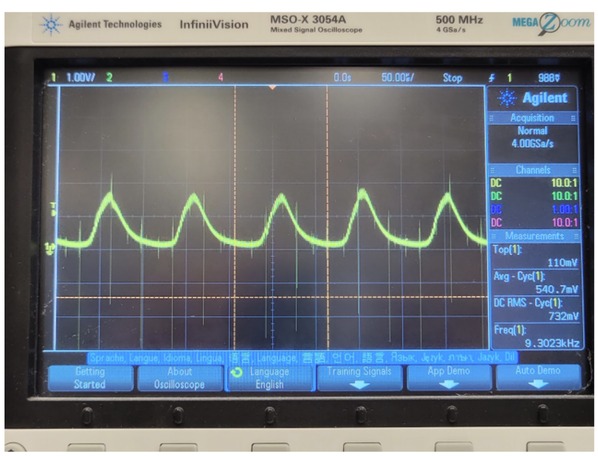


Figure 9: Waveform after being filtered through a low pass filter

Finally, to make this waveform a little more compatible with the other chips in the schematic and to raise the voltage to a logic level, the waveform goes through the non-inverting amplifier. This process amplifies the waveform beyond 5V, but because the op-amp is only being powered with 5V, it cuts off the waveform leaving with a somewhat smooth cutoff (Figure 10).

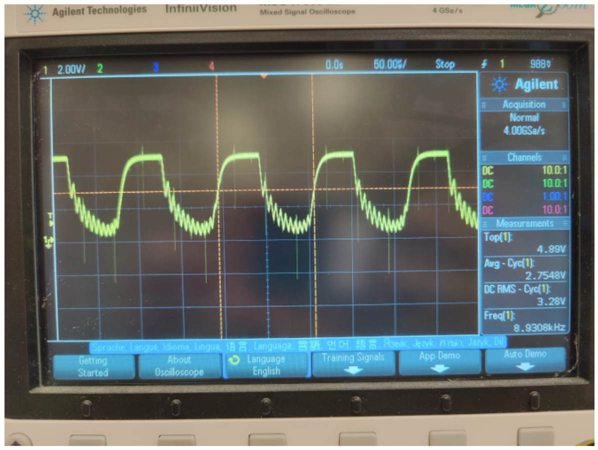


Figure 10: Waveform after being amplified to logic voltage levels

4 Module 2

The second module focuses more on the conversion of power for the speaker output. The original intent of the design was to implement a boost converter with feedback to keep the boosted 12V consistent even as the input voltage changes. The input voltage change is meant to represent a battery draining. However, after several different iterations of implementing feedback, I decided to use just a boost converter due to time constraints.

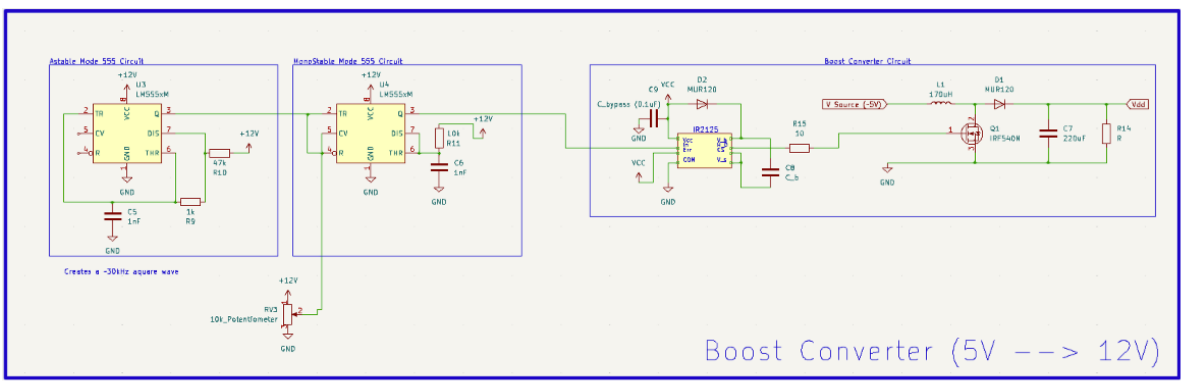


Figure 11: Module 2 Boost Converter

To control the boost converter, there are two 555 timers that allow a voltage to control the duty cycle of the PWM generated (Figure 12).

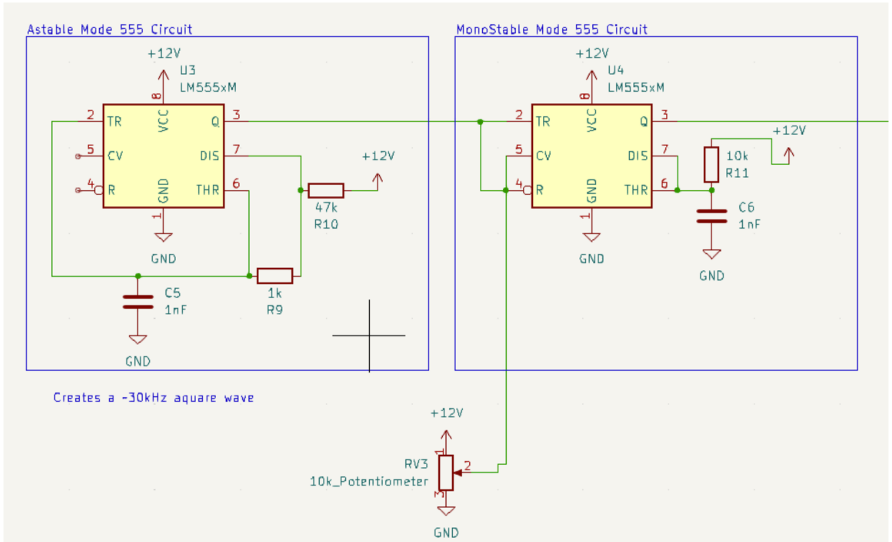


Figure 12: 555 timer configuration to drive boost converter

There are several different circuit options to create this PWM, but I chose this circuit because it is new to me, expands on the content in the class, and allows for easier integration of feedback. The first 555 timer operates in Astable mode and generates a 30kHz square wave which is then fed into the next 555 timer. This second 555 timer operates in Monostable mode and uses the input of the Astable timer to allow voltage input to drive the duty cycle. The result of this 555 timer pair is then fed into an N-channel MOSFET to drive a traditional boost converter (Figure 13).

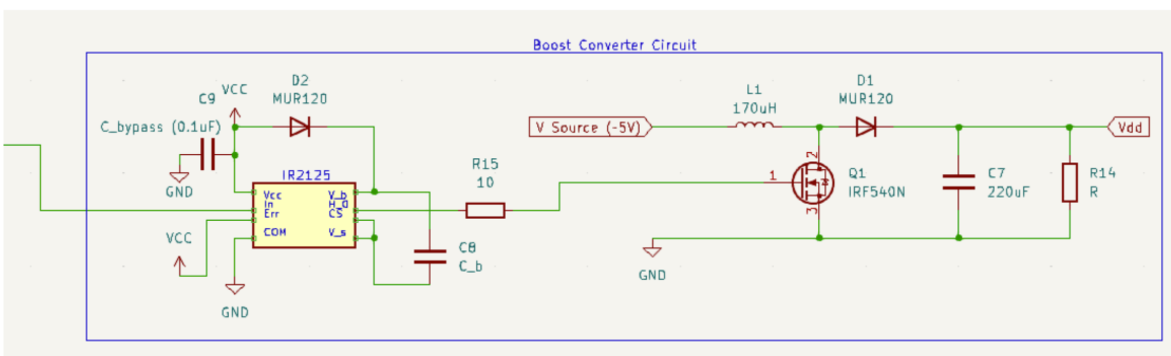


Figure 13: Signal from 555 timer pair going into traditional boost converter circuit

This boost converter receives a 5V input from a power supply acting as a battery and boosts it up to 12V (Figure 14) using an IRF540N, a MUR120, a 220uF cap, and a 1k resistor. This boosted voltage referenced as Vdd will later be routed into a “totem pole” configuration to serve at the input voltage to the speaker.

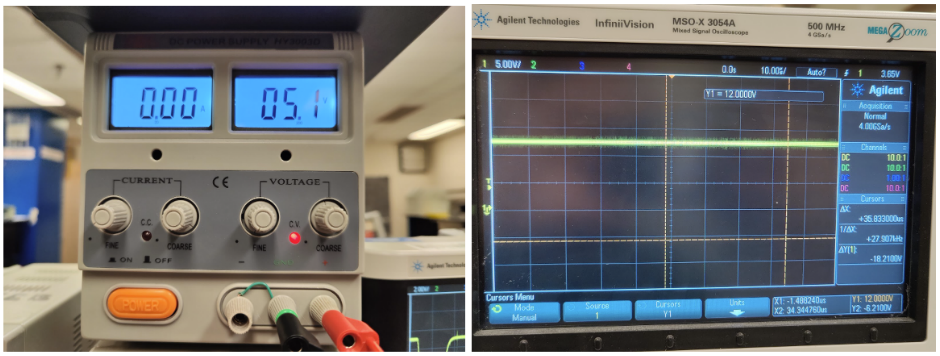
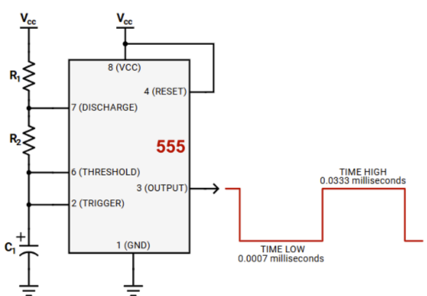


Figure 14: Input and output voltages

To calculate the frequencies of the 555 timers, I used the equation for an Astable 555 timer which gave me 29.3878Hz, and the equation for a monostable 555 timer. Because the Monostable 555 timer is dependent on the input voltage at pins 4 and 5, only the Astable 555 timer calculations are shown.

$$T = 1.1R_1C_1$$



$$T_h = 0.693(R_1 + R_2)C_1$$

$$T_l = 0.693R_2C_1$$

$$f = \frac{1.44}{(R_1 + 2R_2)C_1}$$

Figure 15: Astable 555 timer calculations

5 Module 3

The third module is focused on converting the oscillation circuitry into something that can manipulate a half-bridge totem pole.

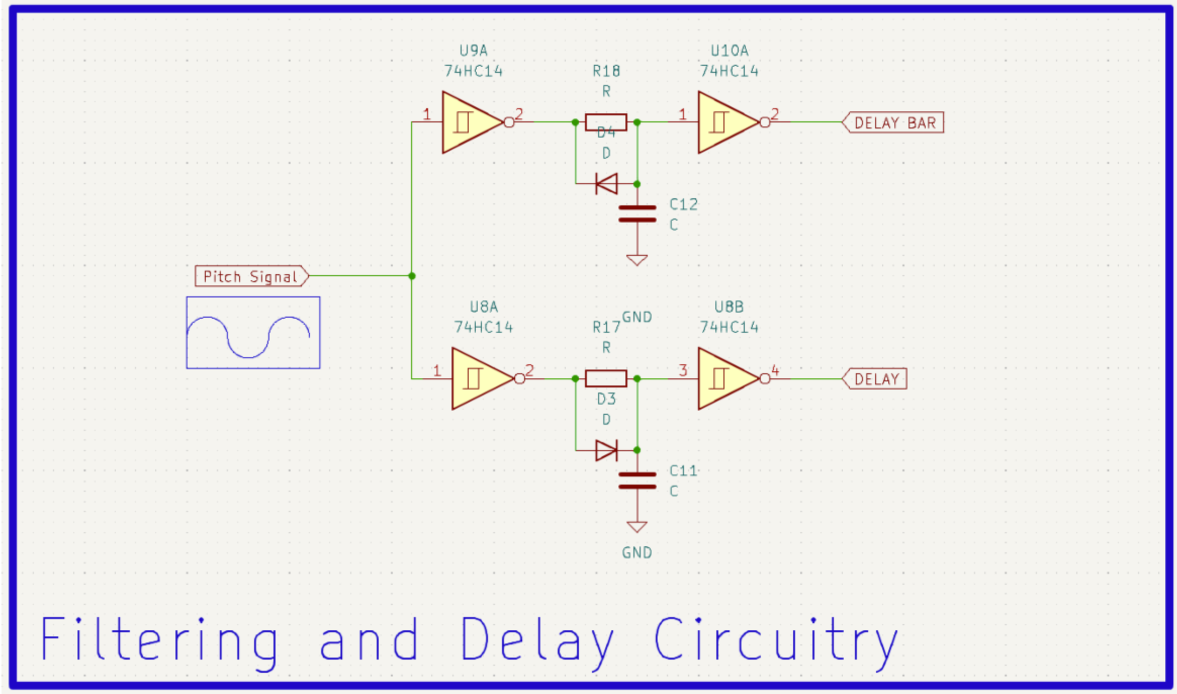


Figure 16: Module 3 Filtering and Delay Circuitry

Although the input frequency isn't an ideal square wave, the inverters read the voltage in the same way as they pass the threshold of the inverters switch conditions. Using this standard delay circuitry, a DELAY and DELAY BAR are created to manipulate two MOSFETs in the next module. Below in Figure 17 are the input signal and the two DELAY signals produced.

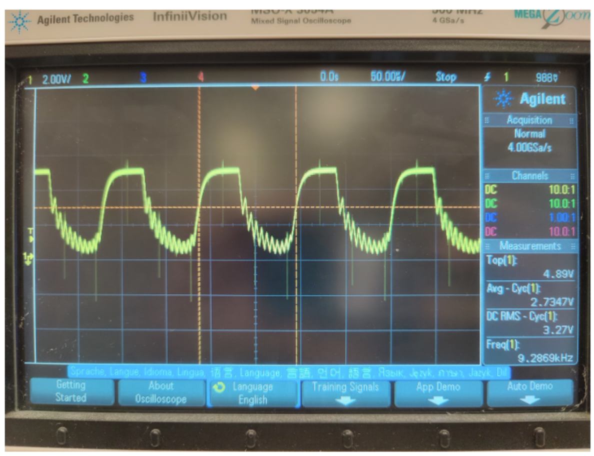


Figure 17: Input pitch signal

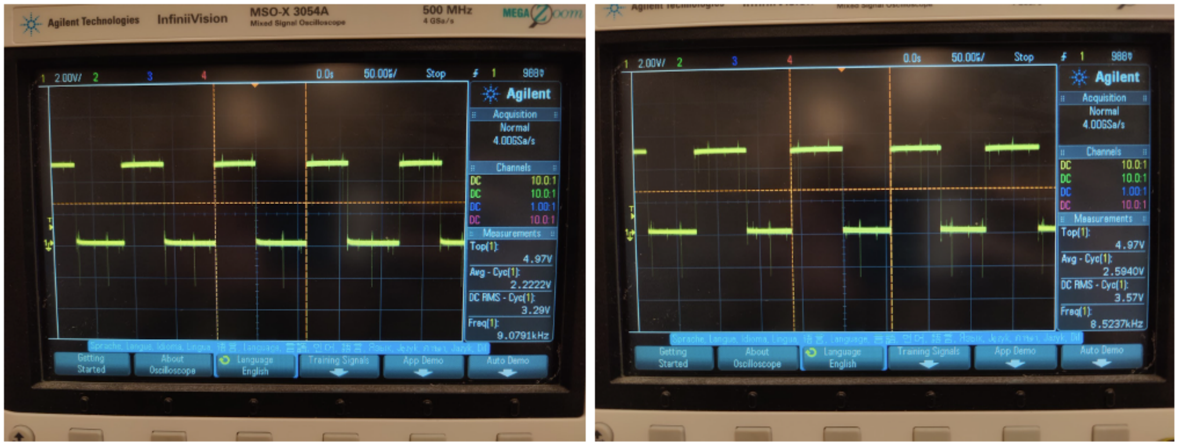


Figure 18: Input waveform, DELAY, and DELAY bar outputs

To calculate the delay period of this circuit I used the RC relationship with a resistor of 1 ohm and a capacitor of 0.1uF. This gave me a time constant of about 1e-6.

6 Module 4

The fourth module is essentially the integration of the two parallel systems in this project. The first is the waveform control generation and the second being the power manipulation. The boosted 12V from module 2 is input into this module as Vdd in the totem pole. The DELAY and DELAY BAR are then used to run the N-Channel MOSFETs seen below.

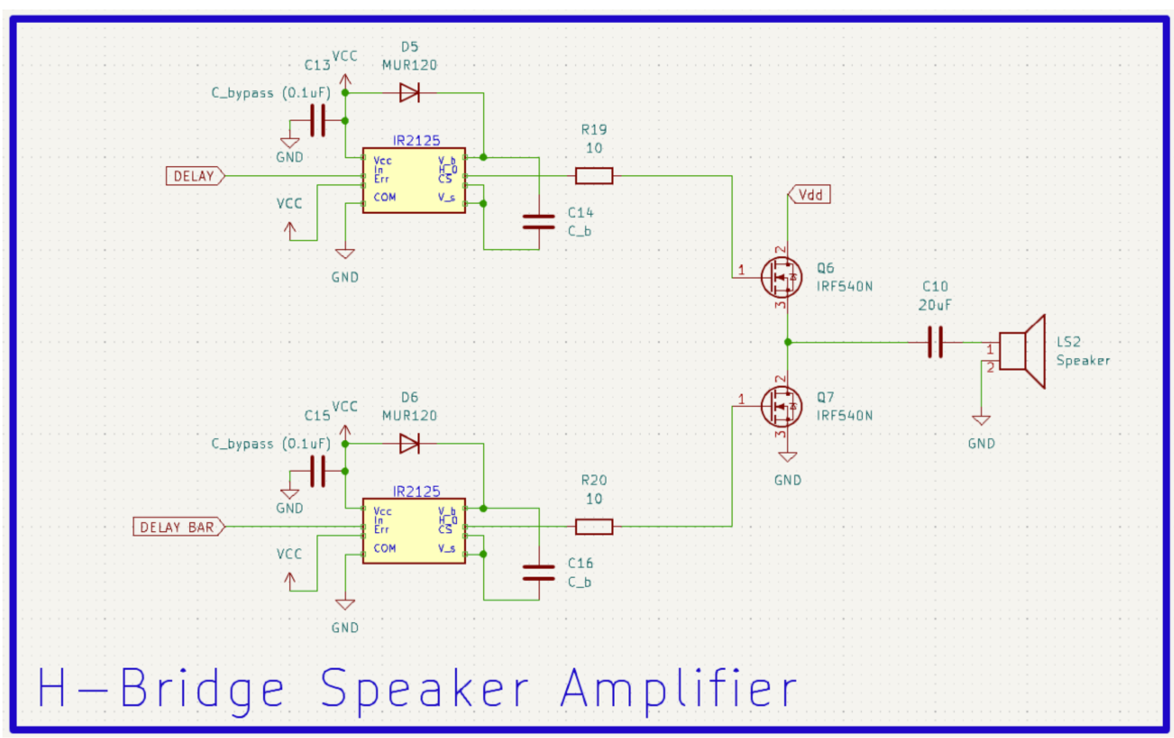


Figure 19: Module 4 half-bridge speaker amplifier

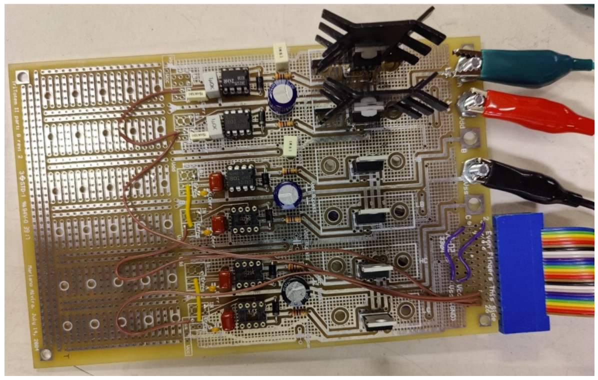


Figure 20: Half-bridge implemented on Totem board

Below in Figure 21 is one of the DELAY signals going into the IR2125 to drive the MOSFET. This signal is then processed and output by the 2125 to drive Vdd at the requested frequency. This waveform is shown in Figure 22.

Figure 21: DELAY waveform into IR2125

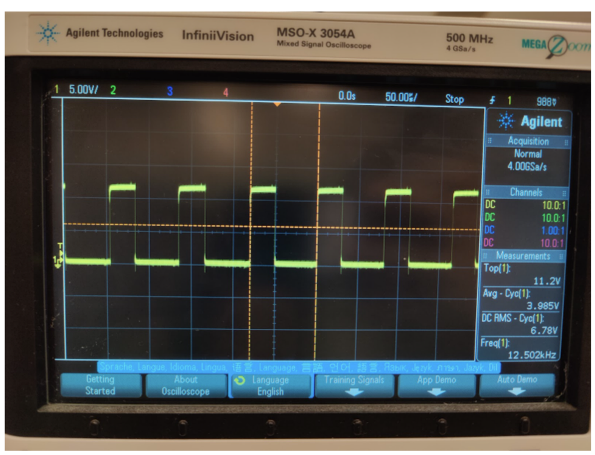


Figure 22: IR2125 totem pole manipulation

After the waveform of the desired duty cycle, frequency, and voltage is produced, it then needs to be offset to produce an AC signal to the speaker. This is done with a 20uF capacitor which centers the signal at the ground as seen in Figure 23. This component was not calculated because I knew as long as it was decently large, I wouldn't have any problems.

Figure 23: AC shifted output into speaker

7 Takeaways and Results

Going into this project, I knew a boost converter with feedback would be difficult. After several different attempts, feedback ended up not making it in the final prototype, but I learned how sensitive boost converters can be with feedback and how unstable they can be when not treated well.