Musical Hand Design Document Check

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Team 24

Ramsey Foote (rgfoote2)

Michelle Zhang (mz32)

Thomas MacDonald (tcm5)

TA: Hanyin Shao

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I. Introduction

We will build a wearable instrument in the form of gloves that is accessible to more music enthusiasts of different socioeconomic backgrounds. Many instruments are costly in both the initial purchase and the maintenance, which can make it difficult for families of lower income to afford. Musical Hand aims to address this issue by providing a low cost, low maintenance, and easily portable instrument. Our project does this by using affordable commercially available components in its construction and utilizing accelerometers instead of sensors reliant on physical contact/stretch. As a result, the initial purchase value of our product is capped and the product undergoes less physical wear and tear.

II. Visual Aid

Figure 1. Visual representation of our solution

III. High-level Requirements

The requirement for a minimally viable product are as follows:

A. While wearing the product, the user must be able to fully extend their arms directly to the side and downwards; in addition, the user must be able to bend their fingers by at least 90 degrees without resistance.

B. The vibrato effect caused by the right hand's movement can maximally change the extent of vibrato by +/- 100 cents (one semitone).

C. The product must output frequencies ranging from 196 Hz (G3) to 1760 Hz (A6); each finger will approximately cover two octaves.

IV. Block Diagram

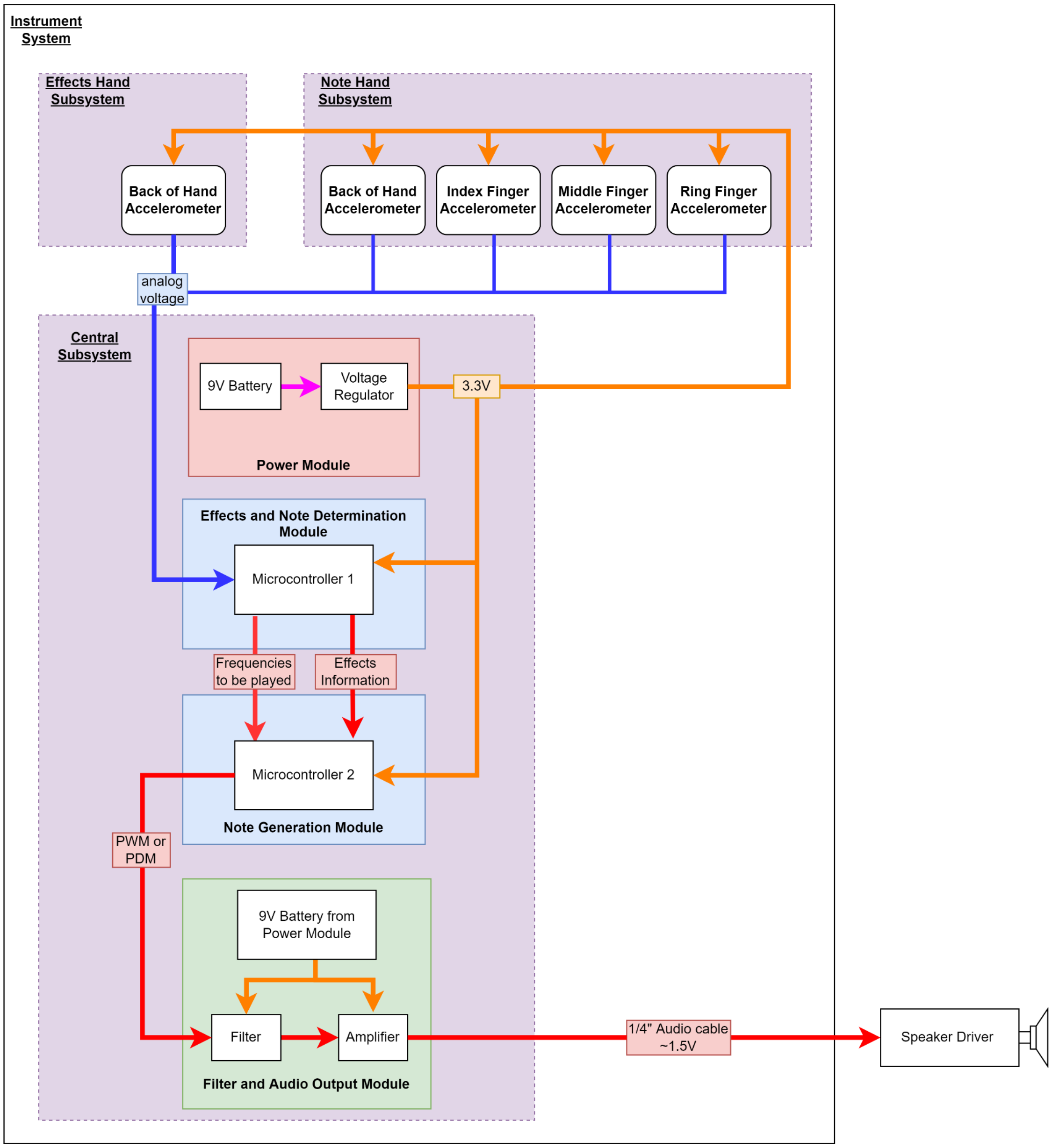


Figure 2. High level block diagram of entire system

V. Requirements & Verification

Requirements	Verification
1. Output waveform voltage must be between 0.25V - 3.3V when driven by a 3.3V Peak- Peak PDM signal. 2. Cut-off frequency of filtered signal is 10 kHz +/- 11% with 40dB/dec +/- 10dB/dec attenuation after cut-off point. 3. The Op-Amp IC must not exceed the maximum temperature rating of 70°C under operating conditions. [1]	1. With a function generator set to a 3.3V peak-peak square wave, measure the output voltage of the filter with an oscilloscope, ensuring that it stays between 0.25V - 3.3V sweeping the DC% from 0-100% during the test. 2. a. Connect filter input to a function generator set to drive a 3.3 V peak-peak sine wave. b. Connect filter output to oscilloscope. Starting at 7 kHz, sweep the frequency upwards to 20 kHz. c. Record oscilloscope output data, verifying the location of cut-off is within +/- 5% of 10 kHz and the attenuation follows a 40dB/dec slope within +/- 10dB/dec. 3. Using an IR thermometer, monitor the temperature of the Op-Amp during Verification 1 and 2, verifying an under 70°C temperature throughout.

Table 1. Requirements and Verification table for Multiple Feedback filter

VI. Plots and Flowcharts

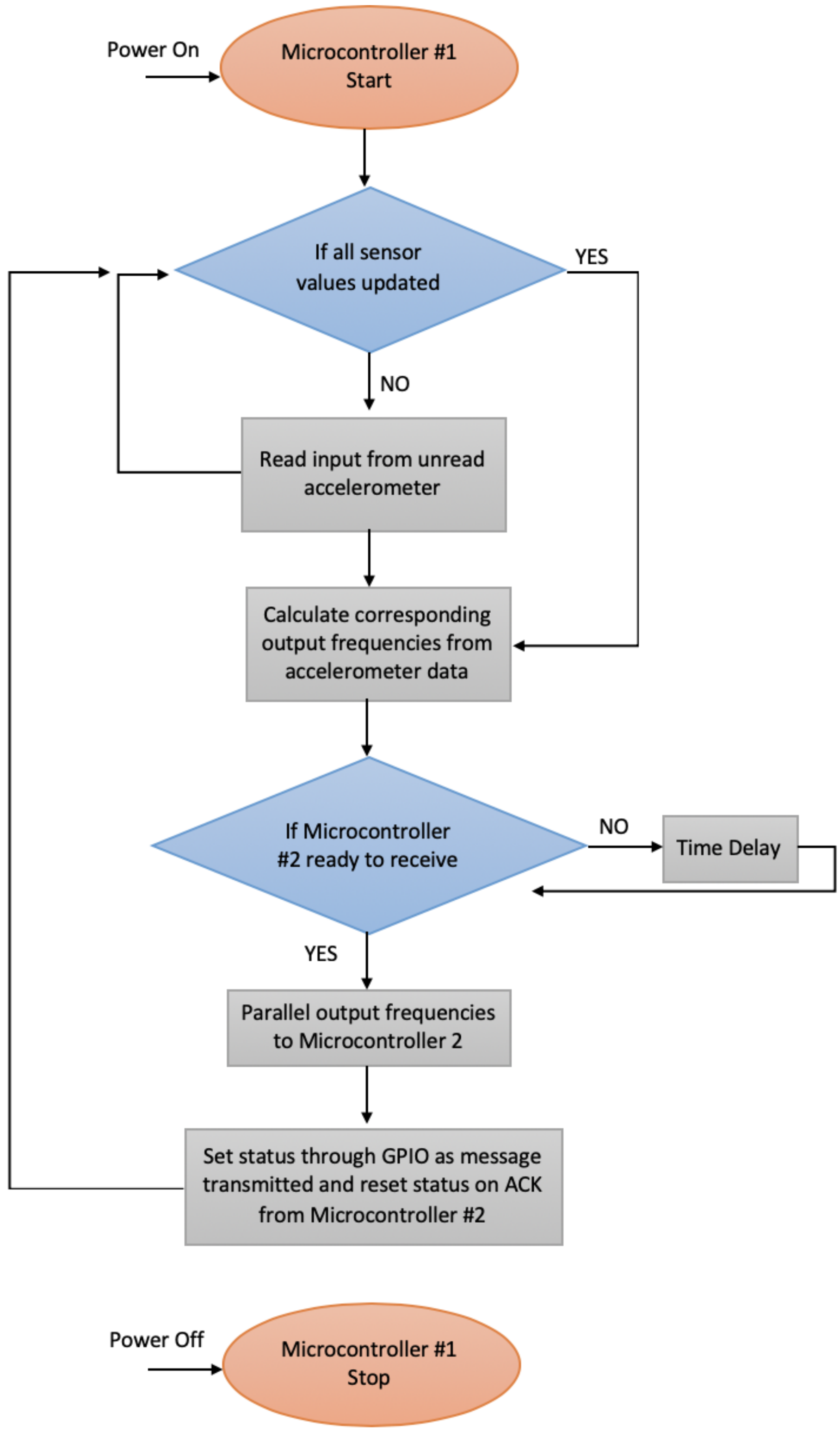


Figure 3. Program flowchart for Microcontroller #1

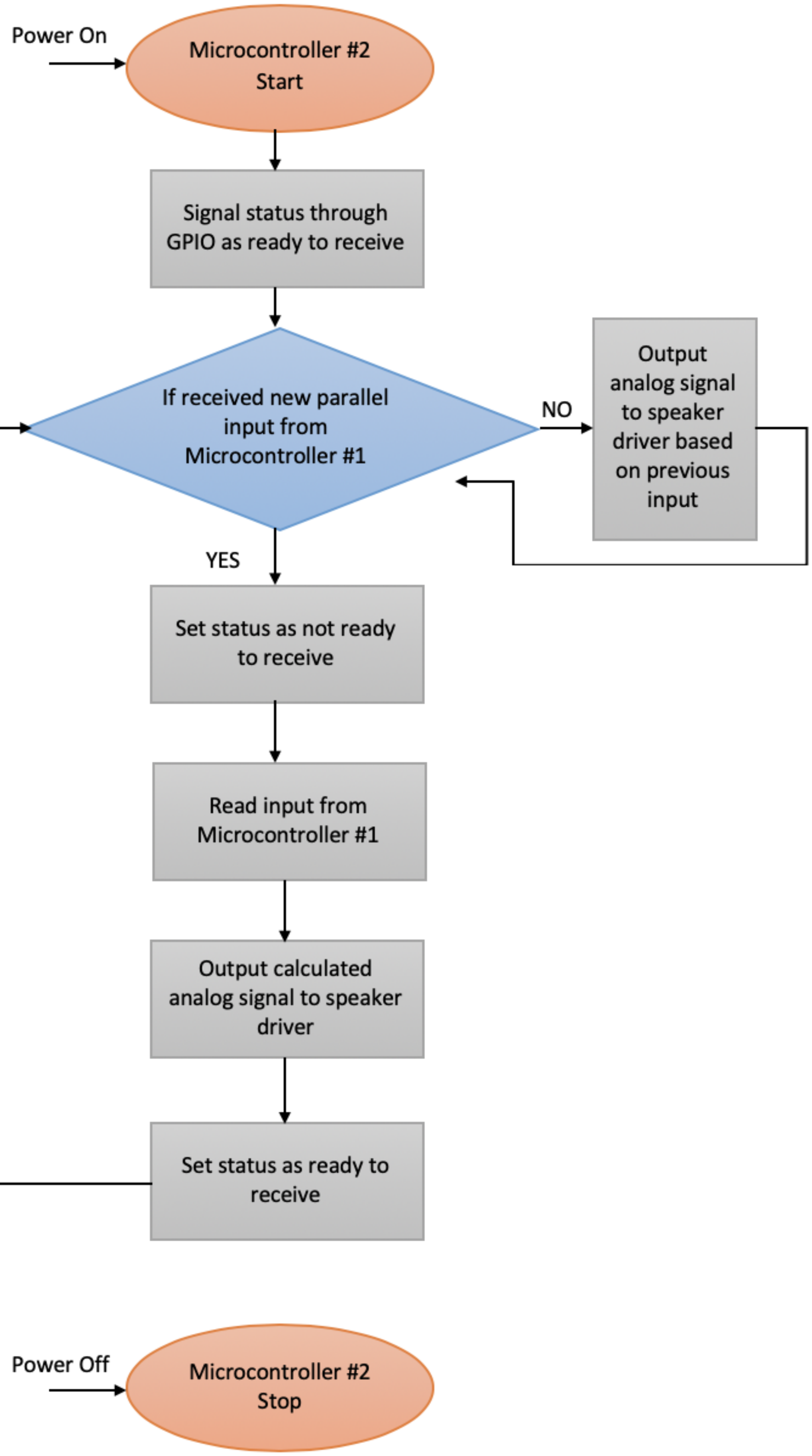
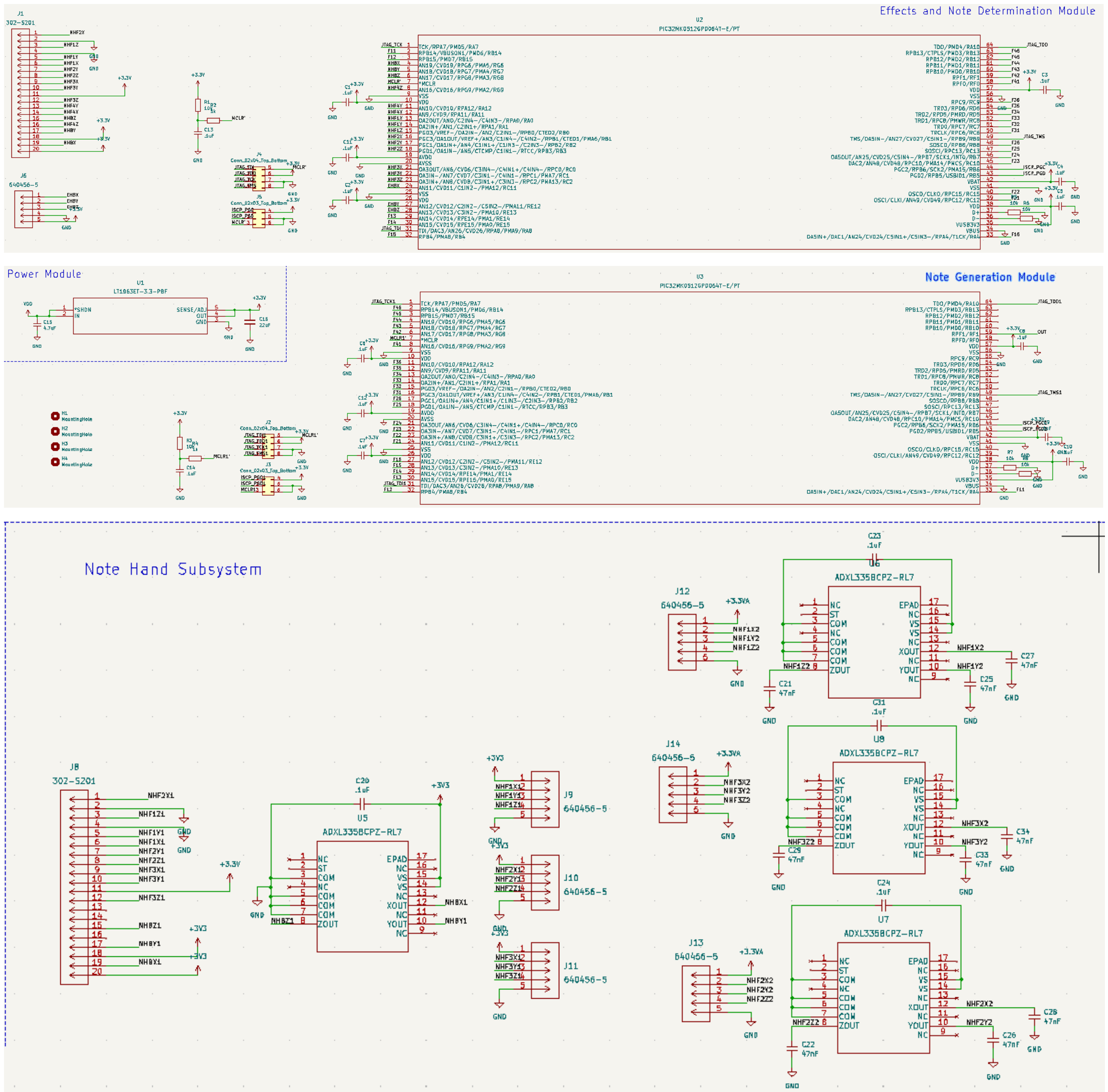


Figure 4. Program flowchart for Microcontroller #2

VII. Circuit Schematics

Here is a link to the full schematic.



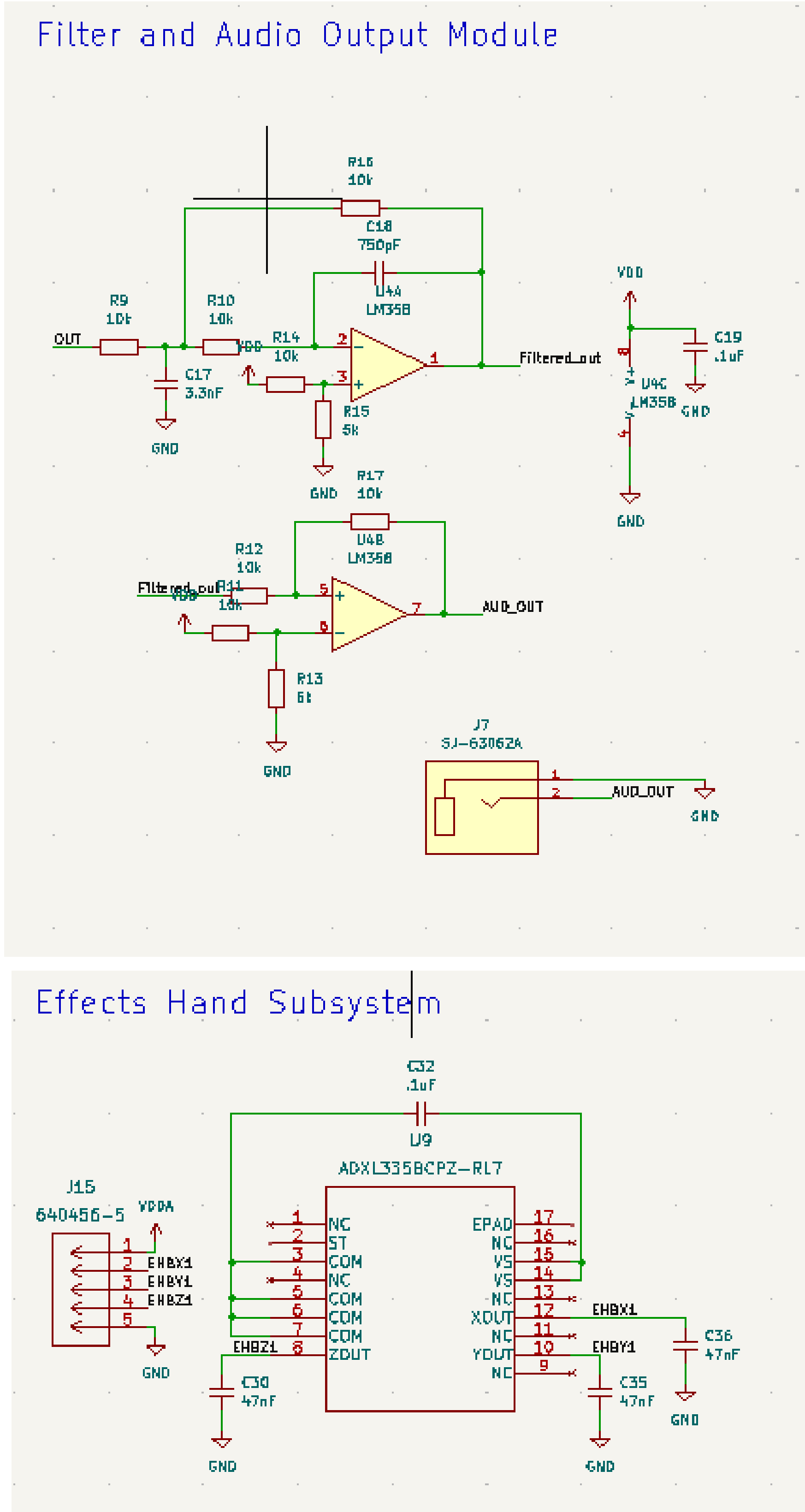


Figure 5. Schematic

VIII. Tolerance Analysis

The filter and amplifier module is the part of the design that requires the most consideration in regards to tolerance. The system uses a LM358 dual op-amp to make a second order filter with a 10kHz cutoff frequency and an amplifier with a gain that can be easily adjusted by modifying a single resistor. The second order filter topology used is a multiple feedback architecture. This sort of architecture has a cutoff frequency equal to $\frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$. These values and the equation were found from this application report [2] from TI. We set all resistors to 10kΩ and capacitors with 3.3nF and 750pF, this gives us a cutoff of 10.12kHz. If all resistors and capacitors are 5% larger than expected due to their tolerance, we get a cutoff of 9.17kHz, and if all were 5% lower than expected, we would get a cutoff of 11.21kHz, both of which fall within the 11% range that we specified. The reason that this is an important figure is that the highest frequency that we will output is 1.76kHz. By ensuring that the cutoff frequency is far away from this maximum value, we can ensure that little to no attenuation will occur at our notes and that the noise from the PDM switching will be attenuated to a significant degree.

Another tolerance analysis that needs to be done revolves around the battery and the op-amps. The op-amps have a certain range of the supply rails that it can drive a voltage. For the op-amp used, the output needs to be 1.5V away from the positive supply and 20mV from the negative supply if the supply is at 5V, with the difference increasing as the supply increases. This means that with the 3.3V input logic, we need a supply voltage of at least 5V to ensure that our op-amp works as intended. Given that we want the system to be portable, this means that the powering method can’t be 3xAA batteries as the 4.5V would not be enough. For this reason, a 9V battery will be used to power the system. This will give the filter a larger range to work with which in turn will allow us to have more tolerance on the biasing for the op-amp and allow for a larger gain at the output.

The following plots are simulations to demonstrate these considerations. The schematic used is shown first. This is the same circuit that will be used in the actual design. The first plot is with the 9V supply, a unity gain, and an input frequency for 440Hz. We can see that the output voltage is about the same amplitude, just at a higher DC bias. We can see from the second plot what happens with a 5V supply. The signal gets clipped at both ends due to it getting too close to the supply rails at different points in the circuit. While some tweaking of values can make this effect minimized, it will be incredibly reliant on proper matching of values. For example, if the voltage divider of the filterstage gets a resistor larger than 5.7k in series with the 10k resistor, the simulation breaks down due to ill-behaving outputs. Plot three shows the 9V supply and a 100kHz input while plot 4 shows a 1MHz input voltage. As we can see, there's significant attenuation at these frequencies, and at 1MHz, the output looks like a DC voltage.

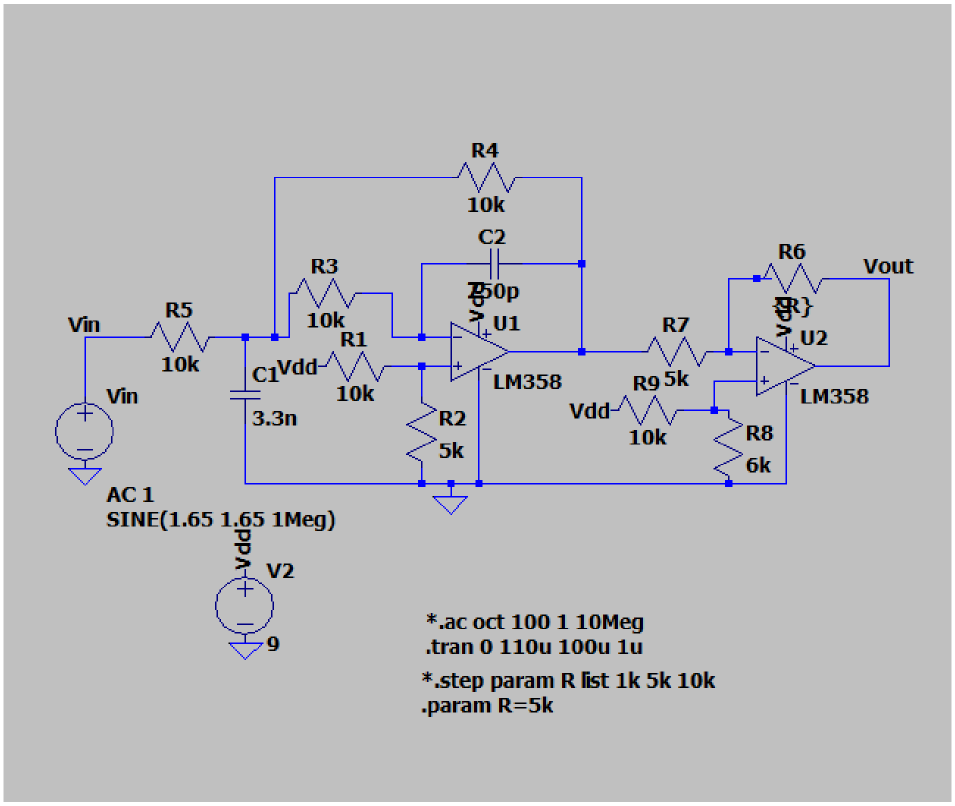


Figure 6. Multiple Feedback filter and amplifier circuit

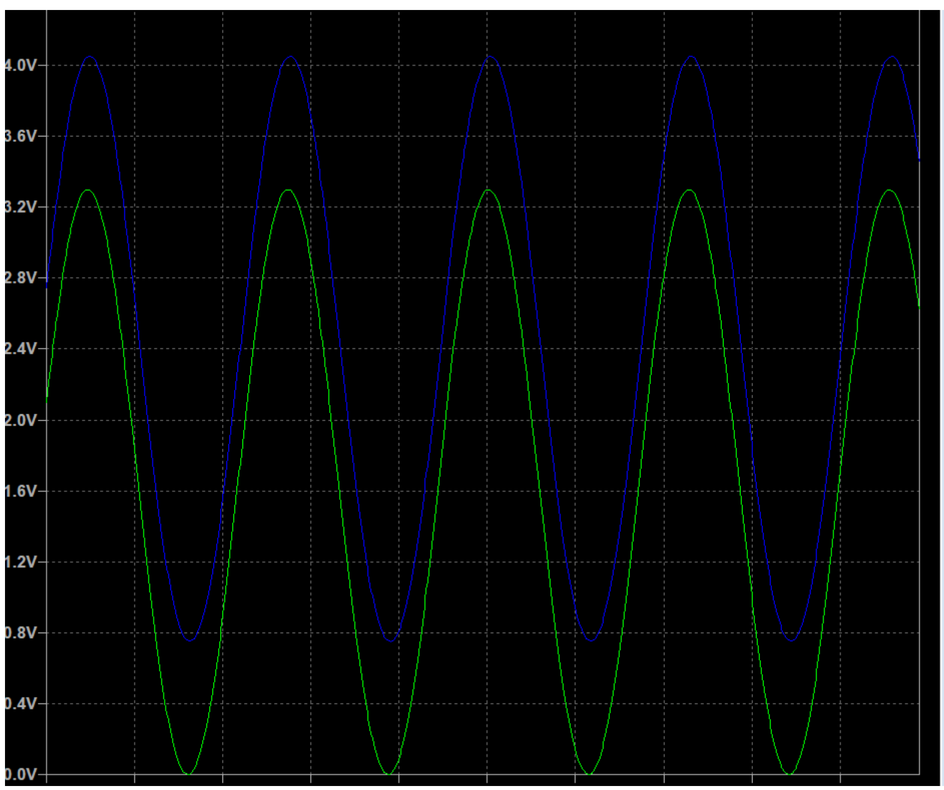


Figure 7. Nominal output of circuit in Figure 6

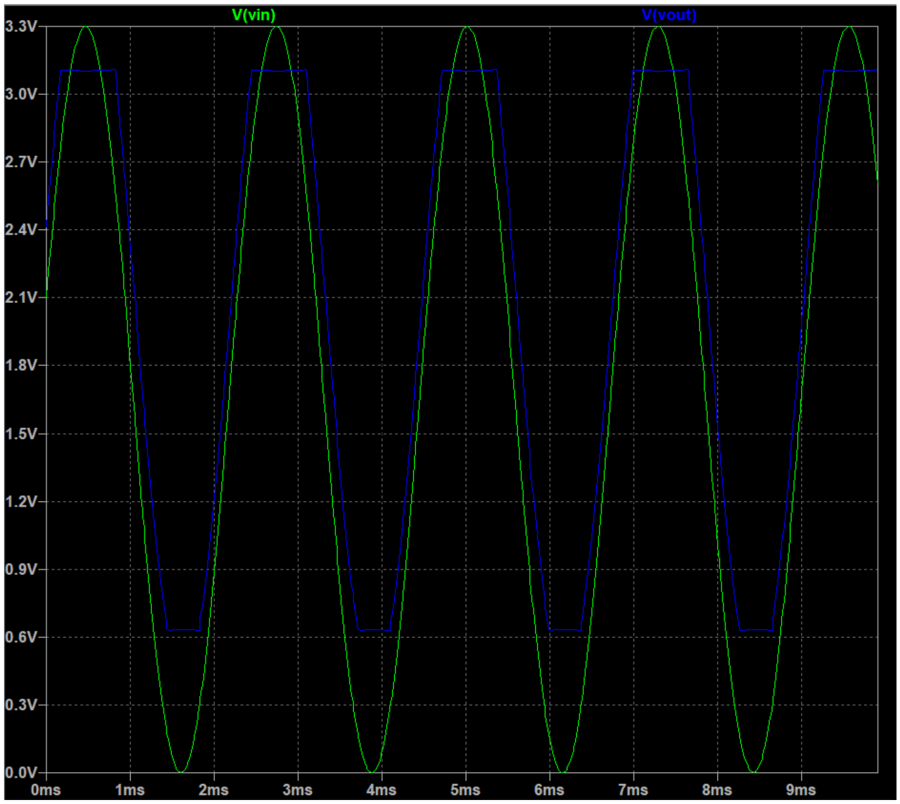


Figure 7. Output of Figure 6 circuit with 5V supply and 440 Hz input

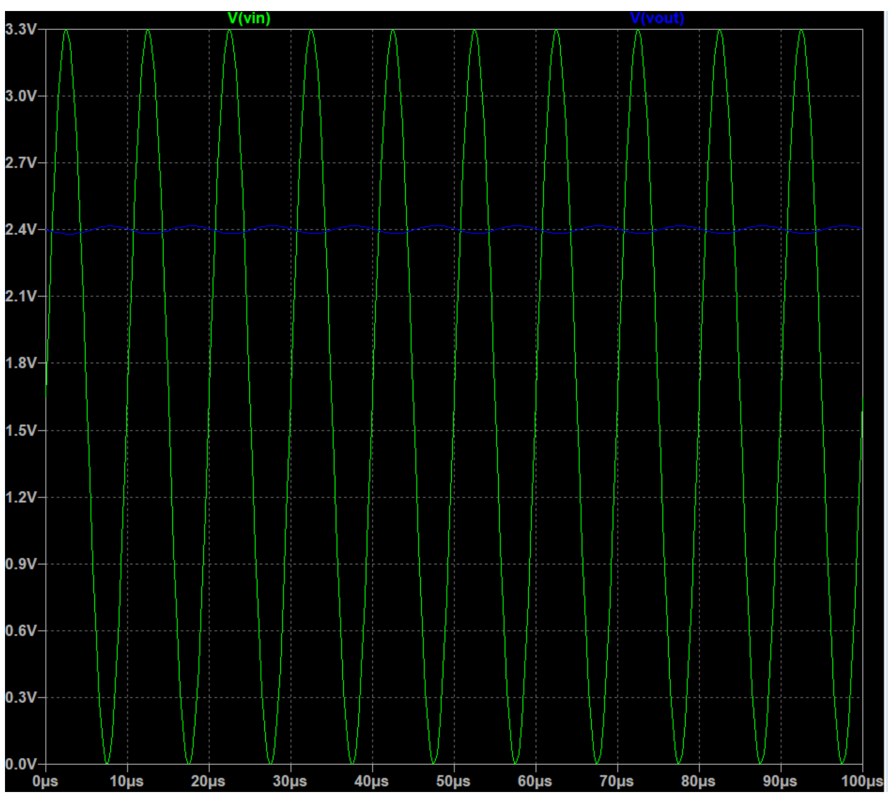


Figure 8. Output of Figure 6 circuit with 9V supply and 100 kHz input

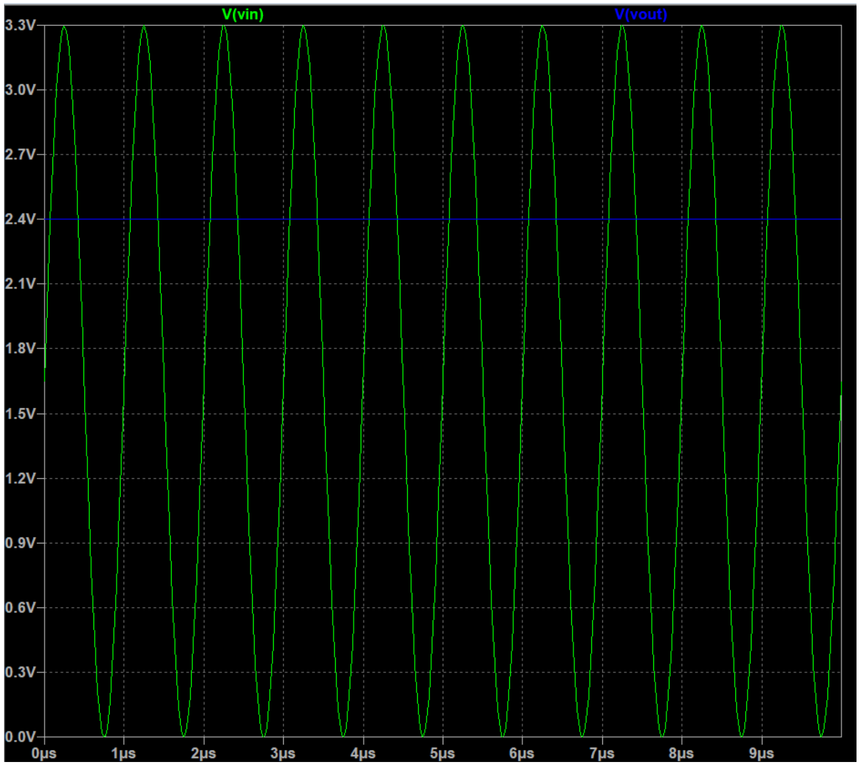


Figure 9. Output of Figure 6 circuit with 9V supply and 1 MHz input

IX. Safety & Ethics

Keeping with the IEEE code of ethics [3], safety and health must take priority. In this regard, the main ethical and safety concerns of our project involve the audio output and power source. Since the power source is part of the chest mount, we must ensure that it does not overheat and burn the user. This requirement can be effectively tested by setting the central unit containing the power source on a table during development and verification. Using this method, there will not be any direct contact with the power source and limited risk for burns. As for the audio output, we must ensure that our product maintains a reasonable volume and does not generate any frequencies that cause discomfort (ex: very high frequencies). While some frequencies and volumes can become uncomfortable, they do not pose a serious health risk and can be tested without additional users outside of the development team.

X. Citations

1. "LMx58-N Low-Power, Dual-Operational Amplifiers." Texas Instruments, Dallas, Texas, Dec-2014.
2. M. Steffes, "Design Methodology for MFB Filters in ADC Interface Applications." Texas Instruments, Texas, 2006.
3. "IEEE Code of Ethics," *IEEE*. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 21-Feb-2022].