COVID Hearing Aid

ECE 445 Final Report

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Abstract

Amidst the COVID 19 pandemic, muffled voices and lack of lip reading are common communication issues that result from health guidelines such as mask wearing and six-feet-apart social distancing. Although a hearing aid would prove valuable at these times, traditional hearing aids are usually very expensive and are generally only designed for people with medically diagnosed hearing loss. To address these issues, we set out to create a special-purpose hearing aid that is more affordable, accessible, and ergonomic. This report details our design process, verification and testing, and cost analysis.

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1. Introduction

1.1 Problem and Solution Overview

Due to the COVID-19 pandemic, people around the world have been recommended or even required to wear masks to prevent themselves and others from becoming infected. There is consistent scientific evidence that this levels the curve of infection, and thus mask-wearing is now an important societal norm [1]. However, this causes communication issues, as mask-wearing muffles speech and prevents lip reading; this problem is especially exacerbated for people who are hard of hearing [2]. Existing solutions such as clear masks and wearable amplification systems must be used by the speaker and would require every person to use one. Furthermore, clear masks actually muffle a speaker's voice even more than cloth masks because they are made of plastic. Standing closer to the speaker is also not a good solution because physical distancing is also necessary to curb the infection rate [3].

Alternatively, there are plenty of hearing aids on the market to raise the volume at which the listener hears the speaker. However, these can be quite expensive and cost up to thousands of dollars [4]. Also, these are usually general purpose hearing aids, meaning that they must be worn on the ears at all times and amplify incoming sounds in an omnidirectional manner, including undesired noise. To solve this issue, we focused on the perspective of the listener alone.

1.2 Objective

Our sponsor Ryan Corey informed us, "the most reliable ways to amplify a talker's voice and remove background noise are to bring the microphone closer to the talker, to use a directional microphone, or both." To accommodate for social distancing, our solution is a hearing aid that can amplify sounds that come from at least 6 feet in front of the listener through the use of a directional microphone. Additionally, by request of our sponsor, we made the device as affordable and simple as we can to allow for DIY replication in times of COVID.

This device is a handheld gadget which the user points in the direction of a sound source to be amplified. The device features a uni-directional microphone to capture audio, a tunable amplifier that allows the user to adjust the volume, and a 3.5mm auxiliary jack to output the audio to the user via headphones. Our device is accessible to a wider range of consumers because it is much cheaper and does not have to be worn at all times. Instead, the user can hold it in their hand when necessary and use the device's audio jack to plug in their own headphones, which is a commonplace item that almost everyone already owns. Figure 1.1 displays the typical usage scenario for our device. The device itself was made from a few simple circuits and can be easily recreated by others.

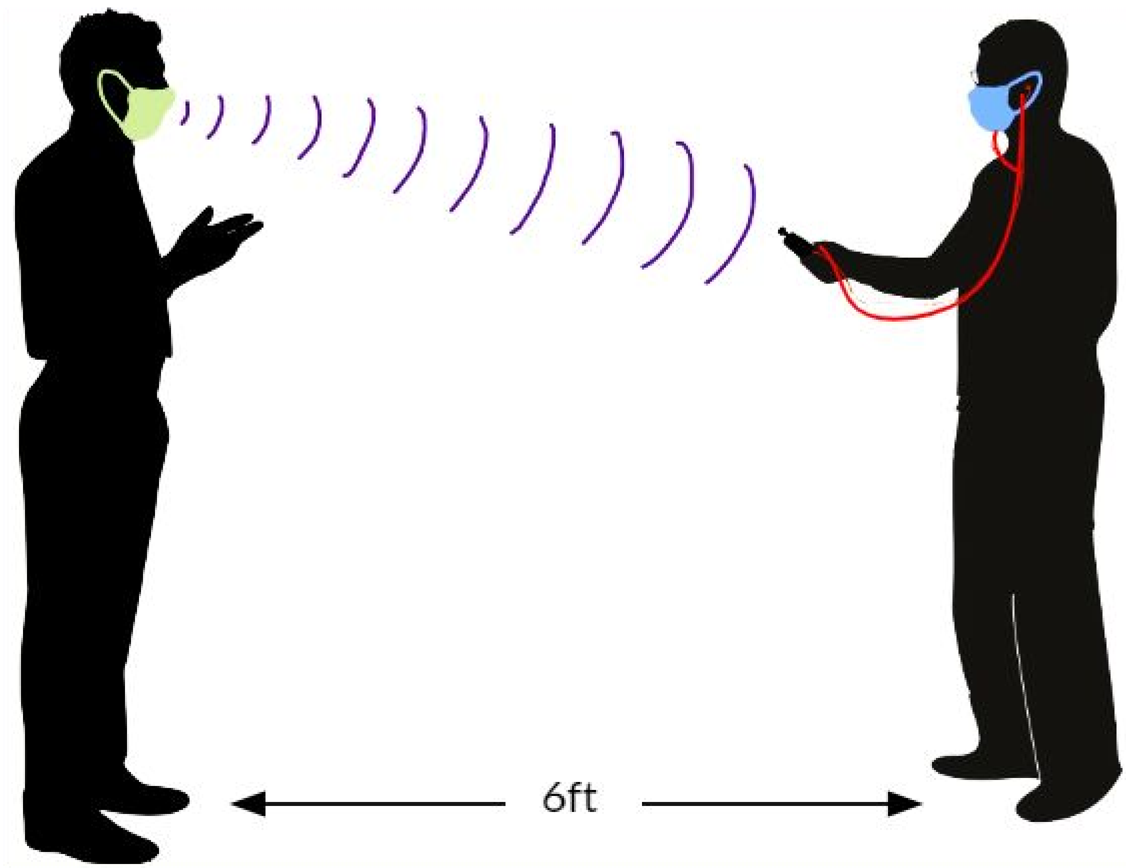

Figure 1.1 : Typical Usage Scenario - The listener (right) is holding the device towards the speaker (left). The speech's sound waves are captured by the device and the amplified playback is redirected to the user via wired headphones.

2. Design

2.1 Block Diagram

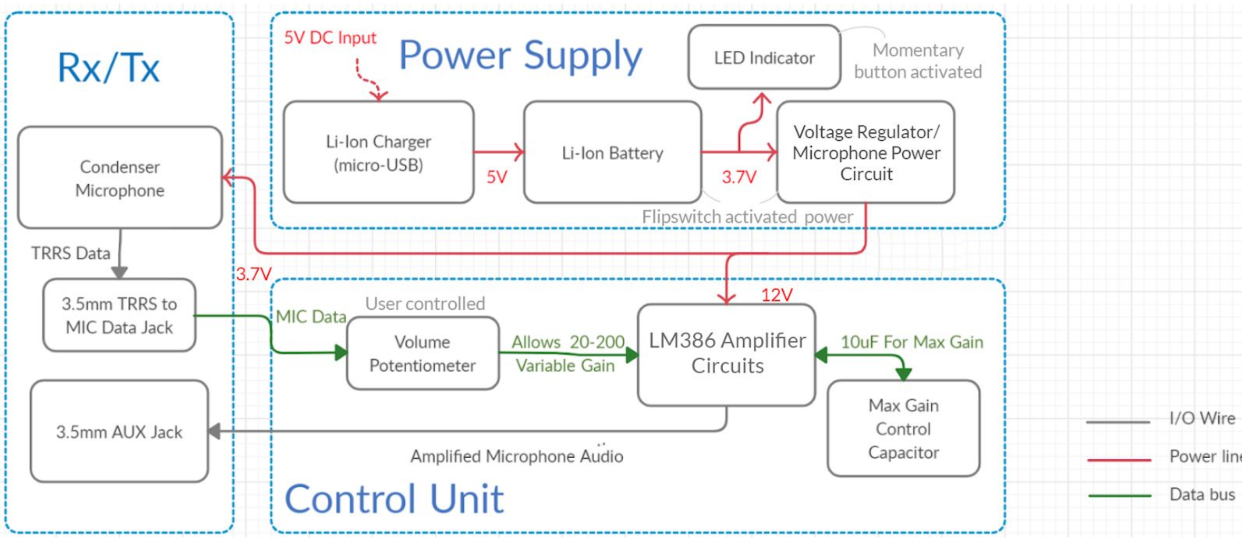

Figure 2.1 : Detailed Block Diagram

2.2 Physical Design

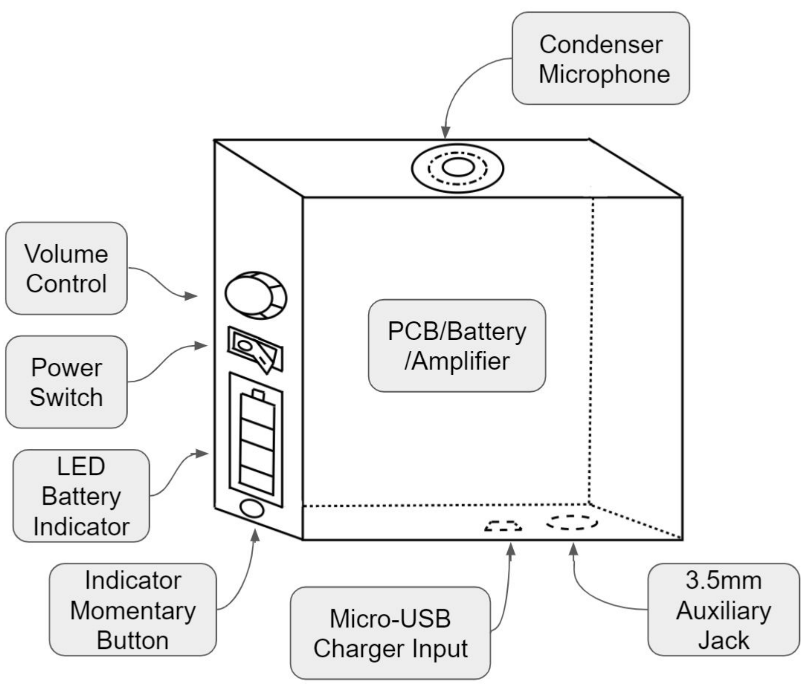

Figure 2.2 : The physical design contains all hardware within the device while exposing the key features of the user interface on the parameter.

2.3 Power Supply

2.3.1 Li-ion Charger

The circuit charges the li-ion battery through the TP4056 charger module. This is powered by an external source with a maximum charging voltage and current at 5V and 1A respectively via micro-USB. Of this only 4.2V gets sent to the battery. This is because the TP4056 charger module has on-board protection circuits to charge the battery until stable conditions. While charging, a red LED remains active. Once fully charged the LED shines green and any new current is redirected away from the battery to prevent overcharging. At maximum capacity this will charge the battery in approximately 2.2 hours.

2.3.2 Li-ion Battery

We used an 18650 battery because they are easily recharged and can operate at voltages required for the device. Running at 2200mAh, the battery will be quick to charge and last for around 15.7 hours with a 140mA discharge (120mA peak current draw for LED indicators and 20mA max draw from the LM386). [14, 15] Although the design is for low power consumption, there is always the risk of overheating either when operating or charging a li-ion battery. The TP4056 charger module and a IR thermometer will assist in making sure the battery doesn't reach dangerously high temperatures that could damage the internal circuits or become hot in the users hand.. The battery will open output power when the device is powered on through the use of a simple flip switch.

2.3.3 Voltage Regulator

This voltage regulator acquires more than the minimum required voltage (2V) from the li-ion battery (~3.7V) and converts the voltage to 12 V, which is needed to operate the amplifier circuits at full power. With the maximum allowed current output being 1100mA, there's more than enough of a margin to operate this simple device without overheating.

2.3.4 Microphone Power Circuit

This circuit was scrapped from the microphone we've purchased for the device. This takes the voltage directly from the battery (~3.7V) rather than from the voltage regulator (12V). This is because we don't want to over power and damage the microphone. The maximum operating voltage for the microphone is 10V. In addition to powering the microphone, this circuit also provides a pinout for the audio signal generated by the condenser.

2.3.5 LED Indicator

This will help the user understand how long the device will run before it needs to be charged. To see this there are 4 LEDs in place to show the output voltage of the battery.

Beginning at 3.2 V the lowest LED will power on. Increasing by 0.2 V, each LED after will also light up if there is sufficient voltage. Each LED corresponds to 25% battery life remaining and can be seen with a press of a momentary tactile button. Peak current for each LED is 30mA for a max current of 120mA to drive the indicator. [15]

2.4 Control Unit

2.4.1 Amplifier

The amplifiers we use rely on an LM386 IC to receive input from the microphone and amplify the signal to be read across the board at a higher decibel rating (dB). Since the microphone is not a standard condense, having a pull up resistor, R2 in Figure 2.4, will not provide enough power to the microphone. In its place we've opted to scrap the microphone power circuit from the microphone we've purchased. This circuit is simply to pass voltage through the microphone and receive back an audio signal generated from the condenser. Still, the audio signal is very low. This is where the amplifier comes in. The LM386 is capable of amplifying its input 20 - 200 times depending on the capacitor used between pins 1 and 8. To achieve maximum gain from this preamplifier, a 10uF capacitor is used.

Additionally using a 0.1uF capacitor in line to the data in from the microphone, we remove the DC component of input signal and only allow the AC signal (the audio signal) to be fed into LM386. In series with this capacitor is a 100k ohm potentiometer. This acts as our tunable amplifier to set the amplitude of the audio signal. This is done with voltage division from the voltage from the regulator and the microphone. Thus the potentiometer works as the master control for volume output. The LM386 IC only needs 3V to operate and has a max current drag of 20mA, allowing extended use alongside the Li-ion battery. [14] By operating at 12V, we allow for lower latency when amplifying the audio signal, as well as producing less distortion in the amplified signal. [14]

Following the pinout of LM386 IC, pin 7 represents the bypass pin. By placing a capacitor here we can pull away the excess voltage in the IC. Pin 5 is the output pin for the LM386. This also has a few capacitors in place to further clean up the signal. In Figure 2.4, the capacitor, C3, in series with resistor, R1, are working as a filter also called the "Zobel network." The purpose of this filter is to remove the sudden High frequency oscillations or noise. [5] Finally the capacitor, C2, is used to remove the DC component of the amplified signal that could otherwise damage the speaker used for playback. In the case for our design we've implemented two identical amplifier circuits to further boost the signal before passing it off to the auxiliary jack. In Figure 2.5 we can see the clearly labeled PCB as well as the components used to build the rest of the circuit. The build of this circuit has been made as simple as possible to allow others to replicate.

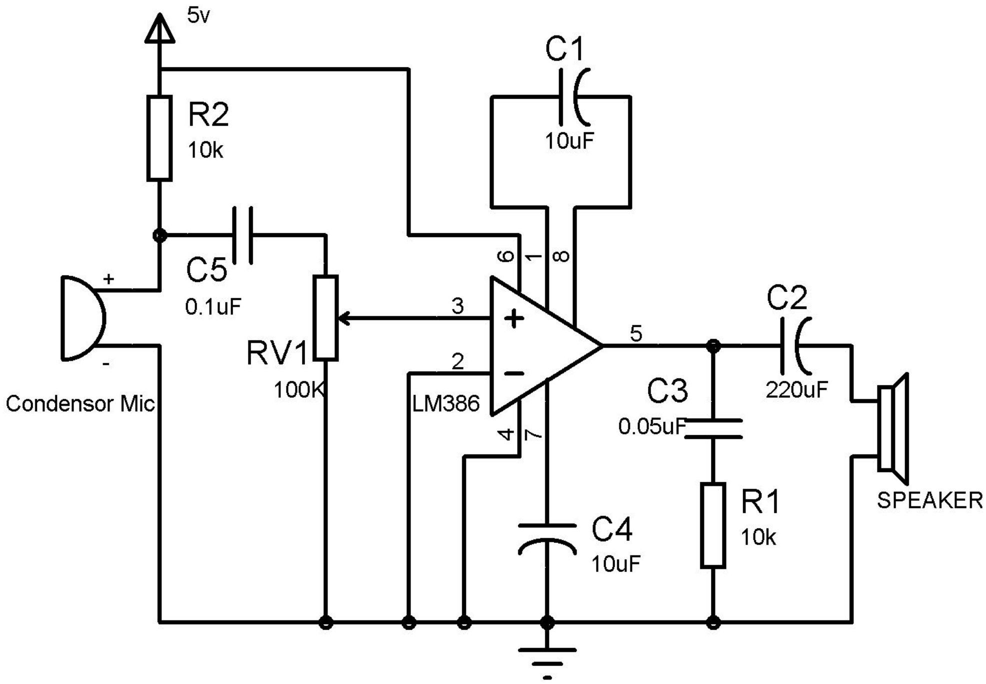

Figure 2.3 : LM386 circuit diagram reference for preamplifier [5]

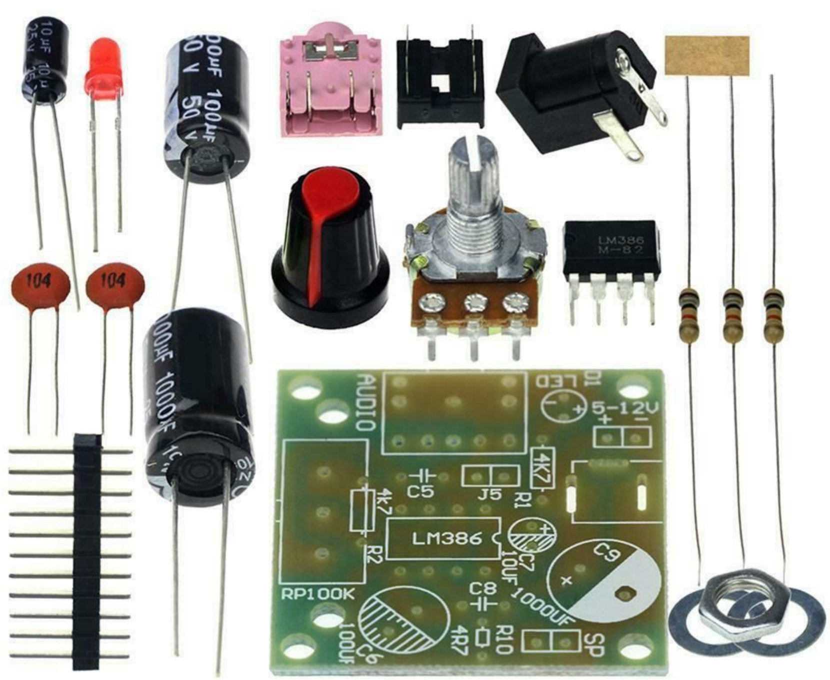

Figure 2.4 : PCB and other components necessary to complete the LM386 amplifier circuit. [19]

2.5 Rx/Tx

2.5.1 Condenser Microphone

We've purchased many microphones and tested them out before landing on our final choice. The Bietrun YXM04 is a cardioid microphone, meaning that it is designed to be a unidirectional microphone. As shown in the lower image of Figure 5, the microphone works to best gather input from directly in front of the device. The microphone will be connected from a 3.5mm TRRS auxiliary input. Using an auxiliary cable the microphone plugs into the microphone power circuit. This not only gives the microphone the necessary voltages to operate, it also gives direct access to the data coming from the microphone. The signal is then filtered and passed through the potentiometer to act as the input to the LM386 amplifier. The YXM04 works between 45 and 20k Hz so it's more than capable of capturing the human speaking voice, which stands to be around 80-260 Hz. [7]

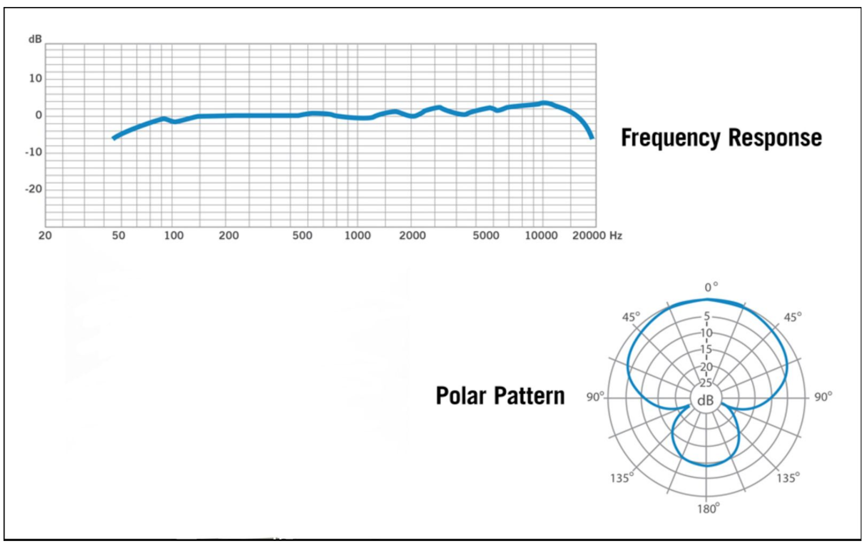

Figure 2.5 : Specifications of a typical cardioid condenser microphone. The above graph is the audio volume, in dB, across the operational frequencies of the microphone. Below depicts the cardioid polar pattern. This displays the amplitude of captured audio (in dB) at a given angle to the microphone. [18]

2.5.2 Auxiliary Jack

The 3.5mm Auxiliary (AUX) jack works to provide the user with a way to listen to the amplified audio from the LM386. Connecting each signal to the left and right termails of the jack to the output of the LM386 allows the user to hear the amplified signal from a low power speaker device such as headphones. By also adding the signal to the MIC terminal of the jack allows the microphone to remain a microphone for amplified audio recording purposes.

3. Design Verification and Testing

3.1 Tolerance Analysis

One of the most important tolerances we had to consider was the amplification volume. Although we want a very efficient amplifier, we don't want to damage the ears of our user. To use the output power we first reference the input from the microphone. In reference to the user manual of Bietrun YXM04, we get the microphone sensitivity as -42 dB ± 1 dB, with 0 dB producing 1 V/Pa as reference [8]. The following expression gives the gain between a reference voltage V_0 and a measured voltage V_1:

$$20 \times \log \frac{V_1}{V_o} \quad \text{Eq. 1}$$

Since every -6 dB decreases voltage by one half, we calculate V_0 as follows:

$$V_0 = 1\,\text{V} \cdot \left(\frac{1}{2}\right)^{\frac{-42\,\text{dB}}{-6\,\text{dB}}} = 7.8125\,\text{mV} \quad \text{Eq. 2}$$

Next, we multiply this value by our gain to obtain V_1:

$$V_1 = 7.8125\,\text{mV} \cdot 200\,(\text{Gain}) = 1.5625\,\text{V} \quad \text{Eq. 3}$$

Now use these values to calculate the gain (A_V) in dB:

$$A_v = 20 \cdot \log\left(\frac{1.5625\,\text{V}}{7.8125\,\text{mV}}\right) \approx 46\,\text{dB} \quad \text{Eq. 4}$$

Noting that 1 Pa (pascal) equals 94 dB sound pressure (SPL), we can find the sound pressure level in dB after amplification as follows:

$$94\,\text{dB} - 42\,\text{dB} + 46\,\text{dB} = 98\,\text{dB} \quad \text{Eq. 5}$$

Therefore, we can amplify our audio to higher than 90 dB while also staying below the 110 dB regulation for hearing aids. [11]

3.2 Verification and Testing

3.2.1 Lithium-ion Charger

Our original requirement for the li-ion charger was that it should charge to 3.3–3.7 V when a continuous 4.2 V input voltage is applied. As a result of our test for our LED indicator, we instead required the charger to charge to 4 V for a continuous input voltage of 4.2 V. To verify this, we charged the battery with 1 A at 5 V and used ALICE and saw that the battery outputs 4 V when all the indicator LEDs turned on.

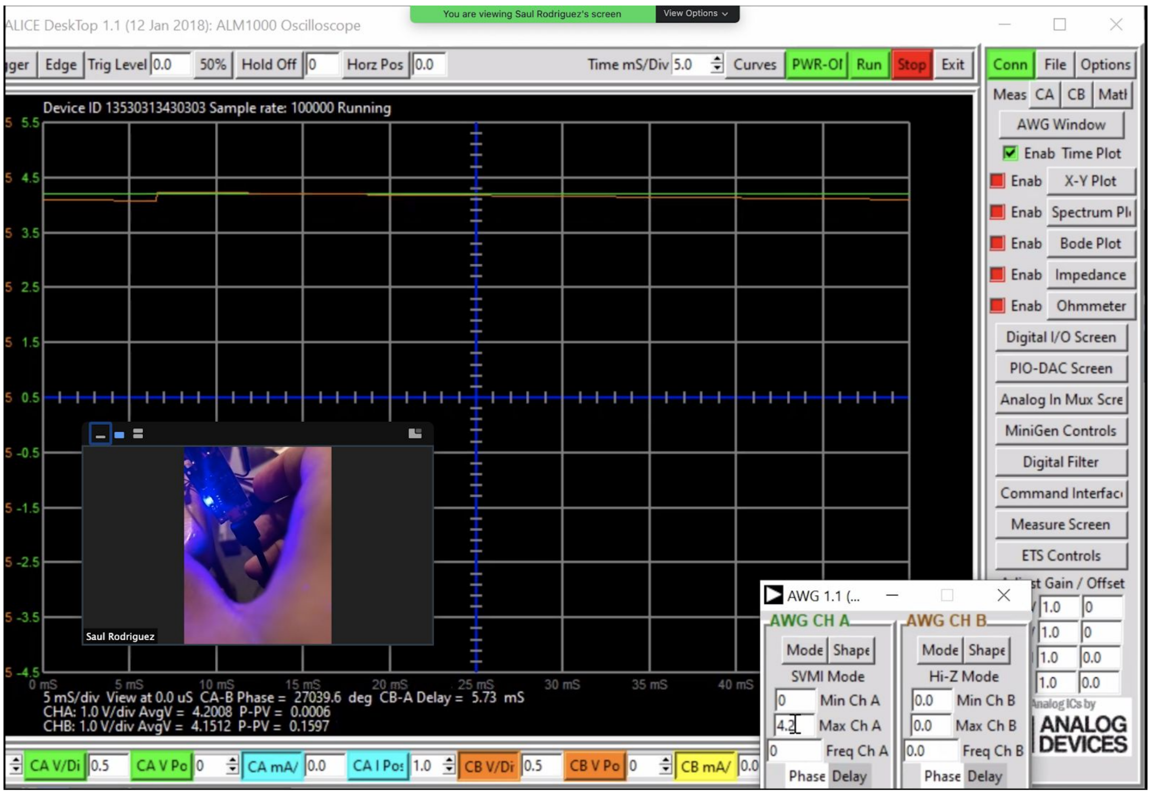

Figure 3.1: Verification for Li-ion charger. The green line displays 4.2 V continuous input, and the orange line displays the output voltage from the battery, which approximately remains at 4 V.

3.2.2 Battery Life

To ensure the long battery life we desired for our device we've left the device once and checked on it periodically. For this test we aimed to exceed 6 hours of continuous use at full capacity. This meant the momentary button for the LED indicator was held active and the amplifier was set to its maximum. To measure the capacitor of the battery, we used a voltage probe to measure the terminal voltage on the battery. At a full charge the battery was at 4.1 V. As depicted in Figure 3.2, for every 30 minutes that elapsed a new voltage was measured and

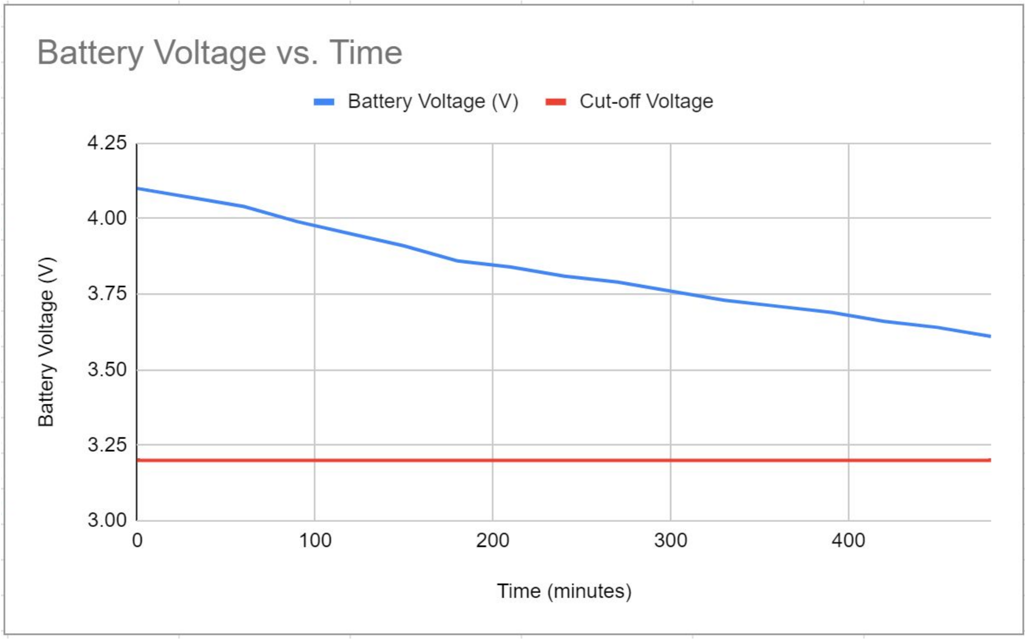

Figure 3.2 : A plot of the battery voltage against time while being operated at full capacity.

recorded. After 8 hours of testing, we've surpassed our goal of 6 hours and have obtained enough data to apply linear regression for an estimate of how long the battery would last.

The formula derived for this calculation is as follows:

$$\hat{y} = -0.00102X + 4.07725 \quad \text{Eq. 6}$$

Where ŷ is the voltage at time x. Setting ŷ to the cut-off voltage (3.2 V), the estimated run time equals approximately 860 min or 14.33 hrs.

3.2.3 LED Indicator Accuracy

For the LED indicator, as a preliminary test, we supplied varying amounts of voltage to the battery and measured the output voltage of the battery and counted the number of LEDs in the battery indicator that were turned on. We measured and displayed these voltage values using ALICE, as shown in Figure 3.3. The green line represents the input voltage and the orange line represents the output voltage. We found that the highest voltage supplied to the battery such that all the LEDs were inactive was 3.2 V, and for this input, the battery outputs 4 V. Thus we consider 3.2 V to be the lowest input voltage for which the battery is turned on. Next, we found that for every 0.2 V increase in the input voltage, one additional LED light would turn on. Since there are four LED lights, all four are turned on at an input of 4 V. This is very close to what we

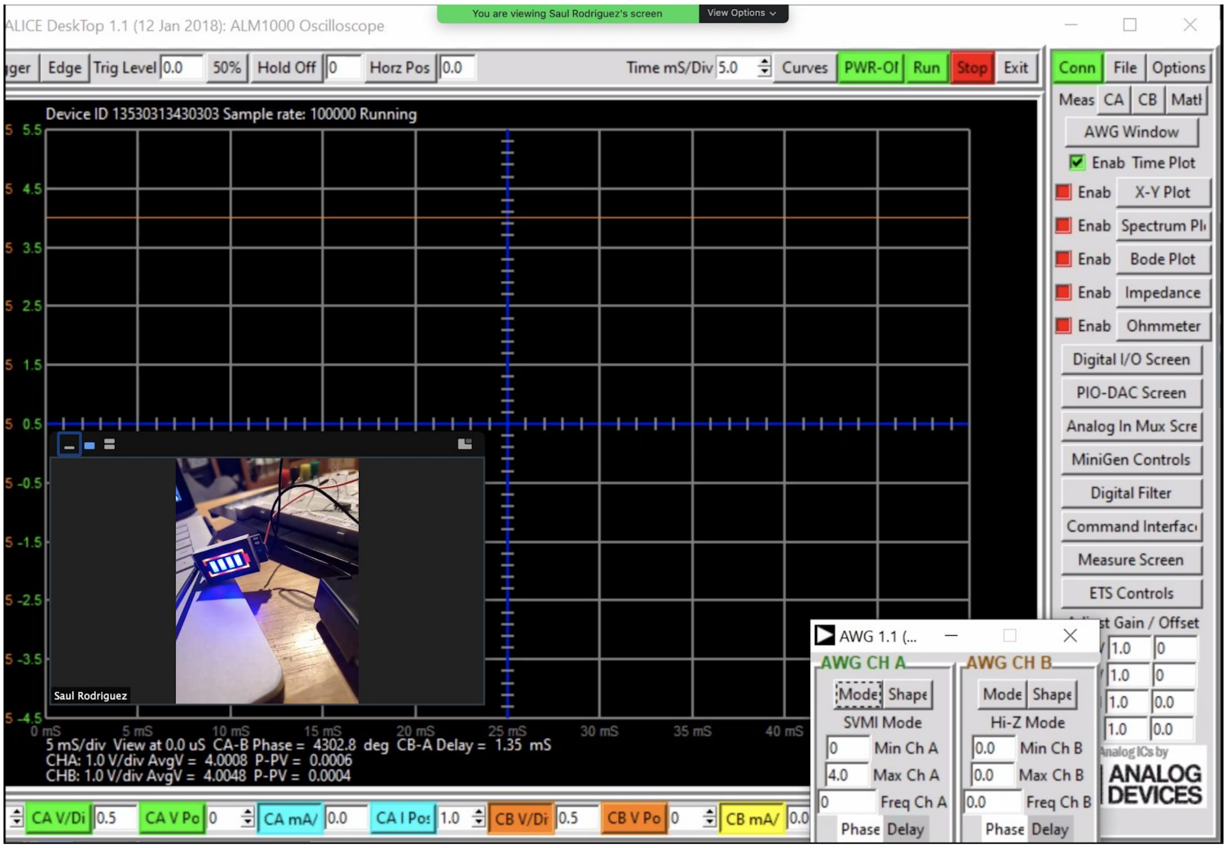

Figure 3.3: 4.0 V input to the battery results in all four LED indicators being turned on. For each 0.2 V decrease in input, one LED indicator turns off.

were expecting, because in our design document, we predicted that the first LED would turn on at 0.3 V input and one more would turn on with each incremental increase of 0.2 V.

3.2.4 Voltage Regulator

The first requirement for our voltage regulator was that a 3.7 V battery source should provide a 12 V output with 5% regulation. We verified this by measuring the output voltage using a voltmeter. When operating at full capacity we read 11.71 V on the voltmeter. Given that 5% of 12 V would be 11.4 V, we made sure to stay within the bounds planned for our device.

3.2.5 Amplification Tunability

The next test we needed to conduct was the amplifier circuit. We've already tested the amplifier itself to work problem in Appendix A, however in order to test the amplifier with the microphone we needed to wire the two together, as it would be in the final device. This takes the audio signal that is isolated from the microphone power circuit and applies it as the input signal

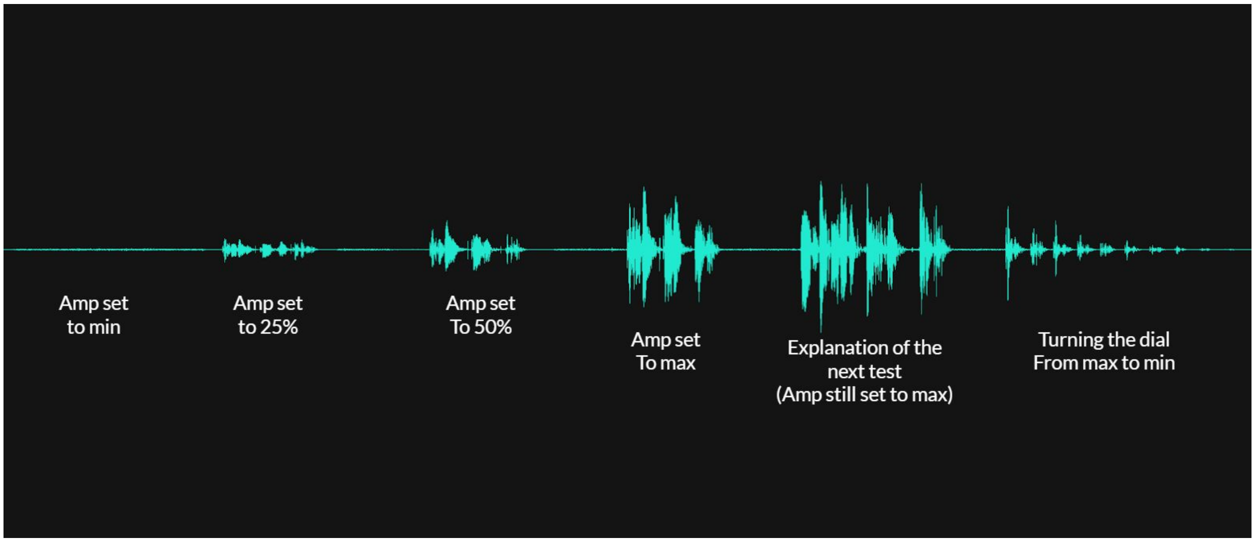

Figure 3.4 : Audio signals captured for testing the amplifier's tunability. Displays how the received signal's amplitude increases as the dial is set from minimum to maximum, then decreases as the dial is turned back.

to the LM386 amplifier circuit, from which the amplifier then sends to an additional amplifier, and out to the AUX jack. The first amplifier acts as the main control, with the tunable potentiometer for the circuits on the outside of the device. The second has been preset to further boost the maximum signal of the prior amplifier.

For our test we followed a similar set up to the unidirectionally test. Here we plugged in an AUX cable to the jack located at the bottom of the device and the other end to Saul's laptop. This allowed us to record the amplifier signal from the microphone. Beginning the test we run the device with the potentiometer set to its minimum. As time progressed we turned the dial 25% with each additional test. The word "testing" was stated at a normal speaking volume at each instance for a test, aside from the moment where Saul explains the next test as seen in Figure 3.2. The test proceeding this explanation starts with the dial at its maximum and slowly turns it to its minimum while the word "testing" is being repeated. We can conclude that the dial and amplifier did in fact work as indicated by the amplitudes of the recorded signal displayed by the *WavePad Audio Editor.*

3.2.6 Microphone Unidirectionality

For testing purposes we used the Analog Devices ADALM1000 Evaluation Board alongside ALICE Desktop to simulate battery operations and analyze nodes on a breadboard. Being able to use a breadboard for testing allows me to test the components before trying to solder them together. The ADALM1000 has features such as: "Measuring and sourcing current (- 200 to +200mA) and voltage (0 to 5V) simultaneously on same pin" and "Oscilloscope (100 kSPS), function generator (100 kSPS)."[17] With the channel output we can set the DC voltage to mimic the battery running at full capacity without worry about draining it and having to stop to recharge. Additionally there is a channel input that can display the corresponding output from the circuit design to the ALICE window on Saul's laptop.

The ADALM1000 has been a great assistance in probing and analyzing, however it has a maximum operating voltage of 5V. Using a 12V supply for the amplifier board as well as seeing the very low signals from the microphone before amplification we need a more accurate and less limited multimeter. We decided to go with the AstroAI DT132A, since it is also equipped with thermal couplings that can help ensure our project is operating within safe limits. Adding to the equipment use, we also used Saul's laptop and an application called *WavePad Audio Editor* to record and analyze sound.

Once the device was built, our first test we wanted to do was make sure we had the right microphone for the project. We were aiming to use a unidirectional cardioid microphone. These kinds of microphones pick audio best from the front and sides of the device with a decreasing capture ability as you circle around to the back. [20] The range of capture can be seen in the polar pattern of Figure 2.5. To test this we connected the microphone to Saul's laptop and recorded someone speaking towards the mic from various points. We chose to start the sample directly facing the mic. Then each additional test Saul would orbit the mic, keeping himself at a 6ft radius. He did this test and orbit 3 times, moving 15 degrees between each test. As seen in Figure 3.1, the microphone picks up more audio the more inline he was to the front of the mic. This is indicated by the decreasing amplitude size in the soundwaves displayed by the *WavePad Audio Editor*.

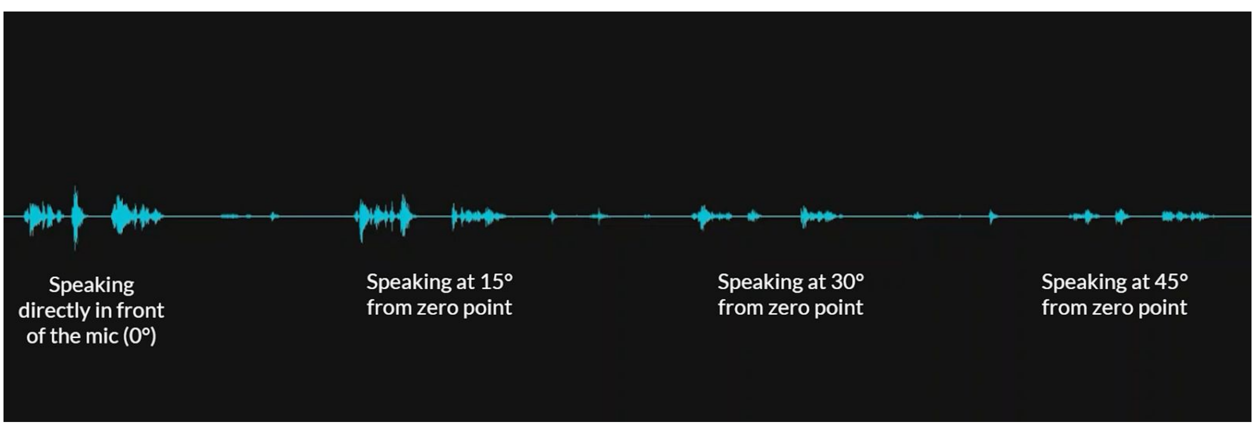

Figure 3.5 : Audio signals captured for testing the microphone's unidirectionality. Displays how the received signal's amplitude decreases with angular offset to the microphone.

4. Costs

4.1 Labor

Name	Hourly Rate	Hours	Total	Total × 2.5
Kartik Kansal	$35	160	$5,600	$14,000
Saul Rodriguez	$35	160	$5,600	$14,000
Total				$28,000

Table 4.1 : Labor Costs

4.2 Parts

Part #	Description	Manufacturer	Vendor	Quantity	Cost/ Unit	Total Cost
LGDBHG21	Rechargeable Battery	LG Chem	18650 Battery Store	1	$5.99	$5.99
RK-0500500	Micro-USB Charger (x6)	DZS Elec	Amazon	1	$1.165	$6.99
MT3608	Voltage Regulator (x10)	WOWOONE	Amazon	1	$0.995	$9.95
-	On/Off Switch (x10)	VQVAAQ	Amazon	1	$0.698	$6.98
YXM04	Mini Cardioid Condenser Microphone	Bietrun	Amazon	1	$23.63	$23.63
COM-11996	Momentary Button	Sparkfun	Sparkfun	1	$0.95	$0.95
GR-US-145	Battery Capacity Indicator (x2)	DAOKI	Amazon	1	$2.995	$5.99
2914	Audio Plug Terminal Block	-	Adafruit	1	$2.50	$2.50
2915	Audio Jack Terminal Block	-	Adafruit	1	$2.50	$2.50
LM386	Mini Power/Audio Amplifier Board/Volume Adjustable Control (x2)	Acxico	Amazon	1	$3.595	$7.19
Total					$45	$72.31

Table 4.2 : Component Costs with unit costs and total costs tabulated.

5. Conclusion

5.1 High-Level Requirements Achieved

- A portable and rechargeable power delivery system allows the device to function on the go for at least 8 hour.
- The microphone can pick up on sounds that are at least 54 dB and from 80 to 260 Hz.
- The device can amplify sounds to at least 90 dB but no more than 110 dB in order to accommodate those with profound hearing loss. [11]

5.2 Design Considerations and Changes

Since the beginning of our project, we've tried following the flow of design we initially laid out. This however showed that a couple of our numbers were different than what we theoretically planned for. For example, we changed the 2500mAh battery with a 4.2 V max voltage mentioned in the DD for a 2200mAh with a 4.1V max voltage simply because the original was not properly functioning with our LED indicator. We have reason to believe this was because the battery exceeded the operational voltage of the indicator.

The choice of microphone proved to be a rather difficult task for us as it was hard to find an efficient microphone at an affordable price. The idea to use a dynamic microphone was ran by us, as they've been known to be better at capturing vocals. [21] This seemed like it would be a perfect fit since we are focusing on amplifying human speech, however the microphone has an omnidirectional polar pattern rather than the unidirectional pattern we desired. In the case of an omnidirectional microphone, all audio surrounding the microphone is captured. For our device, we only wanted to primarily amplify the audio source the user is pointing the microphone to. Because of this we've opted to keep the unidirectional microphone design.

In the case of the microphone being used for our unidirectional audio capture, we've found a very similar, but more open sourced microphone to the BOYA BY-MM1 we initially planned to use. The Birtrun YXM04 has the same microphone specifications as the BOYA, and also shares its operation voltage as well as maximum impedance for the device. Although these could be similar to the BOYA, there was no way to tell for certain without waiting to hear back from the manufacturer. This led me to picking the Bietrun microphone for getting specific results when testing. [18] In addition to the microphone itself, we've also implemented a wind guard otherwise known as a "dead cat." This helped to isolate some of the background noise.

As for the amplifiers used in our device, the initial plan was to only need a single amplifier circuit. Upon testing the device, we noticed that the signal at max amplification was still not perceived as too loud at 90 dB. When referring to the math for our theoretical analysis, we planned to reach 98 dB. This however was the best ideal case, and the loss in amplitude was attributed to any losses in voltage across the circuit as well as not being able to produce a 1 Pascal audio signal that the microphone was rated at for its maximum sensitivity. To counteract these unplanned losses, we used an additional amplifier in series to the first to further boost the overall signal obtained by the microphone. With the second amplifier in place we were capable of getting playback to 101.69 dB.

Aside from boosting the signal solely from the microphone, the second amplifier also unfortunately boosted the noise generated by the first amplifier. This in turn created a noticeable buzzing noise through the connected headphones. The problem remained even when testing with other headphones as well. The buzzing volume would also increase with the audio signal by turning the dial to the potentiometer toward its max. We did have a few capacitors in place to try to reduce noise as much as possible but this mainly accounted for standard current buildup across the wires. Thankful when the amplifier is set to 50% the buzzing is barely noticeable and the intended vocal audio can be clearly heard. Oddly enough when connected to a laptop the device's buzzing is no longer heard. This allowed for use to continue to gather all of our analytical data with no issues.

5.3 Ethics and Safety

While building this project we made sure to adhere to the IEEE Code of Ethics—in particular, "to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design…" [6].

One of the safety concerns was the use of the lithium ion battery, which could have overheated and caused damage to someone's skin or could have started a fire. The other electrical components, like wires, posed a similar concern. We made sure this didn't happen by monitoring the battery temperature and measuring the amount of power supplied to the components. In our Design Document, we originally stated that we would keep the battery temperature below 125ºC. However, we changed this limit to 45ºC because heat-pain receptors in human skin typically start responding to this temperature level and higher [16]. Furthermore, we encased all the electrical components in cardboard to insulate them and eliminate any possibility of the user experiencing electric shocks.

Another safety concern was the possibility of audio being over-amplified. We wanted to be able to accommodate people within the profound hearing loss range, which is 91+ dB [10], but we also wanted to make sure that sounds would not be amplified higher than 110 dB, which is an established safety regulation for hearing aid devices [11]. The highest sound intensity level we ever recorded (with the volume dial turned all the way up) was 101.69 dB, meaning that we complied with this guideline. Furthermore, since we also wanted people with normal hearing to be able to use our device, we implemented a volume dial because prolonged sounds above 85 dB are considered harmful to normal human ears [12].

5.4 Future Work

If we were to continue working on this project, there are three main aspects of our device that we would focus on improving. In terms of affordability, the biggest drawback is that the microphone we are currently using accounts for a little over half of the cost of our device. Ideally we would be able to find a condenser microphone that is much cheaper.

Next, we would try to filter out the buzzing noise that outputs from our device. We had to use two amplifiers in succession to ensure the device's output was loud enough. This created an issue where any undesired noise passing through the first amplifier became even more intense after passing through the second amplifier. If we had access to an oscilloscope, we could use RC filtering to determine and remove whichever sound frequencies we do not want, thus eliminating this buzzing noise.

Finally, we would incorporate AA batteries as the power supply instead of the lithium-ion rechargeable battery. This is a suggestion from our sponsor Ryan, as he wanted this device to be more a DIY type of project that anybody could replicate on their own, without needing any of the electrical equipment or software we used. AA batteries would also be easier for the average person to obtain, and they would also be cheaper, which would bring down the cost of the device even more. Furthermore, AA batteries typically have a power rating that is similar to that of our Li-ion battery, which is 2200 mAh, meaning that AA batteries could power our device for a similar amount of time. Also, some AA batteries are also rechargeable, so we would not even need to make a tradeoff by using them.

The current final product for our device can be seen in Figure 5.1 and 5.2 The hefty design size was made more open for displaying the circuits in a way that represented the flow of our block diagram. This can be scaled much thinner to attract the appeal of being a portable device in a finalized commercial device.

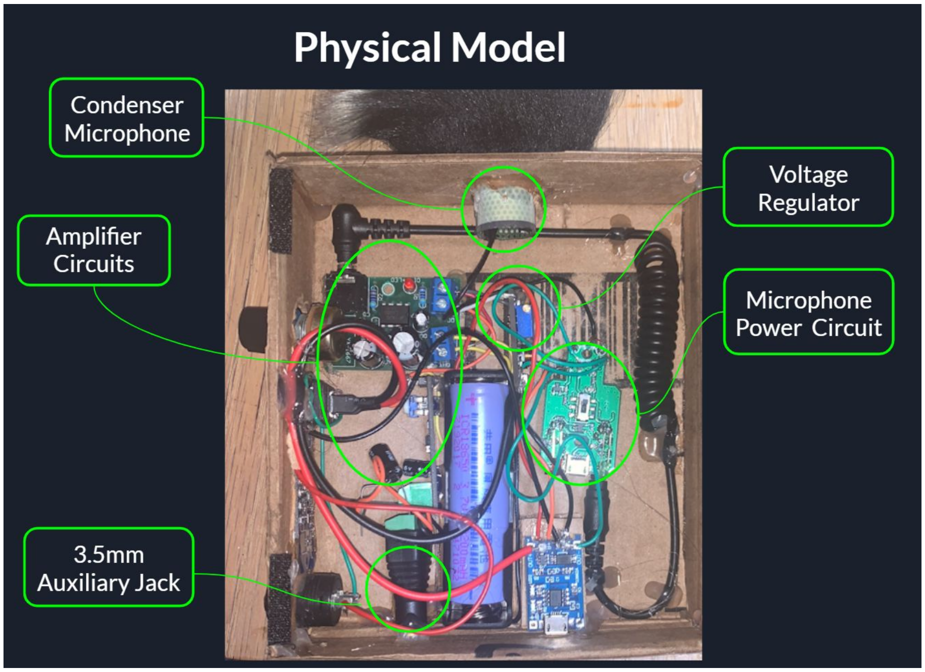

Figure 5.1 : The physical model of our device with the side panel opened to clearly show all the circuits that make the device work.

Figure 5.2 : The side profile of the device. This is where the user can interact with the device such as powering on, checking the battery and adjusting amplification.

Appendix A - Requirement and Verification Tables

Table A1 : Requirements and Verifications (R&Vs) of the Li-ion Charger.

Requirements	Verification
1. 1. Li-ion battery charges to 4.1 V when a continuous 4.2 V input voltage is applied	1A. Discharge the battery to 3.2 V 1B. Charge the battery with 5V and 1A. 1C. Use ALICE to measure that the voltage supplied to the battery is 4.2 V. 1D. Once the LED on the charger indicates a full charge, use a voltmeter to ensure terminal voltage across the battery is 4.1 V.
2. Maintain thermal stability below 45°C	2. Use a temperature probe to ensure that the IC stays below 45°C.

Table A2 : R&Vs of the Li-ion Battery.

Requirements	Verification
1. Must provide sufficient voltage to drive any component of design. (min = 3.2 V)	1A. Use a voltmeter probed to each of the battery to check the terminal voltage 1B. Connect the battery to the voltage level indicator to check if the lowest LED remains active, which indicates 3.2 V received.

Table A3 : R&Vs of the Voltage Regulator.

Requirements	Verification
1. Provide 12V, with 5% regulation, from a 3.7V battery source.	1. Measure the output voltage using a multimeter ensuring that the output voltage stays within 5% of 12V.
3. Maintain thermal stability below 45°C.	3. Use an IR thermometer to ensure the IC stays below 45°C.

Table A4 : R&Vs of the LED Indicator.

Requirements	**Verification**
1. Accurately represent the voltage output from the li-ion battery.	1A.Completely charge the li-ion battery and make sure each LED is active. 1B. Drain the battery until the highest placed LED shuts off. 1C. Measure the voltage terminals of the battery to ensure a 0.2 V drop. 1D. Repeat 1B-1C until all LEDs are inactive.

Table A5 : R&Vs of the Amplifier.

Requirements	**Verification**
1. Operate with the voltage from the voltage regulator to produce a gain of 200x.	1. Probe the input and output from the LM386 to see if there is infact a 200x gain without the potentiometer.
2. Adjust the amplitude (volume) of the microphone with the use of a potentiometer.	2A. Power the LM386 and feed it input data. 2B. Probe the corresponding output to measure voltage. 2C. Turn the potentiometer and check that voltage varies with resistance.
3. Amplify the input data from the microphone to audible output signal.	3A. Power the LM386 and feed it input audio. 3B. Connect a small speaker to the output as seen in Figure 2.3 to check that audio can be heard.

Table A6 : R&Vs of the Condenser Microphone.

Requirements	**Verification**
1. Must be able to pick up sounds between 80 and 260 Hz	1. Play sounds of various frequencies from a speaker and check the MIC data corresponding to the varying frequencies
2. Can pick up sounds as low as 54 dB, which is incoming sound pressure level from a normal conversation from 6 feet away [9].	2. Use a decibel meter to measure the audio from a speaker then check the microphone to see if the audio is captured
3. Reduce any audio received not directly in front of the microphone.	3A. Speak directly in front of the microphone and record the output in dB. 3B. Orbit the microphone at various angles, keeping a 6ft distance. 3C. Measure that the audio received at any angle test is in fact lower than in 3A.

Table A7 : R&Vs of the Auxiliary Jack.

Requirements	**Verification**
1. Provide stereo output from the LM386.	1. Connect headphones to the jack and be sure that both left and right speakers are transmitting audio.
2. Work as an input source for audio recording.	2A. Connect a male to male 3.5mm auxiliary to the jack and to a computer. 2B. Record a video on the computer using the microphone for audio input. 2C. Playback the video to ensure the microphone captures audio.

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