COVID Hearing Aid

ECE 445 Design Document

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10/1/2020

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 to allow lip reading or wearable amplification systems must be used by the talker, and would require every person to use one in order for the hard of hearing to be able to understand everyone. Furthermore, clear masks actually muffle a speaker's voice even more than cloth masks because they are made of plastic. And standing closer to the speaker is not a good solution because physical distancing is also necessary to curb the infection rate [3].

To solve this issue, we must focus on the perspective of the listener alone. Our solution is a hearing aid that can amplify sounds that come from at least 6 feet in front of the listener. This device will be a handheld gadget which the user points in the direction of a sound source to be amplified. The gadget will feature a directional microphone to capture audio, amplify it, allow the user to adjust the volume, and then output the audio to the user via headphones.

1.2 Background

Currently, there are plenty of other hearing aids on the market. 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. This differs from our device, which is meant to be a special purpose hearing aid that amplifies sound from the general direction a user points it in. Furthermore, we expect people who are hard of hearing to already possess a medically recommended, general purpose hearing aid. But due to muffled speech and lack of lip reading, even people who do not otherwise have hearing problems often find it difficult to hear a mask-wearing speaker. Our device will be accessible by a wider range of consumers because it will be 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.

1.3 High-Level Requirements

- A portable and rechargeable power delivery system should allow the device to function on the go for at least 6 hours while turned on.
- The microphone should be able to pick up on sounds that are at least 54 dB and from 80 to 260 Hz.
- The device should be able to amplify sounds to at least 90 dB in order to accommodate those with profound hearing loss.

1.4 Visual Aid

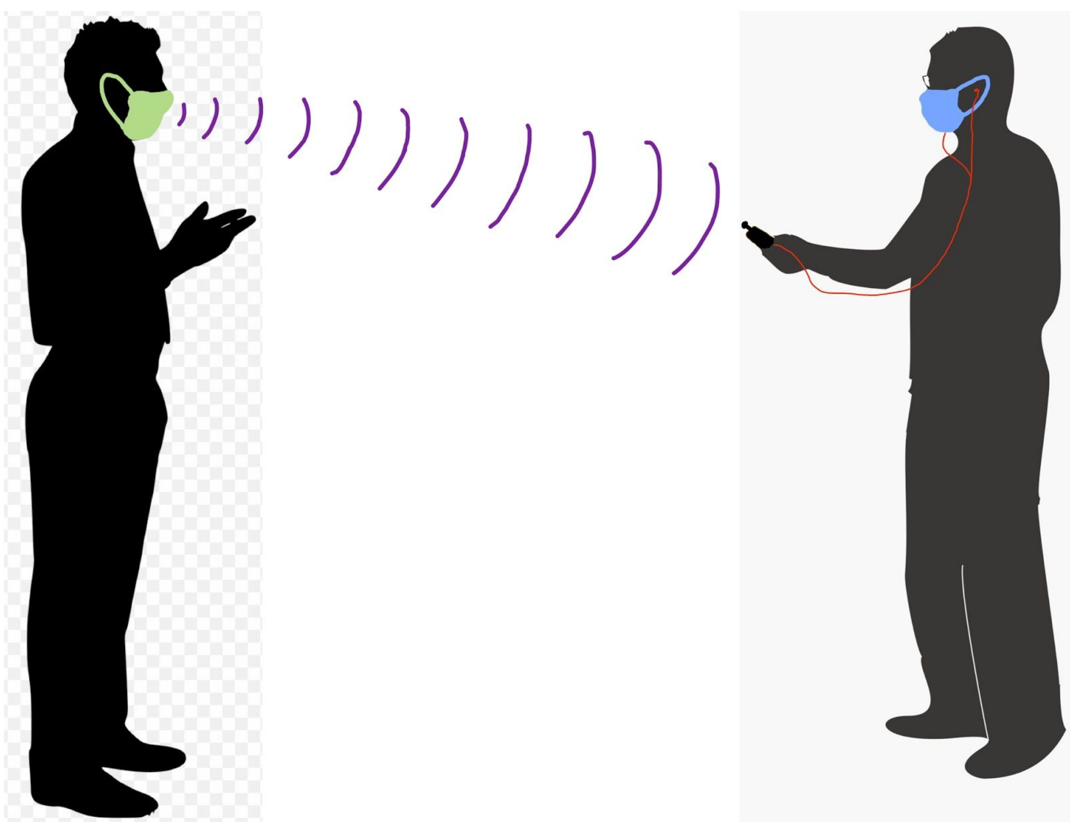

Figure 1: Typical Usage Scenario

2 Design

2.1 Block Diagram

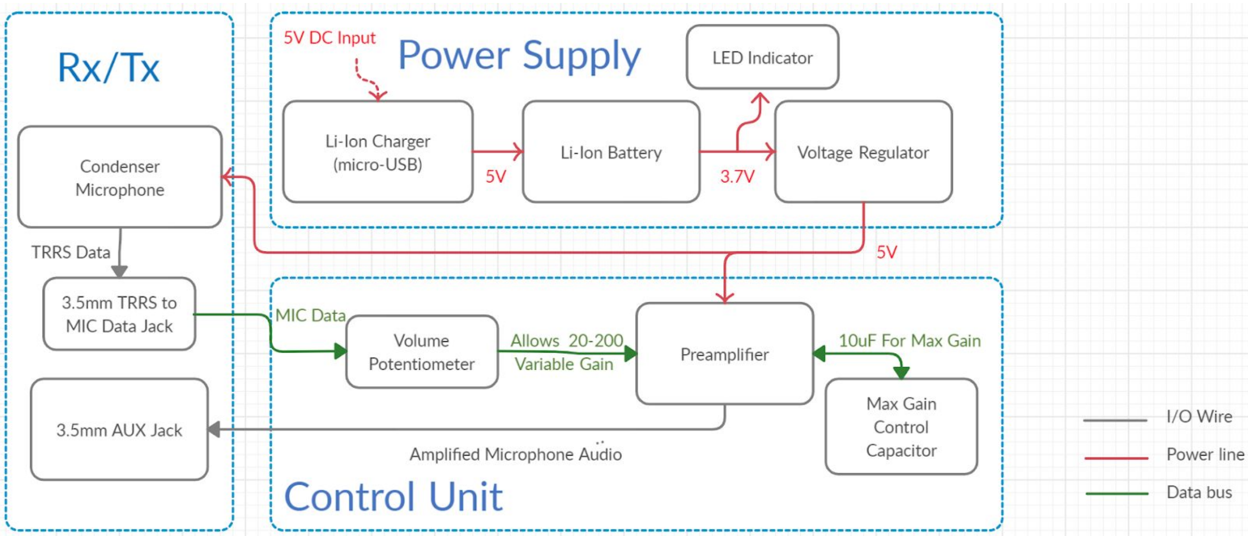

Figure 2. Block Diagram

2.2 Physical Design

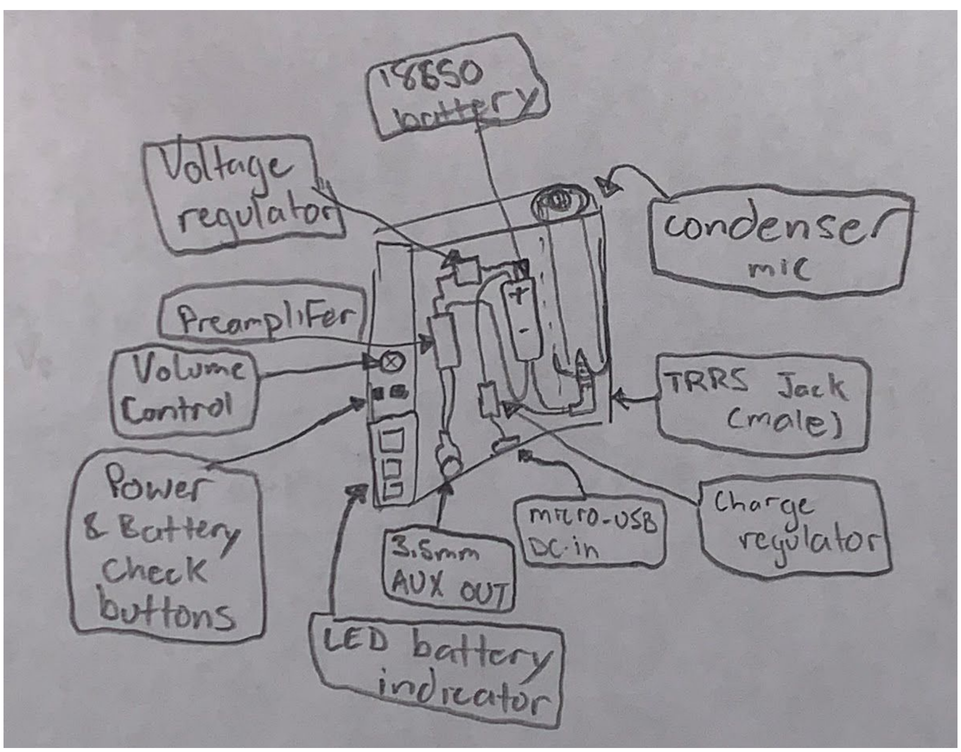

Figure 3. Physical Design

2.3 Power Supply

2.3.1 Li-ion Charger

The node will charge the li-ion battery through the TP4056 charger module. This will be powered by an external source with a maximum charging voltage and current at 5V and 1A respectively via micro-USB. The TP4056 charger module has on-board protection circuits to charge the battery until stable conditions. At maximum capacity this will charge the battery in 2.5 hours.

Requirements	**Verification**
1. 1. Li-ion battery charges to 3.3-3.7V when a continuous 4.2 V input voltage is applied 2. Maintain thermal stability below 125°C.	1A. Discharge the battery to 3.3 V 1B. Charge the battery with 5V and 1A. 1C. Use a voltmeter probed to both ends of the battery and ensure terminal voltage is between 3.3 and 3.7 V. 2. Use an IR thermometer to ensure the IC stays below 125°C.

2.3.2 Li-ion Battery.

An 18650 battery will be used as they are easily accessible and can operate at voltages required for the device. Running at 2500mAh the battery will be quick to charge and last for around 17 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 (125°C). The battery will open output power when the device is powered on through the use of a simple flip switch.

Requirements	**Verification**
1. Must provide 3.4-3.7 V sufficient current to drive the circuit. (140mA)	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.

2.3.3 Voltage Regulator

This voltage regulator acquires more than the minimum required voltage (3V) from the li-ion battery (3.7V) and converts the voltage to 5.2 V. The extra voltage is to help account for voltage drop over cables. 5 V is needed to operate the preamplifier and with the max current output being 1100mA, there's more than enough to power the circuit without overheating.

Requirements	**Verification**
Voltage Regulator 1. Provide 5V, with 5% regulation, from a 3.7V battery source. 2. Can operate current within 0-800mA. 3. Maintain thermal stability below 125°C.	1. Measure the output voltage using a multimeter ensuring that the output voltage stays within 5% of 5V. 2A. Connect the output of the voltage regulator to ALICE Desktop analyzer 2B. Use a potentiometer resistor to analyze max current flowthrough ALICE. 3. Use an IR thermometer to ensure the IC stays below 125°C.

2.3.4 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 3.3 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]

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.

2.4 Control Unit

2.4.1 Preamplifier

The preamplifier uses an LM386 IC to receive input from the microphone and amplifies the signal to be read across the board at a higher dB. Since the microphone does not provide a power of its own the audio signal is very low. 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 and series with a 100k ohm potentiometer to set the amplitude of before passing through the preamplifier. This is done with voltage division from the voltage from the regulator and the microphone. Thus the potential 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]

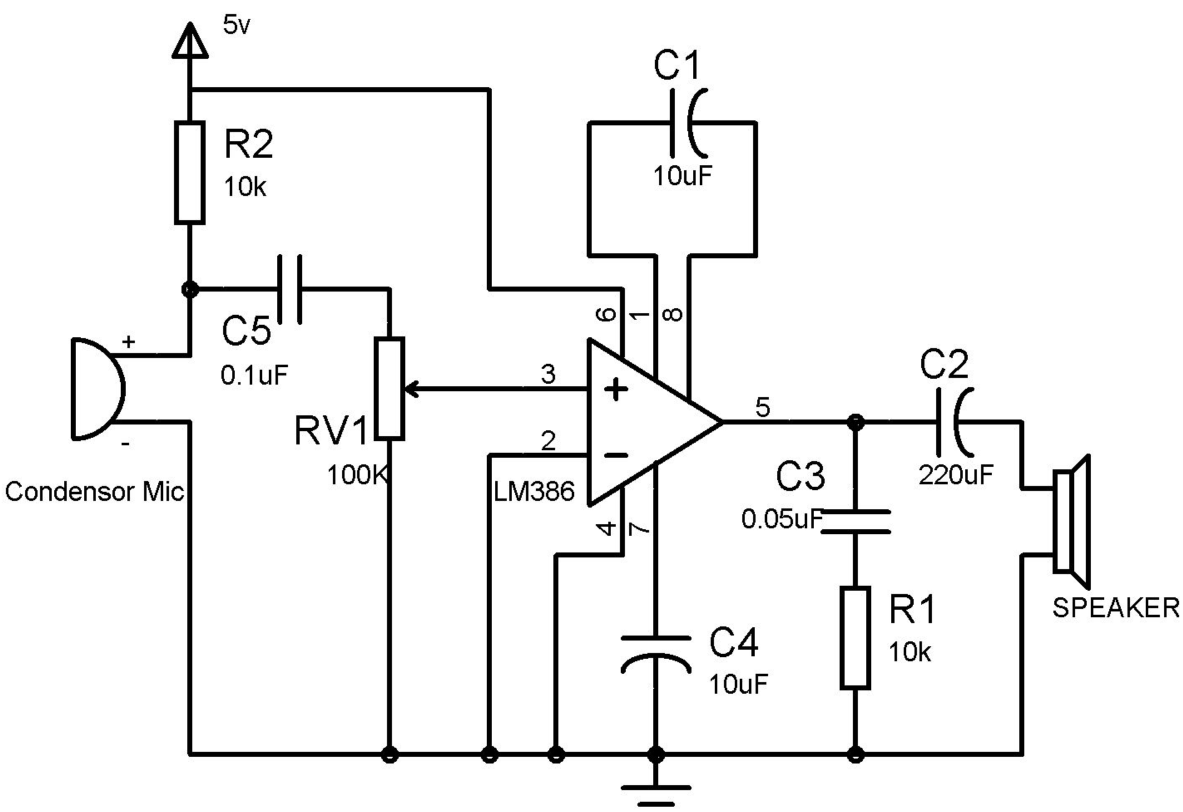

Figure 4. LM386 circuit diagram reference for preamplifier [5]

Requirements	Verification
1. Operate with the voltage from the voltage regulator to produce a gain of 200. 2. Adjust the amplitude (volume) of the microphone with the use of a potentiometer. 3. Amplify the input data from the microphone to audible output signal.	1. Probe the input and output from the LM386 to see if there is infact a 200dB gain without the 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. 3A. Power the LM386 and feed it input audio. 3B. Connect a small speaker to the output as seen in Figure 4 to check that audio can be heard.

2.5 Rx/Tx

2.5.1 Condenser Microphone

The BOYA BY-MM1 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. This gives direct access to the data coming from the microphone. Powered with the voltage coming from the regulator (5V), the mic data will be filtered through the potentiometer and act as the input to the LM386 preamplifier. The microphone works between 20 and 20k Hz so it's more than capable of capturing human voice, which stands to be around 80-260 Hz. [7]

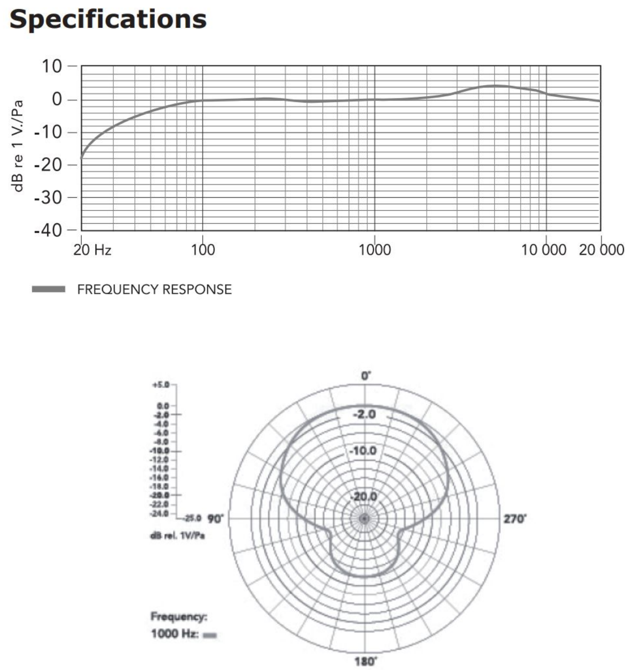

Figure 5. Specification on the BOYA BY-M1 from the user manual. The above graph is the audio volume in dB across the operational frequencies of the microphone. Below depicts the angle of captured audio in polar coordinates. [8]

Requirements	**Verification**
1. Must be able to pick up sounds between 80 and 260 Hz 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]. 3. Reduce any audio received not directly in front of the microphone.	1. Play sounds of various frequencies from a speaker and check the MIC data corresponding to the varying frequencies 2. Use a decibel meter to measure the audio from a speaker then check the microphone to see if the audio is captured 3A. Play audio from a speaker directly in front of the microphone and record the output in dB. 3B. Pivot the microphone at various angles away from the speaker. 3C. Measure that the audio received at an angle is in fact lower than in 3A.

2.5.2 3.5mm AUX Jack

The 3.5mm 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.

Requirements	**Verification**
1. Provide stereo output from the LM386. 2. Work as an input source for audio recording.	1. Connect headphones to the jack and be sure that both left and right speakers are transmitting audio. 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.

2.6 Tolerance Analysis

One of the most important tolerances we have to consider is 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 BOYA BY-M1, we get the microphone sensitivity as:

Sensitivity: -42dB +/- 1dB / 0dB=1V/Pa, 1kHz [8]

Noting that 1 Pa (pascal) equals 94 dB sound pressure (SPL) and

The dB equation for voltage is $20 \times \log \frac{V_1}{V_o}$
where V1 is the voltage being measured, and V_0 the reference level [13]

we can solve for our total output in dB.

-42dB converts to 1/(2^7) = 7.8125 mV Eq. 1

Now multiple this with our gain:

$$7.8125 \text{ mV} * 200 \text{ (Gain)} = 1.5625 \text{ V} \qquad \text{Eq. 2}$$

Converting back to dB:

$$20 * \log (1.5625\text{V} / 7.8125\text{mV}) = \sim 46\text{dB} \qquad \text{Eq. 3}$$

so the SPL will be:

$$(-42) + 46 = 4 + 94 \text{ (SPL=1 Pa)} = 98 \text{ Db SPL} \qquad \text{Eq. 4}$$

This sets us up to amplify our audio at above 90 dB as desired while staying below the 110dB regulation for hearing aids. [11]

3 Cost and Schedule

3.1 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 1: Labor Costs

3.2 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	Charger (x6)	DZS Elec	Amazon	1	$6.99	$6.99
MT3608	Voltage Regulator (x10)	Eiechip	Amazon	1	$11.99	$11.99
-	On/Off Switch (x10)	VQVAAQ	Amazon	1	$6.98	$6.98
BY-MM1	Mini Cardioid Condenser Microphone	BOYA	B&H	1	$32.95	$32.95
COM-11996	Momentary Button	Sparkfun	Sparkfun	1	$0.95	$0.95
GR-US-145	Battery Capacity Indicator (x2)	DAOKI	Amazon	1	$5.99	$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	$7.19	$7.19
Total						$84.03

Table 2: Component Costs

3.3 Schedule

Week of...	Kartik	Saul
10/12	Do research on audio circuit design	Order parts
10/19	Design and order PCB	Design and order PCB
10/26	Record data from component testing	Test components
11/2	Observe and record building process	Build circuit, solder components
11/9	Design prototype with casing	Build prototype with casing
11/16	Prepare for final demonstration	Prepare for final demonstration
11/23	Start working on final paper	Star working on final paper
11/30	Finish final paper prepare for presentation on Zoom	Finish final paper and prepare for presentation on Zoom
12/7	Submit final paper	Submit final paper

Table 3: Schedule

3.4 COVID-19 Contingency Planning

Both partners in our group are already working online and remotely this entire semester. Because of this, our project is already planned and designed within the constraints of an online semester, and nothing about our project will change if the university goes fully online.

4 Ethics and Safety

While building this project we will be 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 is the use of the lithium ion battery, which could potentially overheat and cause damage to someone’s skin or even start a fire. The other electrical components, like wires, pose a similar concern. In order to prevent this, we can monitor the temperature of the battery while testing and ensure that the power supplied to the components is not high enough to damage them. If possible, we will also try to contain all electrical components in a plastic casing to eliminate the possibility of electric shocks to the user.

Another safety concern is the possibility of audio being over-amplified. On one hand, we want to be able to accommodate people within the profound hearing loss range, which is 91+ dB [10]. It should be acceptable for us to amplify sound to at least 91 dB, because according to a consensus paper from various hearing associations, which established recommended regulations for hearing aids, sounds can be amplified up to 110 dB, but no higher, in order to accommodate those with more severe hearing loss [11].

On the other hand, we also don’t want to damage the hearing of people who have normal hearing but choose to use this device for COVID-related reasons. Prolonged sounds above 85 dB are considered harmful to normal human ears [12]. To address this issue, we are adding a volume control option for the user. A user can choose to not have the audio output at max volume, similar to how someone would lower the volume on their phone if they found it too loud.

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