Wireless Modular Mixer

Design Document

ECE 445: Senior Design - Fall 2018

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1 Introduction

1.1 Objective

Sometimes, it can an inconvenience for amateur musicians to gather for a jam session. You have to worry about where to play. Musicians must consider the noise level of their instruments and its effect on their immediate environment. Necessary equipment such as cables and amplifiers can be a hassle to carry around.

The premise of this project is to provide an affordable and portable way for bands with electric instruments to be able to practice or “jam” without causing distraction to their peers and neighbors. For electric instruments, setting up to play involves bringing their instrument, an amplifier, and the necessary cables to their gathering. This in itself can be a burden. Our mixer will allow musicians to “jam” with others without being tethered to a cord. It will also allow for “quiet” playing because everything will be heard through wireless headphones. Because our mixer design will be wireless and compact, this will help solve the problem of portability.

1.2 Background

As consuming music has become increasingly more wireless, it is surprising that producing music has not moved forward at the same rate. The market for wireless mixers is both small and expensive. Our initial searches have found other wireless analog mixers with MSRPs starting at $280 [1]. It also seems that even though these mixers are wireless, a cord must still be used to connect an electric instrument directly. On the instrument side, electric guitar transmitters start at around $100 [2]]. With our solution, everything will be completely wireless, and will come with the equipment (i.e. instrument transmitter) necessary for playing. This will cut down on the price of buying transmitters on their own.

The concern for noise is becoming more relevant as people have started choosing apartments for their housing. For example, on the University’s campus it can be difficult for students to find a suitable location to play music without causing concern of a noise complaint. The campus facilities are not always available when needed. For people in areas without access to facilities like this, coordinating a good time or place can be cumbersome.

1.3 High-Level Requirements List

1. The analog mixer must have a high Signal-to-Noise Ratio (SNR) at the output, with a noise floor near or below -75dB ± 5%.
2. The equalizer must be able to adjust the amplitude of the audio signal centered at five distinct frequency: 80 Hz, 350 Hz, 2500 Hz, 6000 Hz, and 12000 Hz.
3. The instrument module must be able to connect to its paired Base modules and transmit audio from a distance of at least eight meters with a battery life of at least 30 hours.

2 Design

2.1 Block Diagram

The design consists of 4 modules: the power unit module, master base module, slave base module, and the instrument module. There is a slave unit that can physically connect to either side of the master unit. A maximum of four instrument modules connect each instrument to the base modules via bluetooth connectivity. Each instrument sends signal to the base units, where it handles the mixing and equalizing of the audio signals. The final output is sent to each pair of bluetooth-connected headphones. The high-level block diagram is shown in Figure 1.

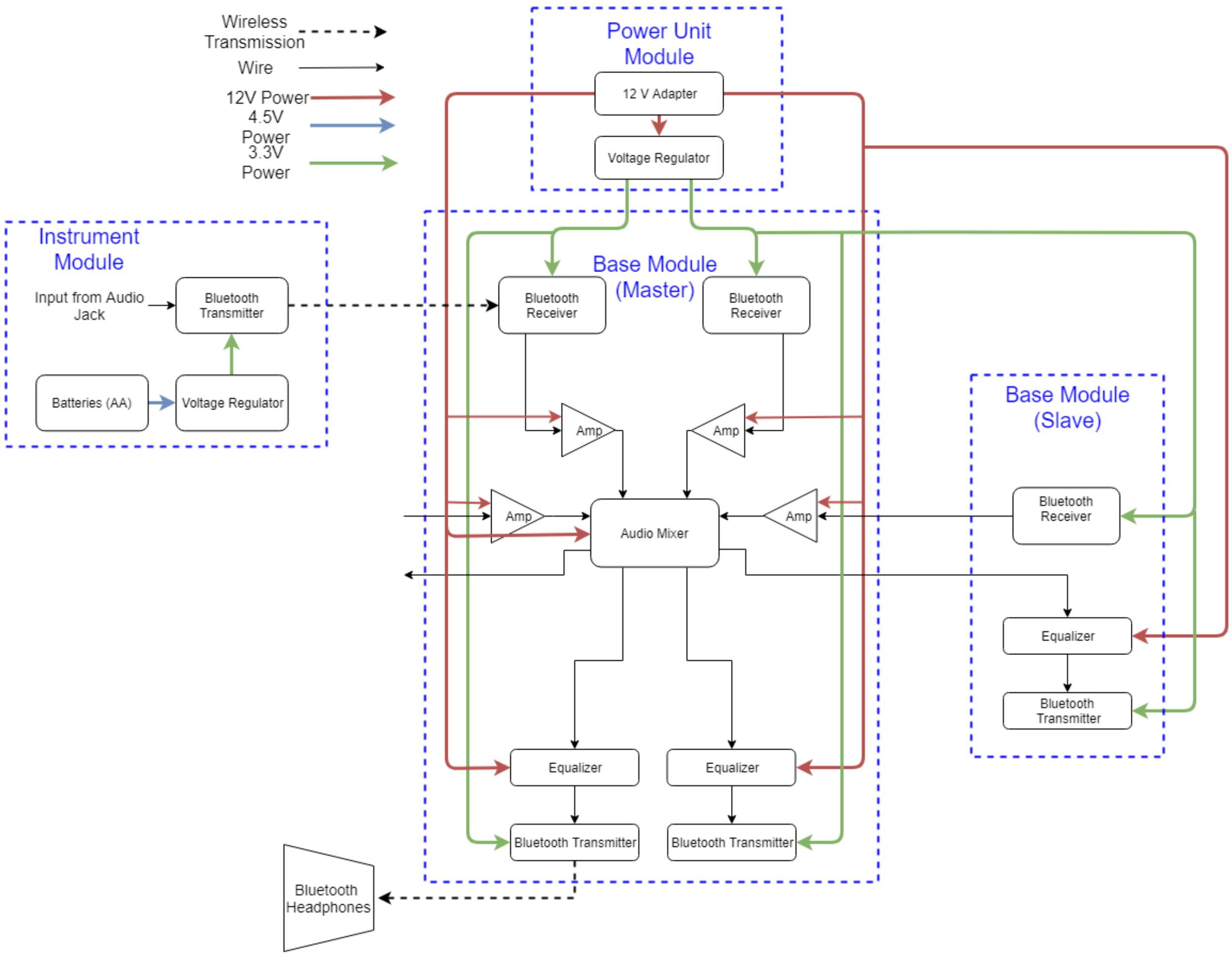

Figure 1: Modular Mixer Block Diagram

2.2 Physical Design

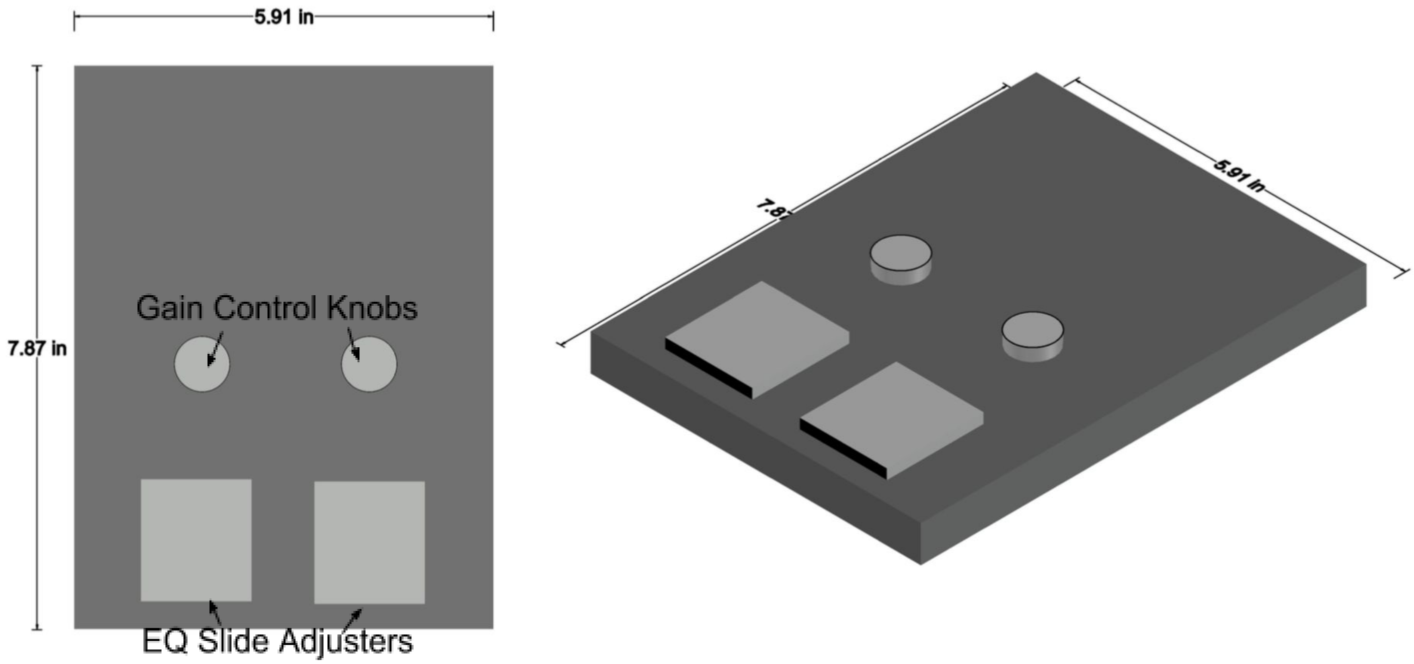

Figure 2: Top View of Base Module (left); 3-D View (right)

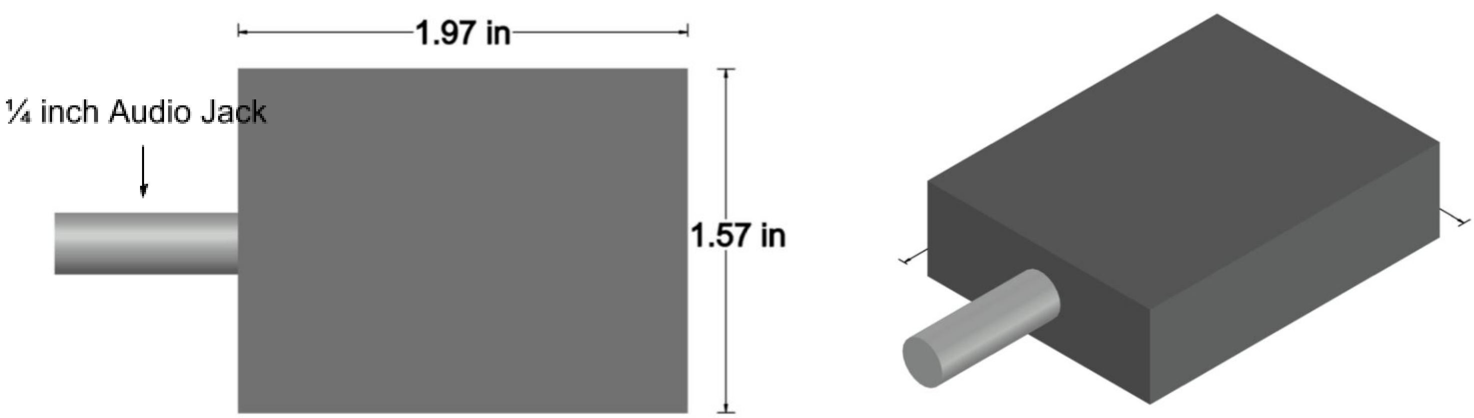

Figure 3: Top View of Instrument Module (left); 3-D View (right)

2.3 Instrument Module

2.3.1 Bluetooth Transmitter

This block will consist of a bluetooth module that will utilize the Advanced Audio Distribution Profile (A2DP) to stream audio to the base module. We have chosen the RN-52 as our Bluetooth module due to its onboard Analog-to-Digital converter, Microcontroller, and antenna. It requires 3.3V ± and 10mA during transmission. The onboard MCU will be programmed to accept the analog input from the instrument and enable transmission to the base module's receiver. The transmitter will be given a Bluetooth "friendly" name for use when pairing. The onboard ADC will be configured to convert the analog input with a 16-bit resolution sampled at 44.1kHz.

Requirement	Verification
1. The onboard ADC must convert a microphone-level input to a digital audio signal with a 16-bit resolution and sampling frequency of 44.1kHz	1. Connect an audible dummy signal to the microphone inputs of the Bluetooth module. 2. Enable the Probe the I^2S output of the Bluetooth module with an oscilloscope. 3. Using the oscilloscope, confirm that the frame is 16-bits wide. 4. Using the oscilloscope, verify that the bit clock frequency is 44.1kHz * 16 * 2 = 1.4112 MHz for stereo and 44.1kHz * 16 = 705.6 kHz for mono.
2. Transmitter must have a range of at least eight meters.	1. Pair the Bluetooth module with a compatible Bluetooth speaker. 2. Using a function generator, create a 1KHz sine wave and connect the output to the microphone input of the bluetooth module. 3. Verify that the audio can be heard while standing at a distance of eight meters.

2.3.2 Battery Module

The batteries will be used to supply power for instrument module. This module also contains a voltage regulator to supply the correct voltage for the transmitter and ADC. The TI LM1117 regulator with a fixed 3.3V output will be used to keep a constant voltage for the Bluetooth Transmitter.

Requirement	Verification
1. Voltage regulator provide 3.3V ± 5% from a 4.5V source for the Bluetooth Transmitter module. It must provide current between 0mA and 25 mA.	1. Attach a grounded resistive load to Vout of the voltage regulator of 132 Ohms. 2. Measure the output voltage using an oscilloscope. Verify that the output voltage stays within 5% of 3.3V.
2. Battery Module should be able to provide power to the instrument module for 30 ± 5% hours.	1. Using the same setup, measure the amount of time required for the battery to drain while outputting 25mA.

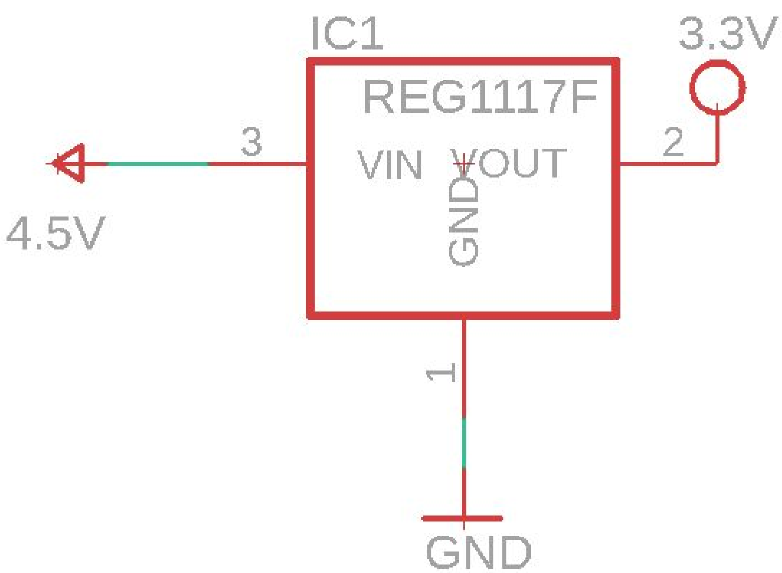

Figure 4: Battery Module circuit

The resistive load can be calculated using Ohm's Law

$$V = IR \rightarrow R = V/I \quad (1)$$

$$R = 3.3 / 0.025 = 132\ \Omega$$

2.3.3 Input from Audio Jack

We will be using a ¼" mono input jack to be able to interface with as many instruments as possible. The input impedance of the input should be between 6KΩ (for microphone-level) and 30KΩ (for line-level) to be compatible with the microphone input from the bluetooth module. Our input will have an impedance of 10KΩ ± 5% for the instrument-level input for the Bluetooth Module.

Requirement	Verification
1. The connector to the instrument should have an input impedance of 10KΩ± 5%.	1. Connect the terminals of a multimeter to the input and outputs of the audio jack circuit. 2. Measure the reading from the multimeter to verify that the impedance is correct.

2.4 Base Module

2.4.1 Voltage Regulator

Because some modules will need lower voltage to power them, a voltage regulator will be used to step down the voltage.

Requirement	Verification
1. Voltage Regulator must step down from 12V to provide 3.3V±5%% to the Bluetooth module and 12V± 5% to the equalizer and mixer modules.	1. Attach a grounded, variable resistive load to Vout of the voltage regulator. 2. Measure the output voltage using an oscilloscope. Verify that the output voltage stays within 5% of 3.3V.

2.4.2 Audio Mixer

This will be an Active 'virtual earth' mixer. It will take in two audio signals, mix them, and output a mixed signal. Because our mixer will have the option of mixing up to four instruments, each Slave base module will send an audio signal to the master for mixing. The mixer PCB will output a mixed audio signal of up to four instruments. The final output will be sent to the different equalizer modules for further customization. Voltage Requirements: 11.5-12.5 V

Requirement	**Verification**
1. The output from the mixer must be the summation of the inputs to the mixer.	1. Using a function generator, create two sine waves, one with a 1KHz frequency, and the other with a 800Hz frequency as inputs to the mixer. 2. Attach output of mixer to a speaker. 3. Verify that the output is a mix of both the input tones with an oscilloscope probing the output.
2. Must have Signal-to-Noise Ratio (SNR) between 60dB - 80dB, with a noise floor near or below -75dB ± 5%	1. Using a function generator, create two identical sine waves with a 1KHz frequency as input. 2. Using an spectrum analyzer, probe the output and verify the SNR.

The mixer module will consist of a preamp and ‘virtual ground’ summing mixer. The preamp will be designed in a parallel configuration. Using a parallel configuration will help reduce external noise and internal op-amp noise while amplifying the input signal. Once each signal has been sent through a preamp, they will be sent to the ‘virtual ground’ mixer which will handle the mixing of the two input signals. The following schematics show the individual performance of the OPA134 low-noise op-amp chips for the preamp, mixer, and full mixing module.

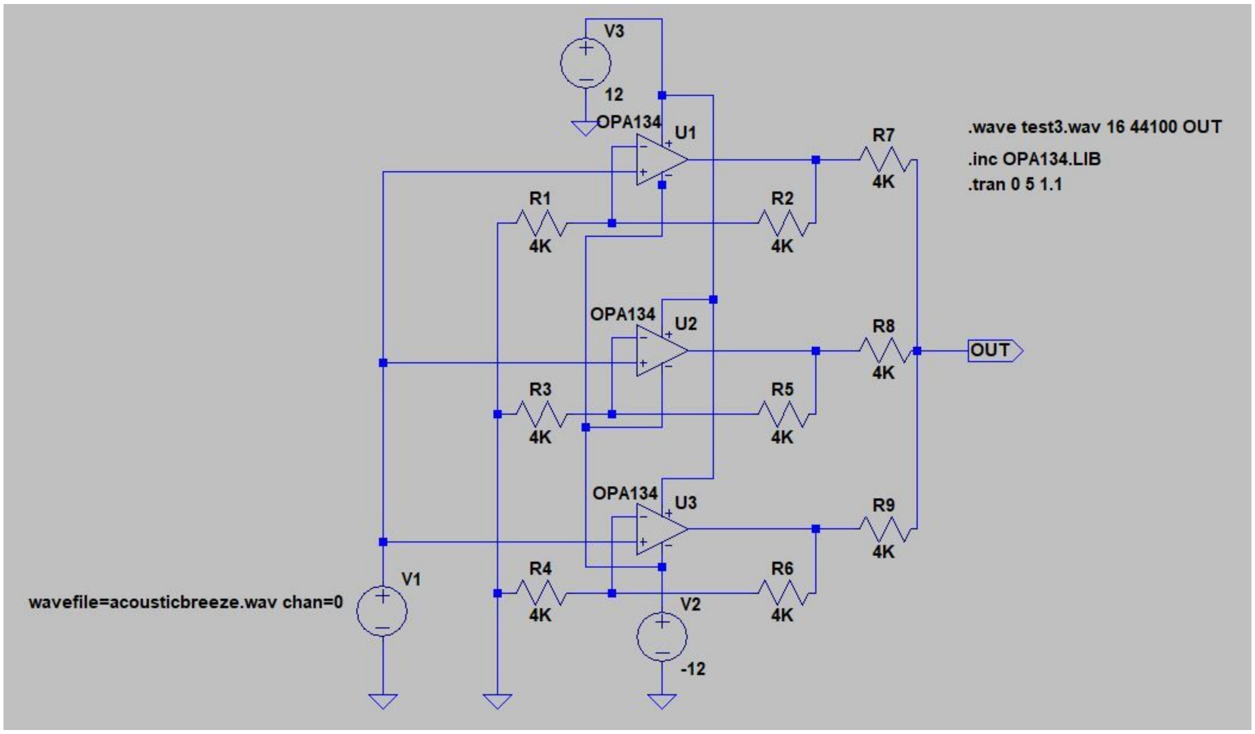

Figure 5: Preamp Design for Single Signal [12]

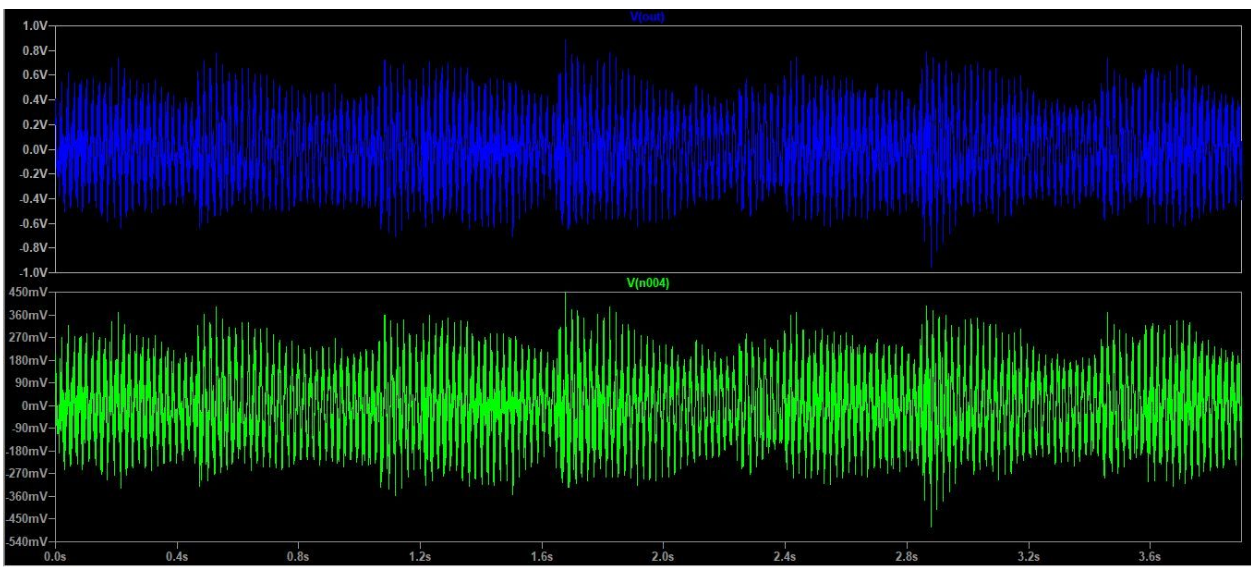

Figure 6: Waveforms of Amplified Audio Signal: Amplified Signal (Top); Pre-amplified Signal (Bottom)

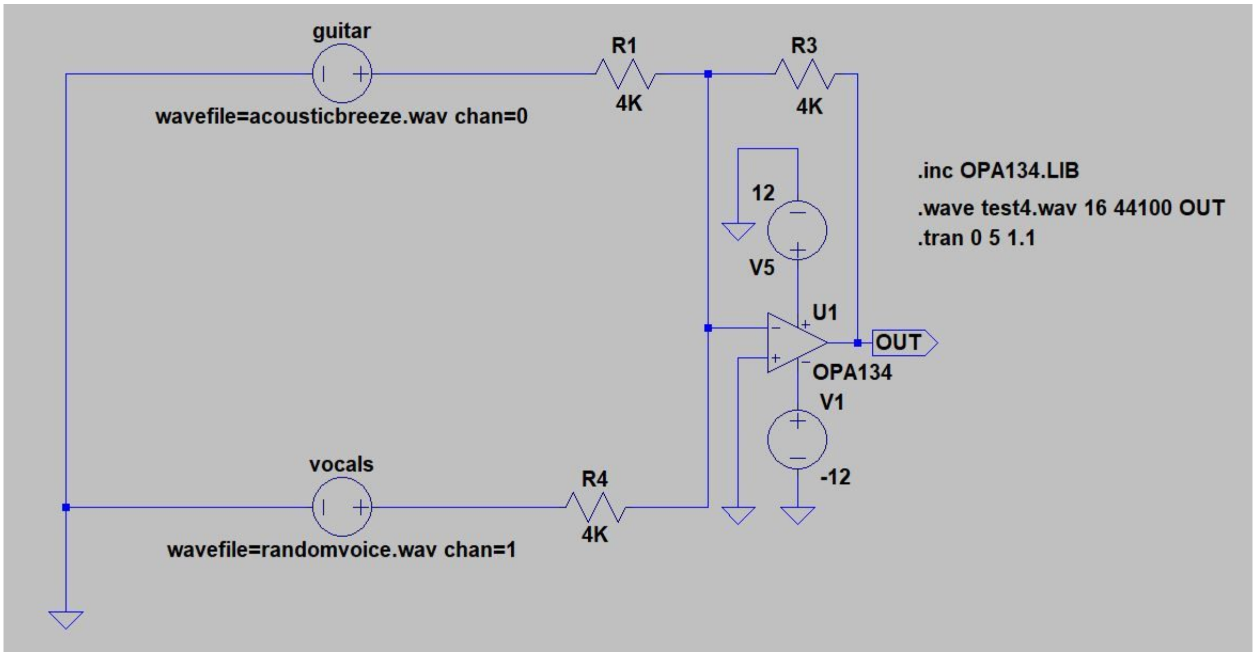

Figure 7: ‘Virtual Ground’ Summing Mixer Design

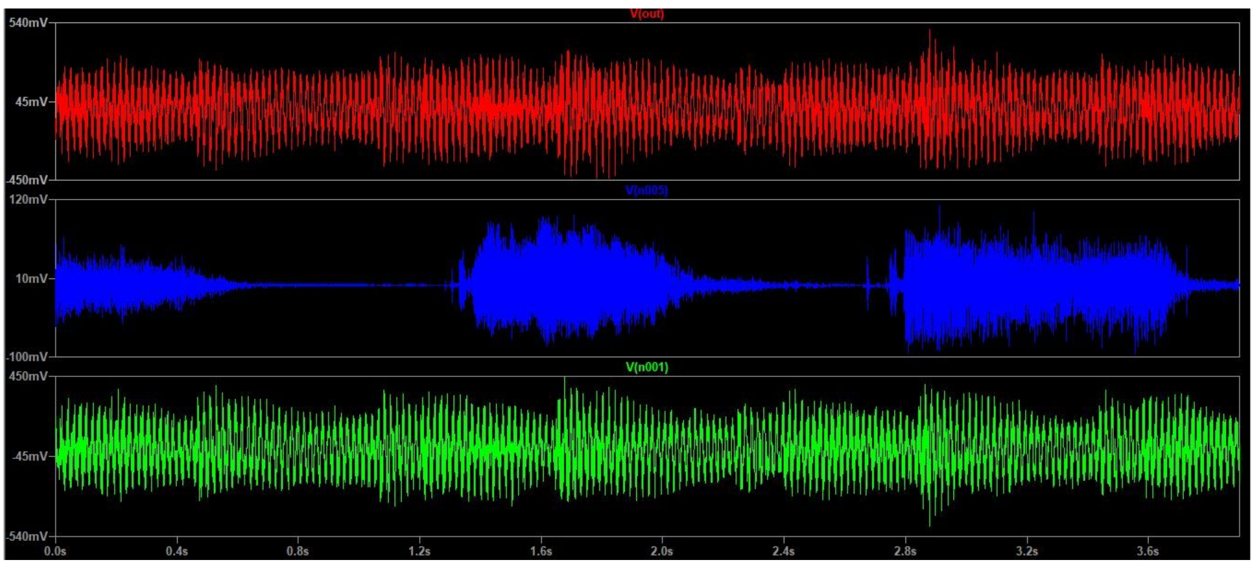

Figure 8: Waveforms of Mixed Audio Signals: Mixed Signal (Red); Random Voice Signal (Blue); Guitar Signal (Green)

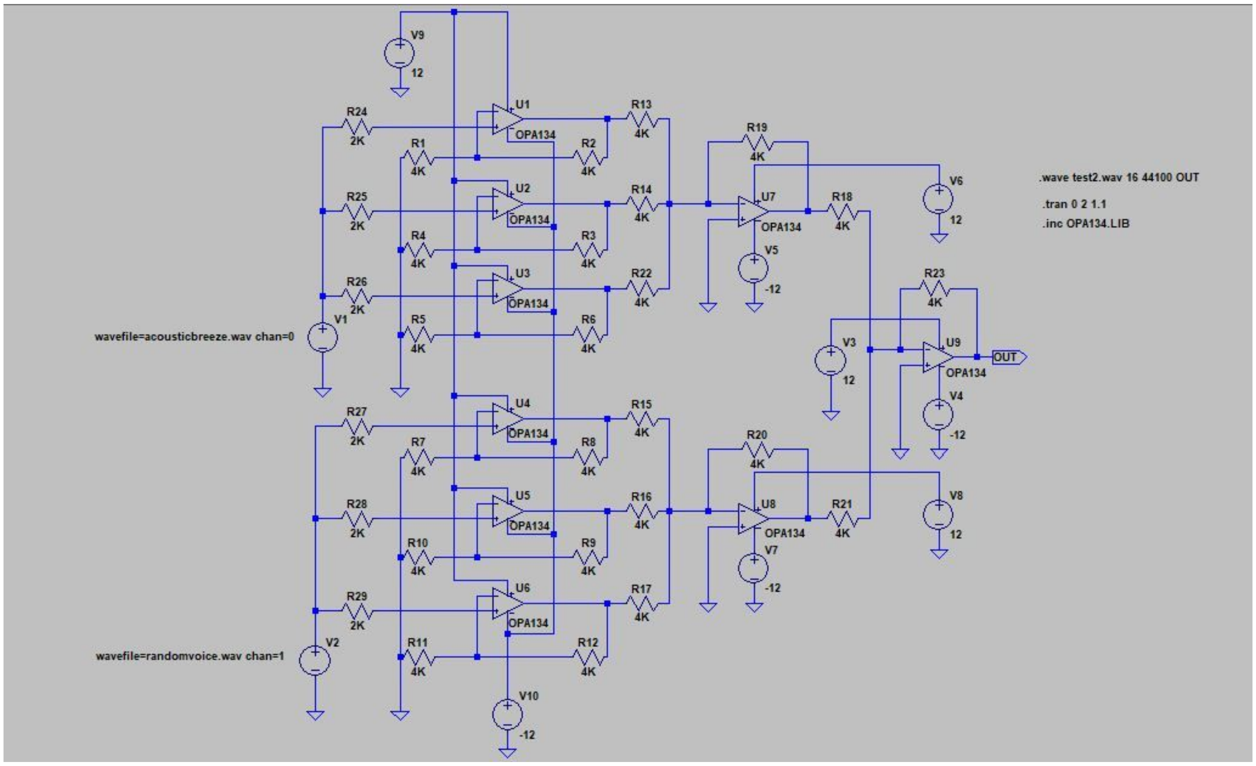

Figure 9: Complete Mixer Module

Gain Calculations

The calculation of gain using a 'virtual ground' configuration, for the mixer, simplifies the math greatly.

$$Gain = \frac{V_{out}}{V_{in}} \tag{2}$$

Since the voltage on the non-inverting side of the amplifier is zero this implies a zero voltage on the inverting side of the amplifier. Thus, the kirchoff current law becomes:

$$i_{in} = i_{s1} + i_{s2} \tag{3}$$

$$i_{out} = \frac{V_{out}}{R_f} \tag{4}$$

$$i_{out} = i_{in} \tag{5}$$

$$\frac{V_{out}}{R_f} = i_{s1} + i_{s2} \tag{6}$$

where i_{s1} and i_{s2} is the current of the first and second input signal, i_{in} is the current after mixing, i_{out} is the current at the output of the op-amp, and R_f is the feedback resistance. The input current can then be expressed in terms of the voltage and resistance of each source and the Gain is realized from some simple algebra.

$$i_{in} = \frac{V_{s1}}{R_{s1}} + \frac{V_{s2}}{R_{s2}} \tag{7}$$

$$\frac{V_{out}}{R_f} = \frac{V_{s1}}{R_{s1}} + \frac{V_{s2}}{R_{s2}} \tag{8}$$

$$\left|V_{out}\right| = \frac{R_f}{R_{s1}} V_{s1} + \frac{R_f}{R_{S2}} V_{s2} \tag{9}$$

Therefore, if $R_f = R_{s1} = R_{s2}$ the op-amp produces unity gain. Another useful calculation is the signal-to-noise ratio. This will help understand the strength of the mixed signal with the noise floor of the op-amps and external noise. By using a parallel configuration of op-amps, the input signal gain increases by a multiple of 2 while the noise gain increases by a multiple of $\sqrt{2}$. This helps further separate the strength of the input signal from the noise floor thus reducing distortion in the output signal. To demonstrate the benefits of using this configuration, the following equations were used:

$$S_{in_{tot}} = S_{in} + N_{in} \tag{10}$$

$$S_{out} = S_{in} * G \tag{11}$$

$$N_{factor} = \frac{R_f}{(R_{mix}/N)} \tag{12}$$

Where $S_{in_{tot}}$ is the total rms power at the input stage of the op-amp, S_{in} is the rms power of the input signal, N_{in} is the rms power of the external noise, S_{out} is the rms power of the output signal, G is the gain, N_{factor} is the noise gain multiple, R_{mix} is the equivalent resistance at the mixing bus, and N is the number of channels being mixed.

$$SNR(1\ op - amp) = \left(\frac{S_{out}}{N_{out}}\right)^2 = \left(\frac{S_{in}*G}{(N_{in}*G)+N_{amp}}\right)^2 \tag{13}$$

Where N_{amp} is the internal noise associated with the active op-amp. With two op-amps in parallel the SNR becomes:

$$SNR(2\ op - amps) = \frac{(2S_{in}*G)^2}{\left[(2N_{in}*G)^2+\sqrt{2}\left(N_{amp1}{}^2+N_{amp2}{}^2\right)\right]} \tag{14}$$

$$= \frac{(2S_{in}*G)^2}{\left[(2N_{in}*G)^2+\sqrt{2}\left(N_{amp_{tot}}{}^2\right)\right]} \tag{15}$$

2.4.3 Equalizer

Each equalizer will be designed to be able to customize what each person connected wants to hear. The equalizer will be designed to be a 5-band equalizer. It will consist of a band-pass filter to accommodate for each frequency band. Each band will allow for a specific range of frequencies: 80 Hz, 350 Hz, 2500 Hz, 6000 Hz, and 12000 Hz. The output of each equalizer will go to a bluetooth module for transmitting the final audio signal. Voltage Requirements: 11.5-12.5 V

Requirement	Verification
1. Each band-pass filter in the equalizer must provide ± 3dB for the 5 frequency bands centered at 80 Hz, 350 Hz, 2500 Hz, 6000 Hz, and 12000 Hz.	1. For each frequency band, set the level to +3dB and the rest to -3dB. 2. Connect a function generator to the input of the equalizer and run a frequency sweep across 20Hz to 16kHz. 3. Connect a spectrum analyzer to the output and analyze the frequency response. The amplitude of the center frequency should be +3dB relative to the input. The other frequency bands should be -3dB.

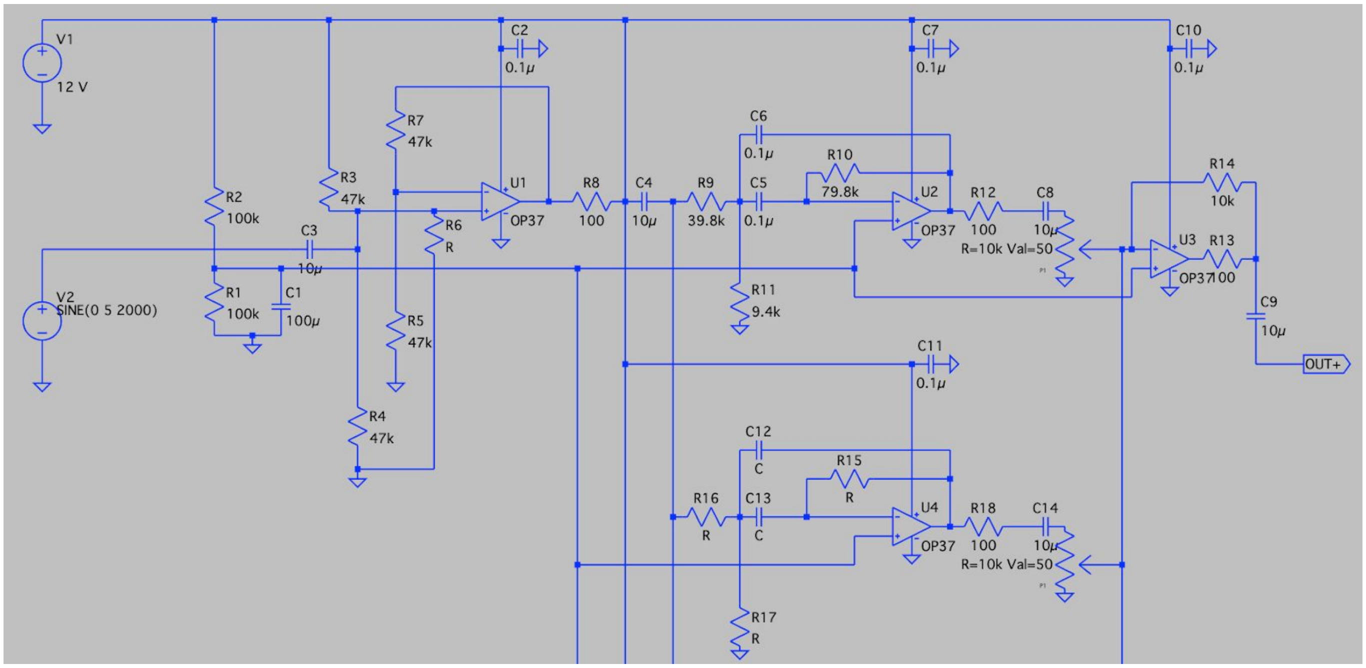

Figure 10: Equalizer Schematic

Calculations for Equalizer Parameters

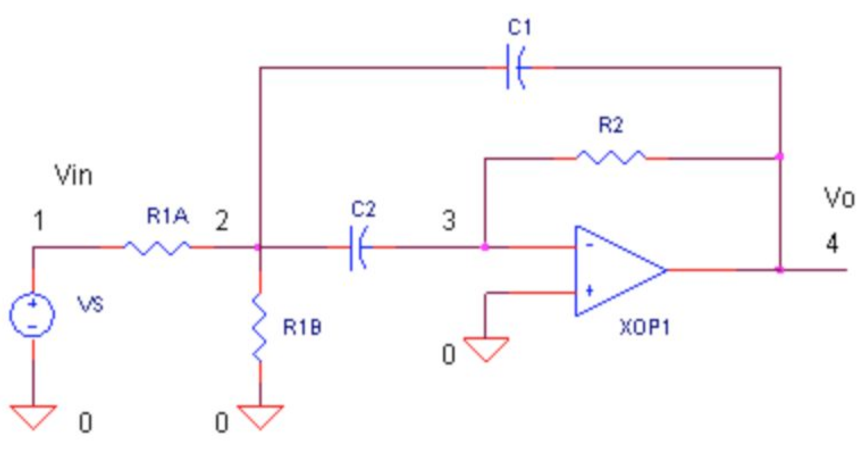

Figure 11: Multiple Feedback Bandpass Filter [10]

For a straight-forward design of MFB filter, let C1 = C2 = C. Using the equations below, we can calculate the parameters for each MFB filter [10][11]:
Assume f_0 = 80 Hz and C = 0.1 μF ,

$$f_0 = \frac{1}{2\pi\sqrt{C_1 C_2 R_1 R_2}} = \frac{1}{2\pi C\sqrt{R_1 R_2}} = 80\ Hz \qquad (16)$$

$$Q = \frac{f_0}{BW} = \frac{1}{2}\sqrt{\frac{R_2}{R_1}} = \frac{80}{100-60} = 2 \quad (17)$$

$$k = 2\pi f_0 C = 2\pi(80)(0.1 * 10^{-6}) = 5.03 * 10^{-5} \quad (18)$$

$$R_{1A} = \frac{Q}{Hk},\ want\ H = 1 \rightarrow \frac{2}{1(5.03*10^{-5})} = 39.8\ k\Omega \quad (19)$$

$$R_{1B} = \frac{Q}{(2Q^2-H)k} = \frac{2}{(2*2^2-1)(5.03*10^{-5})} = 5.7\ k\Omega \quad (20)$$

$$R_1 = R_{1A}||R_{1B} = \frac{R_{1A}R_{1B}}{R_{1A}+R_{1B}} = \frac{39.8(5.7)}{39.8+5.7} \approx 4.99\ k\Omega \quad (21)$$

$$2 = \frac{1}{2}\sqrt{\frac{R_2}{R_1}} \rightarrow\ 4 = \frac{1}{4}\frac{R_2}{R_1} \rightarrow 16R_1 = R_2 \rightarrow R_2 = 79.8\ k\Omega \quad (22)$$

where f_0 is the center frequency of the band-pass filter, BW is the bandwidth, Q is the quality factor, and H is the mid-band Gain. We want to keep the quality factor, Q, constant. Therefore, we chose f_0 and the bandwidth, BW, based on the quality factor equaling 2. The parameters of the equalizer are shown below in Table 1.

Table 1: Equalizer Parameters

f_0 **(Hz)**	f_L **(Hz)**	f_H **(Hz)**	**C (µF)**	R_{1A} **(kΩ)**	R_{1B} **(kΩ)**	R_2 **(kΩ)**
80	60	100	0.1	39.8	5.7	79.8
350	262.5	437.5	0.1	9.1	1.3	18.2
2500	1875	3125	0.047	2.7	0.387	5.4
6000	4500	7500	0.0022	24.1	3.4	48.2
12000	9000	15000	0.0022	12	1.7	24.1

2.4.4 Bluetooth Transmitter

Two Bluetooth transmitter modules will be used to transmit the mixed audio signal to two seperate bluetooth headphones. Verification will be done in the same way as the transmitters on the instrument module.

2.4.5 Bluetooth Receiver

Two Bluetooth receiver modules will be used to receive the audio signal (digital) from the instrument modules. Verification will be done in a similar way as the transmitters on the instrument module.

2.5 Tolerance Analysis

Because our design is intended to be portable and allow for continuous transmission, battery life for the instrument module becomes a design factor. If the battery is too large, the device weight becomes a factor when in use with instruments such as the electric guitar. If it is too heavy, the plug has the potential to disconnect from the instrument. Due to both the placement of the instrument module and cost concerns, we elected to not use a lithium-ion polymer battery. Our instrument module's design will use standard 3 AA batteries as its power source.

To calculate the battery life of our instrument module, we will have to consider the power requirements for the Bluetooth module. While in use (actively transmitting), the Bluetooth module requires 9.2mA at 3.3V and 0.07mA at 3.3V while in standby. These are the two most common scenarios that the instrument module will be in and thus the battery life is evaluated in these connection states.

Transmitting:

$$3.3V \cdot 9.2mA = 30.36mW \tag{23}$$

Standby:

$$3.3V \cdot 0.07mA = 0.231mW \tag{24}$$

We can calculate the efficiency of the voltage regulator of the circuit by first calculating the power lost.

$$P_{LOSS} = (V_{IN} - V_{OUT})I_{OUT} + V_{IN}I_Q \tag{25}$$

Transmitting:

$$33.54mW = (4.5V - 3.3V) \cdot 9.2mA + 4.5V \cdot 5mA \tag{26}$$

Standby:

$$22.58mW = (4.5V - 3.3V) \cdot 0.07mA + 4.5V \cdot 5mA \tag{27}$$

We can then estimate the efficiency of the circuit while transmitting.

$$(\frac{V_{OUT}I_{OUT}}{V_{IN}(I_{OUT} + I_q)}) \cdot 100\% \tag{28}$$

Transmitting:

$$(\frac{3.3V \cdot 9.2mA}{4.5V(9.2mA + 5mA)}) \cdot 100\% = 47.5\% \tag{29}$$

Therefore, the worst case current and power consumption for our Bluetooth module would be:

$$\frac{30.36mW}{3.3V} \div 47.5\% = 19.37mA \tag{30}$$

$$19.37mA \cdot 3.3V = 63.92mW \tag{31}$$

Energizer AA batteries have a nominal voltage of 1.5V [15]. With three cells, we would have a nominal voltage of 4.5V. The maximum current draw from the battery can be calculated using this nominal voltage and the maximum power requirement from equation 33.

$$63.92mW \div 4.5V = 14.2mA \tag{32}$$

These batteries have an approximate capacity of about 3000 mAh at 0.8V [15]. The Wh capacity is:

$$3000mAh \div 0.8V = 2.4Wh \tag{33}$$

Using this capacity, we can approximate our worst case battery life at 4.5V to be approximately:

$$\frac{2.4Wh \div 4.5V}{14.2mA} = 37.56[hours] \tag{34}$$

This is a long enough battery life to last multiple jam sessions and fulfills our requirements for the battery module.

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor Costs

Utilizing the average starting salary of an EE graduate at the University of Illinois [13], we can calculate a reasonable labor rate.

($67,000 / (52 weeks * 40 hours)) = $32.21 per hour

$32.21 * 3 members * (15 hours/week) * 15 weeks = $21,741.75

3.1.2 Part Costs

Part Name	Quantity	Unit Price	Total Cost
Microchip Technology RN52-I/RM116 Bluetooth Module	9	$17.72	$159.48
Texas Instruments OPA134 Low-Noise Op-Amp	10	$2.42 per chip in bundles of 10	$24.20
Texas Instruments OPA4134 Low-Noise Op-Amps	10	$4.61 per chip in bundles of 10	$41.60
Texas Instruments LM1117 3.3V Linear Regulator	5	$1.10	$5.50
Bourns PTA4543 Slide Potentiometer- 5kOhms	3	$1.47	$4.41
Bourns PTA4543 Slide Potentiometer- 10kOhms	3	$1.41	$4.23
Piher PC16S Knob Potentiometer	6	$4.69	$28.14

Neutrik NYS224G ¼” Conductor Plug	4	$1.67	$6.68
Generic 12V DC Power Supply	1	$7	$7
Miscellaneous Capacitors, Resistors, and Wires	N/A	$15	$15
		Total	$296.24

3.2 Schedule

Week of:	Justin:	Jeff:	Will:
10/8	Simulate and test various signals through equalizer schematic	Obtain lab kit and run further simulations on mixer module	Order parts and break out BT Module
10/15	Complete Eagle Schematic and PCB layout for equalizer	Complete Eagle Schematic and PCB layout for mixer module	Complete Eagle Schematic and PCB layout for instrument module
10/22	Order PCB for equalizer and mixer & begin physical testing of equalizer using breadboard	From PCB dimensions, work out actual size of chassis & Begin tests on mixer using breadboard	Configure Bluetooth module firmware for transmitters
10/29	Work out potential roadblocks in equalizer design and test with mixer	Work out potential roadblocks in mixer design & test with equalizer	Set up analog input for the Bluetooth module.
11/5	Final PCB design and ordering	Assemble mixer portion of PCB & test functionality again	Final PCB design and ordering
11/12	Assemble master and slave modules	Assemble master and slave modules	Assemble the instrument module and help with base

			assembly
11/19 (Break)	Integrate PCB’s into chassis and start final report	Integrate PCB’s into chassis and start final report	Integrate PCB’s into chassis and start final report
11/26	Run tests on overall design and prepare for demo	Run tests on overall design and prepare for demo	Run tests on overall design and prepare for demo
12/3	Demo Week	Demo Week	Demo Week
12/10	Final Report and Presentation	Final Report and Presentation	Final Report and Presentation

4 Ethics and Safety

Batteries can potentially be dangerous and must be implemented in a way such that extended overheating and fires are not a concern for the instrument module. 9-V batteries are particularly prone to shorts because the terminals are close together, which could potentially cause a fire. The mixer’s voltage regulator must also supply proper voltages to the various modules in order to avoid overheating and electrical failures.

Proper listening volume is a concern for the end user. Users must take care to avoid listening to music with their headphones at maximum volumes (about 100 dBa) for over 15 minutes to avoid permanent hearing damage [2]. This information will be disclosed to the end user in accordance to the IEEE Code of Ethics [3].

The base module will receive power from a 12V AC. The slave modules will be powered through an electrical connection to the master base. These connections must be shielded to prevent any harm to the user.

Because our mixer is a Bluetooth device, there are several FCC regulations that must be adhered to in order to guarantee safety and legality. The Bluetooth module must be qualified with the Bluetooth SIG. We intend on using an unmodified, pre-qualified Bluetooth module to satisfy these requirements. This module will be using the approved A2DP profile during transmission of our audio signals.

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