VibroSonics: Haptic Audio Sensations Project Document

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1. Overview

1.1 Executive Summary

The Vibrasonics: Haptic Audio Sensation project is a multidisciplinary project with electrical engineering, computer science, and mechanical engineering students. This project aims to design a device that translates musical and other sounds from the human spectrum of hearing into tactile-haptic vibrations for the human body. Vibrasonics allows those that are hard of hearing or deaf the ability to feel vibrations within their body which create the same sensation as sound. This system would allow deaf and hard of hearing people to experience music in a new way. In addition this system can be used in VR systems which allows users to truly be immersed in their virtual reality. This could also help individuals in high-volume locations because it would allow them to receive social cues that can help them react and avoid accidents.

This project is still in its design and prototyping phase. The electrical engineering team has decided to use bass shakers to allow the user to feel and hear audio as the main way to translate audio into vibrations. The main control system of our system will be an ESP-32 as our microcontroller the system will allow for the programming of input and outputs. In addition, we will use an amplifier for the bass shakers and design a power supply for our system.

The team has completed our final system for capstone. The final system included a power supply printed circuit board (PCB) that included a rechargeable battery circuitry and the buck converter to power the system's ESP-32. The power supply PCB also has batteries connected to it to power the full system and recharge, limiting the need for the user to change the batteries continuously. In addition to the power supply PCB, the system also included an audio amplifier board connected to two bass shakers and a board with an ESP-32, our microcontroller, with a microphone and audio jack. The fully electrical system was enclosed in a wearable enclosure made out of TPU, designed and printed by our Mechanical Engineering team. The TPU enclosure will then be inserted into a backpack to complete the wearable aspect of our system. This project is not only designed to translate sounds into vibrations but also to create a wearable product. Therefore the system can switch inputs from both a microphone and an audio jack while having easy access to a potentiometer to adjust the audio level of the full system.

Another main focus of our team right now is working on documentation. Our capstone project will be continued next year, so we are collecting all the information and research we have completed these past few months in a single document to pass to our project partner. In particular, we are working on converting our PCB files to EagleCAD from KiCad and writing engineering documentation explaining our design choices and any issues that came with those choices. Since we do have a working system, the team next year can use it as a starting point and as a way to make new design choices and meet new project partner requirements.

Our team is all working on the documentation based on what blocks they championed during our project. We are all working on different aspects of the documentation with the goal of completing it in the next two weeks.

1.2 Team Contacts and Protocols

Table 1: Contact Information

Farhiya Osman	osmanf@oregonstate.edu
Tyler Roelle	roellet@oregonstate.edu
Thomas Fealey	fealeyt@oregonstate.edu
Quentin Onyemordi	onyemorq@oregonstate.edu

Table 2: Team Protocols

Protocol	*Assessment Parameters*
Participate in weekly meeting on Wednesdays to discuss progress and any issues that have come up	Team members arrive to meetings with updates about their assigned work as well as any questions they have.
Google Team Drive	All information is stored in the Virbosonics->ee_deliverables->EEcourserequirements shared drive
Completed Work	Work is completed a day before due date which gives time to make any last minute changes or make last minute adjustments
Respectful Team Communication	Via discord communicate with team members respectfully and in a timely manner. In BaseCamp we need to use an extra level of professionalism since this is the main form of communication with our project partner.
Absences	If a team member misses a meeting please try to notify team members before the meeting. If possible we will reschedule the whole meeting or accommodate accordingly
Team Meeting notes from recitation	Any extra meeting notes that need to be accessed by all team members should be shared via discord and if necessary saved in our shared drive.

The primary roles for our team have been divided into two groups. Two people are working on the Power Supply (Farhiya and Quentin) and two people are working on the audio input conditioning (Tyler and Thomas). Farhiya is working on the regulator and Quentin is working on the battery charging aspect. Thomas is ensuring the bass shaker is outputting the correct vibrations for the inputted frequency while Tyler is working on designing the PCB that will include the ESP 32, amplifiers, connectors and system inputs and outputs.

1.3 Gap Analysis

The VibroSonics project aims to provide hard of hearing or deaf individuals the ability to immerse and experience music in a new way. In particular it will allow users to experience a wider range of frequencies then what is on the market right now. This product can also be used in VR systems and for individuals in high-noise environments. Its increased frequency range to experience audio is going to help users experience music at its full potential. During the design process we have made the assumption that users want to be able to experience all the ranges of music through vibration on the human body. We are also making the assumption that this is a product that customers are interested in because of its lightweight and wearable aspect. Through discussions with our project partner and stakeholder, we learned that current products can produce vibrations between 20-80 Hz, but sound's full potential includes frequencies from 12-1200 Hz. This will give individuals more range to the audio types users can experience through vibrations. This is essential to our team during our design process to understand the ranges necessary for our product to work successfully.

1.4 Timeline/Proposed Timeline

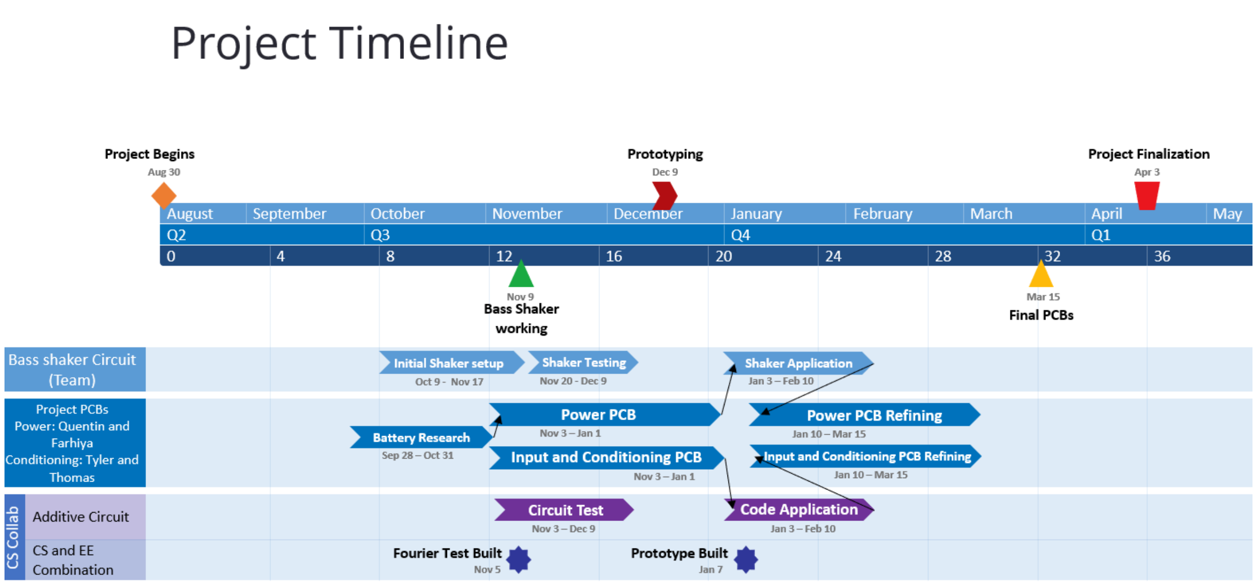


Figure 1.1 : Screenshot of our project timeline

Thomas and Tyler are working on the input and output audio conditioning aspect of our circuit. Thomas is working on making sure the audio amplifier and bass shaker are compatible and the bass shaker outputs enough vibration for our system. While Tyler is working on building a printed circuit board that will hold all the regulators, microcontrollers and connectors for the remainder of the system. He also needs to take into consideration the connection from the power supply as well. These initial designs will be completed by week 10 but iterated throughout winter term.

Farhiya and Quentin are responsible for the power supply. Farhiya is creating the PCB design for the regulator while also writing an engineering report explaining why she chose the specific regulator and battery and its comparison to other regulators and batteries on the market. She is also designing the PCB that will combine all systems included in our PCB: a rechargeable battery and the buck converter circuit with accurate connector locations so all systems will have accurate power output. Quentin is doing something similar for the rechargeable aspect of power supply. Quentin is designing a circuit that allows the system to recharge. The main goal of both their work is to have working PCB for each individual block and have the completed power supply PCB ordered by week 10 of winter term.

1.5 References and File Links

1.5.1 References

[1] A. Industries, "Stereo 20W class D audio amplifier - MAX9744," *adafruit industries blog RSS*. [Online]. Available: https://www.adafruit.com/product/1752. [Accessed: 17-Nov-2022].

[2] "Dayton Audio," *Fuber.com*. [Online]. Available: https://www.daytonaudio.com/product/1104/tt25-8-puck-tactile-transducer-mini-bass-shaker. [Accessed: 17-Nov-2022].

[3] "ESP32-S3 series - espressif." [Online]. Available: https://www.espressif.com/sites/default/files/documentation/esp32-s3_datasheet_en.pdf. [Accessed: 18-Nov-2022].

1.5.2 File Links

[1] "WK6 Design Impact Assessment Team," *Google Docs*. [Online]. Available: https://docs.google.com/document/d/17eE0bm3WeyHodWd8wfbehgaKuNI5jimTcTJHR-Eh_5U/edit?usp=sharing. [Accessed: 17-Nov-2022].

1.6 Revision Table

10/11/2022	Farhiya Osman: Initial Document Creation, updated executive summary and Team Contacts and Protocols

10/11/2022	Tyler Roelle: Updated Revision Table, updated timeline/proposed timeline, gap analysis, and references and file links.
11/01/22	Quentin Onyemordi: Added title page
11/03/22	Farhiya Osman: Updated Executive Summary
11/17/22	Farhiya Osman: Edited all of section 1 for final
11/18/22	Thomas Fealey: Added Timeline and fixed spacing
3/12/2023	Farhiya Osman: Updated Sections 1 + 2 with winter term info

2.Impacts and Risks

2.1 Design Impact statement

This impact assessment aims to bring awareness to the broad system impacts of our Vibrasonics project. In particular, we will look at how our design choices directly impact safety, welfare, and public health both short-term and long-term. The goal of this assessment is to objectively look at these issues to consider and allow them to influence our possible design decisions in the future. The implications of design choices are essential in the engineering world; therefore, analyzing and understanding them early on in your design process allows you to be aware of the various negative impacts. Proper preparation at this stage of development provides the best opportunity to accommodate a broader scope of people from a different perspective. Another essential benefit of this assessment is its ability to inform both project partners and stakeholders of the implications of our design choices down the road.

During the initial stages of our project, it is important to acknowledge our project's public health, safety, health, and cultural impacts. The public health impacts we will address during this assessment include plastics and battery waste in the environment since both batteries and plastics can affect the ground and water needed for our lives and animal lives [1]. Regarding the safety and public health impacts, we will discuss the possibility and implications of a possible battery leak and the inability to recycle or discard the hardware from our system once it becomes obsolete [2]. The cultural and economic impacts discussed will include speaker packs' effects on the public and more specifically, deaf communities [3] and how unemployment will affect the demand for our product since many deaf people can struggle to find a job [4]. All of these topics are gone more in-depth in the attached documentation.

2.2 Risks

Table 3 : Risk Assessment and Action Plans

Risk ID	Risk Description	Risk category	Risk prob-ability	Risk impact	Performance indicator	Action Plan
R1	Limited number of part options due to chip shortage	Technical	Medium	High	Availability of parts	Reduce ● Research potential parts early ● Check Availability of parts often.
R2	Battery leaks from faulty design	Public Health	Low	High	Safety of system	Remove ● Take care in developing a safe system by thorough research and testing.
R3	Failing to meet project partner deadlines	Schedule	Medium	High	Meeting deadlines	Reduce ● Prepare well and communicate on a realistic timeline.
R4	Electronic Waste Buildup	Public Safety	Medium	HIGH	Excessive amounts of electronic waste in landfills	Reduce ● Use components that will not become obsolete in a few years and possibly design it in a way components can be interchanged.
R5	Materials Used	Environmental Impact	Medium	High	Limit Plastic use.	Reduce ● Use harmful materials only when necessary in our system. Make a conscious choice when

						using materials like plastic.
R6	Battery shorting	Safety	Medium	High	While charging if the battery shorts and possibly injures the user.	Reduce ● Make sure the system has fuses or protection if the battery shorts while charging.
R7	Bass shaker/ speaker malfunction	Safety/Technical	Low	High	While being used the bass shakers break and the speakers blow causing injury to people around.	Reduce ● Create limiters on the base shaker to limit the maximum intensity.
R8	Audio Output malfunction	Safety/Technical	Low	Medium	While in use the audio output creates a high frequency that could cause damage to ears.	Reduce ● Have a filter to prevent high frequency noises automatically.

2.3 References and File Links

2.3.1 Reference

[1] McElwee, Holli. “Battery Recycling Is Important for Environmental Health.” *Gallegos Sanitation / Republic Services*, 20 Jan. 2020, gsiwaste.com/battery-recycling-is-important-for-environmental-health.[Accessed: 03-Nov-2022]

[2] “OSHA issues warning about wearable lithium battery-powered devices " CBIA,” *CBIA*, 22-Aug-2022. [Online]. Available: https://www.cbia.com/news/hr-safety/lithium-battery-powered-devices/. [Accessed: 03-Nov-2022].

[3] Neary, Walter. "Brains of Deaf People Rewire to 'Hear' Music." *UW News*, 27 Nov. 2001, www.washington.edu/news/2001/11/27/brains-of-deaf-people-rewire-to-hear-music [Accessed: 04-Nov-2022]

[4] Garberoglio, Carie Lou, et al. "DEAF PEOPLE AND EMPLOYMENT IN THE UNITED STATES: 2019." *National Deaf Center on Postsecondary Outcomes*, Jan. 2019, www.nationaldeafcenter.org/sites/default/files/Deaf%20People%20and%20Employment%20in%20the%20United%20States_%202019%20(7.26.19)(ENGLISH)(WEB).pdf. [Accessed: 04-Nov-2022]

2.3.2 File Links

[1] Design Impact Assessment Documentation

2.4 Revision Table

11/01/22	Quentin Onyemordi: Created Section and added risks 1-3
11/03/22	Farhiya Osman: Added some references and file links
11/17/22	Farhiya Osman: Added to Risk Assessment and Action Plans
11/18/22	Thomas Fealey: Added to Risk Assessment table and fixed spacing
11/18/22	Tyler Roelle: Added to Risk Assessment table
04/27/23	Thomas Fealey: Added Introduction and references

3. Top-Level Architecture

3.1 Block Diagram

The image below is our systems block diagram. It contains all the blocks of our system which we will have more in-depth descriptions in section 4.

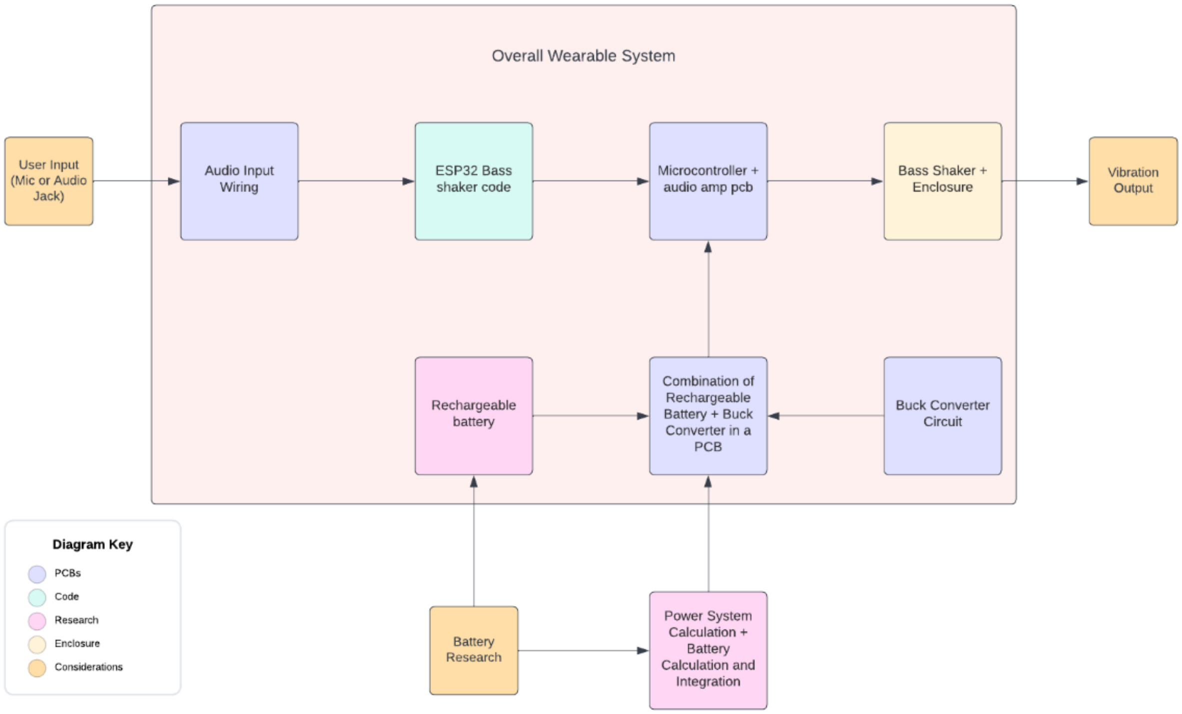


Figure 1.2: System Block Diagram

Below is the black box diagram for our full system. It has two input interfaces and one output interface. The **otsd_rchrgbl_bttry_crctry_dcpwr** is the input from the rechargeable battery aspect of our system which will recharge and power the batteries. The other input **otsd_mcrphn_data** is the input data from the microphone that our system is receiving. The output of our system is the interface **ad_mp_otsd_usrout** which is the vibration felt from the bass shaker.

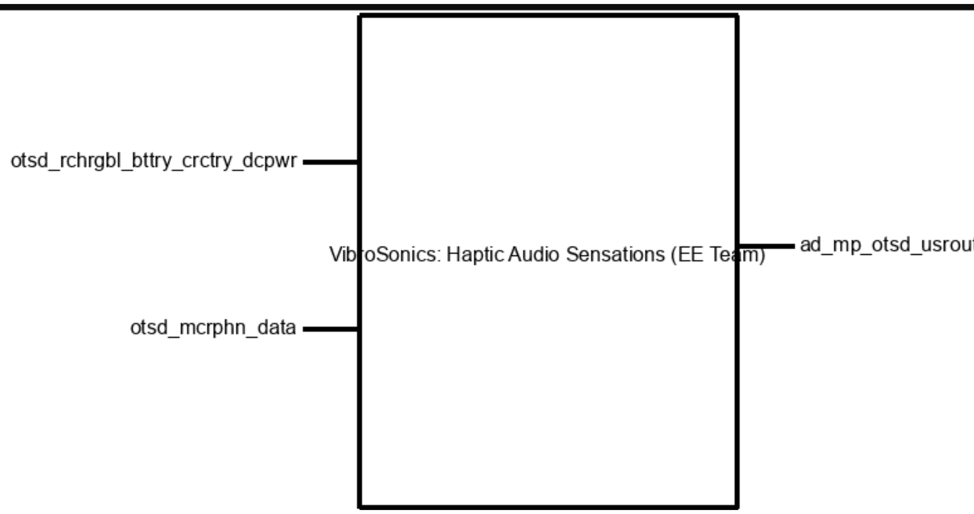


Figure 1.3: System black box diagram

3.2 Block Descriptions

Name	Description
uC PCB Champion: Tyler Roelle	This is a custom design PCB that will connect the ESP32 feather, MAX9744ETH+ amplifier chip, speakers, and various different parts that will allow for audio to go from input to then push the output to the bass shakers. This PCB will be connected to the 12V buck converter to supply 3.3V to 5V to the ESP32 feather and the amplifier chip.
Buck Converter Circuit Champion: Farhiya Osman	The buck converter circuit block is a section of the power supply block for our system. It will step down the voltage source from the battery to the accurate voltage needed for the ESP-32 feather. This block will also include a switch that will assist in powering off the full system. This block is valuable to the system because most components run off different voltage values, and it steps down the voltages to their needed values. This block, in particular, takes in voltages with a possible min of 7.4 V and maximum of 8.4 V from the battery and steps it down to a voltage between the minimum of 3.3 V and a maximum of 5 V to power an ESP-32 feather for our system. It also contains a power switch for the full system. This block will include a regulator with a 66% efficiency to provide enough power for the whole system for a minimum of 2 hours. Along with making sure the regulator has a high enough efficiency, it's important that our system's connectors are functional with the other system components. The block will connect to the ESP-32 feather via the USB pin. It will receive power from the battery or the rechargeable printed circuit board. The main purpose of this block is to step down our input voltage into a usable voltage to power our system ESP-32 feather. This block will directly connect to other PCBs in our system: one with the audio amplifier and one ESP-32 feather, the rechargeable

	battery PCB, and the battery powering the full system. This block is important in helping lower our system's power input because it allows us to take in a higher voltage while still outputting our desired output voltage for each unique component. This block is also important to integrate the power supply with our system's other two components: an ESP-32 feather and an audio amplifier with a bass shaker.
Rechargeable Battery Circuitry Champion: Quentin Onyemordi	The rechargeable battery will need to restore the battery's power if it depletes. This block contains the circuitry associated with recharging the selected battery to its minimum battery life of 2 hours per charge. This block also requires the battery and rechargeable components to be compatible with the same battery chemistry.
Audio Amp Champion: Thomas Fealey	This block consists of two combined parts that are needed to test. The first part of this test is the bass shakers, which are tactile transducers that convert low frequencies to a physical sensation, which in this case are vibrations. The second part of the block is the audio amp, which converts an I2C file to an analog signal and outputs it to the bass shakers. The amp is not only supposed to make this conversion but also output these signals at a proper volume and frequency. This bass shaker/ audio amp system will take in power from a power supply, an audio signal from an ESP32, and output the signal to two bass shakers. These bass shakers will then vibrate an enclosure, allowing the user to feel and see the power of the shakers. This system will also be controlled by a potentiometer enabling the user to choose what intensity they want to feel. This system has the capability to produce noise, but using smart filtering, those frequencies will be shifted down and compressed in the bass section, where the shakers will have the best response and produce the slightest noise.

Power System Calculation + Battery Calculation and Integration Champion: Quentin Onyemordi	The power system calculation takes into account every item that will draw power and calculates it to understand how big the battery will have to last. This calculation will help determine what battery to use, what kind of charger to use, and how the system will deal with various voltage and current draws.
Amp Code Champion: Thomas Fealey	The ESP32 Bass Shaker code is a backup in case the CS team cannot meet the requirements or their code does not function. This code will output sine waves between 20 to 80 Hz or play audio from a given .wav file. This code should be readable for the audio amplifier as well and utilize left, right, and ground audio inputs. This code should be able to read from a .wav file and output vibrations on the bass shaker.
Microphone Champion: Tyler Roelle	The microphone block is one of the ways in which our system will receive audio input. It will sense sound, take the frequencies, and transmit them to the ESP32. The microphone our system uses is a MAX4466 that is powered via the ESP32 3.3V pin. Including the microphone allows us to have a system that can switch between two audio inputs.
Power Supply PCB Champion: Farhiya Osman	This block will be a PCB block for the power supply. It will include a rechargeable battery system and a buck converter circuit to step down the voltages necessary to power the ESP-32 feather in our system. The rechargeable circuit is important to our system because it will allow for the system to be a wearable device while also improving the battery life of the system. The rechargeable battery system will take four hours to recharge the batteries, and our system can last for at least two hours. The PCB will be taking in an input voltage of 7.4 V to 8.4 V and 1.5 Amps at its maximum. It will take in this voltage and go through a switch, then output the 8 V at 0.800 A for the audio amplifier, and then input the voltage into a buck converter circuit that will output 5V at 0.250 A to power the

	ESP-32. This block will also contain screw terminals to meet our system's universal connector requirement.

3.3 Interface Definitions

Name	Properties
otsd_rchrgbl_bttry_crctry_dcpwr	• **Inominal:** 2 A • **Ipeak:** 3.2 A • **Vmax:** 18 V • **Vmin:** 4.5 V
otsd_mcrphn_data	• **Other:** 9 out of 10 users can use the microphone • **Other:** Recieves frequencies 0-1600Hz • **Protocol:** I2S
uc_pcb_ad_mp_dsig	• **Logic-Level:** I2S • **Vmax:** 5V • **Vmin:** 0V
amp_cd_ad_mp_data	• **Datarate:** 32 Samples per second • **Other:** Receives and processes a mic input • **Protocol:** I2S
bck_cnvrtr_crct_uc_pcb_dcpwr	• **Inominal:** 0.20 A • **Ipeak:** 0.250A • **Vmax:** 5 V • **Vmin:** 3.3 V
ad_mp_otsd_usrout	• **Type:** The sound output will be under 80dB

	• **Type:** Vibrations between 10-100Hz • **Usability:** 9 out of 10 users will feel an output
pwr_systm_clcltn_bttry_clcltn_nd_ntgrtn_bck_cnvrtr_crct_dcpwr	• **Inominal:** 0.200 A • **Ipeak:** 0.250 A • **Vmax:** 8 V • **Vmin:** 7.4 V
pwr_systm_clcltn_bttry_clcltn_nd_ntgrtn_pwr_spply_pcb__dcpwr	• **Inominal:** 0.200 A • **Ipeak:** 0.200 A • **Vmax:** 8.4 V • **Vmin:** 7.0 V
mcrphn_amp_cd_dsig	• **Max Frequency:** 8000Hz • **Vmax:** 3.3V • **Vnominal:** 1.65V
pwr_spply_pcb__uc_pcb_dcpwr	• **Inominal:** 0.200 A • **Ipeak:** 0.250 A • **Vmax:** 8.4 V • **Vmin:** 7.4 V

3.4 References and File Links

3.4.1 References

[1] "HUZZAH32 - esp32 feather guide datasheet by Adafruit Industries LLC," *Digi*. [Online]. Available: https://www.digikey.tw/htmldatasheets/production/2314596/0/0/1/huzzah32-esp32-feather-guide.html. [Accessed: 10-Feb-2023].

[2] "LP953743_3.7V_1500mAh," *Lipo Battery Datasheet*. [Online]. Available: https://www.lipolbattery.com/LiPo-Battery-Datasheets.html. [Accessed: 10-Feb-2023].

3.4.2 File Links

3.5 Revision Table

3/12/2023	Farhiya Osman: Added block diagram, black box diagram, descriptions and system interfaces

4. Block Validations

4.1 Buck Converter Circuit

4.1.1. Description

The buck converter circuit block is a section of the power supply block for our system. It will step down the voltage source from the battery to the accurate voltage needed for the ESP-32 feather. This block will also include a switch that will assist in powering off the full system. This block is valuable to the system because most components run off different voltage values, and it steps down the voltages to their needed values.

This block, in particular, takes in voltages from 7.4 V - 8.4 V from the battery and steps it down to a voltage between 3.3 V - 5 V to power an ESP-32 feather for our system. It also contains a power switch for the full system. This block will include a regulator with a 66% efficiency to provide enough power for the whole system for at least 2 hours. Along with making sure the regulator has a high enough efficiency, it's important that our system's connectors are functional with the other system components. The block will connect to the ESP-32 feather via the USB pin. It will receive power from the battery or the rechargeable printed circuit board. The main purpose of this block is to step down our input voltage into a usable voltage to power our system ESP-32 feather.

This block will directly connect to other PCBs in our system: one with the audio amplifier and one ESP-32 feather, the rechargeable battery PCB, and the battery powering the full system. This block is important in helping lower our system's power input because it allows us to take in a higher voltage while still outputting our desired output voltage for each unique component. This block is also important to integrate the power supply with our system's other two components: an ESP-32 feather and an audio amplifier with a bass shaker.

4.1.2 Design

This block will use a TSP54233 chip with supporting components and connectors to power an ESP-32 feather. Figure 1 shows the block box image of the buck converter circuit with its respective interfaces. The block is powered by the **pwr_spply_crct_bck_cnvrtr_switch_crct_dcpwr** interface with a maximum voltage input of

8.4 V. The output of this block is represented by the **bck_cnvtr_switch_crct_uc_pcb_dcpwr,** which will have a maximum output voltage of 5 V. The image below represents the black box diagram of this block, showing the input and output interfaces, respectively.

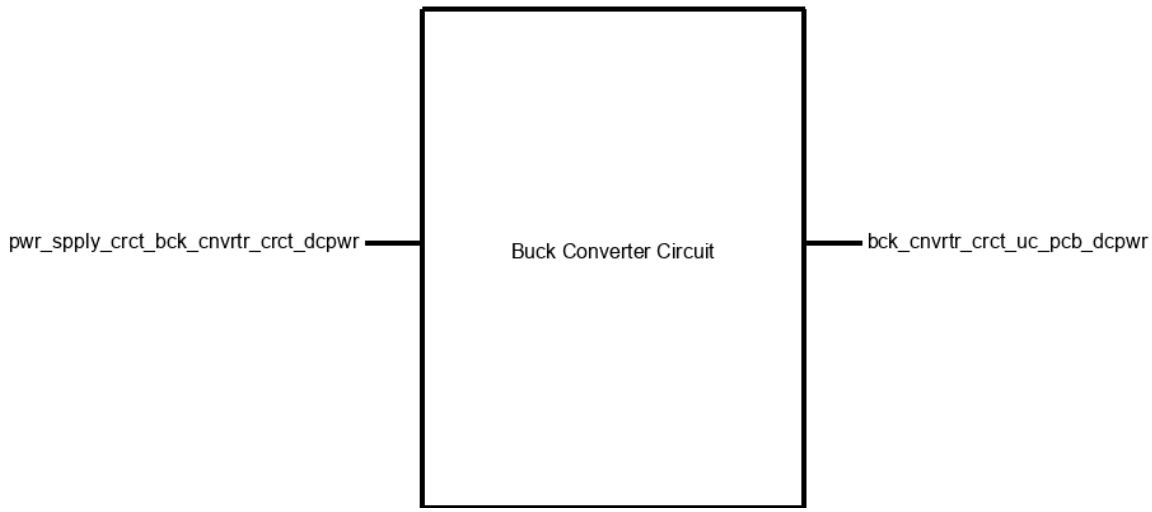


Figure 1: Buck Converter Circuit Black Box diagram

Based on this block's interfaces, the circuit's initial schematic design is shown in Figure 2. The schematic below shows the different connectors, regulators, and supporting components used for the TPS54233. The schematic design for this system has important resistor networks R5 and R6 that determine the output voltage and additional components to help with noise filtering. It uses a step-down DC/DC converter as its main system chip.

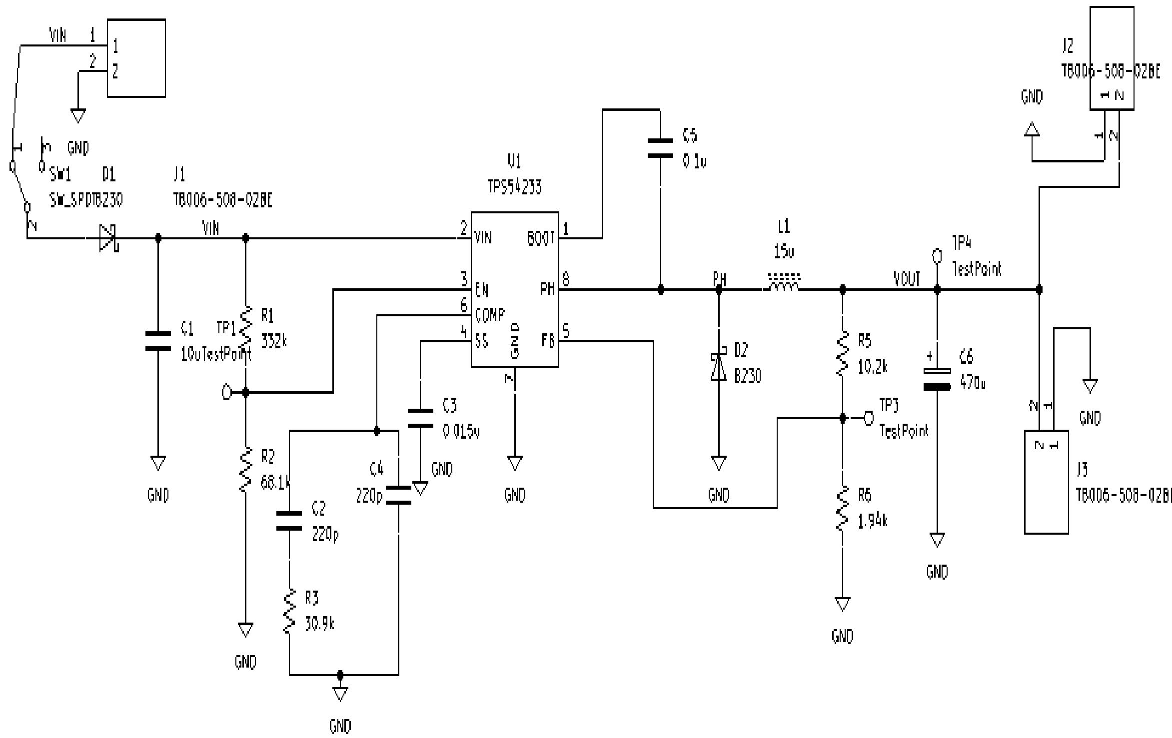


Figure 2: Schematic for Buck Converter Circuit with additional switch component

4.1.3 General Validation

To meet the desired output voltages for other components within our project, we decided to use a step-down converter chip, the TPS54233. This chip, in particular, allows for adjusting its output voltage by changing two resistor values (R5 and R6). The adjustments of resistors R5 and R6 allow for the accurate output voltage from the buck converter circuit of voltages between 3.3 V - 5 V, and the TPS54233 data sheet indicates an efficiency percentage between 85-90% when Vin is 8 V [3]. Since our power budget calculation uses around 66% efficiency, this chip will allow the system to meet the on-time minimum for our system. The calculations for the current draw from the load, an ESP-32 feather, indicate it will last for the minimum system life requirement of 2 hours. The system's battery life is a minimum of two hours, and using an ESP-32 feather as our microcontroller was a requirement given to our team by our project partner. In addition to the components used, we made some decisions on the connectors that will be used in the system. The ESP-32 feather will connect to the system using screw terminals, and the battery connection will be via battery jumper cables; there will also be a switch for the system to power on and off in this block.

To transition to some system design choices made for the circuit. The circuit will use jumper cables on the far right, allowing enough distance from the ESP-32 feather and the bass shaker. This distance is essential because the ESP-32 feather will eventually have a microphone connected to it. The bass shaker produces vibrations; we don't want the microphone to pick up unnecessary noise and distort the inputs. Another design decision was to use an ESP-32 feather jumper connector/male connector to connect the power supply to the ESP-32 feather USB pin instead of a USB connector because it's a cheaper option once we convert our system to a PCB and allows for fewer excess wires. Since the ESP-32 feather connector is on the far right of the circuit, the connector for the audio amplifier will be on the top left of our system. This will provide a large enough distance to ensure no interference. If this distance is not enough, our team has considered other ways to limit the interference: creating a few walls around the microphone or just having a little hole in a box that allows for the concentrated sound. As for the system designs and understanding the necessary surrounding components for filtering from the data sheet of the TSP54233 as well as the data sheets for the switch.

During the design process, I looked into other similar chips, including the TPS5422 and the TS12450, but due to limited stock and limited information on the efficiency rating as well as the filter components, I ultimately selected the TPS54233 chip. I also needed to make a design decision on the switch I would use for the system. In the initial search, there were many options, but ideally, I needed a Single Pole Double throw switch due to its easy accessibility in the given time frame and its ability to successfully power on and off my systems design. This selection process also made me consider some design alternatives. I considered the TPS12450 buck converter chip, but that would remove additional filter components; it lacked the efficiency I needed for my system and made it difficult to integrate the necessary connectors to the other system blocks.

Finally, the buck converter block will interact with other blocks in our system but will also help complete the power supply for our project. In particular, it will work with our system's battery and rechargeable blocks. This block receives the 12 V from the battery block and the rechargeable battery block. This also supplies power to the ESP-32 feather block.

4.1.4 Interface Validation

This next section states what the interface properties will be for both the input and output interfaces shown in the black box diagram in figure 1. Since this block is a power supply block, each interface must have four properties (Vmin, Vmax, Inominal, and Ipeak). The interface values were determined based on system testing my team and I completed to determine what differs between the maximum and minimum electrical characteristics on the datasheet and the maximum and minimum values required by our personal system. The table below lists each interface property while also discussing why the value was chosen and how we know the block design and specifications discussed in the document meet those expectations.

Interface Property	**Why is this interface this value?**	**Why do you know that your design details <u>for this block</u> above meet or exceed each property?**
bck_cnvrtr_swtch_crct_uc_pcb_dcpwr : Output		
Inominal: .20 A	When we tested the ESP-32	ESP-32 feather datasheet:

	feather with the current working code at the desired input voltages and current of the battery, the ESP-32 consistently drew 0.200 amps of current	Continuous use current draw: 200 mA [3, p.22].
Ipeak: .250A	When we tested the ESP-32 feather with the current working code at the desired max output voltage, the current draw rose to 0.250 A.	ESP-32 feather datasheet: Max current draw: 250mA [3, p. 22].
Vmax: 5 V	This voltage value was selected based on the maximum voltage value the ESP-32 feather USB pin can support	ESP-32 feather datasheet: USB Pin Voltage: 5 V BAT pin Voltage: 3.3 V/4.2 V [3,p. 22-25].
Vmin: 3.3 V	This voltage value was selected based on the minimum voltage value the ESP-32 feather USB pin can support	ESP-32 feather datasheet: USB Pin Voltage: 5 V BAT pin Voltage: 3.3V/4.2 V [3,p. 22-25].

pwr_spply_crct_bck_cnvrtr_swtch_crct_dcpwr : Input

Inominal: 0.20 A	This is based on the consistent current draw of the ESP-32 feather at the maximum voltage	ESP-32 feather datasheet: Continuous use current draw: 200 mA [3,p. 22].
Ipeak: 0.250 A	This is based on the maximum the current draw of the ESP-32 feather at the maximum voltage	ESP-32 feather datasheet: Max current draw: 250mA [3,p,22].
Vmax: 8.4 V	This is based on the maximum voltage that can be supplied by the lithium polymer batteries, our system will be using	LP953743 LiPo battery: Nominal voltage: 3.7 V Max Voltage: 4.2 V *Our system is using a two cell-battery in series so therefore, our interfaces are doubled the above-listed values.*

		[2, p. 1]
Vmin: 7.4 V	This is based on the maximum voltage that can be supplied by the lithium polymer batteries our system will be using	LP953743 LiPo battery: Nominal voltage: 3.7 V Max Voltage: 4.2 V *Our system is using a two cell-battery in series so; therefore, our interfaces are doubled the above-listed values.* [2, p. 1]

4.1.5 Verification Process

Below is the steps to verify that the above interface values are met by the hardware schematic presented. These interfaces are tested and validated using two main pieces of equipment: A DC power supply and a DC Electric load. You will also need two sets of cables for your input and output connectors on your system. This board was assembled on a printed circuit board due to the ease of future testing, but it could also be assembled on a protoboard or a breadboard; the TPS54233 chip is very small, so breadboarding may be a bit difficult.

A. Nominal current testing
1. Connect the buck converter circuit block to the DC power supply via the **pwr_supply_crct_bck_cnvrtr_crct_dcpwr** interface at 7.4 V. On the DC power supply, set the V-set to 7.4 V and I-set to 0.500 Amps.
2. Using a DC electric load **bck_cnvrtr_crct_uc_pcb_dcpwr** to draw 0.200 Amps.
3. Power the DC power supply and DC electric load for 30 seconds. Ensure the output voltage is between 3.3 V and 5 V.
4. Repeat steps 2 and 3 for a system with an 8.4 V input voltage via **pwr_supply_crct_bck_cnvrtr_crct_dcpwr** interface.
5. For success, the voltage output on the **bck_cnvrtr_crct_uc_pcb_dcpwr** interface always stays within the range of 3.3 - 5.0 V, and the current draw never exceeds 0.200 A. While the input voltage via **pwr_supply_crct_bck_cnvrtr_crct_dcpwr** interface never exceeds 7.4 V - 8.4 V .

B. Peak current testing
6. Connect the buck converter circuit block to the DC power supply via the **pwr_supply_crct_bck_cnvrtr_crct_dcpwr** interface at 7.4 V. On the DC power supply, set the V-set to 7.4 V and I-set to 0.500 Amps.
7. Using a DC electric load **bck_cnvrtr_crct_uc_pcb_dcpwr** to draw 0.250 Amps.

8. Power the DC power supply and DC electric load for 2 seconds. Ensure the output voltage is between 3.3 V and 5 V.
9. Repeat steps 2 and 3 for a system with an 8.4 V input voltage via **pwr_supply_crct_bck_cnvrtr_crct_dcpwr** interface.
10. For success, the voltage output on the **bck_cnvrtr_crct_uc_pcb_dcpwr** interface always stays within the range of 3.3 - 5.0 V, and the current draw always exceeds 0.250 A. While the input voltage via **pwr_supply_crct_bck_cnvrtr_crct_dcpwr** interface never exceeds 7.4 V - 8.4 V .

4.1.6 References and File Links

6.1 References (IEEE)

[1] "HUZZAH32 - esp32 feather guide datasheet by Adafruit Industries LLC," *Digi*. [Online]. Available: https://www.digikey.tw/htmldatasheets/production/2314596/0/0/1/huzzah32-esp32-feather-guide.html. [Accessed: 10-Feb-2023].

[2] "LP953743_3.7V_1500mAh," *Lipo Battery Datasheet*. [Online]. Available: https://www.lipolbattery.com/LiPo-Battery-Datasheets.html. [Accessed: 10-Feb-2023].

[3] "TPS54233," *TPS54233 data sheet, product information and support | TI.com*. [Online]. Available: https://www.ti.com/product/TPS54233. [Accessed: 10-Feb-2023].

6.2 File Links

[1] F. Osman , T. Fealey, T. Roelle, and Q. Onyemordi,"WK6 Draft Project Document: Section 1+2," *Google Docs*. [Online]. Available: https://docs.google.com/document/d/1NOoQgi1FZgtK3x3ZYF84-wZMc1hf4UZgz7ld61XeRVI/edit. [Accessed: 10-Feb-2023].

[2] F. Osman , T. Fealey, T. Roelle, and Q. Onyemordi, "Blockdiagram VibraSonics," *Google Drive*. [Online]. Available: https://drive.google.com/file/d/1WWps-8zdQUNclFs8_MGBR2Z0FmM8wit0/view. [Accessed: 10-Feb-2023].

4.1.7 Revision Table

1/18/2023	Farhiya Osman: Completed Description, Design section and Verification Plan

1/20/2023	Farhiya Osman: Updated Interface and General Validation section
2/5/2023	Farhiya Osman: Updated interface values and edited verification plan section
2/9/2023	Farhiya Osman: Made appropriate changes that were given to me from professors and peer review documents
2/10/2023	Farhiya Osman: Updated Sections 1-8 to new system design specification and values

4.2 uC PCB

4.2.1. Description

This is a custom design PCB that will connect the ESP32 feather, MAX9744ETH+ amplifier chip, speakers, and various different parts that will allow for audio to go from input to then push the output to the bass shakers. This PCB will be connected to the 12V buck converter to supply 3.3V to 5V to the ESP32 feather and the amplifier chip.

4.2.2 Design

Since we are using a ESP32-Feather there will be a female connection for the ESP32 to slot into on the board. For the audio amplifier we will be using the MAX9744-ETH+ chip; this is the chip that the Adafruit 20W audio amplifier uses. All of the capacitors and resistors will be the ones that are being used on the Adafruit board.

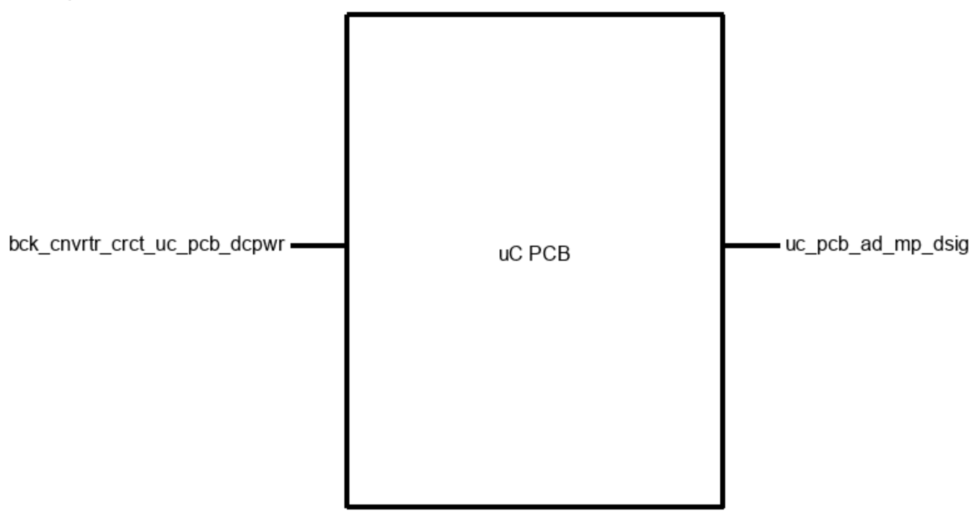


Figure 3: uC Black Box Diagram

According to the wiring

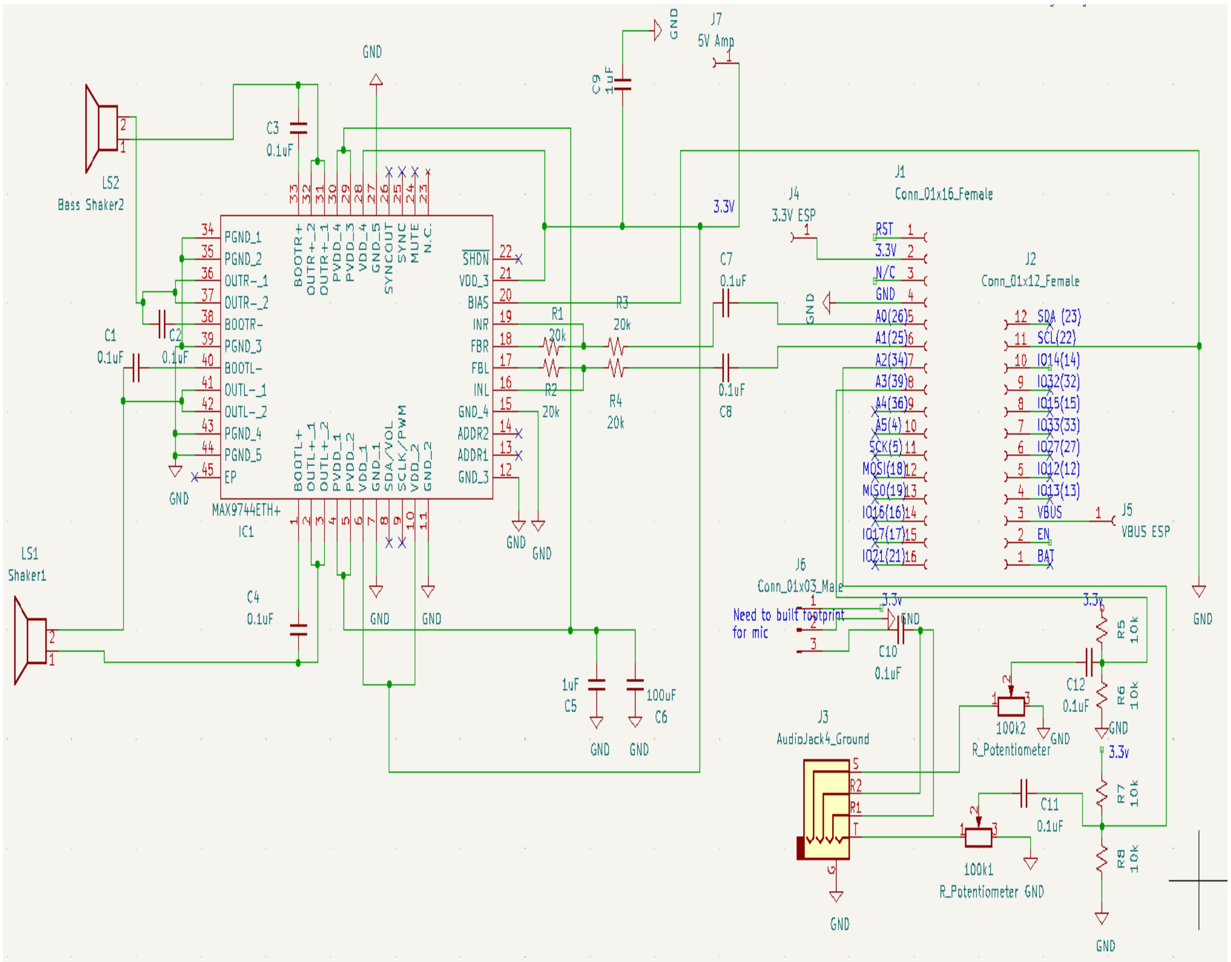


Figure 4: Schematic for uC Circuit

4.2.3 General Validation

Using the information provided for the block interfaces, a verification process will allow for the final design to be tested. This testing will verify that all interface properties will be met and the block is ready to be integrated into the final system.

A. Max Voltage Testing Since this block will be connected to the buck converter, we can simulate the properties with an off-the-shelf power supply. This test will measure the voltage output for all valid input powers. 1. Connect the off-the-shelf power supply to the VBUS pin via the bck_cnvrtr_crct_uc_pcb_dcpwr interface at 5V. This can be measured using a Fluke device or by looking at the power supply display. 2. Repeat step 1 for max voltage at 4.2V.

B. Nominal Current Testing Since this block will be connected to the buck converter, we can simulate the properties with an off-the-shelf power supply. This test will measure the voltage output while supplying nominal current for all valid input powers. 1. Connect the off-the-shelf power supply to the VBUS pin via bck_cnvrtr_crct_uc_pcb_dcpwr interface at 4.2V. This can be measured using a Fluke device or by looking at the power supply display. 2. Energize the system for 30 seconds. At the end of the 30 seconds while still powering the system, ensure that the output voltage is still between 5V and 3.3V. 3. Repeat steps 1 and 2 while powering the system with 3.3V on bck_cnvrtr_crct_uc_pcb_dcpwr.

C. Peak Current Testing Since this block will be connected to the buck converter, we can simulate the properties with an off-the-shelf power supply. This test will measure the voltage output while supplying peakl current for all valid input powers. 1. Connect the off-the-shelf power supply to the VBUS pin via bck_cnvrtr_crct_uc_pcb_dcpwr interface at 4.2V. This can be measured using a Fluke device or by looking at the power supply display. 2. Energize the system for 30 seconds. At the end of the 30 seconds while still powering the system, ensure that the output voltage is still between 5V and 3.3V. 3. Repeat steps 1 and 2 while powering the system with 3.3V on bck_cnvrtr_crct_uc_pcb_dcpwr.

4.2.4 Interface Validation

Interface	Properties
uc_pcb_ad_mp_dsig	Logic-Level: Active High V_{max}: 5V V_{min}: 0V
bck_cnvrtr_crct_uc_pcb_dcpwr	$I_{nominal}$: 200mA I_{peak}: 250mA V_{max}: 4.2V V_{min}: 3.3V
pwr_spply_crct_uc_pcb_dcpwr	$I_{nominal}$: 200mA I_{peak}: 400mA V_{max}: 5V V_{min}: 3V $V_{nominal}$: 3.3V
pwr_systm_clcltn_bttry_clcltn_nd_ntgrtn_uc_pcb_dcpwr	$I_{nominal}$: 200mA I_{peak}: 400mA V_{max}: 5V V_{min}: 3V $V_{nominal}$: 3.3V

4.2.5 Verification Process

1. Connect 5V power from the buck converter to power the ESP32 and connect 7V power to the audio amplifier. To check power for the ESP32, see if there is a flashing yellowish light on the ESP32. To check power for the audio amplifier, connect a Fluke/Voltmeter to the terminals for the bass shakers.
2. Flash the latest code for the ESP32.
3. Connect an input device to the 3mm audio jack.

4.2.6 References and File Links

[1] A. Lady, “Adafruit 20W Stereo Audio Amplifier - MAX9744”, adafruit.com [Online], Available: Downloads | Adafruit 20W Stereo Audio Amplifier - MAX9744 | Adafruit Learning System. [Accessed: 10-3-2023].

4.2.7 Revision Table

3/12/2023	Tyler Roelle: Completed description, design references and files links sections
3/12/2023	Tyler Roelle: Added revision table
5/14/2023	Tyler Roelle: Completed section

4.3 Rechargeable Battery Circuitry

4.3.1. Description

The rechargeable battery block will need to restore the batteries power if it depletes. This block contains the circuitry associated with recharging the selected battery to its minimum battery life of 2 hours per charge. This block also requires the battery and rechargeable battery components to be compatible with the same battery chemistry. This block utilizes a system incorporating an MP2615 chip complete with capabilities suitable for 2-cell Lithium-Polymer application complete with 2A deliverable charge, thermal shutdown protection and charging operation indication among many other features. The power source is 12 vdc coming from a wall outlet through a DC power jack. The 2 batteries will be set up in series thus increasing the voltage from 3.7 v to provide a 7.4 v nominal to the power supply.

4.3.2 Design

This section includes various aspects of the system that directly relates to the design and how it is implemented. The first artifact included in this section is the black box diagram of this block which has been named as the *"Rechargeable Battery"* with a single interface that acts as the source of power for the entire system. The main function of this block is to charge the 2 batteries that will be supplying power to the audio amplifier and ESP32 Feather. This interface supports the use of either LiPo or Li-Ion batteries and supplies a Vnominal of 7.4 volts to the system. Also included in this section is the go-by application circuit included in the datasheet for the charging chip used in this design (MP2615) that was implemented into the system. Below that diagram is the actual schematic used that was completed in Eagle. After that is the actual PCB traces of the system and the layout of the board. The end of the section incorporates the manufactured top and bottom simulations of the board as well as the Bill of Materials of all the components relevant to this system.

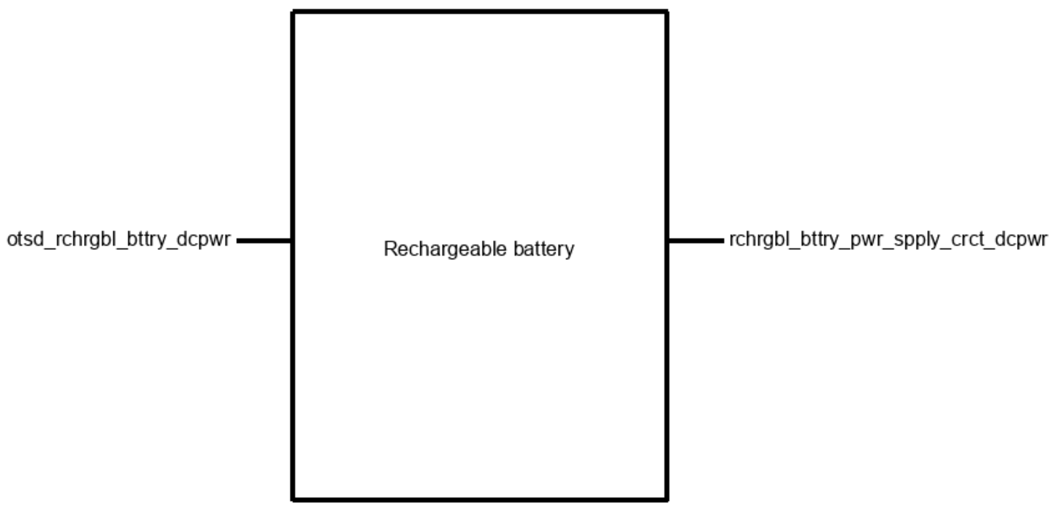


Figure 1: Black Box Image

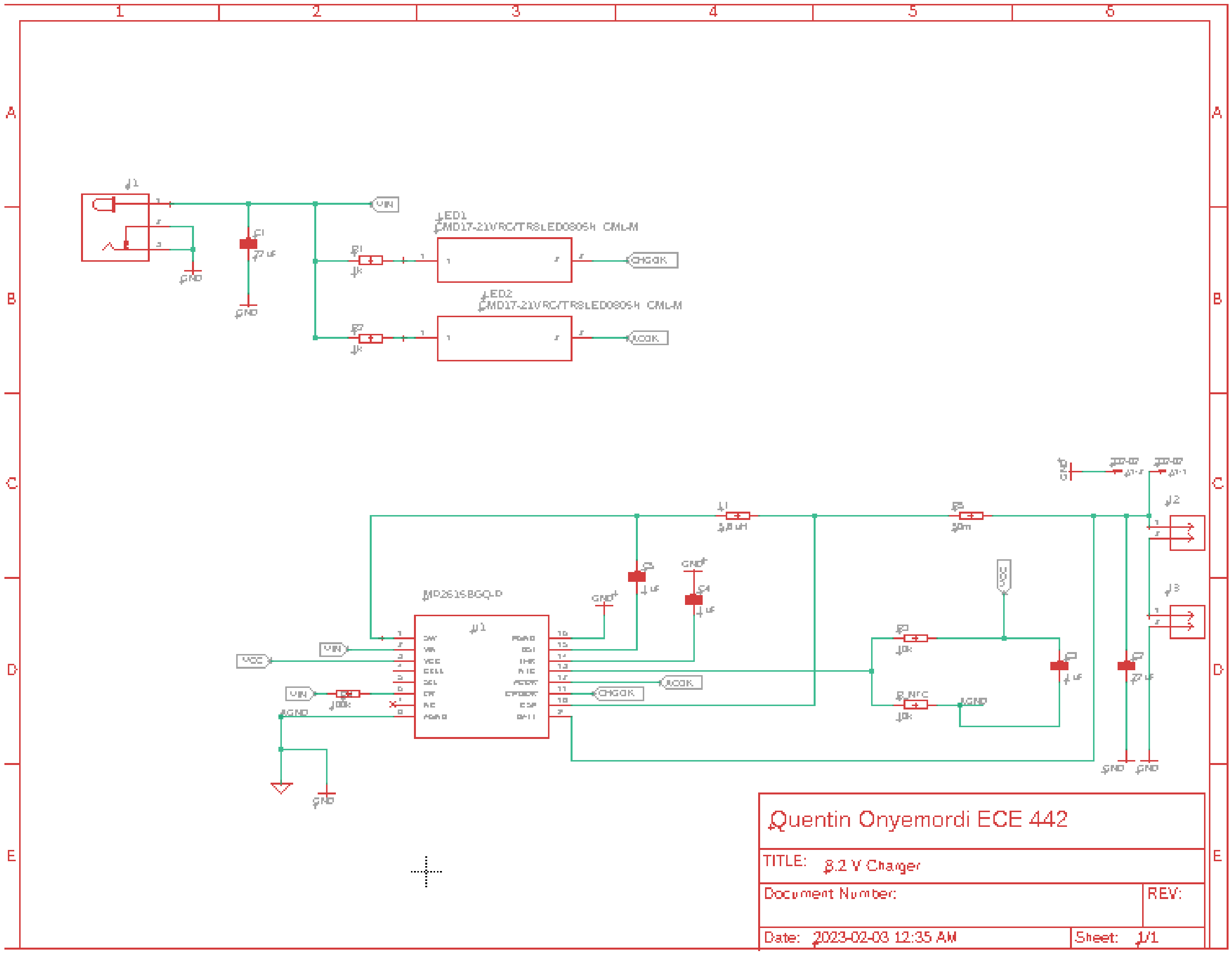


Figure 3: Eagle Schematic (Actual Application)

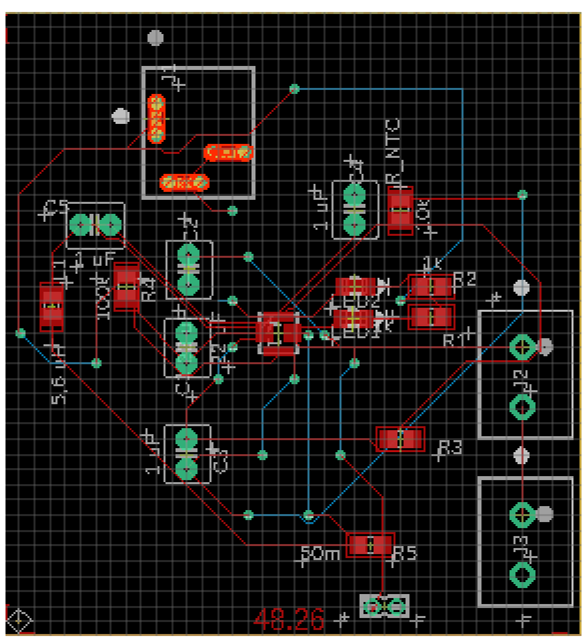


Figure 4: Eagle Board Layout

4.3.3 General Validation

This system design is quite nuanced due to various aspects that impacted how this block is implemented. The battery charger is designed to be powered off of 12 vdc which will be supplied via the DC power jack from a wall outlet. The batteries will be 3.7v LiPo 3700 mAH in series to satisfy the voltage and current requirements suitable for system operation. This chip utilizes a switching charger that integrates high-side and low-side switches of a synchronous buck converter to provide efficiency to allow space to be saved on the PCB area. The system is complete with two open-drain status outputs that are used for charge status indication. To maximize safety this design also includes a negative thermal coefficient thermistor that acts to sense the battery temperature to ensure a safe operation environment for the battery. When the temperature exceeds the window of safe operation the charging is paused until the battery reaches normal operating conditions. Charge current is determined by the sense resistor (RS1) on the output of the CSP (Current Sense Positive Input) pin which is supplying a voltage of 100 mv which would produce a current of 2A for a resistance of 50 mΩ. Another component of the design that was calculated from the guidance of the datasheet is the Inductor (L1). This was found using equation ***3.1*** and the calculation resulted in the use of an inductor of the value 5.6 uH. All other resistances and capacitors were selected based on the application circuit provided for a 2 cell Li-Po battery with a 12v input from the data sheet highlighted in ***Figure 2.2*** above. For the design of the PCB the system takes into account the layout recommendations made by the Datasheet including routing the power stage adjacent to grounds, connecting pin 10 and 9 to minimize length and area of the circuit loop, connecting AGND and PGND at a singl point and placing the input capacitor as close as possible to the VIN and PGND pins to minimize current path loop area.

4.3.4 Interface Validation

otsd_rchrgbl_bttry_dcpwr : Input

Interface Property	**Why is this interface this value?**	**Why do you know that your design details <u>for this block</u> above meet or exceed each property?**
Inominal: 2 A	This nominal current was chosen based on the expected current needs of the system overall that was determined based on the data sheet	The DC power jack will feed in an input of 12V at 2A and based on the MP2615 2.2 A is the current drawn for trickle charge to be activated. [1] pg. 4
Ipeak: 3.2 A	The current maximum of the whole system is not expected to ever spike above this number. The value was	This max current is based on the current expected to be drawn in the Constant Current (CC) mode of

	selected by the use of the data sheet to determine the max current that the MP2615 chip may draw.	charging for the chip to supply current to the batteries. [1] pg. 4
Vmax: 18 V	This value is chosen based on the max voltage that may be supplied for this chip to function however the actual voltage supplied to the DC power jack will be 12 V.	his value is chosen based on the max voltage that may be supplied for this chip to function however the actual voltage supplied to the DC power jack will be 12 V. [1] pg. 4
Vmin: 4.5 V	This value is chosen based on the min voltage that may be supplied for this chip to function however the actual voltage supplied to the DC power jack will be 12 V.	his value is chosen based on the max voltage that may be supplied for this chip to function however the actual voltage supplied to the DC power jack will be 12 V. [1] pg. 4

rchrgbl_bttry_pwr_spply_crct_dcpwr : Output

Inominal: 750 mA	The nominal current was selected based on the necessary current draw of the system and the expected values that were determined from simulation to confirm what current the system will draw during normal operation.	This current was selected based on the values found for the Audio Amp and ESP32 Feather Current draw. At normal operation the Audio Amp draws 0.55 A @ 7.4 V and the Feather draws 0.2 A. This adds up to 750 mA under normal operation. [2] pg. 2 [3] pg. 22
Ipeak: 1 A	The peak current was selected based on the max current draw of the system and the expected values that were determined from simulation to confirm what current the system will draw during peak operation.	This current was selected based on the values found for the Audio Amp and ESP32 Feather Current draw. At the expected max operation the Audio Amp draws 0.75 A @ 8.4 V and the Feather Draws 0.25 A @ 8.4V. Resulting in a total of 1 A at the peak. The Audio amplifier has a maximum input current of 6.4 A [2] pg. 2 allowed and the Feather has a max current of 500 mA at its peak but only 200mA continuous should be budgeted. Therefore the Current should stay below the expected value. [3] pg. 22
Vmax: 8.4 V	This is the value of the maximum voltage for the LiPo battery that will	This value of 8.4 V is the max voltage that 2 LiPo’s in series discharge at

	be provided from 2 batteries in series.	max battery capacity. [4] pg.3
Vmin: 7.4 V	This is the value of the minimum voltage for the LiPo battery that will be provided from 2 batteries in series.	This value of 7.4 V is the min voltage that 2 LiPo's in series discharge at max battery capacity. [4] pg.3

Table 4.1

4.3.5 Verification Process

1. Plug-in batteries
2. Power Circuit (DC Power Jack)
3. Connect a multimeter to the positive and negative end of voltage input on input pins
4. Set DMM to read the input voltage
5. Observe the output voltage reading is between Vmin and Vmax
6. Measure Current
7. Observe to see within Current range
8. Measure Vin
9. Connect a multimeter to the positive and negative end of voltage output on output pins
10. Set DMM to read the output voltage
11. Measure Vout
12. Observe the output voltage reading is between Vmin and Vmax
13. Add a load to the output voltage pins
14. Set the current load to1 A[Inomial]
15. Measure the output voltage for 30 secs
16. Observe the output voltage reading
17. Change the load current to 1.5 xA[Ipeak]
18. Measure the output voltage for 30 secs
19. Observe the output voltage reading

4.3.6 References and File Links

[1] "Monolithic Power Systems," MPS. [Online]. Available: https://www.monolithicpower.com/. [Accessed: 11-Feb-2023].

[2] "Evaluation kit 20W stereo class D speaker ... - adafruit industries." [Online]. Available: https://cdn-shop.adafruit.com/datasheets/MAX9744.pdf. [Accessed: 12-Feb-2023].

[3] L. Ada, “Adafruit HUZZAH32 - esp32 feather,” Adafruit Learning System. [Online]. Available: https://learn.adafruit.com/adafruit-huzzah32-esp32-feather/downloads. [Accessed: 11-Feb-2023].

[4] “Type SR674361P rev 1.0 date 2013-3-8 - Farnell.” [Online]. Available: https://www.farnell.com/datasheets/2369105.pdf. [Accessed: 12-Feb-2023].

4.3.7 Revision Table

Date	Who	What Subsection	What was changed
1/28/2023	Quentin	All	Document Created
2/3/2022	Quentin	All	Draft Created
2/10/2022	Quentin	Interface Validation, Design	Updated Interfaces and expanded on the Design feedback changes

4.5 Power Supply Printed Circuit Board (PCB)

4.5.1: Description

This block will be a PCB block for the power supply. It will include a rechargeable battery system and a buck converter circuit to step down the voltages necessary to power the ESP-32 feather in our system. The rechargeable circuit is important to our system because it will allow for the system to be a wearable device while also improving the battery life of the system. The rechargeable battery system will take four hours to recharge the batteries, and our system can last for at least two hours. The PCB will be taking in an input voltage of a range of 7.4 V to 8.4 V and 1.5 Amps at its maximum. It will take in this voltage and go through a switch, then output the 8 V at 0.800 A for the audio amplifier, and then input the voltage into a buck converter circuit that will output 5V at 0.250 A to power the ESP-32. This block will also contain screw terminals to meet our system's universal connector requirement.

The power supply printed circuit board is a student designed PCB by Farhiya that includes all the circuitry for the full power supply of our system. This PCB is helpful to making our system a wearable device while also condensing the size of our power supply. It will allow for our system to recharge batteries without needing to continuously replace them and switch the full system on and off.

The PCB integrates both the buck converter and rechargeable battery circuitry onto a single PCB. This PCB takes in a 7.4V from 2 batteries in series and recharges them when necessary while also outputting 7.4 V for the audio amplifier and 5V to power the ESP-32. The output locations of both voltage values allow easy wiring to the audio amplifier and ESP-32 while also guaranteeing that the additional microphone hooked up to the ESP-32 does not receive any interference from the bass shakers.

4.5.2: Design

The buck converter will use a TPS54233 chips with supporting componenets to allow it to output a 5V output. The rechargeable battery circuitry uses at MP2615 chip and supporting components to recharge our systems LiPo batteries. This block is powered via the **clcltn_nd_ntgrtn_pwr_spply_pcb_dcpwr** with a maximum input voltage of 8.4 V. This block then outputs via the **pwr_spply_pcb_uc_pcb_dcpwr .**The image below represents the black box diagram of this block which showcases the input and output interfaces.

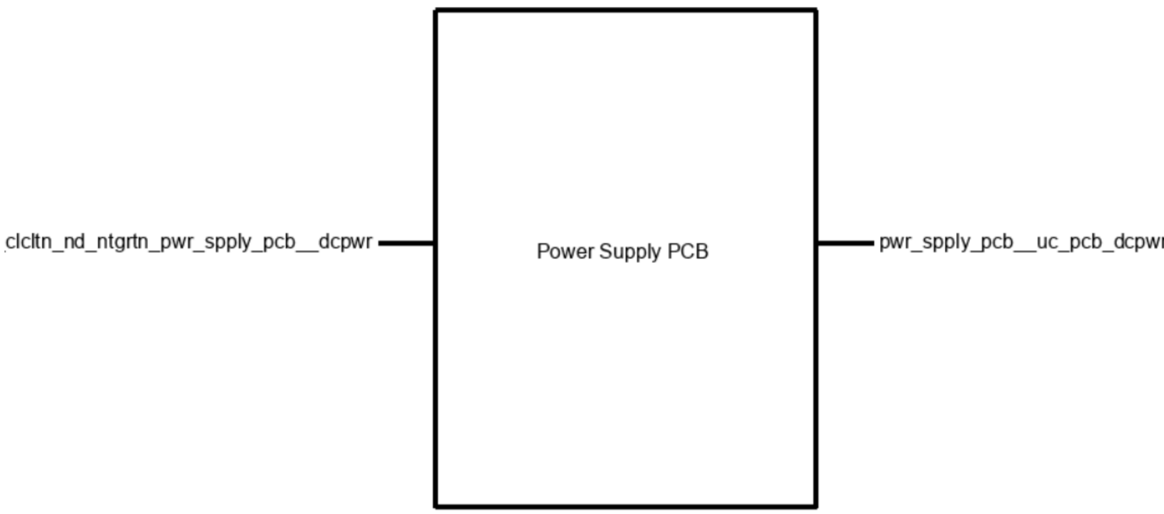


Figure 1: Power Supply PCB Black Box diagram

Based on this block interfaces the systems schematic is shown in Figure 2. The schematic includes both the MP2615 chip used for the rechargeable battery, 2 LED's to indicate when the system recognizes its fully charged and the second LED to indicate batteries are connected. It also includes the TPS54233 chip which is being used for the buck converter circuitry to power the ESP-32. You also notice 4 screw termianls on the system two for the batteries and then one on the top for the audio amplifier/Bass shaker and one on the right for the ESP-32. The buck converter also has an important resistor network R5 and R6 which determine the output voltage of the system. This design also includes a system switch which can turn on and off the full system.

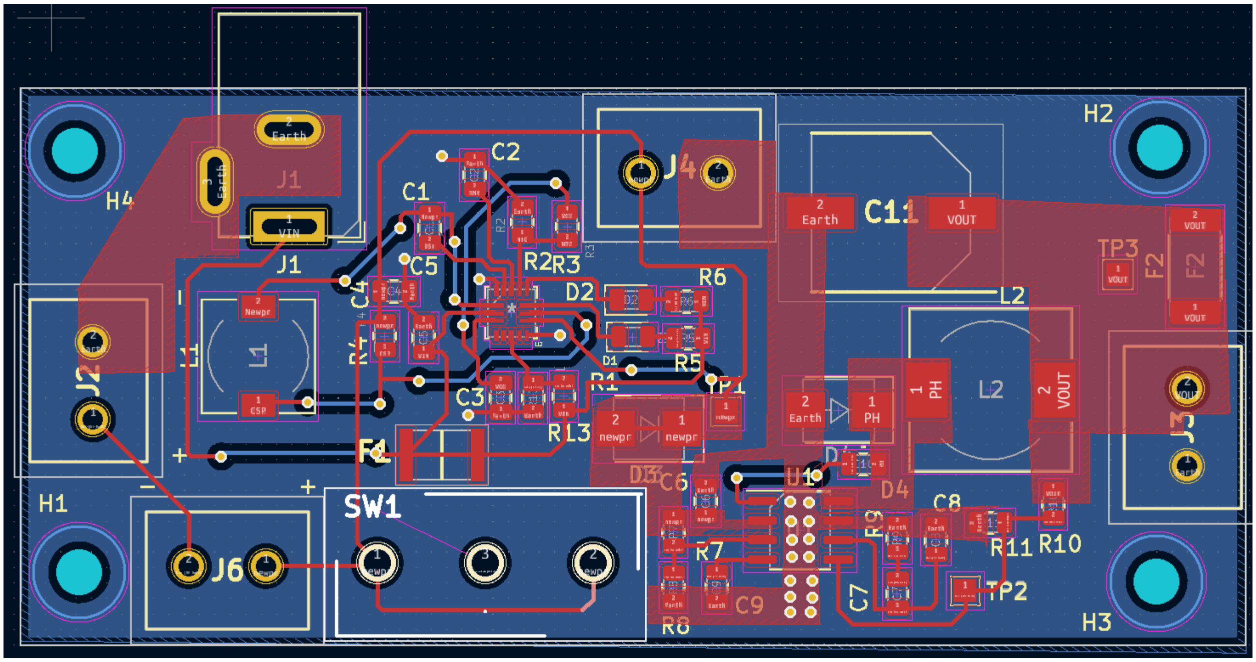


Figure 2: Power Supply PCB Layout

4.5.3: General Validation

We decided to create a single PCB for our full power system due to a specific request made by our project partner. We were told early on that he wanted our full system to contain two main components and the power supply to specifically be on a single PCB. Since we knew we needed a buck converter, rechargeable circuitry and a switch we settled on this single PCB design. The buck converter needs to power an ESP-32 that requires 5 V to power on.

The PCB has a total of four screw terminals. The first two on the bottom left are for the two batteries in series. The terminal on the top is for the audio amplifier/bass shaker and the terminal on the right is for the ESP-32. The system also has a switch on the bottom and a barrel jack on the top right. The ESP-32 and the audio amplifier/ screw terminal ideally were seperated to allow for limited interferance to the microphone once connected. In addition, I followed guidance from the MP2615 datasheet to make the additional resistor and capacitor components as close together as possible to avoid additional noise in our system. The width of the traces were also calculated to ensure they were wide enough for the current we would be sending through. I personally used an online trace width calculator for my PCB calculations and figured out that you need at least a trace width of 15.4 mm for an input current of 2 Amps. This is an issue I ran into with my initial PCB design my trace width was too small limiting the amount of time the full system can run for.

Now to switch gears a bit and discuss teh footprint selection. The majority of our chips we imported a footprint selection to guarantee accurate orientation and size. In addition to the main chips we imported footprints of the screwterminals but build out own footprints for the switch used on the PCB. The components footprints were verified via the dimensions on their datasheet if we decided to use the preloaded ones in kiCad.

4.5.4: Interface Validation

Interface Property	Why is this interface this value?	Why do you know that your design details <u>for this block</u> above meet or exceed each property?

pwr_spply_pcb_uc_pcb_dcpwr : Output

Inominal: 1.3 A	When we tested the ESP-32 feather with the current working code at the desired input voltages and current of the battery, the ESP-32 consistently drew 0.200 amps of current. In addition to powering the ESP-32 the PCB needs to also power the audio amp. When we tested the adio amplifier it drew a range of current from 0.800 A to 1.1 A depending on teh potentiometer setting.	ESP-32 feather datasheet: Continuous use current draw: 200 mA [3, p.22]. Max9744(Audio Amplifier) Datasheet: Shutdown current: 1 uA [6 ,p.15]
Ipeak: 1.5 A	When we tested the ESP-32 feather with the current working code at the desired max output voltage, the current draw rose to 0.250 A. When we tested the potentiometer on the max setting it drew a current of 1.3 A to power the bass shakers from the audio amplifier	ESP-32 feather datasheet: Max current draw: 250mA [3, p. 22]. Max9744(Audio Amplifier) Datasheet: Shutdown current: 1 uA [6 ,p.15]
Vmax: 5 V	This voltage value was selected based on the maximum voltage value the ESP-32 feather USB pin can support	ESP-32 feather datasheet: USB Pin Voltage: 5 V BAT pin Voltage: 3.3 V/4.2 V [3,p. 22-25].
Vmin: 3.3 V	This voltage value was selected based on the minimum voltage value the ESP-32 feather USB pin can support	ESP-32 feather datasheet: USB Pin Voltage: 5 V BAT pin Voltage: 3.3V/4.2 V [3,p. 22-25].

clcltn_nd_ntgrtn_pwr_spply_pcb_dcpwr : Input

Inominal: 0.20 A	This is based on the consistent current draw of the ESP-32 feather at the maximum voltage	ESP-32 feather datasheet: Continuous use current draw: 200 mA [3,p. 22].
Ipeak: 0.250 A	This is based on the maximum the current draw of the ESP-32 feather at the maximum voltage	ESP-32 feather datasheet: Max current draw: 250mA [3,p,22].
Vmax: 8.4 V	This is based on the maximum voltage that can be supplied by the lithium polymer batteries, our system will be using	LP953743 LiPo battery: Nominal voltage: 3.7 V Max Voltage: 4.2 V *Our system is using a two cell-battery in series so therefore, our interfaces are doubled the above-listed values.* [2, p. 1]
Vmin: 7.4 V	This is based on the maximum voltage that can be supplied by the lithium polymer batteries our system will be using	LP953743 LiPo battery: Nominal voltage: 3.7 V Max Voltage: 4.2 V *Our system is using a two cell-battery in series so; therefore, our interfaces are doubled the above-listed values.* [2, p. 1]

4.5.5: Verification Steps

Below is the steps to verify that the above interface values are met by the hardware schematic presented. These interfaces are tested and validated using two main pieces of equipment: A DC power supply and a DC Electric load. You will also need two sets of cables for your input and output connectors on your system. This board was assembled on a printed circuit board due to the ease of future testing, but it could also be assembled on a protoboard or a breadboard; the TPS54233 chip is very small, so breadboarding may be a bit difficult.

A. Nominal current testing
1. Connect the buck converter circuit block to the DC power supply via the **clcltn_nd_ntgrtn_pwr_spply_pcb_dcpwr** interface at 7.4 V. On the DC power supply, set the V-set to 7.4 V and I-set to 0.500 Amps. Also
2. Using a DC electric load **pwr_spply_pcb_uc_pcb_dcpwr** to draw 0.200 Amps.
3. Power the DC power supply and DC electric load for 30 seconds. Ensure the output voltage is between 3.3 V and 5 V.
4. Repeat steps 2 and 3 for a system with an 8.4 V input voltage via **clcltn_nd_ntgrtn_pwr_spply_pcb_dcpwrr** interface.
5. For success, the voltage output on the **pwr_spply_pcb_uc_pcb_dcpwr** interface always stays within the range of 3.3 - 5.0 V, and the current draw never exceeds1.3 A. While the input voltage via **clcltn_nd_ntgrtn_pwr_spply_pcb_dcpwr** interface never exceeds 7.4 V - 8.4 V .

B. Peak current testing
6. Connect the buck converter circuit block to the DC power supply via the **clcltn_nd_ntgrtn_pwr_spply_pcb_dcpwr** interface at 7.4 V. On the DC power supply, set the V-set to 7.4 V and I-set to 0.500 Amps.
7. Using a DC electric load **pwr_spply_pcb_uc_pcb_dcpwr** to draw 1.5Amps.
8. Power the DC power supply and DC electric load for 2 seconds. Ensure the output voltage is between 3.3 V and 5 V.
9. Repeat steps 2 and 3 for a system with an 8.4 V input voltage via **clcltn_nd_ntgrtn_pwr_spply_pcb_dcpwr** interface.
10. For success, the voltage output on the **pwr_spply_pcb_uc_pcb_dcpwr** interface always stays within the range of 3.3 - 5.0 V, and the current draw always exceeds1..5 A. While the input voltage via **clcltn_nd_ntgrtn_pwr_spply_pcb_dcpwr** interface never exceeds 7.4 V - 8.4 V .

4.5.6.1 References (IEEE)

[1] "HUZZAH32 - esp32 feather guide datasheet by Adafruit Industries LLC," *Digi*. [Online]. Available: https://www.digikey.tw/htmldatasheets/production/2314596/0/0/1/huzzah32-esp32-feather-guide.html. [Accessed: 10-Feb-2023].

[2] "LP953743_3.7V_1500mAh," *Lipo Battery Datasheet*. [Online]. Available: https://www.lipolbattery.com/LiPo-Battery-Datasheets.html. [Accessed: 10-Feb-2023].

[3] "TPS54233," *TPS54233 data sheet, product information and support | TI.com*. [Online]. Available: https://www.ti.com/product/TPS54233. [Accessed: 10-Feb-2023].

[4] “Monolithic Power Systems,” MPS. [Online]. Available: https://www.monolithicpower.com/. [Accessed: 13-May-2023].

[5] “Evaluation kit 20W stereo class D speaker ... - adafruit industries.” [Online]. Available: https://cdn-shop.adafruit.com/datasheets/MAX9744.pdf. [Accessed: 13-May-2023].

[6] Evaluation kit 20W stereo class D speaker ... - adafruit industries, https://cdn-shop.adafruit.com/datasheets/MAX9744.pdf (accessed May 14, 2023).

4.5.6.2 File Links

[1] F. Osman , T. Fealey, T. Roelle, and Q. Onyemordi,“WK6 Draft Project Document: Section 1+2,” *Google Docs*. [Online]. Available: https://docs.google.com/document/d/1NOoQgi1FZgtK3x3ZYF84-wZMc1hf4UZgz7ld61XeRVI/edit. [Accessed: 10-Feb-2023].

[2] F. Osman , T. Fealey, T. Roelle, and Q. Onyemordi, “Blockdiagram VibraSonics,” *Google Drive*. [Online]. Available: https://drive.google.com/file/d/1WWps-8zdQUNclFs8_MGBR2Z0FmM8wit0/view. [Accessed: 10-Feb-2023].

4.5.7: Revision Table

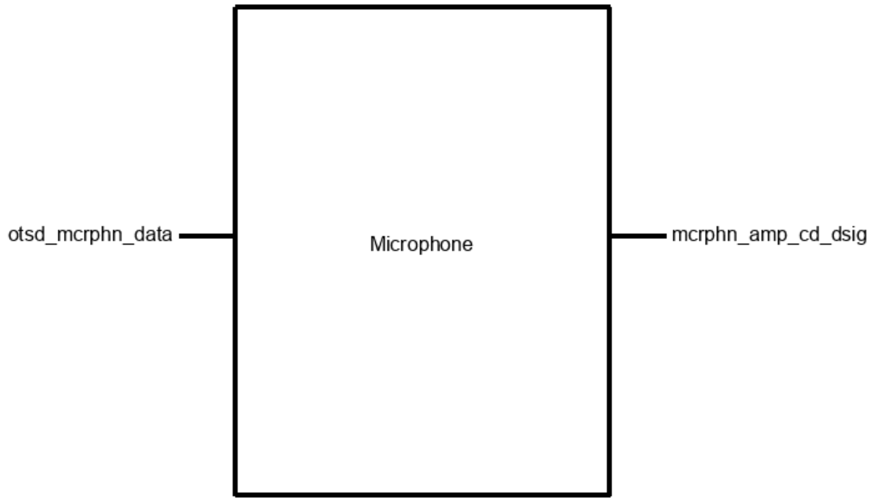
5/13/2023	Farhiya Osman: Completed Description, Design, verification and validation sections
5/14/2023	Edited all sections of document

4.6 Microphone

4.6.1 Description

The microphone block is one of the ways in which our system will receive audio input. It will sense sound and take the frequencies and transmit them to the ESP32.The microphone our system uses is a MAX4466 that is powered via the ESP32 3.3V pin. Including the microphone allows us to have a system that can switch between two audio inputs.

4.6.2 Design



4.6.3 General Validation

This blocks purpose to to receive inputs from a microphone, to validate that the microphone is working correctly: plug into a 3-pin connection converter to audiojack. This will allow the user to tell if the microphone is working correctly.

4.6.4 Interface Verifcation

Interface	Properties
otsd_mcrphn_data	• Other: 9 out of 10 users can use the microphone • Other: Receives frequencies 10-16000Hz
mcrphn_amp_cd_dsig	• Vmax = 3.3V • Vnominal = 1.65V • Max Frequency = 16000Hz

4.6.5 Verification Steps

A) Connect 3.3V to the microphone
B) Connect microphone to the audio amp board
C) Play audio

4.6.6.1 References

[1] “Electret Microphone Amplifier - MAX4466 with Adjustable Gain”, *Adafruit.com*, [Online]. Available: https://www.adafruit.com/product/1063 (accessed 11/29/2022).

4.6.6.2 File Links

4.7 Audio Amplifier

4.7.1 Description

This block consists of two combined parts that are needed to test. The first part of this test is the bass shakers, which are tactile transducers that convert low frequencies to a physical sensation, which in this case are vibrations. The second part of the block is the audio amp, which converts an I2C file to an analog signal and outputs it to the bass shakers. The amplifier is not only supposed to make this conversion but also output these signals at a proper volume and frequency. This bass shaker/ audio amplifier system will take in power from a power supply, an audio signal from an ESP32, and output the signal to two bass shakers. These bass shakers will then vibrate an enclosure, allowing the user to feel and see the power of the shakers. This system will also be controlled by a potentiometer enabling the user to choose what intensity they want to feel. This system has the capability to produce noise, but using smart filtering, those frequencies will be shifted down and compressed in the bass section, where the shakers will have the best response and produce the slightest noise.

4.7.2 Design

The Black Box Diagram (Figure 1) represents how the system will interact with the rest of the project. Further down, these interfaces are expanded upon in table 1. These interfaces are shown with specified properties and use. Each input interface represents a different block that will help comprise the whole system. Despite the audio amplifier being included in testing for this block, it will eventually become a part of a separate PCB, however, for validation and verification the audio amplifier will be used and considered this block.

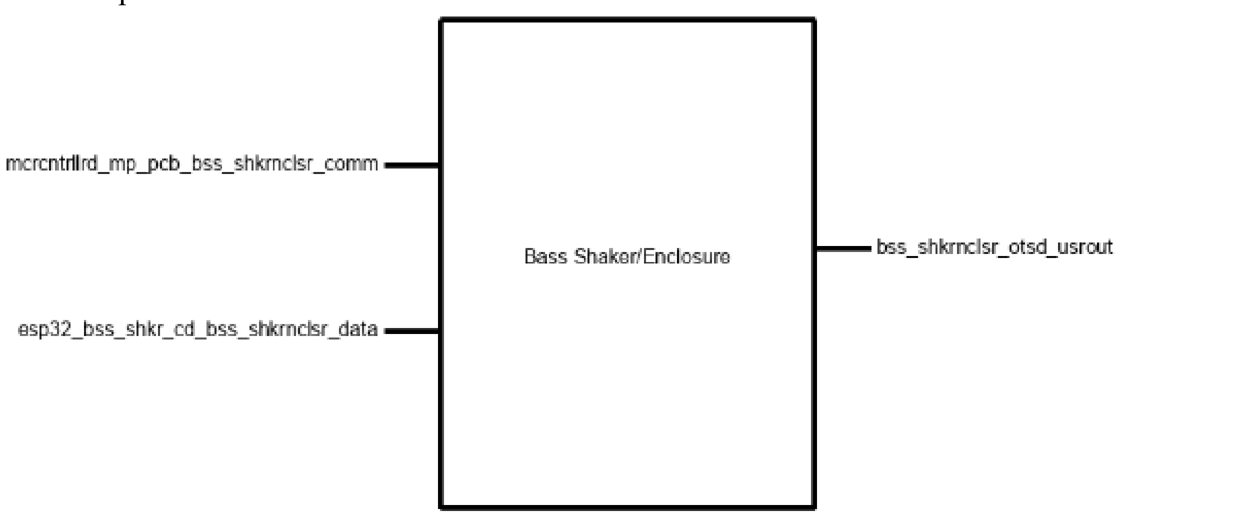


Figure 1. Black Box of the System

Interface	Properties	Purpose
Power Supply to Audio Amp	V_max: 8.4V V_min: 7.4V I_max: 1A I_nom: .65A	This input is for the power supply to the audio amp. This will be a crucial juncture so as to not burn out the amplifier by sending too

		much voltage or current.
Microcontroller to Audio Amp	Logic Level: Active High Vmax: 5V Vmin: 0V	This input is for the microcontroller to transmit frequency data to the audio amplifier using analog write since clean audio is not needed.
Bass Shakers to External	Type: The system output will be under 80dB Type: Vibrations between 10-120Hz. Usability: 9 out of 10 users will feel vibrations.	This output represents how the bass shaker/audio amplifier system will output its data, through a combination of sound and vibration powered by the amp.

Table 1. Interface Table

Below is the block diagram for the amp, including the systems attached to the audio amplifier. The power supply will send power to the audio amplifier. The audio amplifier will not only drive the bass shakers but also power them using the power sent from the supply. The ESP32 will be both code and a physical component that will send data to the amplifier. This data will be processed and then sent to the bass shakers. The potentiometer will allow the user to change the output intensity of the bass shakers using a little knob on the board. The audio amplifier to bass shaker circuit is just two terminal blocks with voltage and ground inputs that the bass shakers slot into. This system will use two bass shakers as a final product, but testing will include only one. The two bass shakers have an impedance of 8 ohms, but in parallel, they will only have 4 ohms, which is ideal for the audio amplifier.

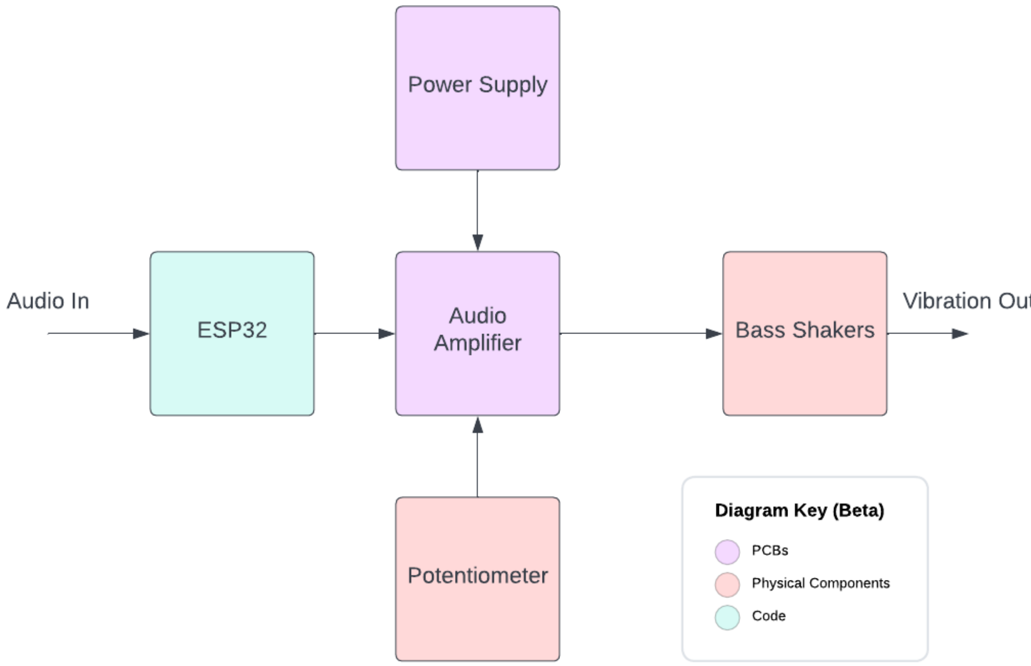


Figure 2. Block Diagram of the System

4.7.3 General Validation

This block fits in with the other blocks nicely and creates a system that will be the basis of the overall project. Since this block is one of the main components of the project, many systems attached to this block have their values chosen based on what this block needs. For instance, the power supply will need to provide a nominal voltage of 7.8V and a maximum of 8.4V at 650mA in order to power the audio amplifier. The ESP32 should send an I2S signal to the audio amplifier with frequency data encoded that is within the nominal frequency range of the bass shakers (20 to 80Hz from the Bass shaker data sheet [1]). The potentiometer should demonstrate a clear difference in vibration intensity when in use as indicated by our project partner.

In this section there will be two main components, the first is the audio amplifier circuit which will be used to demonstrate what power is needed along with what audio signals the block is expecting to see. This test board will also include a potentiometer that will increase or decrease the output intensity of the bass shakers. This system under test is using a premade board with an audio amplifier on it. This amplifier will be placed onto the system's custom PCB, but for validation, this test board will suffice. This test board can be powered by a wall wart that provides up to 12V at 2A and utilizes an audio jack to play music or tones. Both of these will only be used in the event that either the ESP cannot send proper signals to the amplifier, or if the power supply cannot provide the necessary power.

The second half of this validation is the bass shakers themselves. The bass shakers will be used to demonstrate both output intensity and the voltage of the amplifier output. Both bass shakers will output at the same frequency and intensity. These bass shakers have an ideal frequency response between 20 to 80 Hz but can play any frequency if you sacrifice feeling a strong vibration response. The bass shakers do not need to be powered externally and will instead be powered by the amplifier.

The test board bought will be from Adafruit and will come mostly pre-assembled, except for a large capacitor and some terminal blocks. This board has been chosen since the bass shakers by Dayton Audio also fit the specifications given by our project partner. The MAX9744 amplifier is a 20W amplifier and our bass shakers are also powered by 20W. On top of this, the bass shakers have an impedance match with the 4 ohms that the amplifier is expecting to see.

Both components, the bass shaker and test board, individually are off-the-shelf components, but in the final system, the amplifier will have its own custom PCB. Other options for impacters in similar weights and dimensions were considered and can replace the ones currently being used if needed. As for the audio amp, this amplifier is unfortunately the best option available. Other amps exist but they are normally much bigger and more expensive or cannot provide the necessary voltages to drive the bass shakers. If this amplifier doesn't work a more expensive one will have to be implemented onto our PCB. All the components apart of this block, besides the bass shakers themselves will be used in different systems, so it is important to prove if given the correct inputs, they will function correctly together.

4.7.4 Interface Verifcation

Pwr_spply_crct_ad_mp_dcpwr: Input

Value	Reasoning	Justification
V_max: 8.4V	8.4 Volts is over the nominal voltage but is also the maximum voltage our system can produce so 8.4V should rarely be hit.	While the absolute maximum voltage of the MAX9744 is 16V, 8.4V is the maximum our system can produce and gives some breathing room for a higher current.
V_min: 7.4V	The amplifier will still produce sound at this voltage but it will have a smaller gain.	The minimum operating voltage of the MAX9744 is 4.5V so 7.4V is used since it is the minimum our system can produce.
I_max: 1A	1A was chosen because the	The absolute maximum

	power supply should not supply more current than this otherwise the battery may drain too quickly.	current of the MAX9744 is 6.4A but we do not want our system to ever produce that much current so 1A is used.
I_nom: .65A	The ideal current draw for both the amplifier and power supply.	Most wall DC Jacks that provide 12 V provide 2A so something under 2A of current was used.

Table 2. Interface Table for Power Supply to Block

Uc_pcb_ad_mp_dsig: Input

Value	Reasoning	Justification
Vmax: 5V	This value works as an input to the audio amp.	The maximum digital write voltage is 5V.
Vmin: 0V	When not transmitting a frequency we would expect no voltage.	The minimum voltage digital write can send is zero.
Logic Level: Active High	We do not want our system to be producing noise when no audio is playing.	Logic level active high will reduce our current draw when not playing anything.

Table 3. Interface Table for Microcontroller to Block

Ad_mp_otsd_usrout: Output

Value	Reasoning	Justification
Type: The system output will be under 80dB	Our system primarily produces vibrations that should be felt not heard so under 80dB seems appropriate.	80dB is roughly the same as walking down a busy street. We want to avoid having our system produce that much noise.
Type: Vibrations between 20-80Hz	The nominal operation range of the bass shakers is 20-80hz so that is range the response should be felt in.	The bass range of frequencies is from 60 to 250 Hz, which we will partially operate in allowing the user to feel a strong output.

Usability: 9 out of 10 users will feel an output	This system is ultimately built for the users so it is important that most people will feel a response.	While it isn’t possible to make sure every single person will feel the response, we want to come as close as possible.

Table 4. Interface Table for Block to External

4.7.5 Verification Steps

In this section, a detailed action plan will be presented, showcasing the steps of verification, including the building of the actual block. Each step after the first three can be completed in any order, but this is the one recommended to start with. Some tools are needed for assembly: a small Philips head screwdriver, a voltmeter, jumper cables, power supply male-to-male wires, a soldering iron, and solder.

1. The first step is to begin by constructing the amplifier and bass shaker circuit. First, the amplifier board must be assembled, which is soldering on all the terminal blocks and potentiometer onto the board. After the board is assembled, take the bass shakers and screw them into the amplifier terminal blocks, along with the microcontroller wiring. The bass shakers then need to be screwed into the enclosure. Once the system has been constructed, connect the power supply to the power terminal block and power the system at 7.8V.
2. The microcontroller used to test frequencies should have test code on it, if not the necessary code can be found in the resources section under files [1]. This code will be used to test the optimal frequencies by pressing enter to change the frequencies. Once the code is uploaded, the wiring can be assembled based on what the code specifies, but the pins needed are A0, A1, and ground.
3. Now the verification process can begin, first, a simple test using the power supply. Begin by varying the voltage between the maximum and minimum voltage. The system only needs to operate for 3 seconds under these conditions. While this test is happening, take note of the current when operating at both the maximum and minimum voltage. This current should never exceed the stated maximum current and should remain close to nominal despite these voltages.
4. Next it is time to confirm the microcontroller signals, to begin force the microcontroller to output a 1hz frequency and measure the voltage on the terminal block, then force the microcontroller to send an 80hz signal and measure the voltage on the terminal block. Voltages of 0 to 5 should be seen. When the 1hz is sent, the measured voltage should be close to 0V which would demonstrate that the signal sent is operating on an active high logic level.
5. Finally it is time to test the bass shaker output. During other tests, the bass shakers should be responding assuming the system is always receiving power. First, hold the bass shaker and play a tone. Vibrations should be felt, if they are, ask someone else if they can feel an

output. After making sure vibrations can be felt, begin testing the decibel level produced by the bass shaker. Using a decibel tracker online measure the output of the shaker by setting the frequency to 80hz and max intensity on the potentiometer. Lastly, we want to make sure that the frequency of the bass shaker is outputting the frequency we are sending. Get a frequency detector on your phone and confirm that this is the case.

4.7.6 Refrences and File Links

1. Dayton Audio. (2020, December 12). *PUCK™ TACTILE TRANSDUCER MINI BASS SHAKER*. Retrieved February 11, 2023, from https://www.daytonaudio.com/images/resources/dayton-audio-tt25-8-tt25-16-user-manual.pdf
2. *Dayton Audio TT25-16 Puck Mini Sound Exiter*. (n.d.). Speakerbuddies. https://www.speakerbuddies.eu/en/loudspeaker/exciter/product-2700.html
3. Maxim. (2008, September). *20W Stereo Class D Speaker Amplifier with Volume Control*. Retrieved February 11, 2023, from https://www.analog.com/media/en/technical-documentation/data-sheets/MAX9744.pdf
4. *Adafruit 20W Stereo Audio Amplifier - MAX9744*. (2014, March 12). Adafruit Learning System. https://learn.adafruit.com/adafruit-20w-stereo-audio-amplifier-class-d-max9744
5. *Build software better, together*. (n.d.). GitHub. https://github.com/udellc/Vibrosonics/blob/main/Source+code/FFTAndSynth/FFTAndSynth.ino

4.7.7 Revision Table

05/14/2023	Thomas Fealey: Added section

4.8 Audio Amplifier Code

4.8.1 Description

The ESP32 code controls a system consisting of bass shakers and an audio amplifier. Audio is sent into the ESP and is then filtered and converted into an I2C signal. The audio amplifier converts an I2C file to an analog signal and outputs it to the bass shakers. This Smart filtering is applied to reduce noise by shifting and compressing frequencies in the bass section, where the shakers have the best response. This filtering takes in both audio from a microphone and audio from an aux input and shifts the inputs down to within 200Hz.

4.8.2 Design

The Black Box Diagram (Figure 1) represents how the system will interact with the audio amplifier. These specific interfaces are then demonstrated in more detail in the table below.. The interfaces listed show the properties and why those properties were chosen. Since this is a code block, this portion of the system really only interacts with a small part of the whole, but has a big impact on how the system will operate. The code utilized here will be similar to that of the final code for the project. However, currently the code operates in more of a proof of concept state, showcasing specific values and inputs that the final system will both send and receive.

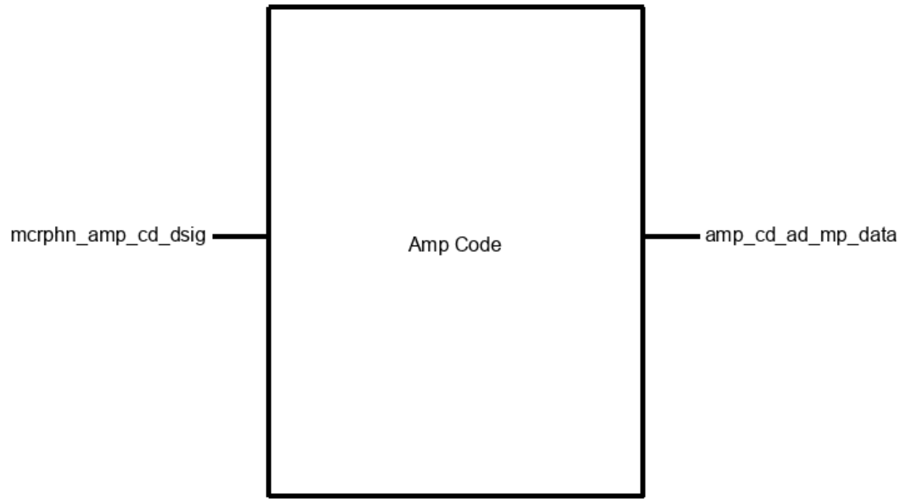


Figure 1. Black Box of the System

Interface	Properties	Purpose
amp_cd_ad_mp_data	Datarate: 32 Samples per second Protocol: I2S Other: Receives and process a mic input.	This output is for the Audio amplifier to receive and process. I2S is used since this is mimicking an audio signal we will need the left and right channels.
mcrphn_amp_cd_dsig	Max Frequency: 5000Hz Vmax: 3.3V Vnom: 1.65V	This input is for the microcontroller to receive a digital signal and process depending on the voltage level.

Table 1. Interface Table

4.8.3 General Validation

The ESP32 code system forms a crucial part of the overall project and seamlessly integrates with the audio amplifier block. Various system parameters are chosen based on the requirements of this code. For example, the microphone can only accept a certain amount of samples per second (32), so this is designed and output in the code. The ESP32 code should send an I2S signal within the bass shakers' nominal frequency range of 20 to 250Hz. The system accepts multiple forms of audio but will only respond to frequencies within 20 to 5,000Hz.

The code system comprises two main components. Firstly, there is the code for the audio amplifier circuit, which determines the necessary power and frequency of the audio signals. A separate test board with an audio amplifier is employed for validation purposes. The test board can be powered by a 12V, 2A wall wart and utilizes an audio jack for playing music or tones when needed.

The second aspect of the validation focuses on the audio input. The input will come from a microphone since wires have not been assembled for the audio jack. The microphone will then be played a test tone and that audio will be read into the ESP32 and filtered. This audio input should be mapped to a frequency range from 20 to 250Hz depending on the input frequency.

A test board from Adafruit, mostly pre-assembled, is chosen for validation as it aligns with the specifications provided by the project partner. The MAX9744 amplifier, with its 20W output power, matches the requirements of the 20W bass shakers. Furthermore, the impedance of the bass shakers (4 ohms) matches the amplifier's expectations. These in combination will help confirm that an I2S signal is sent and that a response is created based on the input.

While the test board and bass shakers are off-the-shelf components, the final system will feature a custom PCB for the amplifier. If necessary, alternative impactors with similar weight and dimensions can be considered. Although other audio amplifiers exist, they are either larger, more expensive, or unable to provide the required voltages for driving the bass shakers. If the chosen amplifier proves inadequate, a more expensive alternative will be implemented on the custom PCB. It is essential to demonstrate the proper functioning of all components in this block when given the correct inputs, as they will be used in different systems throughout the project.

4.8.4 Interface Verifcation

mcrphn_amp_cd_dsig: Input

Value	Reasoning	Justification
Vmax: 3.3V	This is the maximum voltage the microphone can output	The maximum digital write voltage is 5V and 3.3V falls within that.
Vnom: 1.65V	When the mic receives any input it varies the voltage from this point.	No input means the microphone will output 1.65V.
Max Frequency: 8000Hz	While human hearing falls off around 16,000Hz frequencies above 5,000Hz already sound squeaky.	5,000Hz is an acceple frequency for the mic to be able to pick up without any risk of damage.

Table 2. Interface Table for Microphone to Block

amp_cd_ad_mp_data: Output

Value	Reasoning	Justification
Datarate: 32 Samples per second	Anthing above this does not give accurate results.	The ESP can only produce 32 samples without clipping.
Protocol: I2S	I2S is the protocol used when sending audio from the ESP.	I2S a standard communication accepted by the audio amp.
Other: Receives and process a mic input.	This is the main goal of the packets sent by the ESP.	The mic input sends a dsig so the esp must also convert to an I2S signal.

Table 3. Interface Table for Block to Audio Amp

4.8.5 Verification Steps

In this section, a detailed action plan will be presented, showcasing the steps of verification, including the building of the actual block. Some tools are needed for assembly: a small Breadboard and 6 Jumper wires as well as MAX9744 and ESP32 Feather

1. Ensure all the connections are made, ground to ground, 3.3V to In on ther mic. A0 to mic input, A1, A2 to left and right on the amp board. After this plug the ESP32 into your laptop and send the code to the board.
2. Once the connections are made, pull up the serial plotter in arduino to ensure that all the microphone inputs are within 3.3V and that the nominal is at 1.65.
3. Begin Playing test tone frequencies, like 200Hz into the microphone and observe the results on both the amp system and the computer to ensure frequency and intensity.

4.8.6 Refrences

1. *Build software better, together*. (n.d.). GitHub. https://github.com/udellc/Vibrosonics/blob/main/Source+code/FFTAndSynth/FFTAndSynth.ino
2. Maxim. (2008, September). *20W Stereo Class D Speaker Amplifier with Volume Control*. Retrieved February 11, 2023, from https://www.analog.com/media/en/technical-documentation/data-sheets/MAX9744.pdf
3. [1] C. Electronics, Challenge Electronics tel: 1-800-722-8197 ISO 9001:2000 1-631-595-2217 ..., http://cdn.sparkfun.com/datasheets/Sensors/Sound/CEM-C9745JAD462P2.54R.pdf (accessed May 15, 2023).
4.

4.8.7 Revision Table

05/14/2023	Thomas Fealey: Added section

5. System Verification Evidence

5.1 Universal Constraints

5.1.1 The system will not include a breadboard

The syste will include a protoboard and PCB's to connect integrate the full system. The buck converter for the power supply is currently on a PCB and its connected to the batteries via a protoboard. This protoboard is also the connection point for the battery and the audio amplifier which connects to the bass shakers. The ESP-32 and its microphone is also connected to the protoboard from a PCB and with female/male connectors eliminating the need for a breadboard for any component of the system. The image below shows that our system is without a breadboard.

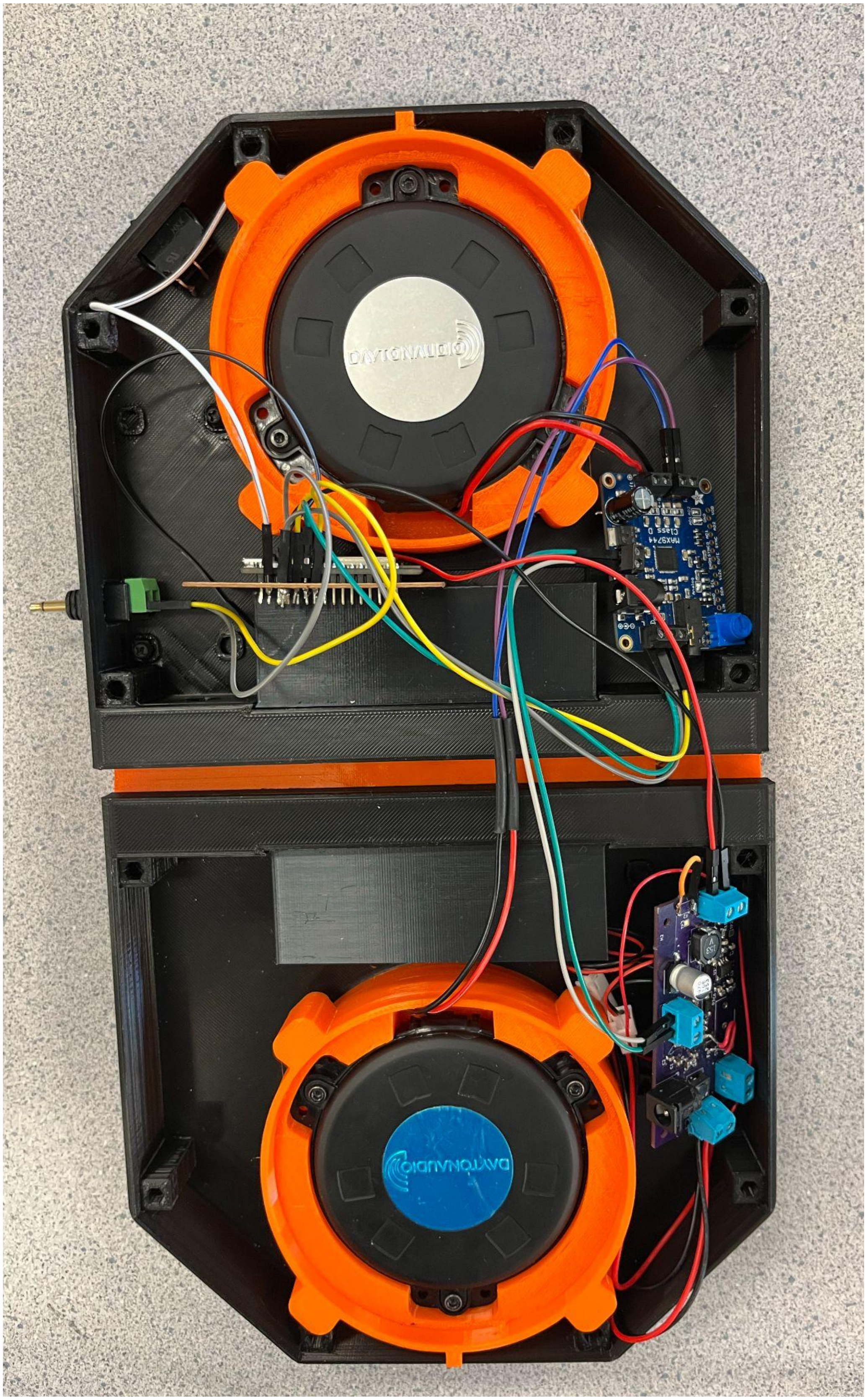


Figure 1.4: The image above showcases the system without a breadboard

5.1.2 The final system must contain a student designed PCB

The system has a power supply that is a student designed PCB that was created by Farhiya and it exceeds the 30 pad minimum for this project. See Figure 1.5 for verification of the Printed Circuit board.

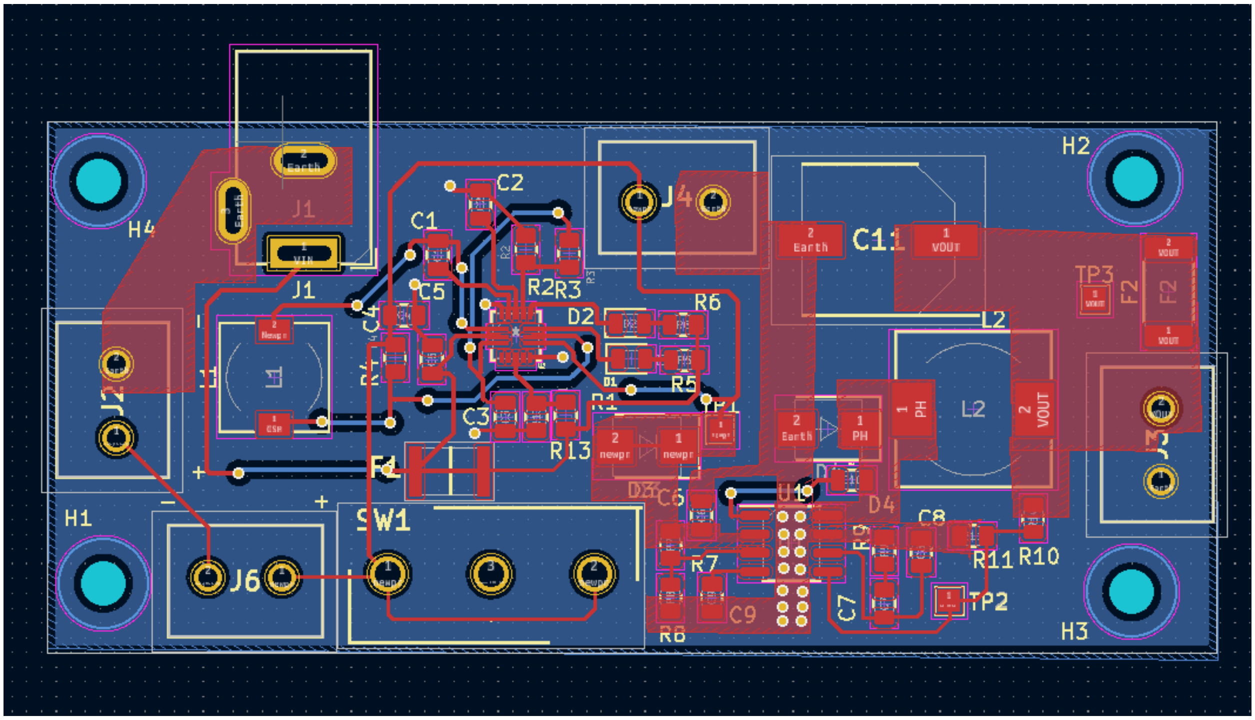


Figure 1.5: Power Supply PCB layout

5.1.3 All connections to PCB must use connectors

This engineering requirement is currently met with the power supply PCB because it does not have wires directly soldered to it. As seen in Figure 1.6 the PCB is supply powering to other modules in our system via screw terminal connectors

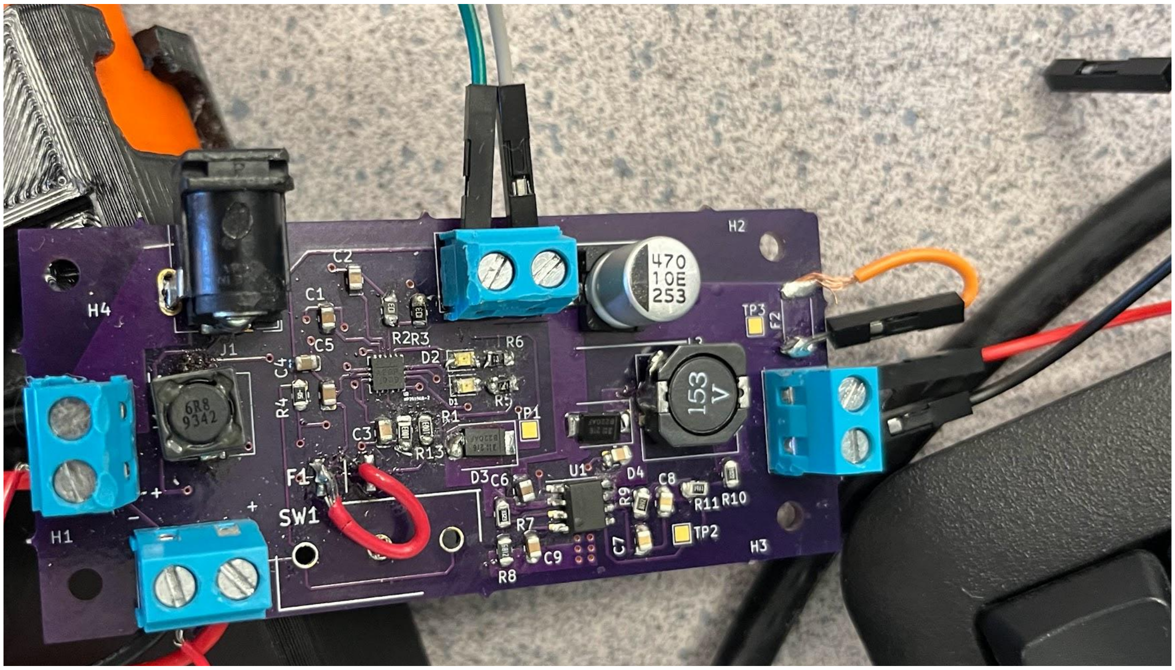


Figure 1.6: Power Supply PCB Connections are all via connectors

5.1.4 All power supplies must be at least 65% efficient

Our system is using a step-down converter for the buck converter circuit. This is the TPS54233 chip and it has a efficiency of 90% for Vin = 8 V and a Inominal = 0.250 A. Since this chip is outputting 5.0 V at 0.200 A for the ESP-32 it gives and input 1.48 VA and an output of 1.0 VA. Therefore from the datasheet and our calculations we know the efficiency rating is approximately 89% for the step-down converter we used in our buck converter circuit. The datasheet that showcases the efficiency of the TPS54232 chip is linked here. The system also incorporates a battery recharging chip (MP2615) The efficiency of this chip is 93% for a system utilizing 12V at 2A. Curve dictating these numbers can be found here.

5.1.5 The system may be no more than 50% built from purchased modules

Modules	Purchased or Built	Statement about Block Contents
Power Supply	Built	This block contains a buck converter and a rechargeable battery circuitry. The batterys are connected to this battery to power both the ESP-32 Feather and the audio amp while also being able to recharge the batteries. The

		Buck converter circuitry supplies 5V to the ESP 32 and at least 7.4 V to the Audio Amplifier
Audio Amplifier/Bass Shakers	Purchased	The audio amp is a purchased board from Adafruit. The Bass shakers will have a wired connection to the audio amplifier. These are purchased from Dayton Audio.
ESP-32 Feather Block	Built	The Esp-32 Feather is soldered to a protoboard. It has a wired connection to the audio amplifier. The board will be powered by our Power Supply PCB; it will receive 5V and 125mA.
Enclosure	Built	The enclosure is 3D-printed out of TPU. This will house our electronics.

5.2 Requirements

5.2.1: Adjustable Audio

5.2.1.1: The system must allow the user to control the audio

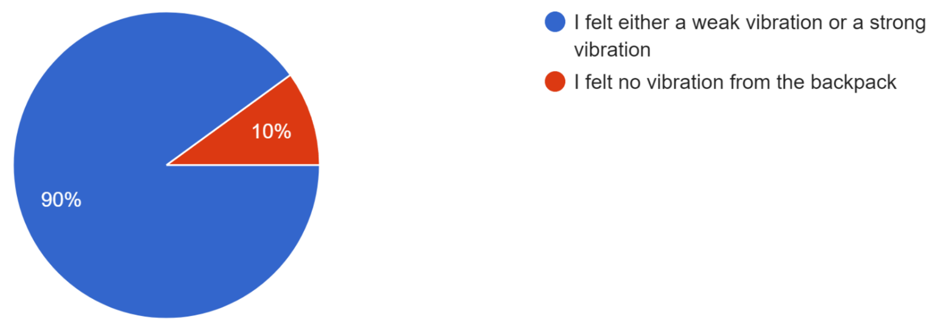
5.2.1.2: The system will allow 9 out of 10 users to adjust the system output reporting that "it can output weak up to strong vibrations."

5.2.1.3 **:** This test can be conducted with the wearable device and will be done following it.

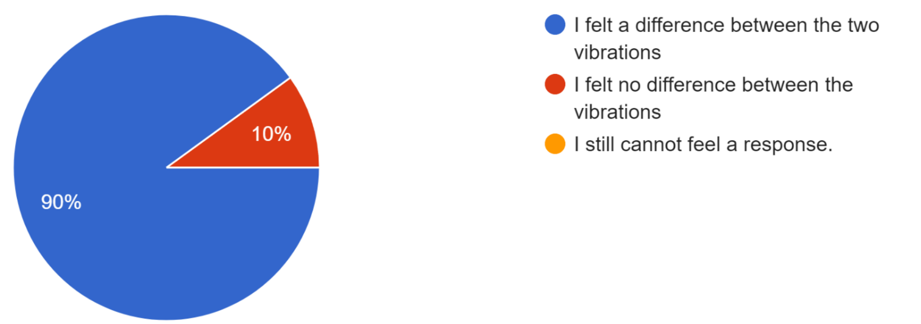
1. The user must play audio into the system and get a feel for the output of the system.
2. The user must then adjust the audio in either direction and report the intensity of the response.
3. After reporting the intensity of the first response, the user must then adjust the intensity knob in the other direction and report the level of response.

5.2.1.4: Video recording on a test subject.

When wearing the backpack were you able to feel either a weak or strong vibration?
10 responses



After adjusting the intensity did you feel a difference between the previous vibration and the new vibration?
10 responses



5.2.2: Audio Output

5.2.2.1: The output needs to be felt by the user (in the bass range)

5.2.2.2: The system will output frequencies between 10 to 90 Hz

5.2.2.3: For this test, a mobile phone app will be utilized.

1. Power on the system and begin playing audio through the system.
2. Open up a frequency analysis app on a mobile device.
3. Hold the mobile device up to the system and begin recording the frequencies.
4. Confirm no signal went over 90Hz consistently.

5.2.2.4: [Video recording of test.]

5.2.3: Battery Life

5.2.3.1: The system has a power supply that will power all parts

5.2.3.2: The system will operate for 2 hours on a single charge

5.2.3.3: Since the length of this requirement is long, we will provide a video demonstration.

1. First we need to power on the system, and begin playing audio to the system.
2. Turn the intensity up to the maximum setting and leave it there.
3. Begin recording and set a timer for 2 hours.
4. Check back with the system at 2 hours and verify that the system is still running.

5.2.3.4: Video Recording

5.2.4: Frequency Range

5.2.4.1: The system accepts audio inputs between the human listening range

5.2.4.2: The system output will respond to 0-1600Hz inputs to the system

5.2.4.3: The below steps verify that the system meets our required frequency ranges

1. Power on the system and begin sending a bass tone to the audio input.
2. Then begin testing the frequency at 40 Hz with an app that generates frequency range sounds.
3. Begin increasing the frequency by 20 Hz until 100 Hz.
4. After 100 Hz increase the frequency by 100 Hz until 1000 Hz.
5. Once 1000 Hz is hit increase the frequency by 1000 Hz until 16000 Hz.
6. Verify that a response is felt at each step.

5.2.4.4: Video of Frequency Range Test.

5.2.5 : Rechargeable Battery

5.2.5.1: The battery must be rechargeable

5.2.5.2: The system will indicate full charge after no more than 5 hours

5.2.5.3: In order to verify that the battery charges in the required time a video will be used.

1. Verify that the batteries have been used and can be charged.
2. Plug the batteries into the power supply and plug the system into the wall power.
3. Record the system and LED and leave the system for five hours.
4. Return after 5 hours and check that the red LED has turned off.

5.2.5.4: Video Recording

5.2.6: Switching Audio Inputs

5.2.6.1: The system can switch audio inputs

5.2.6.2: The system can switch between two audio inputs

5.2.6.3: This system needs to take in different audio inputs.

1. Power the system on and begin playing audio through the aux input, intensity does not matter.

2. After a response is produced by the system, switch the aux input for the mic input.
3. Wait for the system to respond to the new mic input.

5.2.6.4: Video recording of test.

5.2.7: Wearable Device

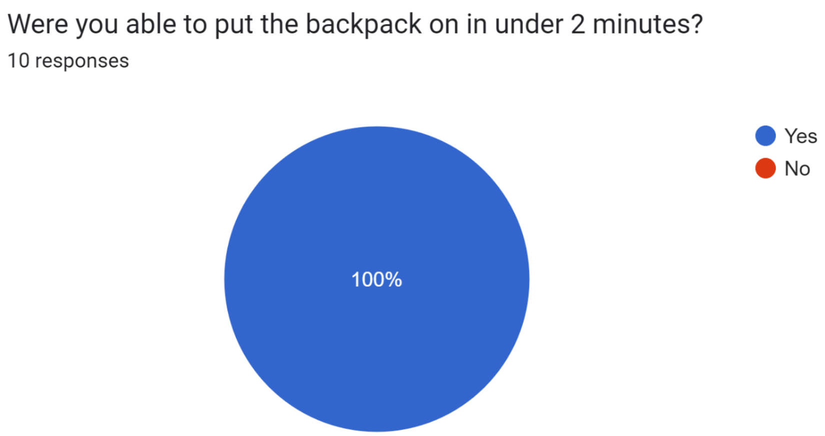
5.2.7.1: The system will be a wearable device

5.2.7.2: The system can be put on by 9/10 people in under 2 minutes

5.2.7.3: Since this is a user test we will provide a video.

1. Begin recording a video with both the user and the system.
2. Have the user try to pick up the system and put it on.
3. Record the time it took to put on the system.

5.2.7.4: Video recording of test subject.



5.2.8: Weight Limit

5.2.8.1: The product must be wearable on someones back

5.2.8.2: The total electrical system must weigh under 5lbs

5.2.8.3: Below are the necessary steps to test the weight limit of our system.

1. Set up the scale for testing
2. Place the enclosure on the scale and zero the system
3. Add all the electrical components that are part of the system into the box onto the scale
4. Read the value on the scale to verify the weight of the system.

5.2.8.4: Photo of system w/boxs.

5.3 References and File Links

5.4 Revision Table

3/18/2023	Farhiya Osman: Updated Universal requirements and the system requirements sections
3/12/2023	Tyler Roelle: fixed format inconsistency
5/9/2023	Tyler Roelle: Added block statements for our system
5/10/2023	Farhiya Osman: Updated Universial requirements section
5/10/2023	Tyler Roelle: Added testing evidence for requirements

6. Project Closing

6.1 Future Recommendations

6.1.1 Technical Recommendations

For future technical recommendations of this project, we would start by consolidating the power board and the amplifier board into one unified PCB. This design choice creates the need for less wiring, which would lead to fewer potential disconnects due to the heavy vibrations created by the bass shaker [1]. In the current design, the wiring is done using screen terminals and some solder, these screw terminals are also a hassle to deal with, which is why combining both PCBs eliminates multiple problems.

The next recommendation is to design all of the PCBs in EagleCAD. While this class will require you to use KiCAD, EagleCAD is able to aid the mechanical team more with their designs, since Eagle can translate a PCB with all of the various component footprints on the board straight to Inventor. EagleCAD can also transfer designs easily over to KiCAD if needed, but KiCAD cannot do the same [2]. The project partner also requests for all designs to be in Eagle, but is okay if it’s not possible, however, it is highly recommended.

This project relies heavily on audio inputs, so an AUX input was used. However, it is not necessary thanks to many different forms of AUX splitters, the main one being a female stereo aux input to three wires, which allows those connections to go directly to the ESP [3]. The Mic that was not implemented can also utilize this as well since it will be possible to route the mic directly to the ESP or through this female aux input.

The final recommendation on the technical side of the project is to add fuses early onto the project design cycle, rather than at the end. Unfortunately, during testing of our buck converter circuit, an ESP was fried because too much current was sent to it [4]. If we had put fuses into our design earlier rather than later, we could've prevented the loss of an ESP. These fuses also help prevent components like chips and traces from burning up in the event of a short. Overall most things went well during this project's life cycle, but with these improvements, the project can be done better and faster.

6.1.2 Global Impact Recommendations

When considering all the global impacts, it is important to think of what is the most costly to the environment and the longevity of the project. For us, the biggest concern was prototyping and the waste associated with it. Our team iterated through three generations of PCBs and ordered parts for them. Those PCBs are no longer used outside of the most recent generation and serve no purpose other than contributing to e-waste. We recommend discussing all PCBs with the mechanical team and the project partner before sending one off to be fabricated. This will reduce e-waste [5] and also save time and money for the project since having multiple layers of quality control can help avoid simple mistakes in the designs.

Another issue that should be addressed is the batteries. Lithium Polymer batteries have been under some scrutiny ever since they were created and for some good reason. They can be prone to leaking and creating fires and in a wearable device that is a major concern. Because of this, we recommend moving away from LiPo do its fragility and problems with charging and moving towards something like solid-state batteries or even magnesium hydrogen batteries [6]. These batteries are more expensive but offer better safety features for similar battery capabilities. It is possible to stick with LiPo batteries as long as they are handled correctly.

6.1.3 Teamwork Recommendations

The hardest part of teamwork on this specific project is about coordinating with the two other teams, the mechanical and computer science teams. While in constant communication with each other, coordinating who will have what resources and who needs what, when can be challenging especially when it comes to PCBs on the EE side. This issue can create delays for all teams and lead to the project getting behind schedule since the ME team may be waiting on hardware from EE or EE might be waiting on code from CS. That is why when starting this project it is recommended that each team meet up and agree to create a unified schedule that all teams abide by so that no one is rushing to meet deadlines and everyone knows what is going on and when it's going on [7].

Another issue is keeping the project partner updated. While it is true that we had weekly meetings with our partner, it can get hard to remember everything that was done, whether it be verbal agreements on what chip to use or a completed PCB, some things just get forgotten about, which can lead to disagreements or delays in the future. That is why it is recommended that at every meeting someone writes down and keeps track of what was done during the meeting as well as what was said so that there is always a record of everything for both the team's use and future teams' use [8]. By following these recommendations all inter-team communication will go smoothly allowing for the project to finish on time.

6.2 Project Artifact Summary with Links

This project has three teams, a mechanical engineering team, a computer science team, and an electrical engineering team. Because of this, many of the project materials are split up across many different teams. The solution to this problem was to create a GitHub where all of the teams added their respective material too. However, we also maintained a shared drive that stores a lot of documentation such as design research, engineering reports, course documentation and videos. The GitHub repository can be found here, which will feature all of our schematics, code, and designs. The system was broken up into nine main blocks shown below in our systems block diagram.

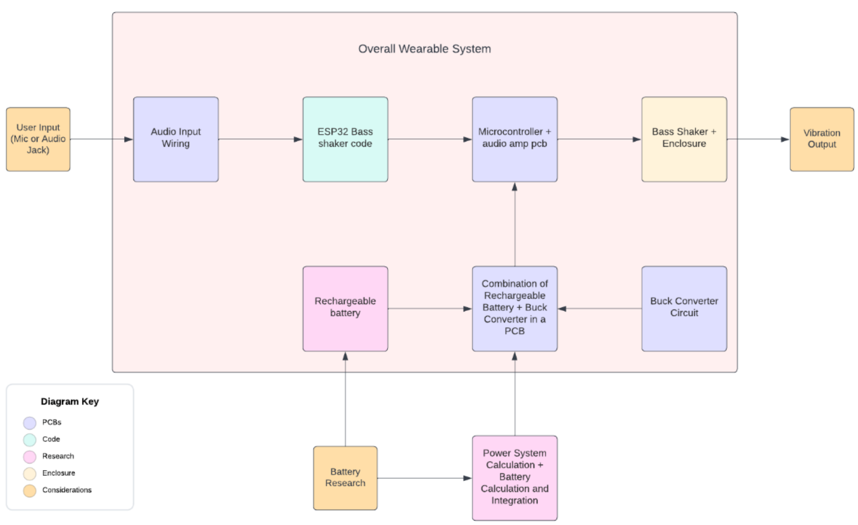


Figure 1: Systems Block Diagram

From this systems block diagram we decided to make the power supply of our system a PCB. A preview of both the power supply schematic and layout is shown below (Figure 2 & 3) . In addition to the power supply PCB schematic and PCB we have our enclosure rendering Figure 4 which shows the intended layout.

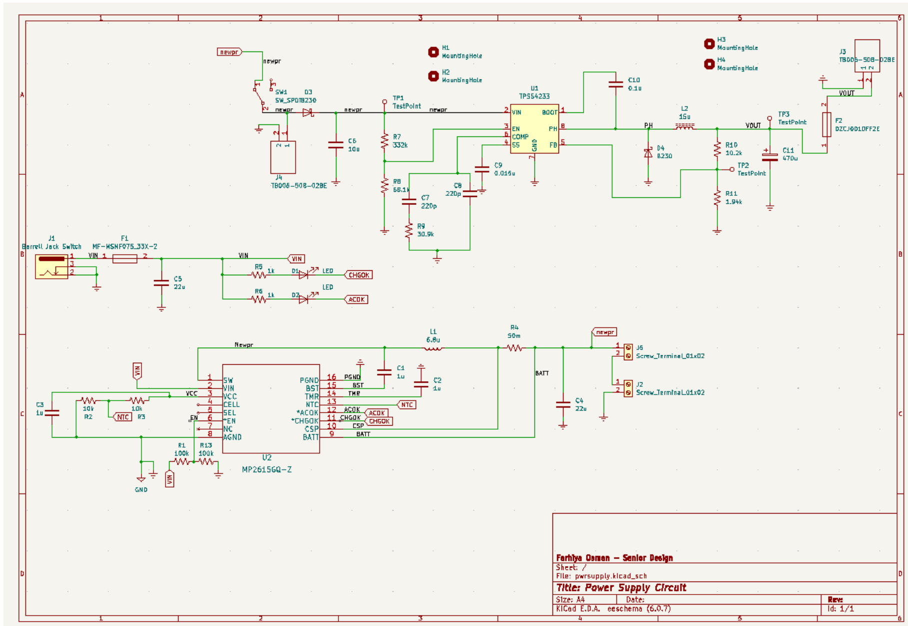


Figure 2: Final Power Supply Schematic

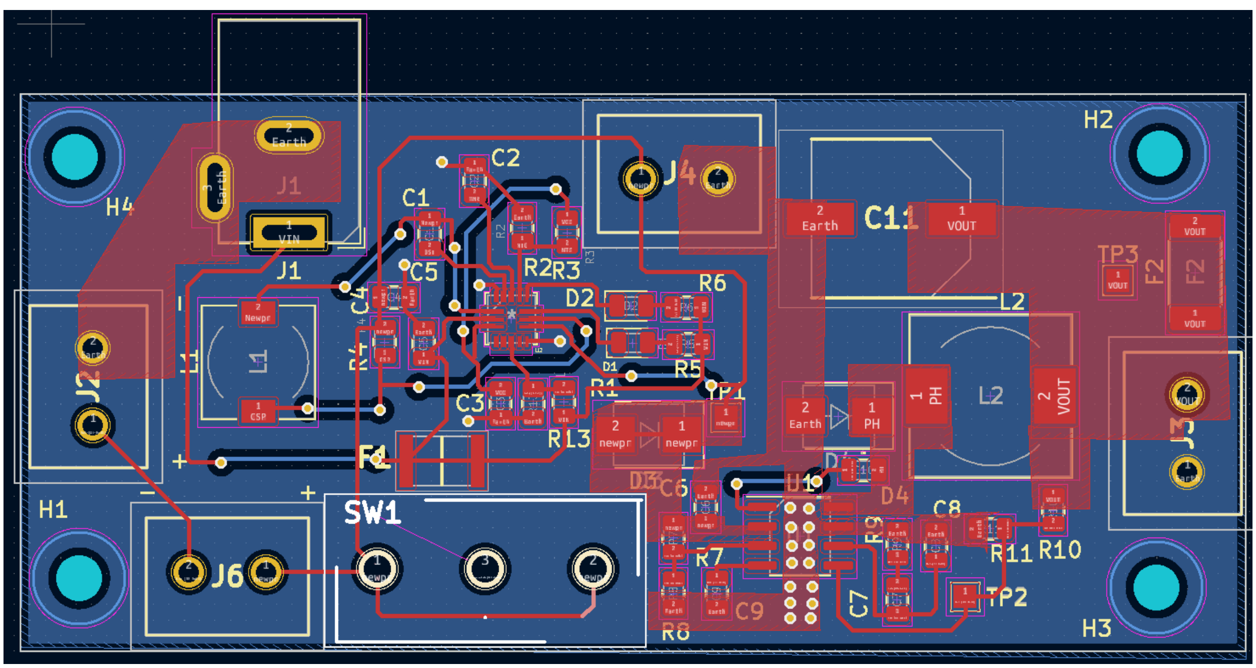


Figure 3: Final Power Supply PCB Layout

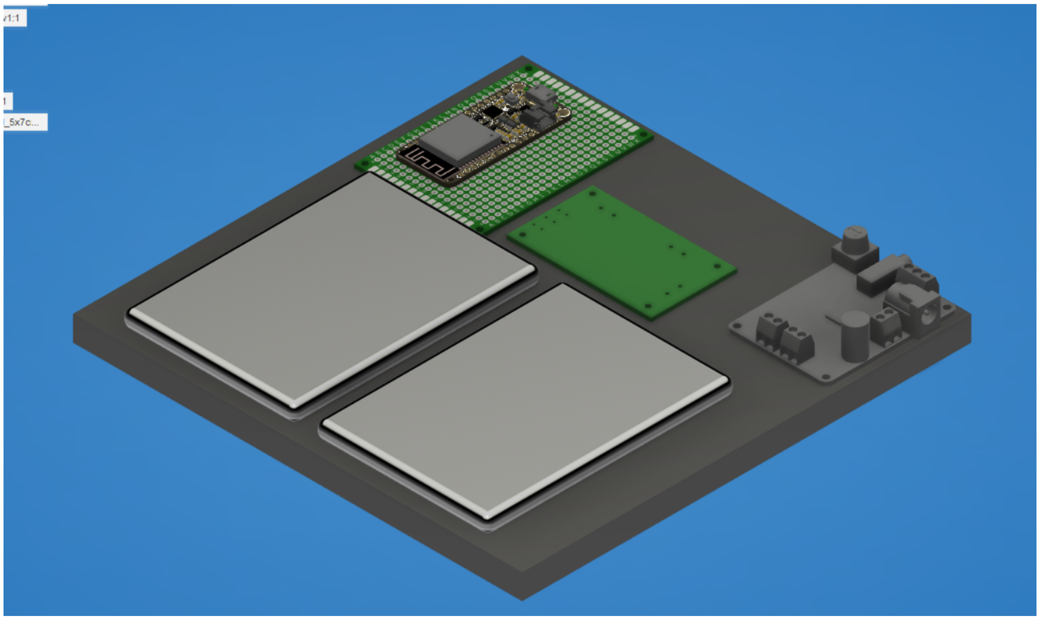


Figure 4: Prototype Enclosure

These renderings were assembled together to complete our design used in checkoff shown below in Figure 5. In the design below it showcases the tradeoffs both the Electrical team and the Mechanical team made to make sure our design would fit all the necessary components while also being a safe system for customers to use. This is why the batteries are placed on top of each other with insulation between them and the components attached to the potentiometer & the switch are located near the sides for easy customer access.

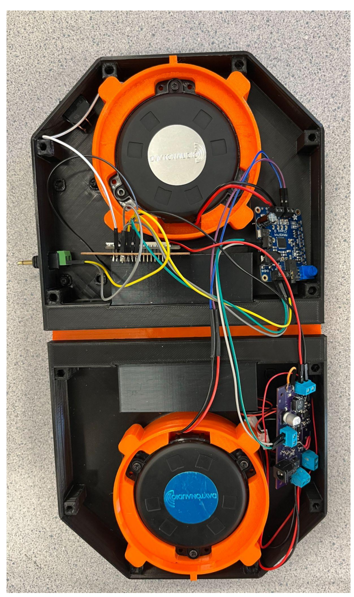


Figure 5: Completed System Design

This design also included some user testing to determine if our system was wearable and if the system had adjustable audio. The survey possible customers used is attached here. Also, a few additional engineering reports were created to help with our design choices. We created an engineering report on the selection of the Regulator for our buck converter which is attached here & a report on what battery we would use which is linked here. We also created a design impact statement which is discussed earlier but we relinked here as well to understand the different impacts our system has outside this course.

6.3 Presentation Materials

This section contains an image of the poster used at the expo as well as a link to the project showcase website which can be found here.

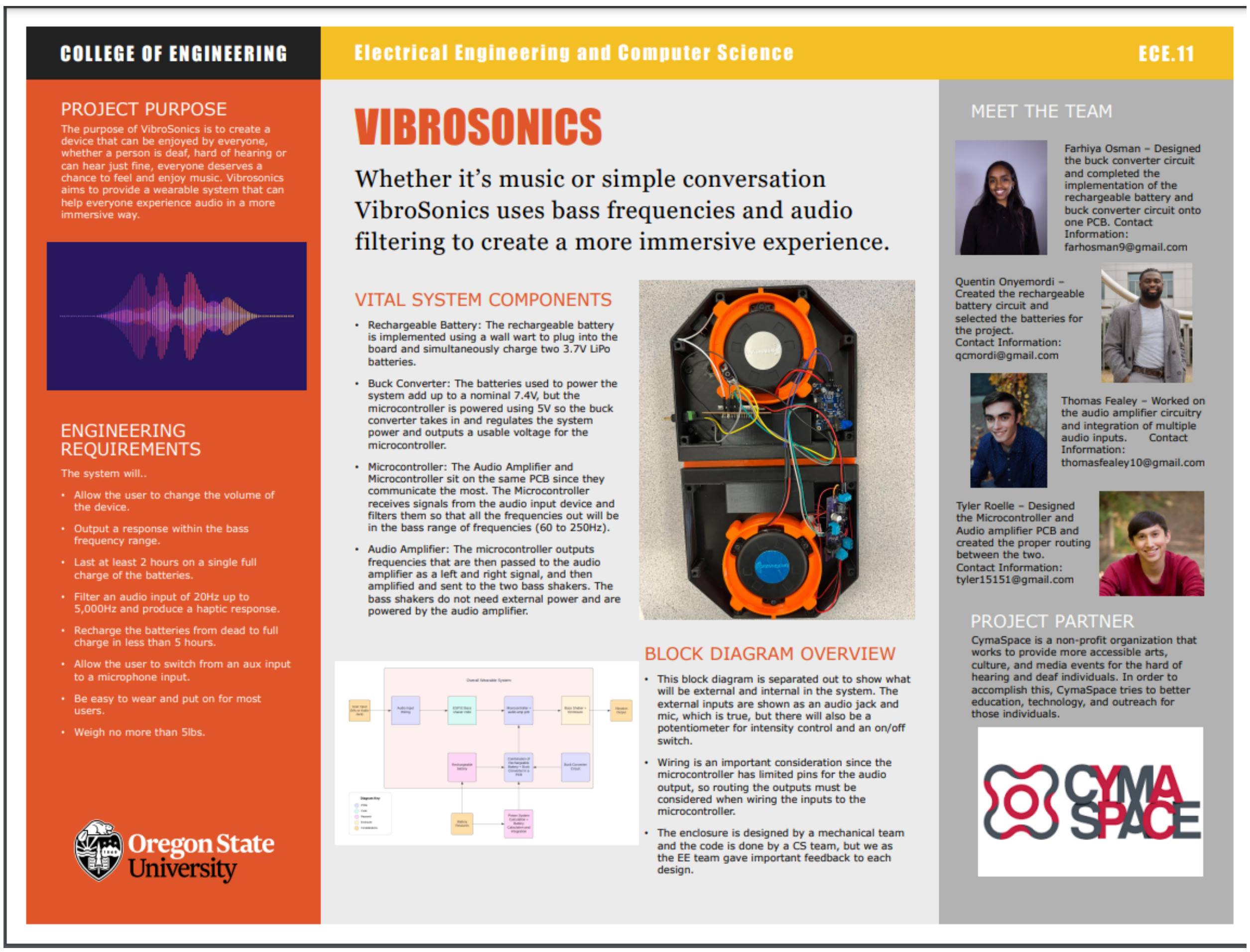


Fig 1. Poster Image

6.4 References

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6.5 Revision Table

04/28/23	Thomas Fealey: Added and populated section 6.