Modular Headphones Add On For Noise Cancelling

Team 18

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ECE 445

1.1 Introduction

Objective:

Problem Statement: There is a burgeoning market for wireless, active-noise cancelling headphones, however, currently, headphones that have these features are very expensive. Many people have wired headphones without active-noise cancellation.

Solution: We will to make an add-on to headphones, attached to the line-in, that modifies a headphone to be noise-cancelling. We will also attach an amplifier and an app alongside the hardware for noise-cancelling variability, frequency adjustment, volume control. By doing this, it will not only be user-customizable, but also cost-efficient. Our goal is a modular device that is capable of removing 50% of background noise, while maintaining 30% of the cost of popular noise cancelling headsets. We understand that headphones are made differently, so we'll also make an application that syncs frequency levels and noise-cancelling levels with the headphone.

Background Information:

Currently the headphone market is divided into two distinct segments: general consumer grade headphones that cost than or equal to $150, and high end "audiophile" headphones that include the latest features and cost $200 and upwards (some headphones, such as the Sennheiser HD 800 model, can cost $1200 dollars!). Due to the recent removal of the 3.5mm headphones connection as a commodity in mobile devices, bluetooth audio has gone from being a luxury product to being priced with regular consumer headphones. Noise canceling technology, however, has remained at the upper range of the market and is still considered a luxury feature. In fact, simply adding noise cancelling to headsets can raise the price by $100 [1,2]In fact, this is quite a modest gain, as some headphones simply double in price with the addition of just one feature. This then creates a void in the market for low cost, yet good performance noise cancelling headsets.

High-Level Requirements:

- One characteristic our final project must have is the ability to reduce external sound levels by a significant amount of at least 20% noise reduction.
- Another requirement the project must satisfy is the ability to make a pair of headphones bluetooth, allowing a wireless connection between the audio device to the headphones.
- A third requirement would be the modular aspect of the project in the sense that if a user decides to not use the features, then they must have the ability to remove our project, and use the headphones perfectly with our addition removed.

1.2 Design and Requirement

Block diagram:

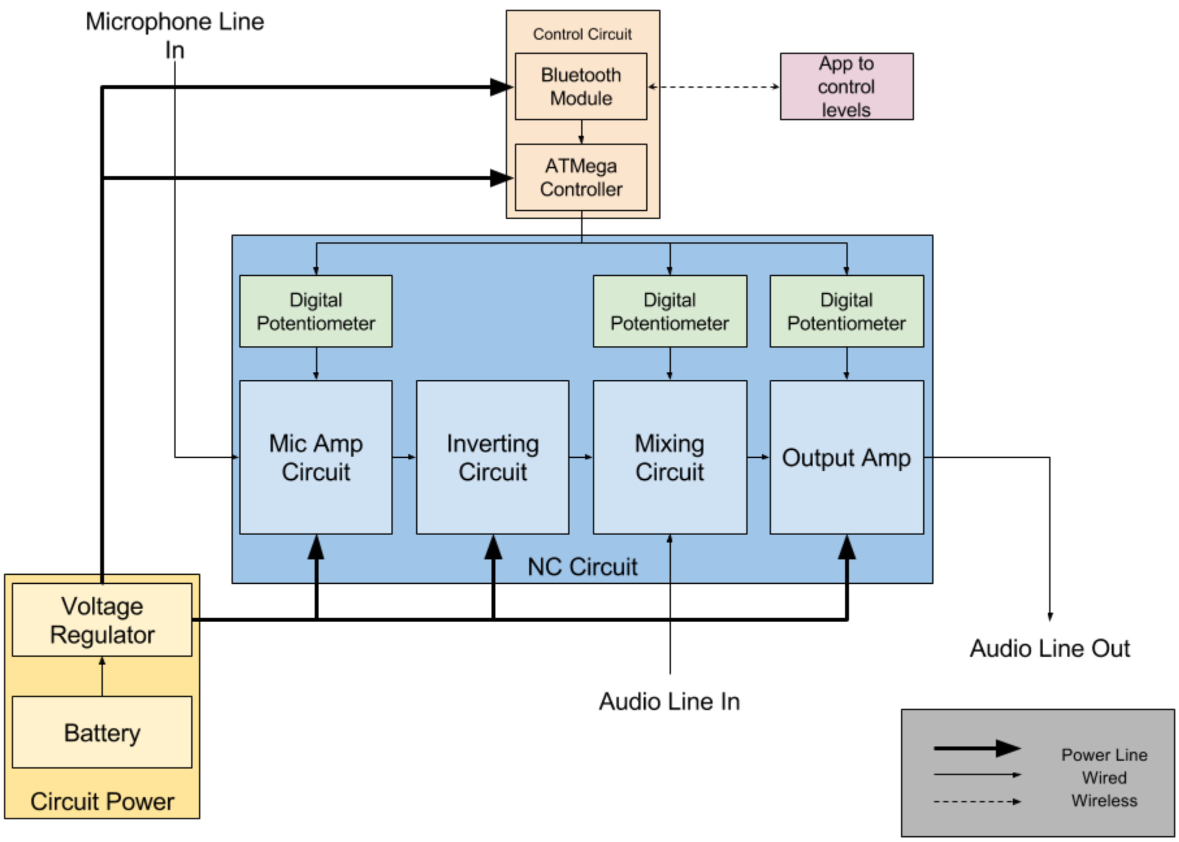

Figure 1: Block Diagram of the product.

Physical design:

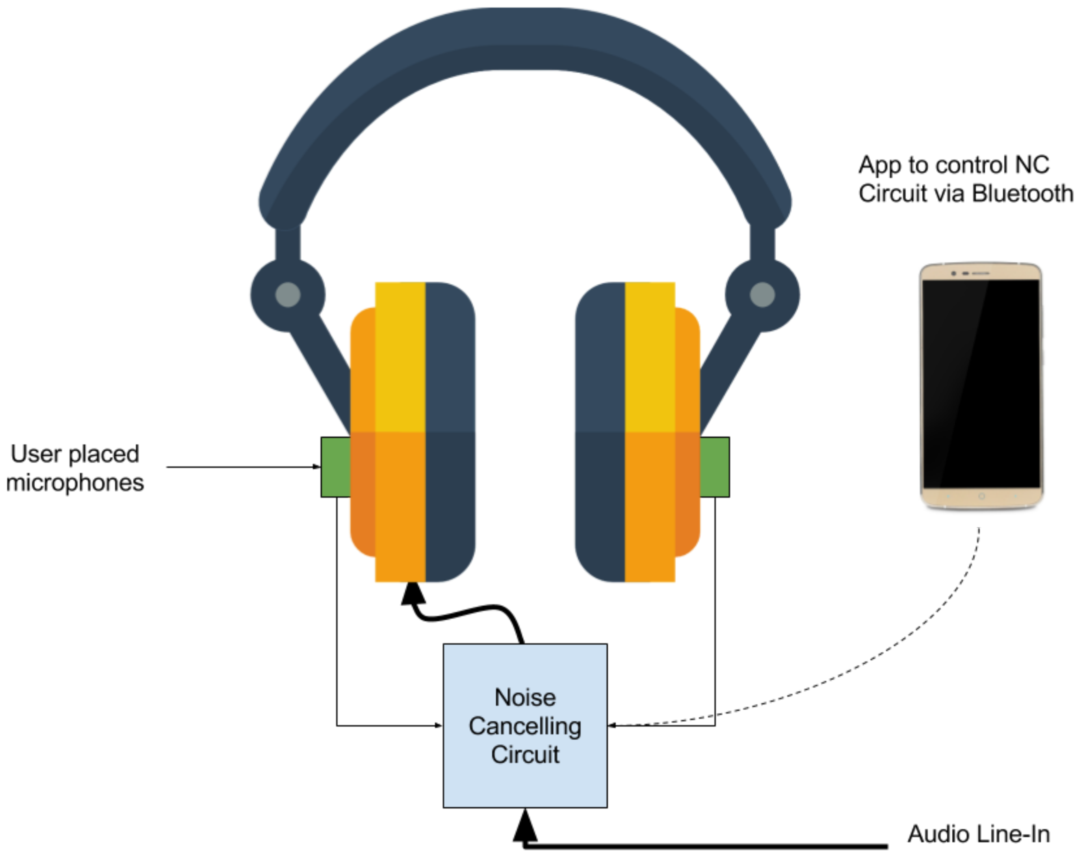

Figure 2: Physical mockup of design

The design of the physical container is expected to look like the following:

Figure 3: Product of similar design.

Where the device can plug into the the user's headphones and the user's audio device will be connected to the device as well.

Functional Overview:

- Control Circuit
    - The control circuit is made up of 2 components, the bluetooth module and the ATMega control, which work together to give wireless control of the noise cancelling circuit via an app that runs on a smartphone. The Bluetooth module communicates with the smartphone running the app so that parameters such as “microphone level”, “microphone mix level”, and “output amp level” can be controlled, allowing for fine-tuning of the NC circuit by the user based on the location/environment they are in. However, the bluetooth module is useless without the ATMega controller, which is used to convert the packets received by the bluetooth controller into actions taken by the NC circuit, effectively acting as a translator between the bluetooth module and the circuit itself.
    - Tolerances:
        - The ATMega328P chip that we will be using is rated for operating voltages between 1.8V and 5.5V at around 6.75mA at 1MHz. This means the ATMega chip will draw up to 37.5 mW while operating at 1MHz.

Requirements	Verification
1. ATMega chip must output signals to control digital potentiometers. 2. Chip must interface with bluetooth module to receive information from bluetooth device.	1. Test output pins of ATMega chip for any sort of output signal. Specifically, tests will be done to ensure bluetooth serial is working as needed through a serial output on a computer and a serial receiver on a smartphone. In addition, pluses for digital potentiometers will be tested on a oscilloscope to ensure the waveform is correct. 2. Check for change in output based on input from bluetooth device and android application. (i.e. the ability to toggle output voltage) a. This can be done easier once android application is complete, but hard coded values can be used to test this as well

Table 1: ATMega/Bluetooth Requirements and Verification

- Noise Cancelling (NC) Circuit:
    - The noise cancelling circuit is made up of four distinct components that act in a pipeline fashion to produce an output that is noise cancelled audio playing through the user's headphones. The first component is the microphone amp circuit, which takes in the signal from the microphones mounted on the sides of the headphones and amplifies said signal. This is done because the signal from the microphone may not be strong enough to be mixed into the incoming audio signal from the user's audio source. The second component is the Inverting circuit. This circuit takes input from the microphones attached to the headphones and inverts the signal. This contributes to the noise-cancelling attribute of the headphones as this step is crucial in cancelling external sound waves. The third stage in the pipeline is the mixing circuit. The mixing circuit takes the inverted microphone signal and adds the user's input audio signal to it. This effectively creates a noise cancelled version of the user's audio. In addition, if there is no audio coming from the user, then the circuit simply acts as a active noise cancelling headset, still providing silence to the user. The final stage in the pipeline is the output amp. This outputs an amplified version of the noise cancelled signal so that the user can control the output volume from the module itself. The digital potentiometers exist to allow for a control interface between the control circuit and the NC circuit. This allows for wireless control of the NC circuit.
    - Tolerances:
        - Each opamp, of which there are 8 total, will output a voltage of 4V max +- .3V , as rated per professional line level for audio, with current required to drive headphones at max impedance of 60 Ohms. This means each opamp will be delivering power of 0.267 Watts +- 0.0411 Watts. Thus total power usage is 2.136 Watts +- 0.0411 Watts.

Requirements	Verification
1. Inverting portion of the circuit must be able to invert any signal with frequency max of 1.5kHz and amplitude max of 8V. 2. Phase delay portion of the circuit should be able to variably change phase of input signal from 0 degrees to 45 degrees, while maintaining amplitude.	1. Test inverting circuit with pure sine waves of 700Hz at 8V, output should be perfectly 180 degrees phase shifted and of same amplitude. 2. Test Phase delay circuit with a pure sine wave of 700Hz at 8V, output should phase shifted with 45 degrees with the same amplitude and frequency as the input.

3. Summing amplifier should be able to take two signals and mix them, while outputting a gain that is set by a potentiometer, with a max voltage output of 5V at 65mA. 4. Inputs to the circuit should be 3.5mm headphone jacks, for compatibility. 5. All potentiometers should be able to be replaced with digital potentiometers that offer granularity on levels of 50 Ohm	3. Test summing circuit with 2 pure sine waves of 700Hz at 8V, output should be in same phase and of double amplitude. 4. Each circuit will then be tested using the same parameters and restrictions, however using different waves, which are detailed as followed: a. 1.5Hz Sine b. White Noise centered around 700Hz c. Audio from a media device played at an amplitude of 5V max. 5. Digital potentiometers will be tested such that op amp gain can be adjusted on scale of 50 Ohm. It should be noted that all tests will be performed on an oscilloscope and will be verified not only by inspection, but by using the mathematical functions available on the oscilloscope. For example, to test the inversion signal, the addition operator can be used to ensure we have an RMS of 0v on the output.

Table 2: Noise Cancelling Requirements and Verification

- Circuit Power:
    - The NC module is made to be powered by a battery, so it can be portable and operate anywhere. This means that two things are required. Firstly, a battery is required to provide power to the entire circuit when it is portable, ideally for extended periods of time. Secondly, a voltage regulation circuit is needed to regulate voltage between the battery and the NC and control circuits to acceptable levels. To charge the circuit, a TP4056 chip; the Vcc and ground signals will be connected to a micro usb charger. Charging is done via a wall charger, the rechargeable Li-ion battery lasting a day.
    - Tolerances:
        - The battery must have a capacity of 3000mAh, and must output 3.7 Volts per cell +- .3Volts. The battery must be able to support power usage of at least 3.136 Watts +- 0.0411 Watts

Requirements	Verification
1. Charging must provide enough power for the controller and NC circuit. 2. Charging must not overheat the module.	1. Once we connect to the NC circuit and Atmega, we can test how much power is actually drawn, and how much energy is used to both determine how many batteries to use. 2. As there might be an issue with overheating, depending on how much power is drawn on the physical device, we can empirically determine if we need heat sinks. a. The charging circuit has a Temperature sense input (TEMP). If this is an issue, we can add an NTC thermistor to the charging chip's TEMP input to disable charging when overheated b. Test control logic (there are many ways to connect) of the TP4056 for smart/safe ways to connect usb for charging

Table 3: Power Circuit Requirements and Verification

- Smartphone App
    - The smartphone app will be used to control and fine tune the noise canceling of the headphones. This is done by connecting the headphones to the app via bluetooth and then being able to regulate the NC circuit via sliders in the app. The fine tuning of the NC circuit is required because a modular NC unit cannot automatically acclimate to the requirements of the user, the environment the NC module is being used in, and also the placement of the microphones on the headset itself.

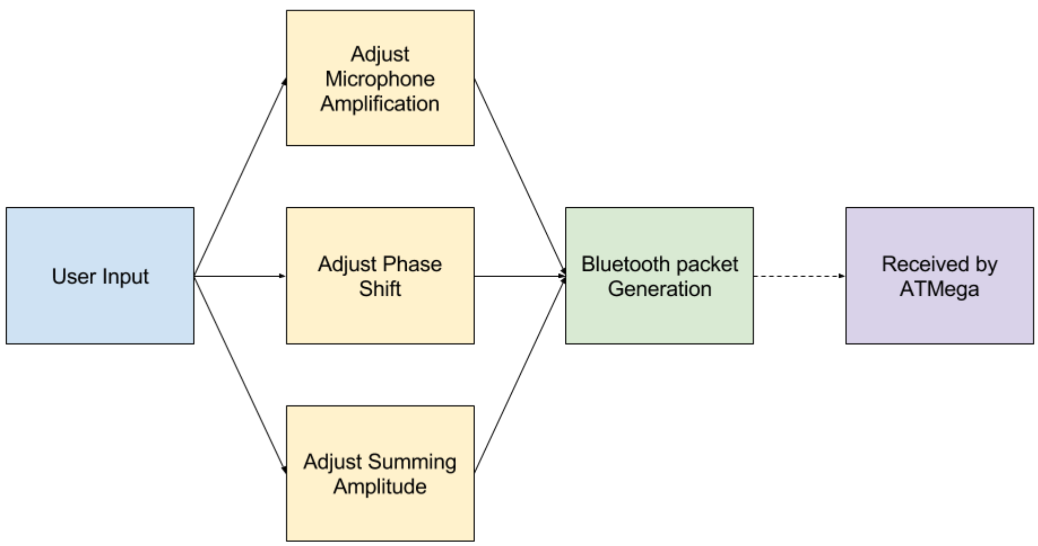

Figure 4: Flow for the smartphone Application

Requirements	Verification
3. Application must be intuitive to use and easily understandable 4. Application should be able to save the previous state of the circuit and restore the state to the circuit. 5. Application should be able to calculate the average frequency of the environment such that the circuit can be automatically tuned. This tuning should lead to noise reduction of 25%.	3. User studies will be conducted to observe how people who are new to the application react to seeing the application for the first time. 4. Saving state can be tested through multiple uses of the application, and through observation, the state saving and restoring can be observed. 5. Accuracy of frequency estimation and calibration can be tested through tests showing how much noise was cancelled in the final setup.

Table 4: Smartphone Application Requirements and Verification

Schematics:

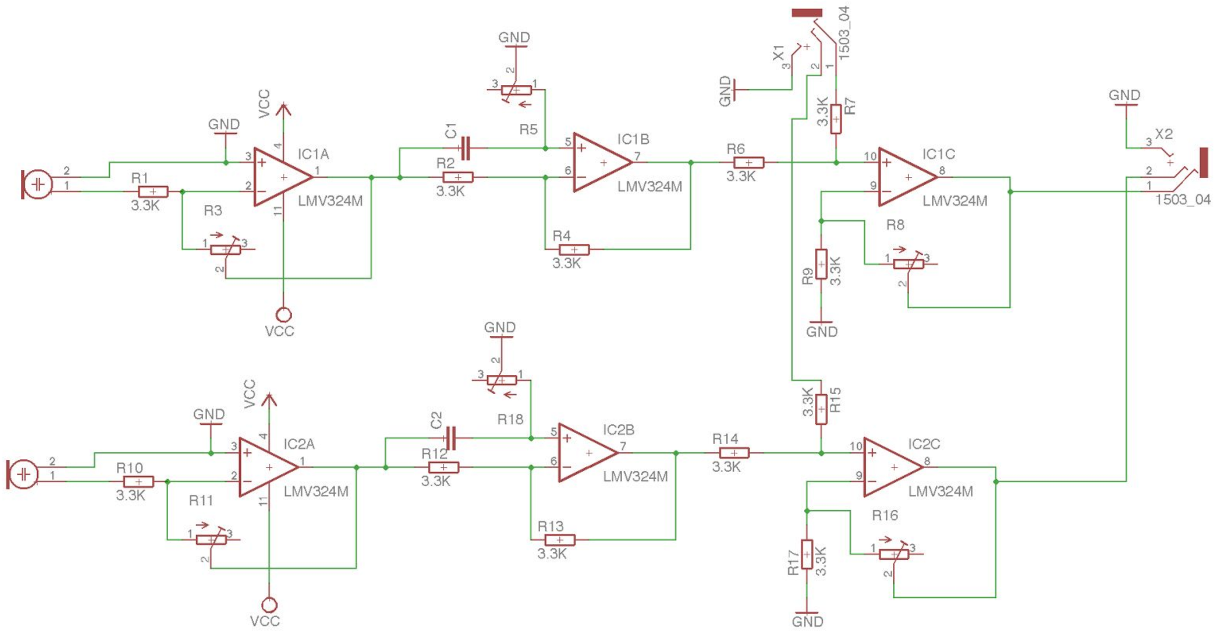

Figure 5: Noise cancelling circuit

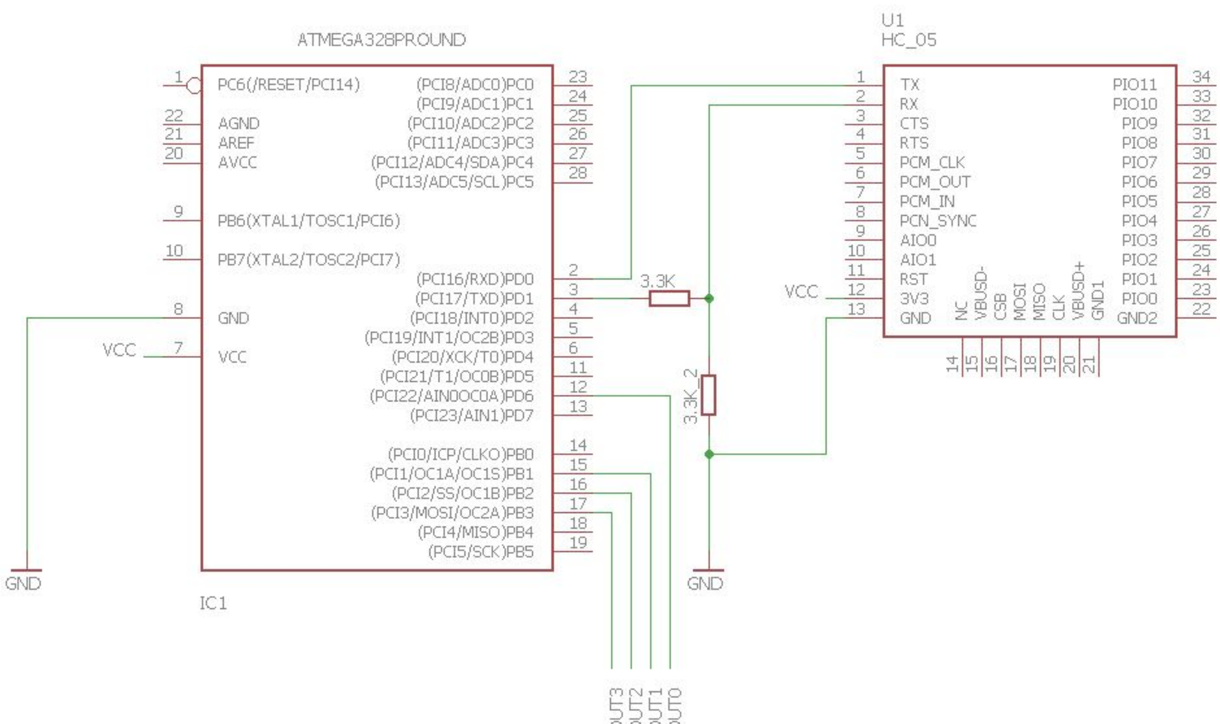

Figure 6: Control Circuit

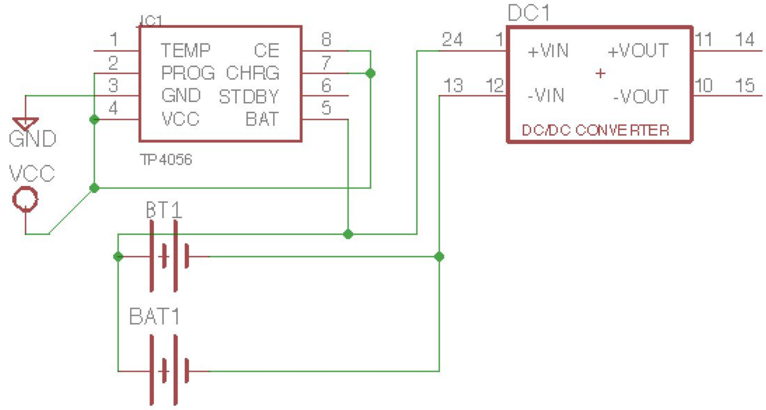

Figure 7: Charging Circuit (without microUSB)

Risk Analysis:

The component that poses the greatest risk to the successful completion of the project is that of the mixer circuit, as it is crucial for full functionality of the headphones. This interface is the most complex as it must mix the inverted input from the microphones with the input from the audio device. If this module is not completed or fully functional, the project itself would not function.

1.3 Cost

One of the main goals for this project is to remain cost efficient, such that any pair of headphones can be bought can cheaply converted to noise cancelling. The following tables details the cost of parts within our project. The total cost with labor is expected to be: $19,240.

Part	Cost Prototype	Cost Bulk (1000+)
LM324 Quad Opamp (2)	$0.52 per	$0.16 per
CMA-4544PF-W Microphone (2)	$r studio 0.82 per	$0.3795 per
MCP4151-103E/P Digital Potentiometers (6)	$0.95 per	$0.71 per
SJ1-3525N Headphone Jack (2)	$0.76 per	$0.3799 per
ATMega328P	$2.18 per	$1.816 per
HC-05 Bluetooth Module	$11.00 per	$11.00 per
3.7V Rechargeable Li-ion Battery 18650 300mAh (2)	$3.26 per	$3.26 per
TP4056 Board (1)	$0.67 per	$0.67 per
.9V-5V Booster Module (1)	$0.41 per	$0.41 per
USB micro 2.0 typeB receptacle (1)	$0.84 per	$0.469 per
Total:	$31.52 per	$26.98 per

Table 5: Parts Cost

	Harrison	Benson	Tanishq
Cost Per Hour	$40	$40	$40
Hours	160	160	160
Total	$6,400	$6,400	$6,400

Table 6: Labor Cost

1.4 Schedule

Date	Description (Must be completed by listed date) Tanishq	Harrison	Yu
Week of October 9th	Can invert arbitrary signal(T)	Mix inverted with another arbitrary signal(H)	------
Week of October 16th	Mix and amplify microphone with arbitrary signal.	Build microphone signal amplifier	Can obtain signal from microphone.
Week of October 23rd	Verify and finalize design of inversion circuit and Microphone amplification circuit.	Verify and finalize design of mixing and amplification circuit.	Have built circuit that can regulate voltage to +/-5 volt rails powered from bench power supply
Week of October 30th	Completed battery research and selection	Smartphone App functional mockup is complete.	Have mockup of battery charging circuit complete,
Week of November 6th	NC All-pass phase shift circuit is built and verified.	Smartphone application can receive and display serial information.	Test charging circuit independently according to RV
Week of November 13th	Assemble ATMega circuit	Smartphone app complete	Program ATMega chip with simple bluetooth code.
Week of November 27th	Integrate NC Circuit with Power and Bluetooth.	Test and assemble Bluetooth compatibility. PCB Design Complete and sent.	Integrate NC Circuit with Power and Bluetooth.
Week of December 4th	Full team verification and final tests. All designs should meet RV Table Minimums		

Table 7: Work Schedule and Split. The “H”, “T”, and “Y” mark group members

1.5 Ethics and Safety

There is one critical component that should raise safety concerns in this project: the battery and charging circuit. Since the battery is of a Lithium-Ion type, it poses dangers such as explosion, and the charging circuit poses dangers such a shock hazards. There are precautions being taken towards each of these. For the battery, there is a two fold plan. Firstly, the charging circuit is being designed to monitor the battery charge level such that the battery cannot be overcharged or overheated, preventing explosion issues on that front. Secondly, the battery is being placed in a reinforced portion of the casing of our NC module, while also being placed in its own plastic sheath internally, so it should be protected from bumps and drops. The charging circuit poses a shock hazard to the user due to the fact that it handles the current to the battery, and thus could cause electrical harm to the user through the casing. This, however, is being prevented through the design of the case itself, which is made of a non conductive material. Secondly, the charging circuit will be monitored by our ATMega controller, on both current and and temperature metrics, so that if unacceptable levels are reached, the charging may be paused, or stopped altogether until safe levels are reached. Such safe levels are defined for usage by the user without them noticing the device operating outside defined limits. The other components will be shielded through non-conductive material, such as a protective epoxy, such that internal arcing may not occur. In addition, the other components in our design do not pose a risk to the user as they are all low-power systems and operate at low temperatures.

Because of the bluetooth wireless communication used in our project, it may infract upon with the IEEE Code of Ethics, #1: “To accept responsibility...” [3]. There are definitely risks with the open communication. However, we believe that the although there are these risks involved, the benefits of having the ability to have open wireless connection drastically outweigh the negative possibilities included.

References

1. "*Bose SoundLink around-Ear Wireless Headphones II Black: Home Audio & Theater*, www.amazon.com/Bose-SoundLink-around-ear-wireless-headphones/dp/B0117RGG8E/ref=sr_1_6?s=aht&ie=UTF8&qid=1504991769&sr=1-6. [Accessed: 20 - Sep - 2017]
2. "*Bose QuietComfort 35 (Series I) Wireless Headphones, Noise Cancelling* www.amazon.com/Bose-QuietComfort-Wireless-Headphones-Cancelling/dp/B01E3SNO1G/ref=sr_1_1?s=aht&ie=UTF8&qid=1504991769&sr=1-1. [Accessed: 20 - Sep - 2017]
3. Ieee.org, "IEEE IEEE Code of Ethics", 2017. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 20- Sep- 2017].