Active Noise Cancelling Headset

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***Abstract*—This paper presents the realization of a unique active noise cancellation headset which uses a combination of hardware and software to achieve promising noise cancellation effects. This project uses a combination of thoroughly researched existing hardware to achieve passive noise cancellation from nearby ambient noises, and the ability to select specific tones that the user deems unwanted to be cancelled. This project was built with the idea of unique, viable consumer electronic, and interesting in mind.**

***Keywords*— Noise cancellation, headset, tones, microcontrollers, analog to digital converter, digital to analog converter, microphone, ARM, senior design project.**

I. Introduction

A common displeasure that people experience is the concept of background noise. The sound of an office workspace, a lawnmower outside, the sound produced by a jet engine all typically result in an uncomfortable distraction. These distractions can have an impact on work efficiency, make it difficult for people trying to enjoy listening to music or a podcast, or even prevent people to have a silent plane flight.

Technology has produced solutions to these inconveniences by producing noise canceling headphones, often resulting in people spending a couple hundred of dollars for such devices. These devices typically are quite large due to their devices being on the actual headphones, themselves. The group's project is to properly produce a headset that can cancel noise this is low frequency ambient noise that is unwanted by the listener by creating generated signal from the noise.

II. System Concept

This accessory's main purpose is to enhance the user's listening experience when it comes to being in an environment with common ambient noise. This report is a documentation of the decision making, such as choosing components and research gone into the project, apart from the common regulations and constraints that must be followed when creating devices. One of the key requirements of the device is the size, it is meant to be portable which resulted in the small size requirement for the device. Like other devices, it will use active noise cancellation which is a very popular method of solving the issue of background noise meaning that it will need some type of input along with some type of error feedback which would result in multiple microphones needed.

The device must be relatively cheap as it should be used as an alternative for other noise cancelling devices. This means that market values and standards will be heavily considered when deciding the device requirements and constraints and user needs, which all affect both the design and process of the project.

The system will be powered by a battery. One connection for this system would be using the Analog to Digital converter with the microphone. The final kind of connection that this system will use will be the connection between the headset and the system itself.

III. System Components

In this section, we will discuss the individual system components which make up our design. Each component was thoroughly researched and chosen to perform a specific purpose within our design within the parameters of cost, safety for the user, and optimal performance. These parameters ensure that the user of our design attains high satisfaction.

Microcontroller

One of our design specifications included designing our product to potentially be marketed as a consumer electronic. Thus, we had to consider parameters such as the strength of our processor and the amount of space allotted for our software inclusions. Although several microcontrollers were considered throughout this design processes, our group ultimately chose Sam G55 microcontroller to accomplish our key design requirement.

The Sam G55 is a microcontroller that maximum speed of 120Mhz. The Sam G55 uses the ARM's Cortex-M4 processor. The Sam G55 has 512 KB flash memory and up to 176 KB SRAM. The Sam G55 support up to 8 KB of Cache. The Sam G55 has one 8 channel ADC. The Sam G55 can support up to 8 flexible communication which include I^2C, SPI, and UART serial communication. The Sam G55 has power consumption of 32.82 µW/MHz, which would fulfil the requirement of having a lower power device. The Sam G55 has a floorplan of 0.119 mm^2 which fulfil the requirement of having a small device [1]. The total cost of the microcontroller is $4.10 on Digikey.

The Cortex-M4 has a performance of 3.40 CoreMark for every MHz CoreMark refers to the metric used to measure the performance of the processor [2]. The Cortex-M4 support architecture that support Digital Signal Processing which is used to create the signal that would cancel out the noise from the surrounding area.

Power Supply

Our group chose to design our own power supply circuit due to our unique design specifications for our product. This power supply would make use of two lithium ion battery rated for 3.7V each to accomplish the requirements of our overall design. This input voltage of the battery however ranges from 3.2V to 4.2V which requires to be considered as a significant input range for the chip being used, and overall impacted the whole design of the power supply as well as charging unit.

Originally a 3.3 V switching regulator was used, that could also produce a 1V output as required by the group. The 1V output was used to improve battery life since it improves the efficiency of the designed circuit. The circuit used a linear regulator that could also produce a 1V and 3.3V output. The linear regulator was used since a switch regulator produced more noise than the linear regulator. The switching regulator has created a significant amount of noise due to the regulator switching on and off which heavily affected the input of the microphone. Thus, to have as little interference with the microphone as possible, the group switched from a switch regulator to a linear regulator. The 1V provide an offset voltage for the microphone to ensure that the analog digital converter would only reads positive voltage values when the microphone was outputting negative voltage.

For the circuit the TI UA78M was used. This regulator supported the 3.3V and produced a 0.5 Amp output which the circuit would need to be powered properly. In terms of the 1 volt due to time constraints and only requiring a voltage offset a voltage divider was implemented to produce a steady 1V output that shifted the microphone signal up by that factor. [3]

In the schematic seen in figure 1, a switch is implemented into the design, to allow the user to choose whether they wish for the circuit on or off, when the circuit is off the on/on switch would be inputting a ground line towards the input of the regulator. When the user is trying to power the system, the user would slide the switch the other way which would input the voltage source.

Originally, only one battery was going to power the whole circuit, however due to the demand input voltage from the regulator, which require a range of 6V-25V input. This require the power block to be powered using two small lithium ion batteries, which require the 2 batteries had to be connected in series as see in figure 1. These batteries together would create a voltage within the range of 6.4 V to 8.2 V which is based on each battery limits as well as current charge that each battery holds. [3]

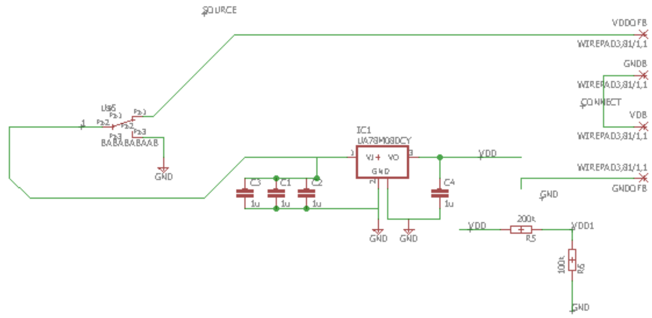

Figure 1 – Power Supply Schematic

Charging station

Our group designed a charging station that charge the lithium ion battery of the power supply, so that the user would have easier time changer the battery of the system.

The lithium ion battery was chosen due the amount of documentation available, the safety standards which our group adhered to, and the ease of replacing the battery in the case of malfunction. The battery itself has a max rating of 2A and a discharge turnoff voltage of 3.2V on top of the it has an overcharging protection unit that comes with the cell inside its packaging that prevents the voltage from going above 4.2V. Should the battery be left alone the discharge rate of the battery is roughly 8% during the time of one month. Our group add a LED light to inform the user that the battery was charging.

This battery charger is powered by the MAX1555 which uses a USB input in this case. This system USB Type A port to charge the system. The input USB connection also contains a decoupling capacitor to prevent any unwanted noise from the voltage input. The chip has the option of also being powered by a DC power supply, however the group found it more convenient to have one external power supply for the charging unit rather than two sources. Adding additional source would increase the space and dimension of the board which in turn would make the housing for the system larger [4].

Overall, the MAX1555 take an input of 5V, and outputs a 100 mA and 4.2V. Another key feature of the chip is that it prevents the battery from overcharging by slowly decrease the output current to the battery when it reaches 4V to prevent overcharging. The current suddenly drops as the chip acknowledges the batteries voltage being close to the output voltage that the chip set which is 4.2 V. This was one of the reasons the MAX1555 was used for the circuit as it was a precaution for the safety of the user. [4]

One thing to note is that the charging station can only charge one lithium ion battery at a time. This was case because the primary design only initially required the use of one battery to power the voltage regulator, thus the user could charge the battery while using the device or even have the option of just charging the device by itself. However, with the implementation of the batteries in series the group was no longer able to implement the design the way it was originally created. This resulted in producing a simple yet effective charging unit that would need to be plugged in every time the user wanted to recharge the battery.

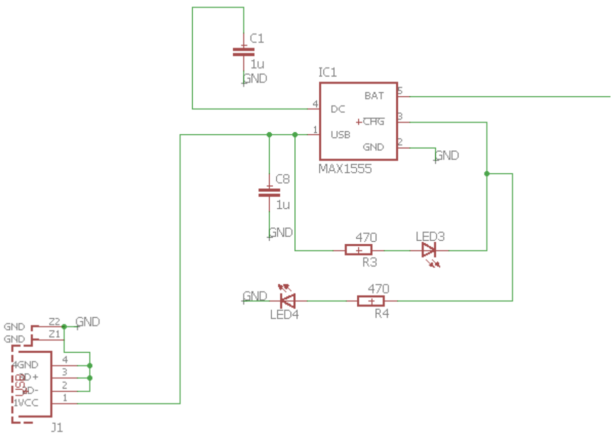

Figure 2 – Charging station schematic

Microphone

For the system to be able to cancel the unwanted noise the signal must be acquired. This made the selection of the microphone to be very important to achieve the objective. The objective of the project and constraint placed from the DAC's I^{2}C communication speed resulted in the need for the microphone to be able to acquire signals of frequencies of between 100Hz and 700Hz. The power system and processer resulted in the microphone to have a low voltage from 1V to 3.3V. The microphone must also be as small as possible to allow for mobility and comfort to the user.

Based on the specifications listed an electret microphone was chosen. It had a size that allowed the group to place the microphone on the inside and outside of the headset. It was omnidirectional allowing the microphone to pick up the noise and allow for the microphone to have more options of placement inside the headset. An electret microphone has the correct operating voltage for our project and in addition the correct frequency response for the desired application.

The design of the microphone circuit began with pushing the microphone sensitivity to DC level. The microphone chosen had a sensitivity of –42dB. The OP then needed to have a gain of 42dB for a sensitivity of 100 SPL for air this resulted in a resistor of 170kΩ. A feedback capacitor was used to block out the voltage that was being feedback by the op amp. The largest possible resistor was used to bias the microphone to limit the noise produced by the op amps feedback. A capacitor was used to block any DC going into the op amp and ensure only the wanted signal would be amplified.

The limitation of the power supply limited the op amp to being a single supply op amp. The voltage used in the positive terminal was set to half the supply voltage in order to achieve the maximum swing for the output. The capacitor at the positive terminal was used to block thermal voltage and the large resistor values were used to limit the drain of the current from the battery. Likewise, a capacitor at the output was used to block out all DC going into the ADC. The resistor following the output capacitor was used to avoid having any charge in the capacitor. Finally, the ADC placed an additional constraint which was that it could only take in positive voltage. A voltage clamper was used to raise the voltage up by approximately 1V.

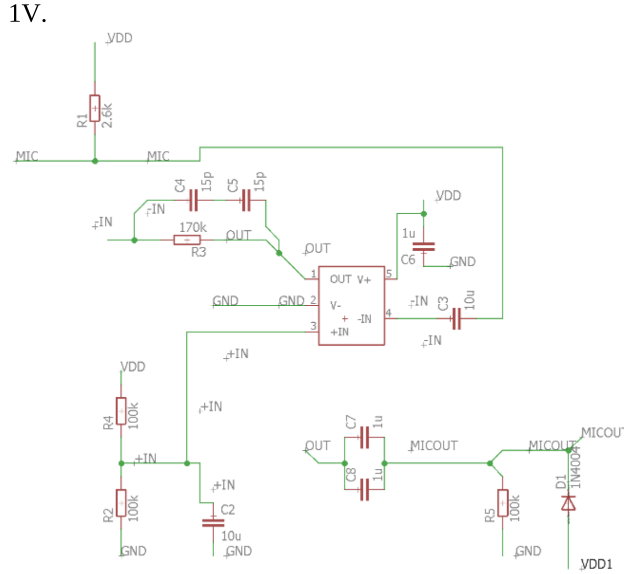

Figure 3 – Pre-amplifier circuit [5]

3D-Printed Headset

To provide proper housing to our microphone PCBs and optimize the performance of our algorithm, our group chose to use a headset CAD model that was optimized per our specifications. The following figure is only the outer portion of the ear piece of the complete headset to be 3D printed:

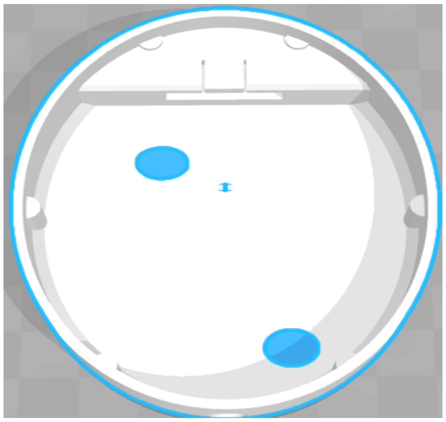

Figure 4 – Headset Ear Piece CAD model

This ear piece was designed to house the microphone PCB its two microphones that will pick up on the tones which our team specifies. The placement of the two microphone slots on the outer portion of the ear-piece, was based on research into existing active noise cancellation headsets and our own knowledge of sound propagation.

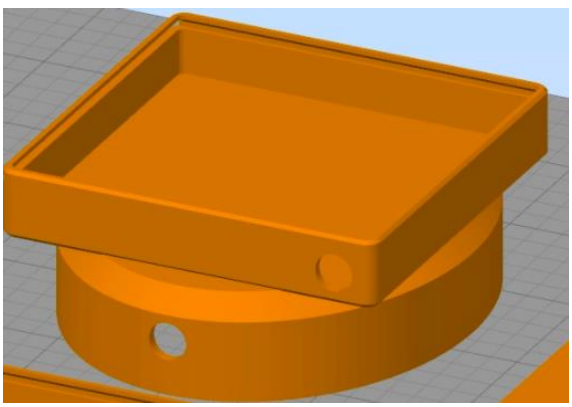

Figure 3 – Microphone PCB housing headset model

The final design of the headset would resemble popular modern-day headsets, but would include the two PCBs on the ears (one for each) and would be connected to the housing of the power PCB on the user's belt or placed nearby (with restrictions of the wire length). The power PCB will also house the processor, which can be programmed to switch between several tones that the user would like to cancel.

Further, once 3D-printed, the headset would have to be both adjustable to the size of the user's head (to provide maximum comfort and adequate passive noise cancellation) and not too tight around the head, as to cause discomfort for extended periods of time. To accomplish this, several bands were 3D-printed, and tested through trial and error and on varying heads of our classmates, before our group felt happy with the design.

To accurately implement our design, our group chose to 3d print the headset using black PLA material. The following figure shows the real representation of the headset:

Figure 4– Complete 3d-printed headset

Analog to Digital Converter

The Analog to Digital Converter (ADC) used in this project will be on the ADC on the microcontroller. The ADC support a 12-bit resolution. It is located on the development board of the SAMG55. It supports up to 16-bit resolution in Enhanced Mode. The ADC support up to 500K sample per second. The ADC can support up to 8 channels. The ADC can support conversion between 0V to VDDIO [1].

Digital to Analog converter

The MCP4725 is a 12-bit Digital to Analog converter (DAC). This DAC supports I^2C communication. The DAC can support standard I^2C communication speed which is 100 kbps, fast communication which is 400 kbps, and High-Speed communication which can support up to 3.4 Mbps. This project can only use the fast I^2C communication because the microcontroller can only support High-Speed communication between two Sam G55 microcontroller. To put communication speed into perspective, each transmission requires 16 bits to transfer. Each transfer will change the value the DAC will output. That mean a standard communication can only support up to 6.25K transfer per second, the fast communication can support up to 25K transfer per second, and the High-Speed communication can support up to 850K transfer per second [6].

The MCP4725 has an operating voltage of 2.7- 5.5V. The range the DAC can support as an input is 0.3 – 0.7 time the operating voltage. The output voltage of the DAC is also dependent on the operating voltage. The MCP4725 can only support 2 MCP4725 connected to the same device. The address of the device is depended on whether A0 is low or high. When A0 is low, the address of the DAC will be 0x62, and when A0 is high, the address of the DAC will be 0x63 [6].

Software Algorithm

It is impossible to create a filter for unknown inputs using time invariant methods. Adaptive filters allow the user to adjust the coefficients of the filter to alter the signal. The adaptive filter used in the project is the identification and noise cancellation model. The LMS algorithm used is the homogenous version.

The goal of the system is to reduce the error in the system. The solution to the error is a parabolic function that has minimum point. Ideally for an infinite number of samples the error in the system will be zero. To implement the filter the assumption was made that the error in the system can be estimated by its finite samples if the change in the system is gradual. Because of the estimation made the weights in the adaptive filter will be closer to the unknown filter as the number of sample increases. The LMS algorithm employs the idea of calculating the minimum point by going against the gradient of the function. The step size needs to be within the specified boundaries of the eigen values of autocorrelation matrix. The homogenous algorithm employs the same idea but uses the signal power to be the step size of the signal in order to improve the accuracy. When the error is at a minimum the noise can be cancelled, and the desired signal will be achieved.

In order to achieve the final objective of the project the algorithm was broken up into sections. The sections were to remove the noise of a known tone and to cancel an unknown tone. If these steps were completed in the allotted time, then the algorithm can be adapted to cancel an unknown tone from a desired single. This would create an excellent foundation to develop more advance techniques and algorithms for more complex situations.

The first step was to remove the echo from a known tone with a known delay. This was accomplished by taking in the signal and using the following block diagram

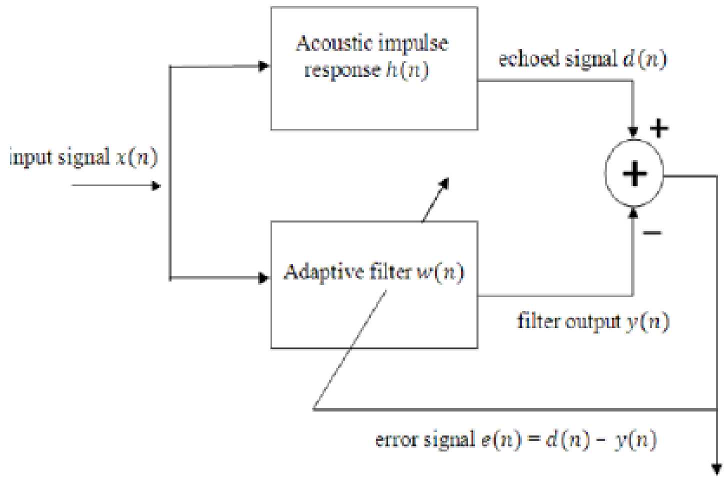

Figure 5 – LMS Block Diagram

The algorithm takes the input (delayed signal) and compares it to the known (desired signal) that is created in the processor. The inputted signal is then ran through the algorithm (LMS) and adjusted to be equal to the known signal. This in affects eliminates the noise, test the hardware and implements the algorithm.

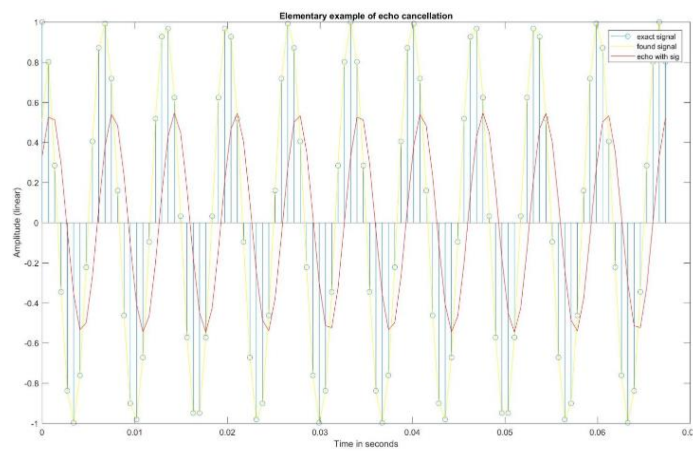

Figure 6 – Echo Cancelation

The second step was to create the inverse tone from an unknown tone with an unknown amplitude, frequency and phase. This was accomplished by calculating when the maximum reoccurs within a certain threshold to calculate frequency. The amplitude was the maximum value in the sampled array. Finally, the phase was found by using a system of equations. The final step was to recreate the procedure done in part A and invert the filter weights.

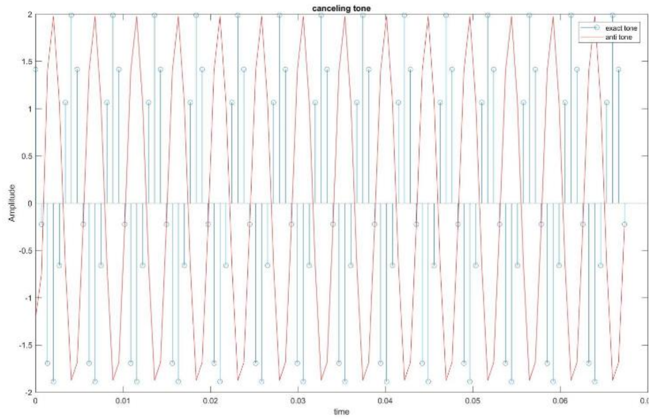

Figure 7- Cancelling tone

PBC Design

To successfully implement the scope of this project, our group considered a variety of options in terms of PCB design. However, through ample research, rigorous tests, and trial and error, our group concluded that our design would be implemented using two PCB designs – one for the microphones needed within the headset and a PCB that would power the overall design.

Our two PCB were designed with through-hole components instead of surface mounted components due to the need for rapid prototyping by our group. Using through-hole components allowed our group to accurately measure various anomalies in our design and make use of all the boards sent to us quite efficiently.

Power Supply PCB

One of these is what we consider our main PCB, which is our power supply for this design and includes the MCP4725 DAC. It will be housed in a small rectangular encasing which can be clipped onto the user's belt or be placed nearby. It is connected directly to the ATMEGA ARM CORTEX-M4 Processor board and the headset microphone PCBs.

The PCB, as mentioned previously, will supply 3.3 volts to the circuit using a lithium ion battery that was purchased. It will be housed in a way that is easily replaceable for the user. The board was minimized as much as possible, to a size of about 2.5x2.5 in, to meet our design specifications.

A Voltage regulator will be used in order to charge the device. What a voltage regulator does is intake a voltage source produce a constant voltage in this case producing a 3.3v and 1v supply. This source is typically smaller. There are two types voltage regulators types are switching and linear. Switching regulators use a switch to power the voltage source, by taking the average of the voltage resulting in a constant voltage. The linear regulator on the other is just a device that compares itself with the reference voltage and adjusts. The advantages and disadvantages of one another affects the component design. The PCB contains the voltage regulator, and digital analog converters for both ears, as well as the charging station and input USB A port which will charge the batteries, when plugged in. In addition, there are nodes for the connections that the processor would use as well as other connections that would send the data and receive the data to the microphone PCB which also contains the speakers.

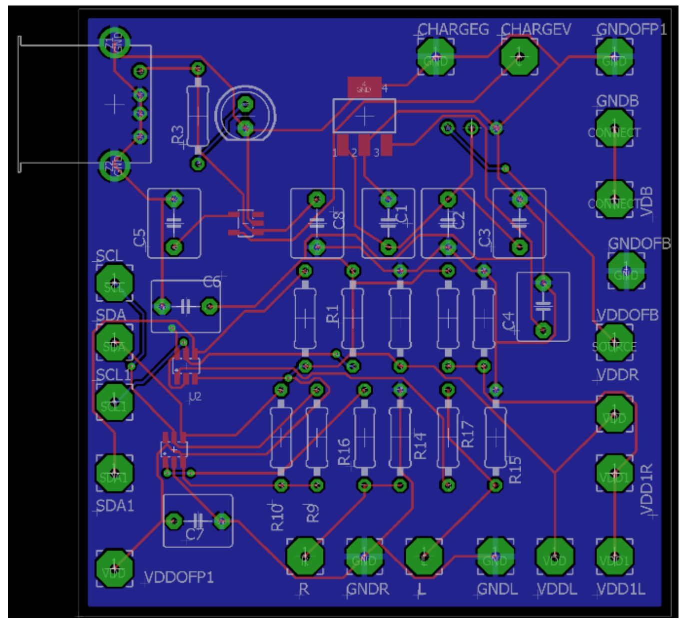

Figure 8 – Main PCB

Microphone PCB

The second PCB within our design is for the microphones, which will be placed within the headset. The board size was minimized as much as possible, to a size of roughly 2.5x2.5 inches, to minimize the size of the headset since part of our design specifications was to make the headset as least bulky as possible. One of the microphones will serve as the outer microphone, which is designed to listen for select tones. While the other will be positioned within the earpiece, and serve as the error mic – ensuring that our algorithm runs optimally. The following figure shows our final PCB design for the microphones:

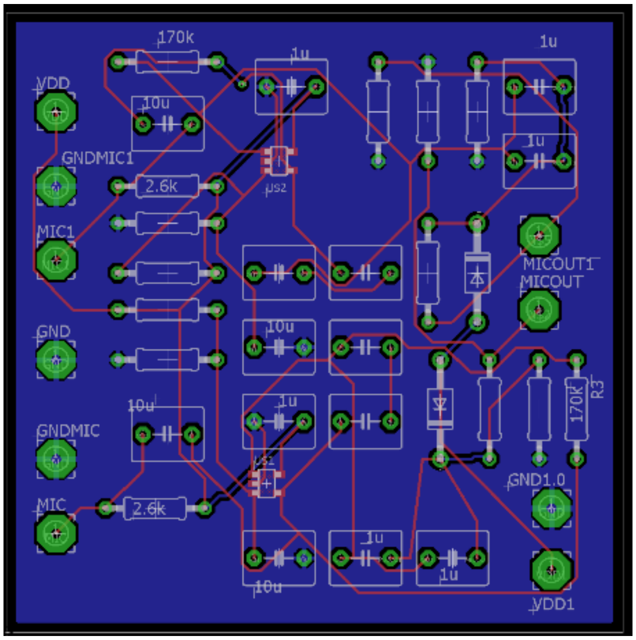

Figure 9 – Microphone PCB

IV. Safety and Standard

Throughout the scope of this project, our group was concerned with the safety of the potential user of our design.

For one, any heat dissipation from our power PCB would cause potential injury to the user (as it is designed to be worn on a belt) and the headset would have to be negligible relative to the user's tolerance for heat. Further, the housing would have to be somewhat resistant to any heat dissipation so that it can properly serve its purpose.

To accomplish this, our group thoroughly researched and adequately implemented the design using a relatively small voltage to accomplish our goals for both the electret microphones and the overall run-time of our design. Miniscule current would be run through our project, hence offering no immediate danger to the user.

Another concern included any discomfort felt by the user while wearing the headset. Due to our initial specifications of modeling our headset in popular noise cancellation headsets in mind, we felt that our headset would have to provide adequate noise cancellation while providing negligible discomfort to the user.

Further, all potentially exposed wires have been wrapped with heat shrink to prevent any shock for the user. All wires that run from the headset to the power PCB have been collected and wrapped in heat shrink as to limit the amount of separate wires in our project. This will also limit the potential of having the wires from being caught on a foreign object and yanking the head of the user or causing damage to the power PCB.

Exposure to the Power PCB and processor has been encased within a 3D-printed housing, as aforementioned that would prevent any potential damage to these important components. The housing includes a slide off component that would enable the user to open it should any inspection, fixing, or replacement of components be deemed necessary. The housing would also prevent the user from potentially being shocked by any of the components within the housing by limiting their access to it.

V. Conclusion

Overall this system was design for the user to safely wear the headset and to have the device cancel out the noise from the surrounding area. Figure 5 summarize the LMS algorithm use to cancel the noise from the surrounding area. For this design, the group had decided to only display the product on one ear. This would show that one of the ears would have the PCB placed onto it, as well as being connected to the power PCB which contains the DAC as well as the charging unit. The designed was changed in terms of power to accommodate for such noise, which is why the power regulation was changed, because it powered the microphone circuit. Future work in the design would consist of a full headset prototype, as well as a more functional DAC that can output more samples in order to increase the output frequency potential.

Acknowledgements

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Biography

Quoc Le

Quoc Le is planning to graduate from the University of Central Florida in December 2017 with a Bachelor of Science in Computer Engineering. He developed the LMS algorithm in C and communication protocol between the devices. He plans to get a Master Degree in Computer Engineering after working for a few years.

Josu Udaondo

Josu Udaondo is a Senior at the University of Central Florida. He plans to graduate in December 2017 with a BSEE. He oversaw develop of the algorithm, microphone circuit, and PCB design. He plans to get a Master Degree in Electrical Engineering within the next couple of years.

Mark Guzman

Mark Guzman is a senior studying Electrical Engineering at the University of Central Florida. He plans to graduate in December 2017 with a BSEE. He oversaw the Power supply of the system, charging station unit, and Hardware testing/ Soldering. Mark will be starting his career as an Electronics Engineer. His areas of interest include Systems and Signal Processing, he plans on getting his Master's degree at UCF in Electrical Engineering within the next couple of years.

Alejandro Capellan

Alejandro Capellan is an Electrical Engineering student at the University of Central Florida. He was in charge of the CAD design for the headset, housing, 3D-printing, and assisting with all electrical engineering testing and design within the scope of the project. Upon graduation, he plans to pursue a career as a system integration and test engineer for Harris Corporation. In the future, he will also attend the University of Central Florida graduate school to pursue a master's degree of electrical engineering with a focus on RF electronics.

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