May 2015

Development of a Novel Portable Signal Acquisition Device for use in Local Mining Industrial Applications

Jacob Walker
College of Engineering - Department of Electrical and Computer Engineering, walkerjacob1393@siu.edu

Noise Induced Hearing Loss, Occupational Hearing Loss, Measurement of Noise Exposure, and Production of Portable Noise Acquisition Device

Jacob Walker

A Thesis submitted to the University Honors Program in partial fulfillment of the requirements for the Honors Diploma

Southern Illinois University

May 8th, 2015

Table of Contents

List of Figures

Acknowledgements

I would like to take the time to thank the following people for their immense contributions of time, expertise and guidance:

Dr. Jun Qin – My researcher mentor, for presenting me with the wonderful opportunity to be a part of his lab and team. For helping to guide and foster my foray into the research domain and helping to further advance myself as an individual and as an engineer.

Dr. Haibo Wang – For his immense and invaluable expertise in the realm of PCB layout and design. Without him, this project would not have been able to achieve the caliber and thoroughness that it can claim.

Chaitanya Varma Danduprolu – One of Dr. Wang's graduate students. For educating me and showing me the intricacies of in-depth PCB design. Without your aid, it would have been much more difficult to perform the necessary tests and simulations in order to verify the functionality of the circuit design. Additionally, I thank you for your wide-versed knowledge of DIPTrace and helping immensely to carry out the full design and implementation.

Chapter 1: Introduction and Background

1.1 What is Noise-Induced Hearing Loss (NIHL)?

Noise exposure is experienced in all aspects of life. Virtually every moment in a lifetime is filled with various types of noise, each varying in frequency and magnitude. Household appliances, traffic, music… these all lead to the experience of sound in our everyday environments. When experienced in safe levels, the constant bombardment of noise does little to hinder or limit an ears hearing capability. However, when the human ear experiences sound that is too loud, even for a short time, damage can occur to the sensitive biological components in the inner ear and bring about noise-induced hearing loss. These harmful occurrences are due to one or both of different types of noise signals, impulse and steady-state noise. Impulse noise "results from hammering, stamping, pressing, and gunfire can be characterized by its instantaneous, short duration… In conditions where several workers hammer, press, or chisel impulses may occur abruptly and randomly in varying frequencies at the rate of several tens per second" [1]. Conversely, white noise is noise that does not change by more than 5dB at a given place and time period. An example of white noise would be a waterfall, the steady noise from a fan, or the hum of a computer. Typically a white noise of 85 dBA or greater is considered hazardous, this limit assumes no more than 8 hours per day of exposure to these high level noises [2]. Meanwhile, complex noise is the combination of these two types of noise.

In order to understand how NIHL can occur, the basic structure and outline of how the human ear detects and processes noise must be outlined. The essential "hearing" of noise occurs through a series of steps that process sound waves that travel through the air into electrical signals that are sent to the brain. The anatomical structure of the inner ear is shown below. Additionally, the step by step process of how sound is converted into electrical signals is given as well.

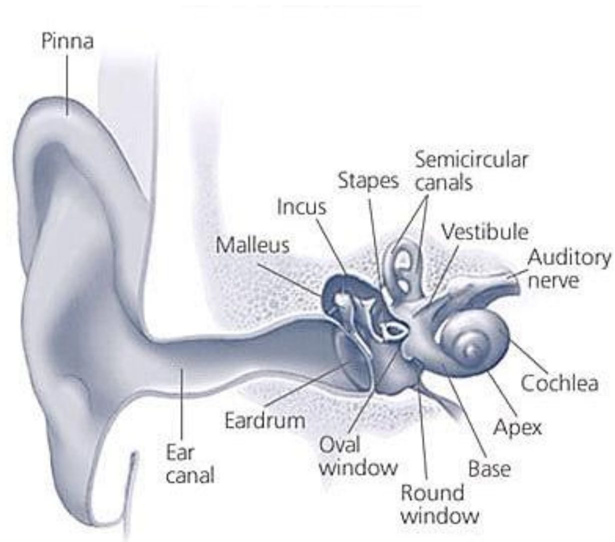

Figure 1: Diagram of Inner Ear

First, sound waves enter the outer ear and travel through the passageway known as the ear canal, which directs the sound to the eardrum. Then, the incoming sound causes the eardrum to vibrate and sends these vibrations through three small bones: the malleus, incus and stapes (hammer, anvil and stirrup). These three bones in the middle ear couple the sound vibrations from the air to fluid vibrations in the cochlea of the inner ear. As a part of the overall system, an elastic partition, known as the basilar membrane, splits the cochlea into an upper and low section. Next, the vibrations in the cochlea cause the fluid to ripple and a travelling wave forms along the basilar membrane. This causes hair cells along the top of the membrane move up and down along with the ripple of the fluid. These microscopic hair-like projections called stereocilia, bump against a structure in the ear and bend, this bending causes mechanically gated channels to open up. This causes positively charged ions such as Potassium and Calcium to rush into the cell and excites a signal. Unlike other electrically active cells, the hair cell itself does not fire an action potential, the rushing of the positive ions into the channel depolarizes the cell, causing voltage gated calcium channels to open and trigger the release of neurotransmitters [3]. This electrical signal is carried by the auditory nerve, which translates it into a sound [4].

There are many steps in the process that biologically translates sound pressure waves into electrical signals that can be interpreted by the brain. Along these steps, there are many sensitive components that can be harmed and can cause NIHL. Chief among them, NIHL is usually caused by the stereocilia becoming damaged or destroyed by excessive loud noises, disease and toxins, and leads to their eventual death [5]. Aging and prolonged exposure to harmful noise causes wear on the hair cells that are vital to the transmission of electrical sound signals to the brain. When the hair cells are damaged or missing, the signals aren't transmitted optimally [6]. Unlike other amphibians or birds, mammalian hair cells do not grow back, once NIHL has occurred it is nearly impossible to reverse. Other causes of NIHL are things such as an ear infection or a ruptured eardrum, which is caused by sudden blasts of noise or changes in pressure that ruptures the membrane and prevents the conversion of sound pressure waves into mechanical waves in your ear [6].

Now that the physical process of NIHL has been examined, it is important to understand the psychological effects of NIHL and the effect it has on quality of life. Many industry workers in the United States are exposed to the harmful effects of complex noise while on the job. This problem is prevalent in adult Americans as about 16.1% of the US adult population suffer from hearing loss problems [7]. Although NIHL is the main reason of hearing related issues in America, noise can have a greater effect on the physiology and act upon multiple non-auditory systems in the human body. Although these correlations are difficult to quantify due to a lack of statistical data, there exists a plausible connection. A comprehensive between the years of 1970 and 1999 by van Kempen looked at the correlation between noise exposure and blood pressure. They found "that there was a significant association between occupational and air-traffic noise exposure and hypertension" [8]. More frighteningly, another study looked at a group of children that lived near a noisy airport. This study examined their systolic and diastolic blood pressure, as well as obtained a quality of life sample from a KINDL questionnaire. A KINDL questionnaire is a metric way of assessing quality of life standards in children older than 3 years of age. This study showed that "that there was an increase in blood pressure in the noisy communities… This questionnaire was used in this study and found that the quality of life in the children living in the noisy community declined significantly over the 18 months of the study" [8]. The aggregation of research available on noise and the quality of life of those who experience excessive amounts of harmful noise, has shown that there exists a plethora of research and evidence that points to heightened levels of stress, significant deterioration in quality of life, disruption of sleep, causes cognitive impairment, and generally leads to many other deleterious and adverse health effects.

1.2 Occupational Hazards Involving Harmful Noise

Now that the background of NIHL has been covered, it is important to look at the implications that it has on many industry workers in the United States. There are a large amount of occupations in the US that exposes workers to harmful levels of noise. In 2011, Argrawal, Platz, and Niparko performed a comprehensive study by analyzing data from the 2001-2008 cycles of the National Health and Nutritional Examination Surveys, which provides a survey designed to assess the health and function of citizens. This study involved subjecting subjects to a speech-frequency pure-tone average of grader than 25dB HL in both ears, while conducted in a sound-attenuating booth. The study concluded that roughly 30 million Americans had bilateral hearing loss during the course of the study. Additionally, an estimate of 48.1 million had unilateral hearing loss [7].

This statistic gets worse for those who work in the mining industry, as reports from the National Institute for Occupational Safety and Health determined that 80% of US miners are exposed to harmful levels of noise while on the job [9]. This consists of an environment where the time-weighted average (TWA) exceeds 85dB, and that 25% exceeds 90dB. This is likely due to the different equipment present in plants that creates the noise. A tabled estimate of noise exposure for plant equipment is given below.

Table 1 – Estimates of Noise Exposure from Plant and Equipment [9]

Noise Source	Range (dB)	Mid-Point
Cutting Machines	83-93	88
Locomotives	85-95	90
Haulage Truck	90-100	95
Loaders	95-100	98
Long-Wall Shearers	96-101	99
Chain Conveyors	97-100	99
Continuous Miners	97-103	100
Loader-Dumper	97-102	100
Fans	90-110	100
Pneumatic Percussive Tools	114-120	117

As shown, there are many different tools present in a mining industrial location that can contribute to the production of harmful noise that can be detrimental to hearing. The biggest producer of noise is the pneumatic percussive tools, which generate noise by impact from the drill bit, vibrations from drills and noise generated by the exhausted. Additionally, auxiliary equipment present in an installation generates noise, such as the fans and blowers used when ventilating a mine. The extractive equipment can as well produce a lot of noise, which comes from the gear system, impact noise from extraction, and continuous noise from the complex conveyor system.

Given these numbers, it is apparent that many miners face hazardous noise levels in the workplace. A recent National Institute for Occupation Safety and Health (NIOSH) study showed that "at age 50, ~90% of coal miners and 49% of metal/non-metal miners had a hearing impairment. By contrast, only 10% of the non-occupational noise-exposed population had a hearing impairment at age 50" [9]. Thus, it is important to develop new and inventive ways to measure and categorize harmful noise level exposure, and develop ways to protect miners from the day-to-day occupational hazards that they will face while on the job at an industrial mining facility.

1.3 Measurement and Categorization of Harmful Noise Exposure

To understand how noise is measured and categorized, background knowledge of the weighting filters used in industry is important topic to cover. Weighting filters are used in signal measurement to suppress or emphasize a set of aspects of a signal for use in better the information present in a signal. Most commonly used in the measurement of audio application is the A, B, and C weighting filters, although the A-weighting filter is most common. Each filter amplifies and attenuates certain frequency ranges given by the graph below.

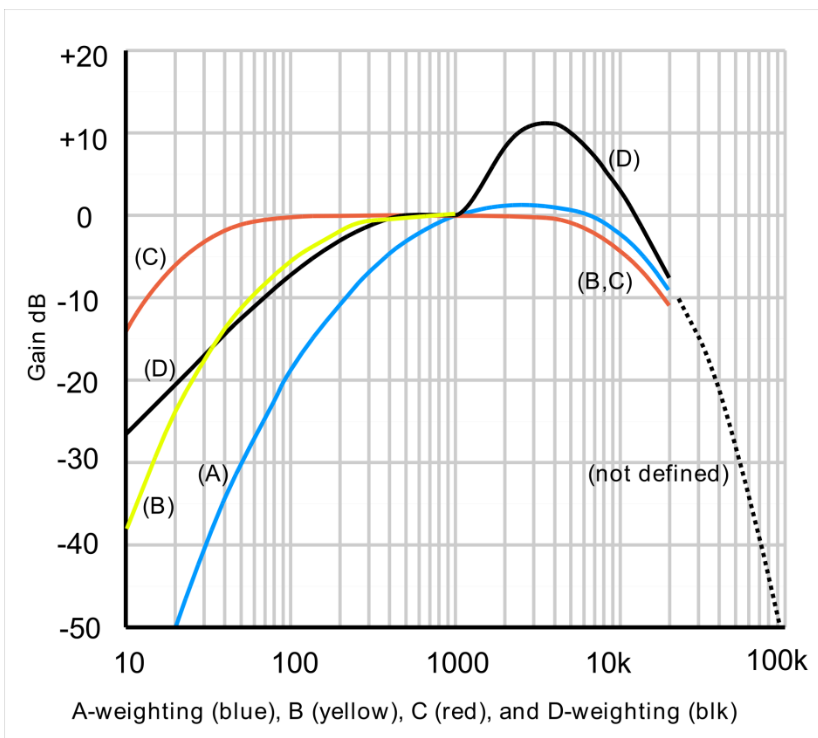

Figure 2: Gain Plot of Weighted Filters

Each filter is designed for a particular use, highlighted below (the D-filter will be ignored as it is used in measuring aircraft noise).

- A Filter: high pass filter designed to emphasized frequencies around 3-6 kHz, where the human ear is most sensitive, and attenuating ranges where the ear is insensitive
- B Filter: designed to simulate medium-level tones, used very rarely
- C Filter: used in removing frequencies outside 20Hz – 20kHz (the human hearing range)

Additionally, while there is a vast amount of knowledge into the causes of noise induced hearing loss (NIHL), not much research has gone into the harmful effects of complex noise. Complex noise is the combination of two types of noises: white noise; such as the hum of a computer or overhead lights, and impulsive noise; an example of which would be a gunshot or loud explosion. Complex noise is the mostly commonly available noise in mining installations, and is why many industry workers are exposed to its harmful effects.

According to Occupational Safety & Health Administration's Occupational Noise Exposure page, exposure to any high levels of noise can cause permanent hearing loss; this includes short term exposure to high intensity impulsive noise and repeated exposure to steady state, white noise [10]. While there has been research into the analysis of this harmful noise, the conventional guidelines are based on the equal energy hypothesis (EEH) - which heavily relies on the acoustical energy, but generally does not apply to higher level impulsive noise. Thus, a current topic of debate is whether or not the effects of impact noise on hearing are the same as the effects of continuous noise. Research into impulsive noise has shown the major drawbacks of EEH; while the EEH is applicable at lower impact levels, after a critical value, the damage to the inner ear increases significantly [11]. This was a demonstrated by researchers Roberto, Hamernik, Salvi, Henderson, and Milone. In their study, they evaluated the EEH given a number of set conditions that they set to measure the accuracy of the EEH. They performed this by exposing four groups of chinchillas to varying levels of impact noise at an intensity of 107-125dB SPL. The power of these exposures were measured by the total hair cell loss in each of group of chinchillas. Additionally, the exposure conditions were counterbalanced so that each group received the same total energy. The results of this study found that "Exposure between 107 and 119 dB were consistent with the EEH in that they produced roughly the same amount of permanent threshold shift (less than 20 dB) and hair cell loss (less than 20%). However, the 125-dB exposure produced substantially more threshold shift and hair cell loss than the three lower intensities [11]. This study highlights many of the issues surrounding the EEH and its accuracy when measuring the effects of impact noise. Many workers in the mining industry are subjected to high levels of complex noise; as such, research into capturing the signal information present inside mining installations can lead to developments to help protect workers while they are on the job.

Since the EEH has been shown to provide inaccurate results at higher levels of impact noise exposure, more research is necessary to provide a new model of which acoustical energy can be analyzed against. This is due to the idea that while all types of noise at a high enough levels can cause hearing loss, a combination of these two types of noise, called complex noise, has been shown to cause significantly more damage to human hearing. Moreover, research has shown that the high-level noise that miners are exposed to while on the job, is complex noise. Because the EEH relies heavily on overall acoustical energy in the system, and doesn't necessarily adapt with different magnitudes, it generally cannot apply to higher level impulsive noise. Therefore, research into the analysis of this complex noise in the mining industry can help prevent and manage NIHL and protect the 90,000 miners in the United States.

1.4 Objectives

At the onset of the project a number of objective were laid out in order to determine the progress of the project as well as provide tangible milestones for the project. These objectives are as follows:

1. Research necessary design constraints in order to fulfill specifications of the device

2. Determine the components that will be implemented in the device based on the aforementioned constraints
3. Begin design of device utilizing Diptrace
    a. Devise necessary subdivision of work by dividing major sections up, as well as their respective subsections
4. As sections are completed, simulate and test their functionality using Diptrace and Spice Simulations
5. As simulations are verified, begin migration of circuit design into the PCB layout kit
6. Continue routing of components on PCB creator, verify device design through DipTrace
7. Send out specifications of PCB design to necessary fabrication and assembly companies

Chapter 2: Methods and Materials

2.1 Introduction of a Portable Noise Acquisition Device

Because of the need for research to be done to replace or improve upon the EEH, new and novel methods of measuring and capturing audio data is necessary. Thus, through the REACH program, the development and production of a new portable noise signal acquisition device has been initiated for research into the acoustical information existent in mining fields. The main objective of this project is to design a customized printed circuit board (PCB) and develop a prototype of a portable signal acquisition device. This device will consist of a dual-channel electret condenser microphone configuration. It will utilize a filter in order to capture the necessary auditory components. Next, it will utilize discrete ADCs to handle the conversion process. Finally, a microcontroller will be responsible for taking the data and storing on an SD card. There exists a secondary objective, time permitting, to analyze and assess the functionality of the device in testing simulations performed in the lab.

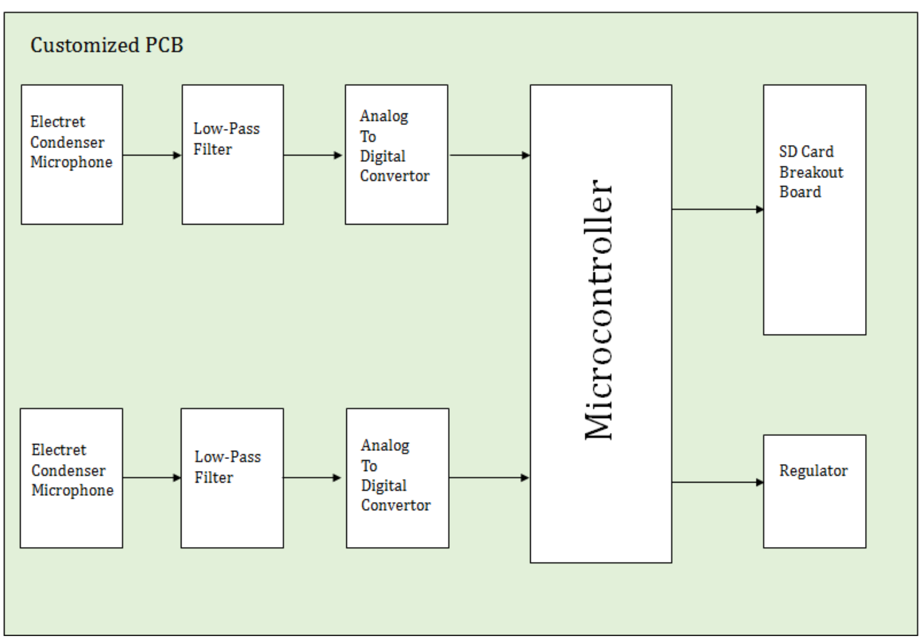

Figure 3: Block Diagram of Device

The first task of the proposed project will focus on the design and a development of the device. This device will have to adhere to specific design specifications laid out by the design team at the onset of the semester. The main design focus is that the device is portable and can detect and store high quality signal information. Furthermore, the proposed device will consist of: a customized microcontroller for data acquisition and storage, two 1/2" electret-condenser microphone with pre amplifier sets. Additionally it will house a low-pass filter as well as discrete analog-to-digital convertors. The customized PCB will utilize surface mounted technology to decrease size and improve functionality. Since this design was chosen over through hole, it will have to be fabricated and assembled using third-party vendors.

The second task of the project will focus on the testing of the functionality of the device. The functionality will be validated using parameters such as accuracy, precision and thoroughness. This process will consist of both lab and field testing. First, in the lab testing, the device will undergo different types of noise stimulations, including: steady state, impulsive and complex noise. This testing will take place in a sound isolation booth inside the engineering building. Additionally, testing will be performed at a coal preparation plant, following the same guidelines as those laid out for the lab experiments.

2.2 Device Overview

The device consists of many different components that augment and increase its functionality. Each component in the device was selected due to design constraints and considerations that have been collaboratively pre-determined. Below is a top view of the final product printed circuit board (PCB) itself that houses the digital signal noise acquisition device.

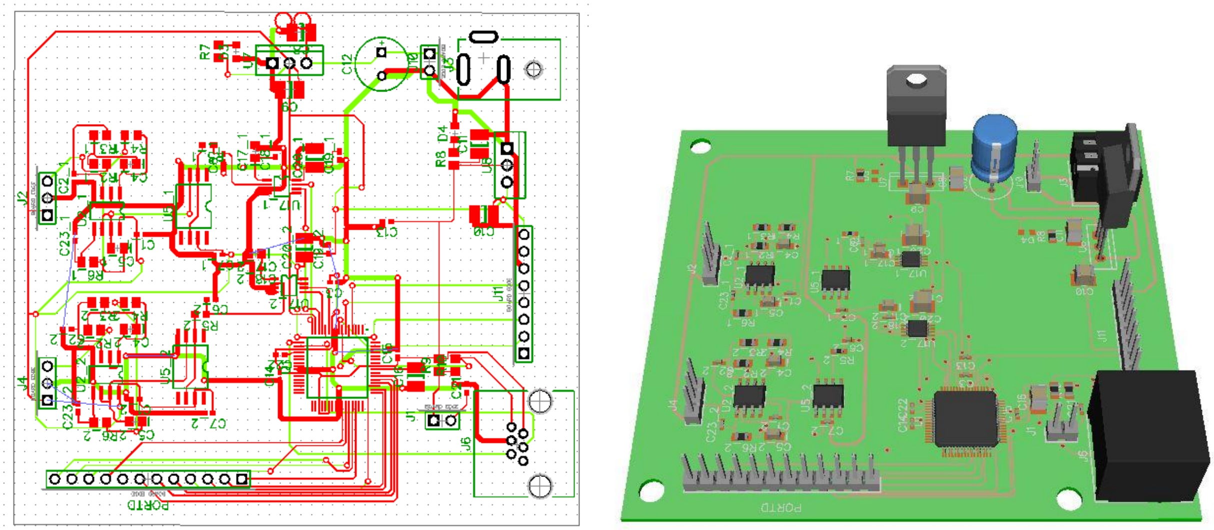

Figure 4: Final Design Printed Circuit Board

Each system present in the device will be individually assessed and reviewed in the following sections. The overall block diagram for how the device will receive audio signal data and process it is listed below. Since this is a dual-channel implementation of the device, there will be in fact two audio inputs as well as filter and ADC implementations.

Figure 5: Block Diagram of Signal Chain

As shown, the analog audio signal will be detected by the preamplified microphones selected for the device. Then, this signal data will be sent through a low pass filter, which will isolate the frequencies present in the human hearing range. After this, it will be converted from its analog state into digital, by way of discrete ADCs. This allows the microcontroller to then take this digitized signal and store it on an SD card module that will be attached. A simplified figure of the wiring present in the PCB is shown below for reference when examining each specific subsection of the design.

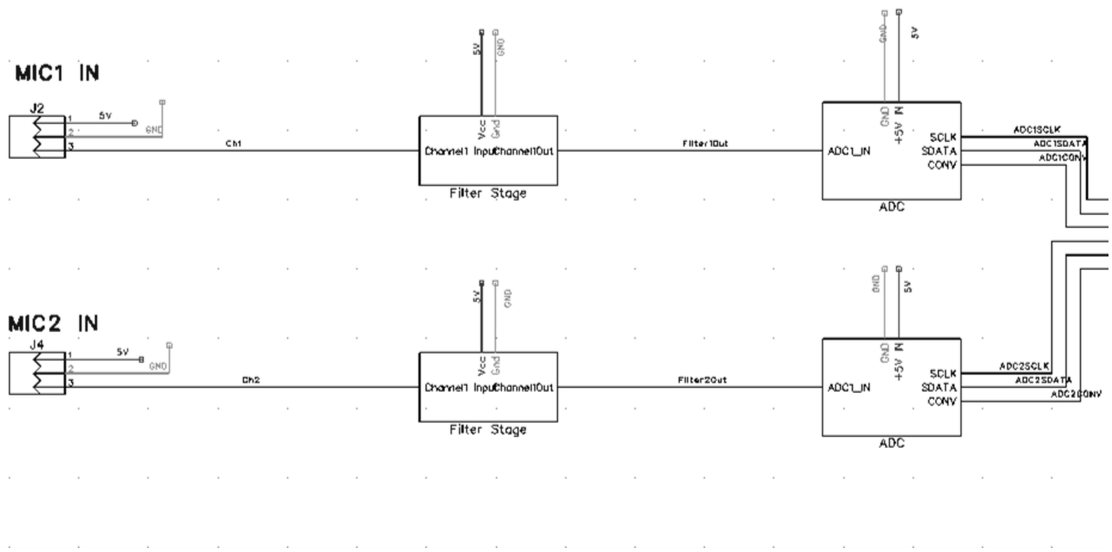

Figure 6: Pseudo Wiring Diagram of Analog Front-End

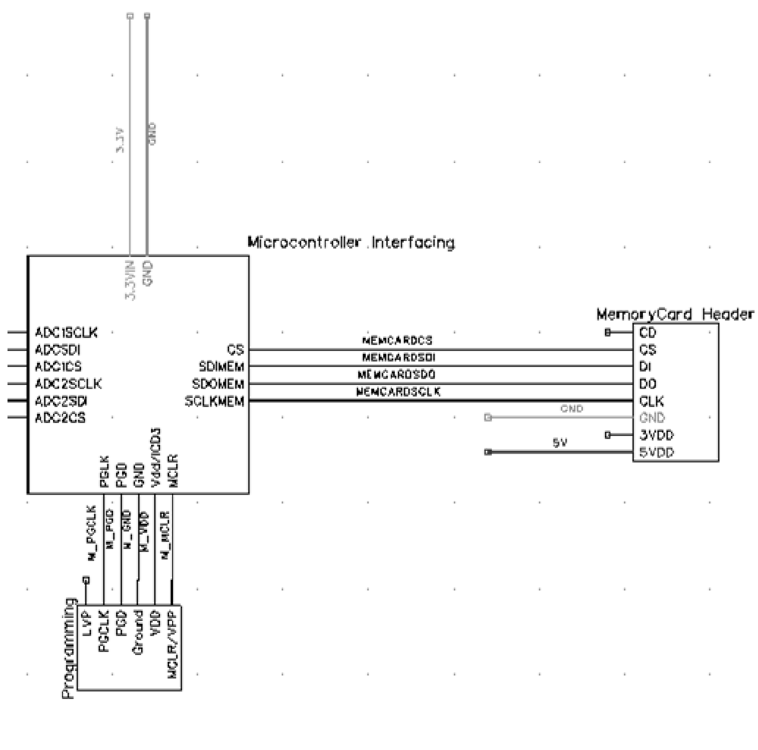

Figure 7: Pseudo Wiring Diagram of Digital Back-End

Chapter 3: Results

3.1 Analog Front-End

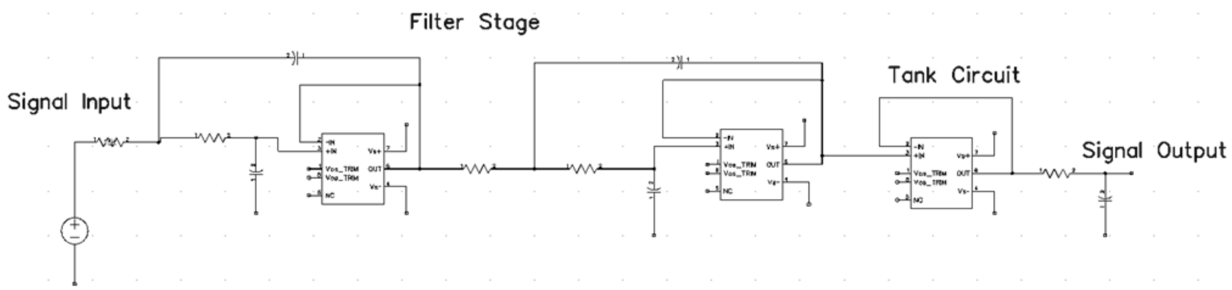

Figure 8: Analog Front End of Device

Pictured above in the figure is the analog front end of the device that is responsible for taking the input analog signal from the microphones and preparing it for storage by the microcontroller. This preparation, again, involves sending the signal through a low-pass filter that will isolate the relevant frequencies. The tank (also known as the unity-gain buffer) circuit is responsible for impedance matching and padding the input to the ADCs of any adverse changes in the input analog signal from the low-pass filter.

3.1.1 Microphone Selection

In order to determine the microphones that would be utilized in the construction of the device, certain design constraints had to be laid out. The following list is what was decided upon in order to achieve satisfactory functionality for the project:

- Utilizing Electret Condenser technology
    - Compact, but with desirable audio quality
- Pre-Amplified
    - Reduces size and improves ease of integration

- Accurate performance up to 20KHz
- Low Power Consumption

Given these design constraints, a preamplified microphone was chosen from Adafruit, an electronics supplier. This unit utilizes a MAX 4466 preamplifier that is soldered directly in with the electrect condenser microphone, resulting in a small package. Due to its input voltage range from 2.4V to 5.5V and adequate frequency response from 20Hz to 20KHz, it was chosen for the final design. Pictured below are the chosen microphones.

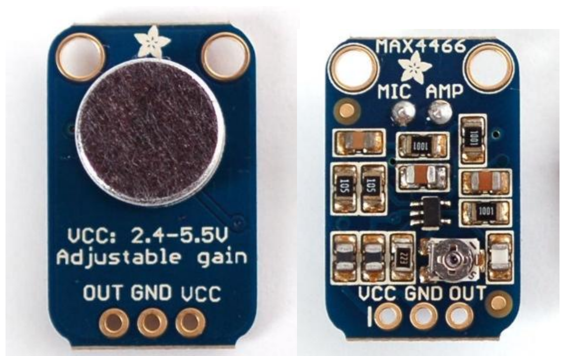

Figure 9: Electret Condenser Microphone with Preamplification

3.1.2 Filter Design

Next, the filter design had to be determined and laid out. This involves a two stage, 4th order low-pass filter utilizing the Butterworth filter topology with two Sallen-Key filters. This topology was determined by way of using a filter design wizard from Analog, an electronics company. This tool is widely used for its precision and ease of use. The chosen cutoff frequency was 50 kHz and the desired frequency gain response is shown in the figure on the following page.

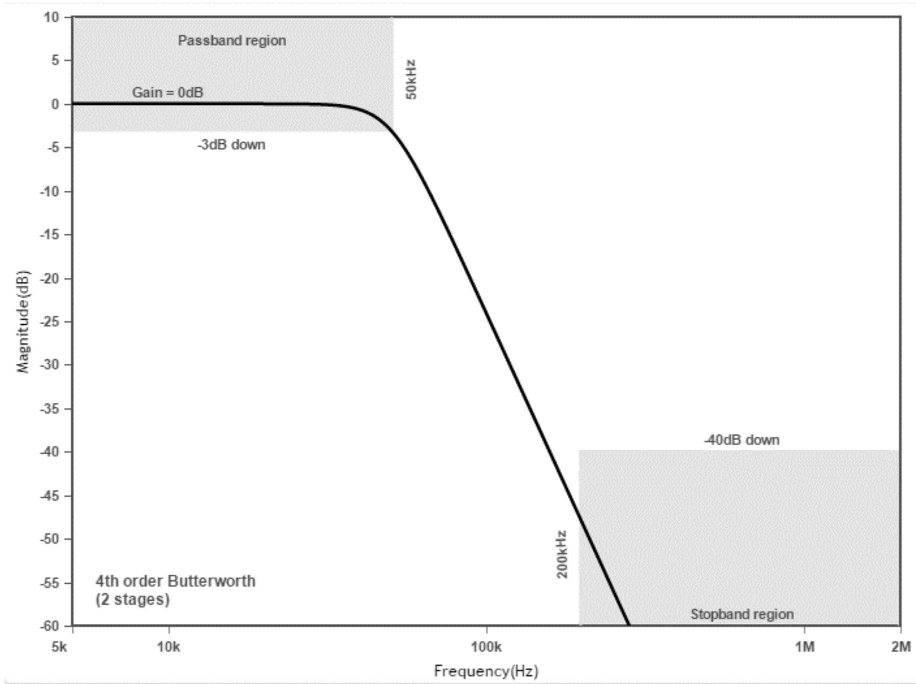

Figure 10: Ideal Low-Pass Filter Gain Reponses

The Butterworth filter topology was selected given that it is design to have a very flat frequency response in the passband region. This characteristic is highly desirable given our input signal. This allows the circuit to allow the input frequencies to remain equally weighted. For this project, it was very important when designing the filter stage to not only completely reject unwanted frequencies, but also have uniform weighting of all desired ones. If weighting is desired thereafter, weighting topologies discussed previously can be applied in order to achieve that outcome.

After the filter design was laid out mathematically, an operational amplifier had to be determined that would be able to support the design demands. This includes having a satisfactory gain and phase margin in regards to the input signals of the microphone. The chosen operational amplifier was the OPA 340 from Texas Instruments. It is a series rail-to-rail OP AMP that is optimized for use in low-voltage, single-supply operation. Additionally, it offers an excellent response with a 5.5 MHz bandwidth as well as 6V/μs signal rejection. Furthermore, the package comes in dual and quad configurations that are electronically and physically isolated which decrease the required surface area of the PCB. Below is a figure demonstrating that it achieves the desired response dictated by the project guidelines.

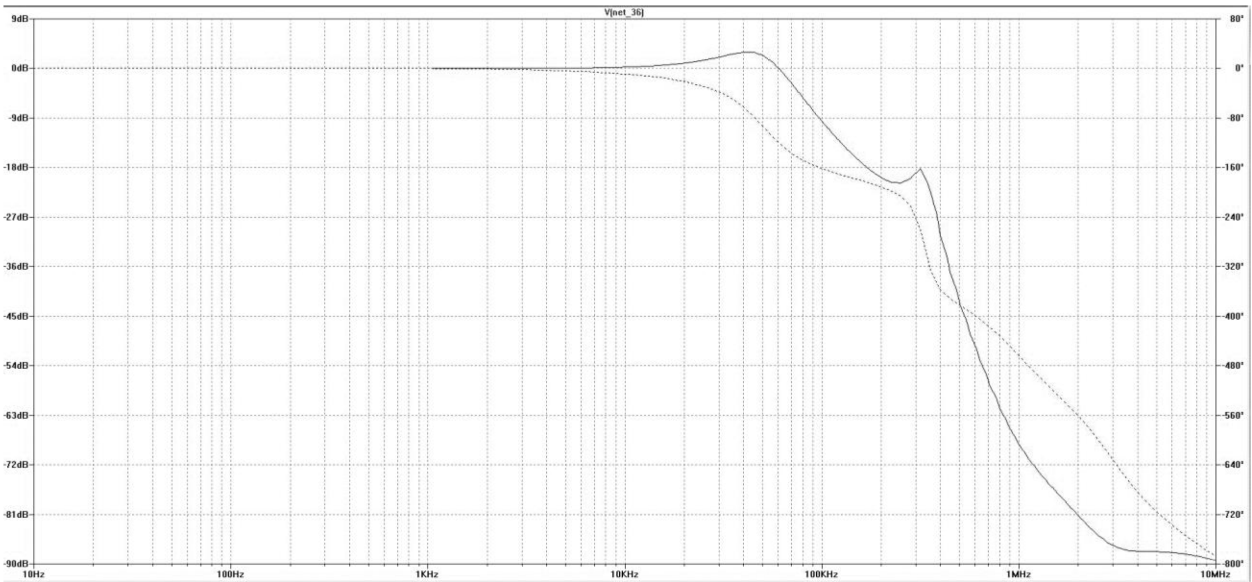

Figure 11: Bode Plot of Low-Pass Filter Response

3.1.3 Tank Circuit

The next stage is a simple unity gain buffer between the analog front end and the digital back end, this is used for impedance matching before the signal is sent to the Analog to Digital Converters (ADC). It utilizes the same OPA 340 amplifier used in the filter circuit. The design of the tank circuit is to act as a voltage buffer against any drastic changes in the input signal. It is used between the analog and digital portions of the overall design, to act as an impedance buffer between one portion with a high impedance level, to one with a low impedance. This will prevent any large changes from the filter circuit from loading the ADC unnecessarily and causing undesirable performance. Other properties of this designed sub circuit include linearity (unity gain) as well as instantaneous response. The performance of the tank circuit was verified in the above bode plot, as it was a part of the final simulations used to verify the analog front-end performance.

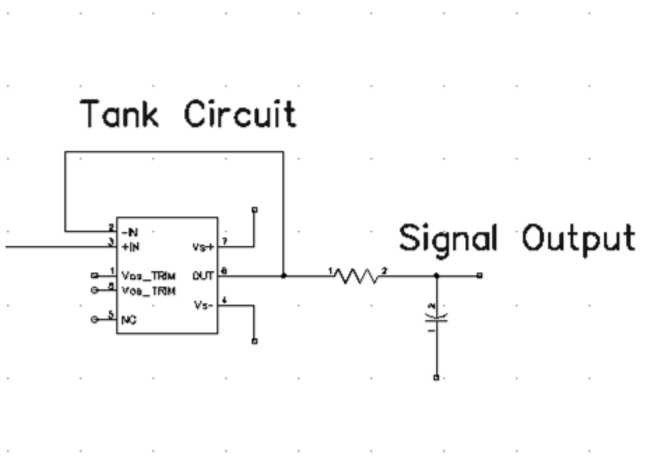

Figure 12: Tank Circuit Design

3.2 Digital Back-End

The digital back end of the devices consists of three main stages: the ADC, the microcontroller, and the SD card interface. Each subsystem will be broken down by their components and discussed in detail in the following text.

3.2.1 Analog to Digital Conversion

In designing the ADC configuration that was desired for the devices, independent ADCs were selected as being a project goal. ADCs work by converting the input signal as a quantity of its voltage, to a value that a microcontroller or computer can understand, digital, which represents the amplitude of the initial quantity. Although modern microcontrollers have onboard ADCs that are capable of performing adequately in most applications, with the addition of independent ADCs we could better control what characteristics and designs that we needed in the device. The following design constraints were then laid out:

- 10 bit resolution
- 60Khz sampling frequency

- Easy communication and control from microcontroller

Due to the design constraints listed above, the ADS7818 ADC was chosen for its excellent performance. It supports up to 12-bit sampling resolution at 500 KHz throughput rate. It also supports many other useful features such as sample/hold functionality, as well as a synchronous serial interface to the microcontroller. It also has a very low power dissipation at 11mW at full 500 KHz sampling. The full ADC circuit implemented in the final design is shown below.

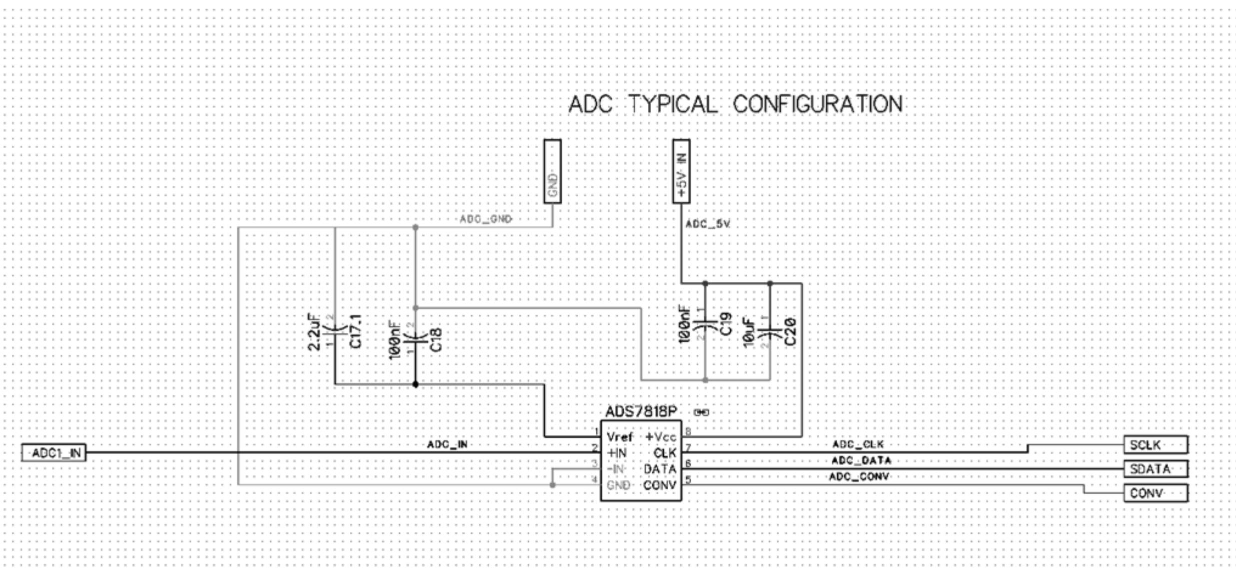

Figure 13: ADC Implementation Circuit

The interface with the microcontroller performs as follows: the conversion pin (conv) is responsible for initializing the ADC sequence in the ADS7818. When this pin goes high, the ADC will then start the conversion process. The SCLK pin is responsible for setting the sampling frequency of the ADC, for our purposes we decided upon 60khz, though higher frequencies are possible. Next, the SDATA pin is the digital output of the ADC that carries the converted signal to the microcontroller.

3.2.2 Microcontroller

Next the digitized signal is sent to the microcontroller, which sole responsibility it to take the data and prepare it to be sent to the SD card. In the future, the microcontroller may be reprogrammed to perform more advanced functionality, such as carrying out advanced mathematical processes on the digitized signal. To be able to send the data to the SD card, the microcontroller must have very high design constraints, since the input digital data will be nearly at 720 kbps. With dual channel implementation, the number then doubles to 1.44 mbps. Thus, the following constraints were required:

- 16-bit interface
- Two SPI Modules to support dual-channel configuration
- UART modules for potential communication with computer
- I^2C Module for SD Card Interface
- Low Power Consumption
- Variety of Available Packages

With these constraints in mind, the dsPIC33 family of microcontrollers were chosen. These are high-end microcontrollers with digital signal processing specialty functionalities that fit all of the criteria listed above. Additionally, they fielded the largest page erase size, program flash memory, and RAM; giving them the greatest room for expandability. The implementation of the microcontroller on the PCB interface is shown in the following page:

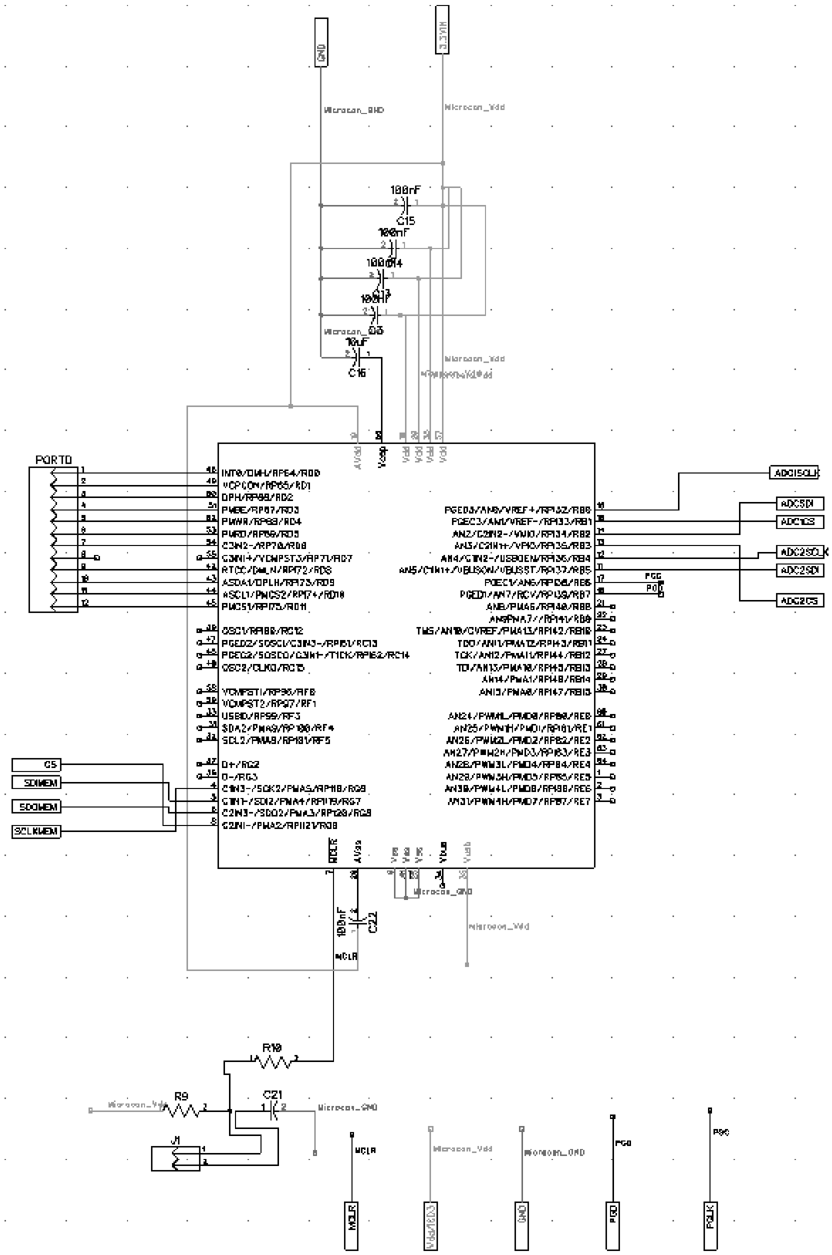

Figure 14: Microcontroller Implementation

3.2.3 SD Card Interface

Remaining is the SD card interface. This will utilize a small 4GB Secure Digital card, which is a form of nonvolatile memory that will serve the purpose of storing the digital data that it receives from the microcontroller. Thus, when searching for a suitable interface, it is important that it can easily communicate with the microcontroller. To this end, the Adafruit Micro SD Card Breakout Board suits the design constraints. It features a dual 5V or regulated 3.3V input, as well as easy communication with a microcontroller utilizing a SPI interface as well as option SDIO mode. It will be implemented on the PCB with an 8-pin jumper layout, for ease of access. Shown below is the pin layout between the interface and the microcontroller, as well as the breakout board itself.

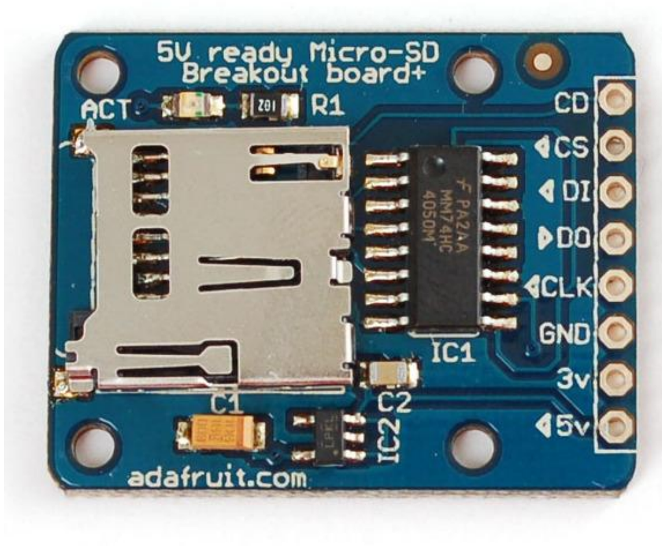

Figure 15: Micro SD Card Breakout Board

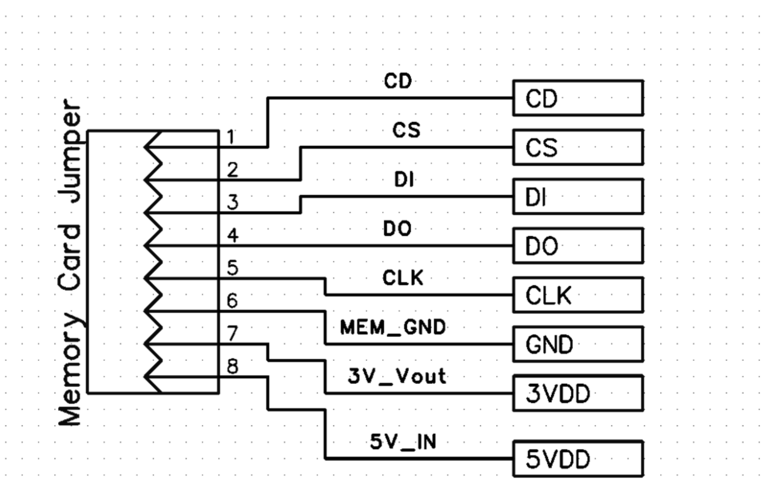

Figure 16: SD Card Layout

Additionally, the above pins have the following functionalities:

- CD – Card Detect, shorted to ground when card is inserted
- CS – Chip Select – Active low
- DO – Data Out
- DI – Data in
- CLK – Input clock from microcontroller

3.3 Design Implementation and Presentation

Given that the foundation of the circuit design has been laid out and examined one section at a time, following the implementation schedule the PCB was to be created and assembled in the Spring of 2015. Additionally, this project and its outcomes were presented at the Undergraduate Research Forum on the Carbondale Campus in April of 2015. 4 total PCBs were to be fabricated, with a total of 3 completely assembled. An extra fabrication board was to be kept on standby should, if by any means, the others were to fail and replacements were necessary. The fabrication and assembly are two different, distinct processes. The fabrication is the laying out of the physical traces present on the board that are responsible for carrying of the electrical signals and mounting of the physical hardware. The assembly is handled by another manufacturer who takes all of the components necessary for the PCB and soldering them onto the fabricated PCB with the output of this being a fully functional product. Thus, the budgetary demands for the project are shown in the table on the following page. Attached are the details of each order and its relevance to the overall project.

Table 2: Budgetary Breakdown of Project

Vendor	Quantity	Description	Price ($)
Microchip	1	MPLab ICD Debugger	159.37
Adafruit	4	Microphone W/PreAmp	37.27
Digikey	6	ADS 7818	45.24
Microchip	2	MicroControllers	14.40
Sparkfun	1	Crystal Oscillators	8.96
BuildyourCNC	1	MicroController Tutorial Kit	150.52
Sunstone	4	PCB Fabrication	158.40
Adafruit	4	MicroSD Card Breakout Board	68.89
DigiKey	N/A	Various Components	463.93
Amazon	1	Header Pins	2.42
Amazon	4	2GB Micro SD Cards	19.00
		Total	**1133.97**

Unfortunately, due to budgetary constraints, the remaining amount that would be necessary to fully assemble the PCBs would reach between $800 and $900, far exceeding the roughly $300 left allotted to the account. This discrepancy was not determined until much later in the course of the project timeline, as the design switched from a low-cost (but highly undesirable) breadboard implementation, to the much more functional surface mounted design. Thus, more funds must be available for the project to achieve fully-functional completion, and are in the process of being acquired.

Chapter 4: Discussion and Conclusion

The causes of NIHL have been extensively covered, the acoustical signals, if in high enough dB level, can damage the sensitive hair cells present in the inner ear, thus preventing a person from being able to hear properly. This noise that is present that can damage the hair cells consists of steady-state white noise and impulsive noise. Their combination, complex noise, has been shown to cause more damage to the sensitive tissue of the ear than either on their own. The Equal Energy Hypothesis, although being a standard for measuring acoustical energy, cannot generally accurately evaluate impulsive and complex noise. Additionally, Research into the higher level impulsive and complex noise has shown the major drawbacks of the EEH. While the EEH is applicable at lower impact levels, after a critical value, the damage to the inner ear increases significantly. Since so many miners are exposed to high levels of complex noise while on the job, research into capturing the signal information present inside mining fields and installation can lead to developments that help protect workers.

Since current measuring devices are based on the EEH, a new signal capturing device was proposed. This device uses a dual-channel configuration utilizing two preamplified electret condenser microphones. These microphones are a part of an analog front-end, which is responsible for isolating the frequencies present in the human hearing range. This analog data is then converted to digital format, which is stored onto a portable SD card by way of a microcontroller and a breakout board. The novelty of such a device is in its expandability and functionality. While there exist other microphone apparatus, they either sacrifice size or accuracy. Many such apparatus are restricted to free-field microphones, whereas this setup can be adapted to use free-field, bidirectional, or focused microphone sets. Additionally, mathematical functions can be performed on the information itself by the microcontroller, such as LAeq as well as Fourier Transformations.

Furthermore, this setup allows for dual-channel configurations and future expansions could include up to 4 channel configurations.

For the outcome of this project, it’s important that this data is readily available for analysis by using modern mathematical programming softwares, such as MATLAB. This digitized information can easily be loaded onto a computer by way of its SD card interface, where mathematical processes and algorithms can be performed on it to determine the kind of audio information present in these environments. With this information available, new ways can be developed in order to protect workers from occupational audio hazards that are faced on a day-to-day basis at many workplaces across the United States.

References:

[1] S. Mantysalo, J. Vuori , " Effects of impulse noise and continuous steady state noise on hearing.," *British Journal of Industrial Medicine*, Vol. 41, no., pp. 122-132, 1984. [Accessed December 1st, 2014]

[2] Military Standard (MIL-STD) 1474D, Department of Defense Design Criteria Standard: Noise Limits, 12 Feb 97.

[3] Chan DK, Hudspeth AJ (Feburary 2005). "Ca2+ Current-Driven Nonlinear Amplification by the Mammailian Cochlea in vitro", NatureNeuroscience **8** (2): 149-155. Doi:10.1038/nn1385. PMC 2151387 PMID 15643426

[4] Noise Induced Hearing Loss, *National Institute on Deafness and Other Communication Disorders*, [Online] 2014, http://www.nidcd.nih.gov/health/hearing/pages/noise.aspx (Accessed: 1 November 2014)

[5] Rzadzinska AK, Schneider ME, Davies C, Riordan GP, Kachar B (2004). "An actin molecular treadmill and myosins maintain stereocilia functional architecture and self-renewal". *J. Cell Biol.* **164** (6): 887–97. doi:10.1083/jcb.200310055. PMC 2172292.PMID 15024034.

[6] Hearing Loss Causes, *MayoClinic*, [Online] 2014, http://www.mayoclinic.org/diseases-conditions/hearing-loss/basics/causes/con-20027684 (Accessed: 2 November 2014)

[7] Agrawal, Y., E.A. Platz, and J.K. Niparko, *Prevalence of hearing loss and differences by demographic characteristics among US adults – Data from the National Health and Nutrition Examination Survey, 1999-2004.* Archives of Internal Medicine, 2008. **168**(14): p. 1522-1530

[8] Seidman MD, Standring RT. Noise and Quality of Life. *International Journal of Environmental Research and Public Health* 2010;7(10):3730-3738. doi:10.3390/ijerph7103730.

[9] McBridge, D.I., *Noise-Induced hearing loss and hearing conservation in mining.* Occupational Medicine-Oxford, 2004. **54(**5): p. 290-296.

[10] Smith, G., *Noise? What noise?* Occupational health & safety (Waco, Tex.), 1996. **65**(3): p.38.

[11] Hamernik, R. P.; Salvi, R. J.; Henderson, D.; Milone, R., "Impact noise and the equal energy hypothesis". *The Journal of the Acoustical Society of America,* Volume 77, Issue 4, pp 1514-1520, April 1985.