

Wildlife Audio Sensing

ECE 445
Senior Design
Fall 2016

Group 33
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Abstract

This report details the senior design project design and testing process. It introduces the basic concept and idea of the Wildlife Audio Sensing project, expanding on further through discussion of the design procedure and details. The testing results, data and graphs are used to verify the project's functionality, and to demonstrate to the reader that all requirements of the design were met.

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1. Introduction

The Wildlife Audio Sensing system is designed to record animal sounds in the wild, such as in a forest. The project is designed to benefit wildlife research, as well as other fields that focus on sound and audio analysis. Most other systems available for these purposes are either very expensive, not long lasting, or recording continuously; wasting storage and energy. The system is designed to be long lasting by utilizing a large power supply as well as energy saving features. The system conserves energy by not always being active and recording data to storage. When the system detects sound, the captured audio is saved and recorded, otherwise the system remains in an idle state and conserves power. The system is also designed to be as affordable as possible, to make it far more attractive to researchers and others. As seen in figure 1, the system consists of three modules: sensors, main control unit, and power supply.

The sensors monitor and capture sound, with the ability to filter out certain frequencies as desired. The main control unit is the brains of the system, detecting audio and storing the audio files, while also being as energy efficient as possible. The power supply provides power to the entire system, designed to be as long lasting as possible, with the goal of lasting around a month.

During the semester, the only changes made to the system design were to separate the battery charger from the rest of the power module, and to change what microcontroller is to be used. The original design included the charger as being directly connected to the battery, and being powered by a solar panel. However, when the benefits and disadvantages were weighed, it was determined that it was an impractical design as the solar panel would rarely receive sunlight inside the dark and dense canopy of a forest, and thus it was more feasible and practical in terms of power to implement two batteries in series without a charger, instead of one connected to a charger. Having two batteries greatly increases the operational lifetime of the system, and as mentioned earlier, the charger can only charge one battery at a time, and thus has to be implemented separately. The other significant change that was made, was changing the microcontroller from a Silicon Labs Tiny Gecko microcontroller, to an Arduino Pro Mini microcontroller which has very similar functionality as well as nearly the same power consumption. The decision was made due to the fact that the Arduino Pro Mini is much smaller in terms of size than the Silicon Labs Tiny Gecko, as well as being much easier to program, more intuitive, and easier to implement.

2. Design

2.1 Design Procedure

2.1.1 Sensors

The sensor module includes the microphone with preamplifier, as well as the passive low pass filter. The microphone will capture audio, sending it through the passive low pass filter, which filters out sound frequencies above 8,000 Hz, and sends them onward to the main control unit. In order for the system to function correctly, the microphone must be able to accurately record sound frequencies from 0 Hz to at least 8,000 Hz, while the passive low pass filter must have a three decibel cut off that occurs at 8,000 Hz, plus or minus five percent accuracy.

The sensor module was designed to capture sound with a large range of frequencies, with the option to be able to filter out certain sound frequencies. The microphone was chosen to be able to capture a wide range of sound frequencies, yet at the same time being very affordable and easily obtained or replaced. The Sparkfun Electret Microphone Breakout was chosen by the Mentor as it is very affordable, easily available, captures a wide range of audio frequencies, and is omnidirectional [1]. The basic circuit design can be seen in figure 3, where the microphone is connected to low pass filter.

The low pass filter was chosen as it passes through low frequencies, while cutting off high frequencies. It was designed to cut off sound frequencies above a threshold frequency by having the three decibel cut off occur around 8,000 Hz, while at the same time consuming as little power if the Mentor decides to use it. For this reason, a passive low pass filter design was chosen, which is comprised of nothing more than a resistor and a capacitor, and requiring no power supply other than ground [2]. For the design of the filter, equation (1) was used, which gives the 3 dB frequency cut off of a filter. Using equation (1), and then simply manipulating it by moving the variables around, equation (2) was derived [3]. Using equation (2), and choosing the cut off frequency as well as the capacitor value, the resistor value was found.

$$f_c = \frac{1}{2\pi RC} \quad (1)$$

$$R = \frac{1}{2\pi fC} \quad (2)$$

2.1.2 Main Control Unit

The main control unit is comprised of the microcontroller and microSD card interface. The microcontroller, an Arduino Pro Mini, acts as the brain of the system, determining when and whether the captured audio signal it receives will be saved and recorded, while the microSD card interface acts to connect the microcontroller to a microSD card to enable storage of audio files. The microcontroller receives analog audio signals from the sensor module, and converts the received signal to a digital version through the built in analog to digital converter, then sends the audio files to be recorded through the microSD card interface when it determines that the audio is to be recorded. The main control unit will employ a basic sound detection and recording program, however the Mentor can later

modify it to implement a more sophisticated and energy efficient program. The microcontroller must be able to accurately convert analog signals to digital, and save data files correctly to the microSD card through the microSD card interface, which can then be later opened and played on a computer.

The main control unit was designed to be able to receive an analog input and convert it to a digital signal. The main control unit will need to be able to differentiate between quiet “no sound” and sound. When it detects sound, it will record the converted analog input to a microSD card as a .wav format. The Arduino Mini Pro was chosen to perform these tasks as the Arduino Mini Pro does not require much power to operate [4]. When the system is in idle, it requires around 0.9 mA and when it is active and recording, the Mini Pro needs around 5 mA. These power consumptions make the Arduino Mini Pro an ideal microprocessor for the project, combined with the fact that the Mini Pro costs around \$10, which is really affordable.

The Mini Pro will be connected to a microSD interface breakout. The Adafruit microSD breakout was chosen for this role. The Adafruit microSD breakout is able to read and write more than 2 Gb to storage and supports many card formats such as FAT32 [5]. The breakout also has a LED feature that will blink when writing or reading a file occurs. This makes it easy to tell and debug when the recording occurs. The breakout also has 5 V and 3 V regulators so can accept a wide range of voltages.

2.1.3 Power Supply

The power supply was designed to provide a long lasting power source for the entire system. The power supply consists of a voltage regulator, under voltage lockout, two D-cell batteries, and a separate linear battery charger as seen in figure 2. The voltage regulator ensures that the microcontroller, microSD card interface, and microphone all receive a properly rated voltage power supply to function correctly. The undervoltage lockout (UVLO) ensures that the batteries are not damaged, by cutting off the power supply before the batteries reach a minimal safe voltage. The UVLO receives input power from the batteries, and outputs power to the voltage regulator. The two D-cell batteries provide all the power for the system, ensuring a maximal operation lifetime for the system before requiring recharging. The linear battery charger is designed to charge nickel metal hydride batteries, however this component is implemented separately from the rest of the system as the charger is designed to charge a single battery, not two.

The microcontroller, microSD card interface, and microphone all require a stable power supply of 3.3 V, and therefore it was determined that a voltage regulator will be necessary as the power supply voltage will fluctuate and change over time as the battery is drained of charge [6]. The voltage regulator must provide a stable 3.3 V power supply output, while it receives a voltage input that ranges from 2.4 V down to 2 V. The Microchip Technology ADM00458 voltage regulator was chosen as it can supply a steady 3.3 V output, while receiving a 0.35 volt to 5.5 V range input. By having this wide range of accepted voltage inputs, it allows for many different choices of battery to be used in the system.

The main source of power for the system was chosen to be a battery as this was the only feasible power source, as the system and its purpose is designed to function in the wilderness and other remote locations where there is no readily available power source. Due to this limitation, a battery with a high capacity was required, while also being readily available as desired by the Mentor. As suggested by the mentor, two D-cell batteries will be used, but for increased functionality, they are to be rechargeable [1]. For this reason, the EBL D-Cell 10,000 mAh nickel metal hydride batteries were chosen.

Since the battery chemistry is nickel metal hydride as opposed to lithium-ion, the battery is more stable and far less prone to fire or other accidents [7].

In order to protect the battery from being damaged by being over drained, an UVLO was necessary [8][9]. The UVLO must output the same voltage that it receives at its input, ranging from 2.5 V down to 2 V, however when it receives a voltage input below 2 V, which is about the minimal safe level, it must output a voltage of nearly 0 V, essentially cutting off the battery. Since the output matches the input down to 2 V, and cuts off power below, it required a circuit that can compare two voltages. For this purpose and general idea of how UVLO work, various designs were observed online but none were deemed satisfactory. Taking the basic idea of using voltage dividers to compare voltages, as well as an operational amplifier and a transistor to cut off power, various designs as created by our team that combined the different aspects of other UVLO were tested in LTSPICE simulator. The first design that was tested, as shown in figure 4, was not successful. After much trial and error, another design was created, this time using a Zener diode to act as a voltage reference, as seen in figure 5. Using basic voltage dividers slightly modified, equation (3) was used to determine the resistors used in the voltage dividers, as well as the Zener diode value.

$$\frac{V_{Cutoff} * R_2}{R_1 + R_2} = V_B = V_{Zener} + \frac{V_{Cutoff} - V_{Zener}}{R_3 + R_4} * R_4 \quad (3)$$

Once the circuit was tested and verified using the chosen components, the printed circuit board was designed using EagleCAD.

The linear battery charger was chosen to be able to charge a nickel metal hydride battery. For this purpose, the LTC4060 Standalone Linear NiMH/NiCd Fast Battery Charger component was chosen. Using the manufacturer's suggested circuit, the charger circuit was designed using the resistors, capacitors, and other components as seen in figure 6 [10]. Then using EagleCAD, the printed circuit board was designed. The charger must provide at least 10 mA of charging current, as this is larger than the average power consumption of the system, and thus is a good threshold.

2.2. Design Details

2.2.1 Sensors

The sensor module as comprised of a microphone and low pass filter did not require much design. The microphone was already chosen and provided by the Mentor, and required little assembly, only being connected to a 3.3 V supply and ground, and having the audio output being connected to the low pass filter or directly to the analog to digital converter of the microprocessor.

The low pass filter receives an analog audio signal from the microphone, and filters out frequencies greater than 8,000 Hz. This is achieved using equation (4) and (5), where the cutoff frequency was chosen as 8,000 Hz, and the capacitor value was chosen as 0.1 μ F [3]. This results in the resistor value of 199 Ω .

$$R = \frac{1}{2\pi fC} \quad (4)$$

$$R = \frac{1}{2\pi(8000)(0.1 * 10^{-6})} = 198.9 \Omega \quad (5)$$

Once the values of the resistor were chosen based upon the desired cutoff frequency and the capacitor value, the low pass filter was drawn in a simulation program, LTSPICE, as seen in figure 7, and was tested over a range of 9,000 Hz to check whether the three decibel cutoff occurs at the desired frequency. Once the cutoff frequency of the filter was verified, it can then be designed as a printed circuit board using a program such as EagleCAD. In order to account for imprecise resistor values, a circuit was designed that can either use one or two resistors in the event that one resistor is not close enough to the desired value. This design can be seen in figure 8, where the two resistors allow for more accuracy when getting the desired resistor value, so that the cutoff frequency occurs as close to the desired threshold as possible. For this reason, when testing the resistor values, the closest that could be achieved was using a 25 Ω and a 175 Ω resistors. The tested capacitor had the desired value of 0.1 microfarads. The desired results. The printed circuit board can be seen in figure 9.

2.2.2 Main Control Unit

The Arduino is programmed by using Arduino software tool. The program is written in C code. The code will instruct the Mini Pro to neglect any input below 900 ADC. When the input is bigger than 900 ADC, it will take the input and record it to the SD card in .wav format. Recording will last for ten seconds. If it detects sound after the ten seconds, it will continue recording for another ten seconds, otherwise it will stop recording.

In order to record sound, both microphone and microSD breakout have to be connected correctly to the Mini pro. The microphone audio pin is connected to A0 on the Mini Pro. A0 is one out of four available ADC pins. ADC will convert analog input into digital input and let the Mini Pro read analog signal. If the sound input is connected to normal pins, such as pin two and pin three, the Mini Pro will read the analog input incorrectly.

The SD breakout has eight pins. They are: CD (card detect), CS (chip select), DI (data in), DO (data out), Clk (clock), Gnd (ground), 3V, and 5V. Since the system does not require to open any files from the SD card and only store data to it, only CS, DI, and Clk need to be connected to the Mini Pro. CS can be connected to any normal pins, such as pin two to thirteen. In this project, CS is connected to pin four. DI has to be connected to MOSI pin. The MOSI pin in the Mini Pro is pin number eleven. Clk has to be connected to SCK pin, which is located in pin 13 [4][5].

To power the Mini Pro and the SD breakout, the NiMH battery will be used to supply the power. The power source will be connected to Vcc pin on the Mini Pro, and 3V pin on the microSD breakout. The ground pins on both devices are connected to ground. The full schematic can be seen in figure 10 [4][5].

2.2.3 Power Supply

The voltage regulator did not require further design other than connecting the correct inputs and outputs, as well as selecting the desired 3.3 V output rating. The regulator input was connected to the output of the UVLO, with input high to high, and input ground to ground. The voltage regulator was connected to supply power to the microcontroller, microSD card interface, and the microphone. Since all three components combined use at most 46 mA, the regulator must be able to supply at least that level of current. This number was achieved from the fact that writing to the microSD card takes 40 mA, and the microphone along with the analog to digital converter use 1 mA as stated by our mentor, and from measuring the microcontroller it was found to draw 5 mA at most when active, yielding the 46 mA maximum current draw. In order to power the microcontroller, microSD card interface, and the microphone, all three components required to be connected to the voltage regulator output. The output high was connected to the high input of the three components, and the output ground was connected to the ground input of the three components.

The UVLO required lots of trial and error testing in simulations, and using the previously used modified voltage divider equation, equation (3), and using a 1.25 V Zener diode, values for resistors R_1 and R_2 were chosen arbitrarily, with $R_1 = 100 \Omega$ and $R_2 = 300 \Omega$. Then using the reference cutoff voltage of 2 V, this allows for nice voltage division. Using the above mentioned values, equation (6), was used [9].

$$\frac{2 * 300}{100 + 300} = 1.5 \text{ Volts} = 1.25 + \frac{2 - 1.25}{R_3 + R_4} * R_4 \quad (6)$$

Solving for the resistor values of R_3 and R_4 , then yields the relationship as seen in equation (7).

$$R_4 = \frac{1}{2} R_3 \quad (7)$$

Choosing the resistor values based upon the previous relation, results in choosing $R_3 = 10,000 \Omega$ and $R_4 = 5,000 \Omega$. Setting up the simulation in LTSPICE, the resistor values were used as found above, and the other components used were Si7137DP PMOS, LT1495 operational amplifier, and LT1389 Zener diode with 1.25 V value. The circuit was assembled as seen in figure 5, and a voltage sweep was run from 2.4 V down to 1.9 V to determine if the voltage output is cut off below a 2 V input. The simulation

results can be seen in figure 11. The circuit was then designed as a printed circuit board using EagleCAD and assembled. The printed circuit board can be seen in figure 12, and the printed circuit board design in figure 13.

The charger did not require any further design other than implementing the manufacturer suggested circuit by designing the printed circuit board using EagleCAD. The printed circuit board can be seen in figure 14, and the printed circuit board design can be seen in figure 15.

The battery did not require any design other than choosing the capacity and chemistry as mentioned earlier. To calculate the lifetime of the battery, the power consumption of the system was required. As mentioned above, the system components consume different levels of current depending on the state. When the Arduino Pro Mini microcontroller is active, it consumes 5 mA, while when it is idle it consumes only 0.9 mA. Writing to the SD card consumes 40 mA, the microphone consumes 0.5 mA, and the analog to digital converter consumes 0.5 mA as stated by the Mentor. Since the Mentor wishes to implement his own more sophisticated program, he explained the stages of the program and how much current they consume overall. As stated by the Mentor, the program is broken down into three subtasks: event detection, event tracking, logging / transmitting of audio events. The average probabilities of the 3 subtasks occurring can be seen in table 1. The calculations as provided for each of the subtasks are as follows: equation (8) for event detection, equation (9) for event tracking, and equation (10) for logging / transmitting audio events. The symbols are the power consumption of different components, and are as follows: W (Writing to SD card), A (Active Microcontroller), I (Idle Microcontroller), T (Audio Processing). The values and further details of these can be seen in table 2, yielding the following results [11].

$$\begin{aligned} &\text{Event detection:} \\ &0.1 (W+A+T) + 0.8 (A+T) + 0.1 (I+T) = 9.59 \text{ mA} \end{aligned} \tag{8}$$

$$\begin{aligned} &\text{Event tracking:} \\ &0.8 (A+T) + 0.2 (I+T) = 5.18 \text{ mA} \end{aligned} \tag{9}$$

$$\begin{aligned} &\text{Logging / transmitting of audio events} \\ &0.6 (A+T) + 0.4 (I+T) = 4.36 \text{ mA} \end{aligned} \tag{10}$$

Then using the average probabilities of the amount of time they occur, as seen in table 1, the average power consumption was calculated in equation (11).

$$10\% (9.59) + 5\% (5.18) + 85\% (4.36) = 4.924 \text{ mA} \tag{11}$$

Due to the fact that a voltage regulator is used, which takes the input battery voltage which can range from 2.0 V to 2.5 V, and amplifies it to 3.3 V, more current is consumed so that power can be conserved. Using equation (12) to find the minimum amplification, equation (13) to find maximum amplification, and equation (14) to find average amplification factor. Then multiplying the calculated current consumption by the average amplification factor, the average current consumption of the system is found in equation (15). Dividing the battery capacity by the average current consumption, yields the expected battery life as seen in Equation (16), which roughly equals two months, much longer than the original Mentor suggested goal of one-month operational lifetime [6].

$$Amplification_{Min} = \frac{3.3volts}{2.5volts} = 1.32 \quad (12)$$

$$Amplification_{Max} = \frac{3.3volts}{2volts} = 1.65 \quad (13)$$

$$Amplification_{average} = \frac{1.65 + 1.32}{2} = 1.485 \quad (14)$$

$$Power \ Consumption_{Actual} = 1.485 * 4.924 mA = 7.31214 mA \quad (15)$$

$$Battery \ Life = \frac{10,000_{mAh}}{7.31214_{mA}} = 1367.6 \ Hours \quad (16)$$

3. Verification

3.1 Sensors

The sensor module was tested by connecting the microphone to a DC power supply at 3.3 V, and connecting the analog audio output to a multimeter and measuring the output frequency. The microphone was then tested by generating various sound frequencies on a phone application, ranging from 0 to 9,000 Hz at 100 Hz intervals, and recording the frequency that the microphone captures by looking at the frequency measurement on the multimeter. The sound frequencies that were recorded were then compared with the sound frequencies generated, and as seen in table 3, the difference between the two is less than a percent. The only significant difference was for frequencies below 200 Hz, as there was too much sound interference in the room to get proper measurements for that range.

The low pass filter was tested by connecting the filter input to a function generator and generating frequencies from 0 to 9,000 Hz, at 200 Hz intervals, and measuring the output by connecting it to an oscilloscope. The input voltage was then compared with the output voltage, and the ratio of them was used to calculate the decibel values as seen in table 4, and figure 16. The filter -3 dB cutoff occurred at around 8,200 Hz, well within the desired range, and the microphone also met the desired accuracy, as required in table 5 [2][3].

3.2 Main Control Unit

The microcontroller and microSD card interface were first tested by connecting microcontroller to the microSD card interface, and writing a simple program to just write a test file onto the SD card, and then checking the file on the computer. Once the recording was determined to be correct, the analog to digital converter was tested by connecting the microphone to the microcontroller and microSD card interface setup as before. Then a basic sound detection program was written, where it records audio file as a .wav to the SD card when sound is detected. By measuring the A0 value of the analog to digital convertor on the microcontroller by using a simple program, it was found that when the microphone had a “silent” input, the A0 value was around 500, while A0 was around 1,000 when there was a louder sound input to the microphone. By writing the sound detection and recording program to start recording when the A0 value was over 900, it gave a testing threshold to test the basic functionality of the system.

The microSD card interface was also tested by checking if the LED on the breakout board light up when active. The LED on microSD breakout represents whether the system is recording or not. When the environment is quiet or below A0 value of 900, the LED should not blink. A sound with A0 value above 900, will then be produced to trigger the system to start recording for ten seconds. This will create a file named 1.wav in the microSD. The next step is to produce another sound above A0 = 900 to test whether the system is able to capture the new sound. A file named 2.wav should be appear if the system works correctly.

A PC will be used to check and read if the sounds are recorded correctly. There should be two files and in .wav format on the microSD. Using any appropriate programs such as Windows Media Player, the files should be playable and produce similar sounds like the original ones. The recorded files contained the two correct files, with the correct audio sound and data, as was demonstrated during the project demos. Since when the files recorded onto the microSD card were opened on the computer, they matched the audio that was to be recorded, they were considered successful. Simply put, the

recorded words heard on audio, matched the words that were spoken into the microphone during testing the system [1]. These results matched the requirements as seen in table 6.

3.3 Power Supply

The voltage regulator was tested by connecting the input to a DC power supply, then sweeping the input voltage from 2.4 V down to 1.9 V at 0.1 V intervals. The output voltage was measured by connecting the regulator output to the multimeter, and measuring the output voltage to confirm that the desired 3.3 voltage is output for the input voltage range. The output current is then also measured to ensure that the regulator can supply at least 46 mA. This ensures that the proper voltage and current can be supplied to the rest of the system. As seen in table 7, the results output the correct voltage of around 3.3 V and over 100 mA.

The UVLO was then tested in a similar manner, by connecting the input to a DC power supply, and sweeping the voltage from 2.4 V down to 1.9 V at 0.05 V intervals. The output voltage was then measured by connecting the output to the multimeter and measuring the voltage that is output. The results, as seen in table 8, have the output voltage matching the input voltage, until it reaches around 1.99 V at input, where the output voltage drops to near 0 V, as was desired.

The battery charger was then tested by connecting its input to a 5 V supply from the DC power supply, and then connecting the charger output to a battery. The battery and charger were then set up in series with the multimeter to measure the current when the charger is off, and when the charger is on. As seen in table 9, the difference between the current when the charger is off and when it is on is approximately 40 mA, indicating that the battery is being charged when the charger is powered on. The additional functionality of the charger was then tested by checking whether the LED's function as intended by the manufacturer's design. When the battery was disconnected from the charger which was still powered on, only LED was on to indicate that the charger has sufficient power supply and that no charging is occurring. When the battery was connected to the charger which was powered on, both LED's were on to indicate that the charger had sufficient power supply, and that charging was ongoing. When the charger was disconnected from power supply, no LED's were on, to indicate that the charger was off. The LED's correct functionality matched what the manufacturer intended.

Since all three power supply components functioned as desired, this meets the requirements as seen in table 10. Overall, the power supply met the desired specifications for the systems, and functioned correctly when it was used for the project demo to power the entire system.

4. Costs

The costs for the entire project from start to finish is comprised of parts/components, team labor, and services labor. The component costs roughly equaled \$110.9 for parts as seen in table 11. The services cost was estimated at \$45 as seen in table 12, for services provided by PCB Shop and Machine Shop which printed the PCB's and assembled the system package. The team labor cost was based upon hours of labor put into the project which roughly equaled 113 hours as seen in table 13, and total labor costs amount to \$8,475 as seen in table 14. The total project cost amounts to \$8,630.90.

5. Conclusions

5.1 Conclusion and Summary

Overall, the project worked as intended. All the components of the three modules of the system, independently worked correctly as verified in earlier sections. When all three modules were assembled and tested, the desired goal of detecting and recording audio as .wav files to a SD card were met. The project was demoed in front of a group of people, who were able to witness that the entire system functioned as intended when fully assembled. The power module powered the other two modules properly, delivering the required voltage and current ratings the system required to function. The sensor module was able to correctly capture and transmit sounds in a wide range of frequencies, while the main control unit was able to correctly record the sounds as audio .wav files onto the SD card. The main control unit was also able to be programmed with a basic code that correctly detected sound, and then recorded it to the SD card. Since all the components were verified in their functionality, both independently and when combined, the system can be used for the purposes that the Mentor intended. The Mentor may now implement his more sophisticated program, or do as he wishes, since this is essentially hardware designed for his software. By accomplishing the goals of creating a long lasting, affordable system that can detect sound, the project can be useful for many purposes such as wildlife research or audio and sound analysis.

5.2 Ethics and Safety

This project poses some hazard due to the nature of NiMH batteries and charging them. NiMH batteries can contain chemicals that may be toxic to nature, and since this system purpose is used to monitor wildlife in the forest or some other location outside, it is important to ensure that the battery does not leak or catch fire, as this may cause a forest fire at the worst case, or a toxic leak [12]. Extreme elevated temperatures may be experienced if a cell is excessively overcharged. This may pose a fire hazard, which can be dangerous as may cause fire and leak chemicals. To solve the issue, a linear battery charger will be used to limit how much the battery can charge so it won't overcharge, as well as separating the charger from the rest of the system. By implementing this component into the design, the threat or hazard of a fire occurring are greatly diminished. To ensure that a chemical leak does not occur, the entire system will be contained inside a watertight plastic box as shown in figure 16.

Our wild life audio sensing project follows IEEE codes of ethics, with the two stated below being the most critical to our project [13].

1. to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;
2. to avoid injuring others, their property, reputation, or employment by false or malicious action;

These two statements are most critical as our system has the potential to cause a fire or chemical leak which is hazardous to nature and the public. To ensure that the above stated codes of ethics are followed, safety measures have been implemented, and the potential hazard have been disclosed as stated in the safety section. By following these guidelines and having implemented appropriate measures in our design, we are complying with the most important ethics that deal with safety, and thus minimizing any potential hazards from occurring.

Appendices

Appendix A Figures

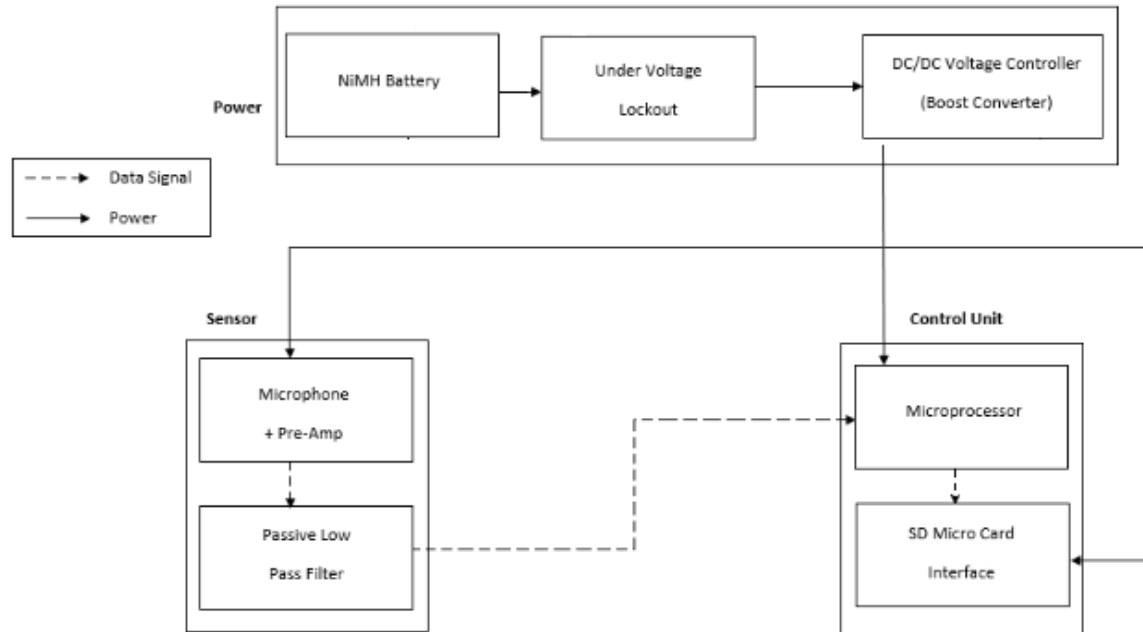


Figure 1. Main block diagram

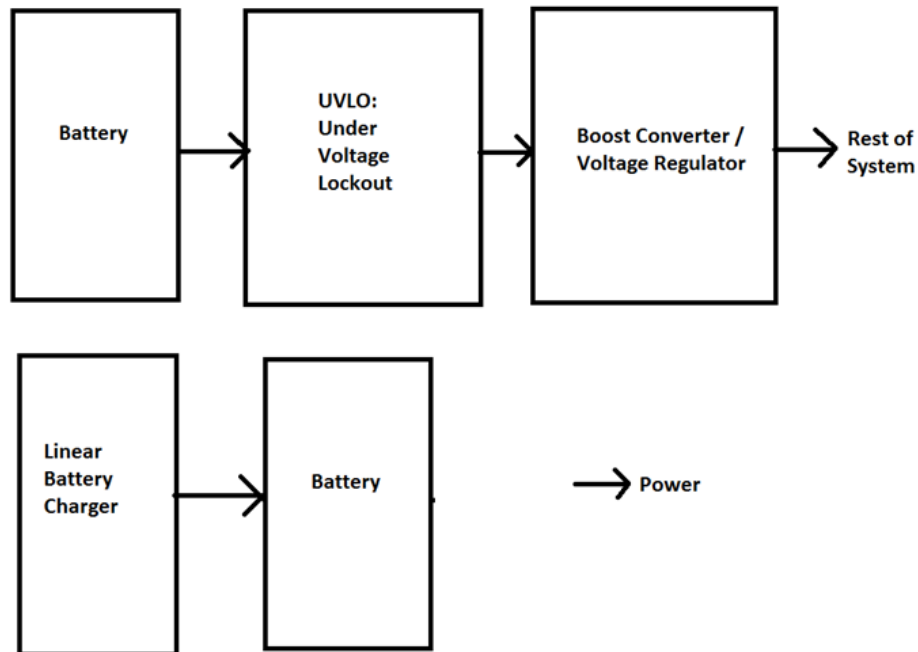


Figure 2. Power block diagram

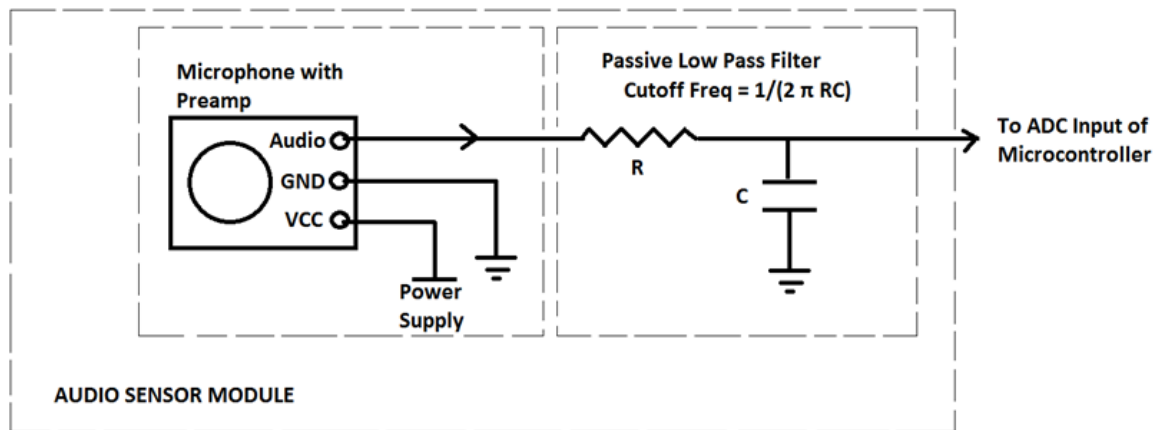


Figure 3. Sensor block diagram

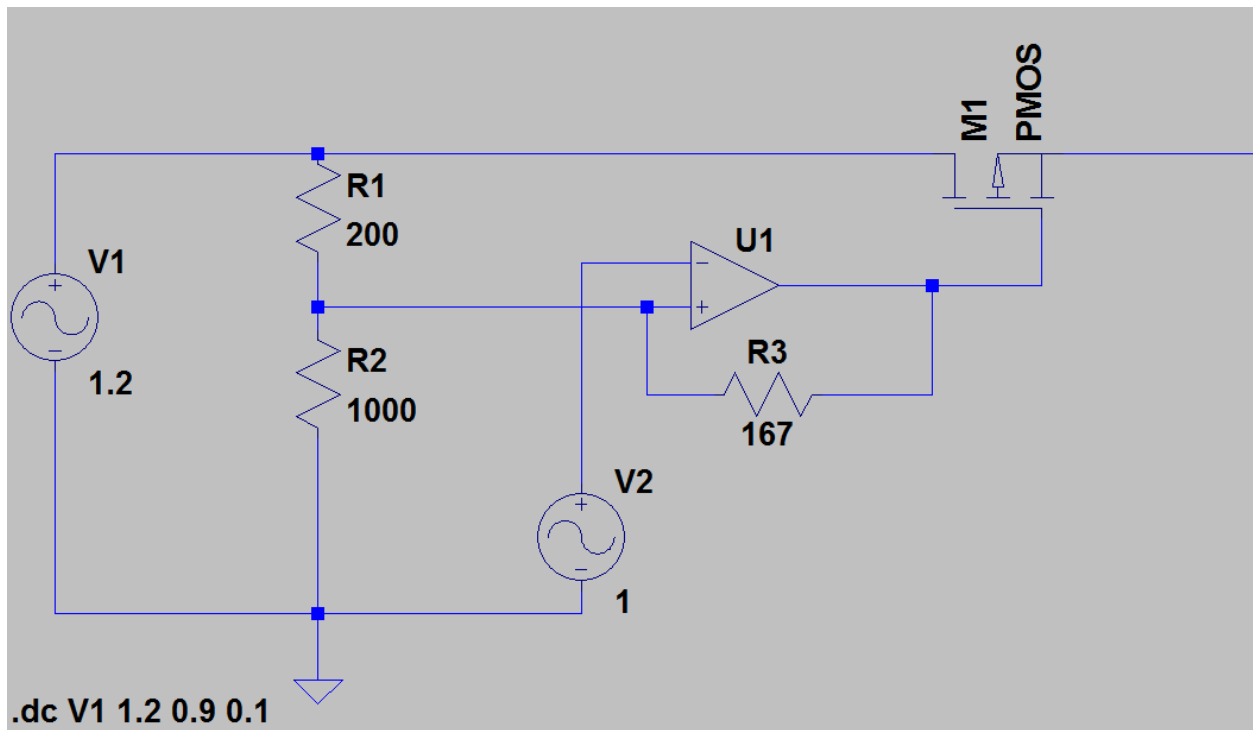


Figure 4. Failed UVLO simulation circuit

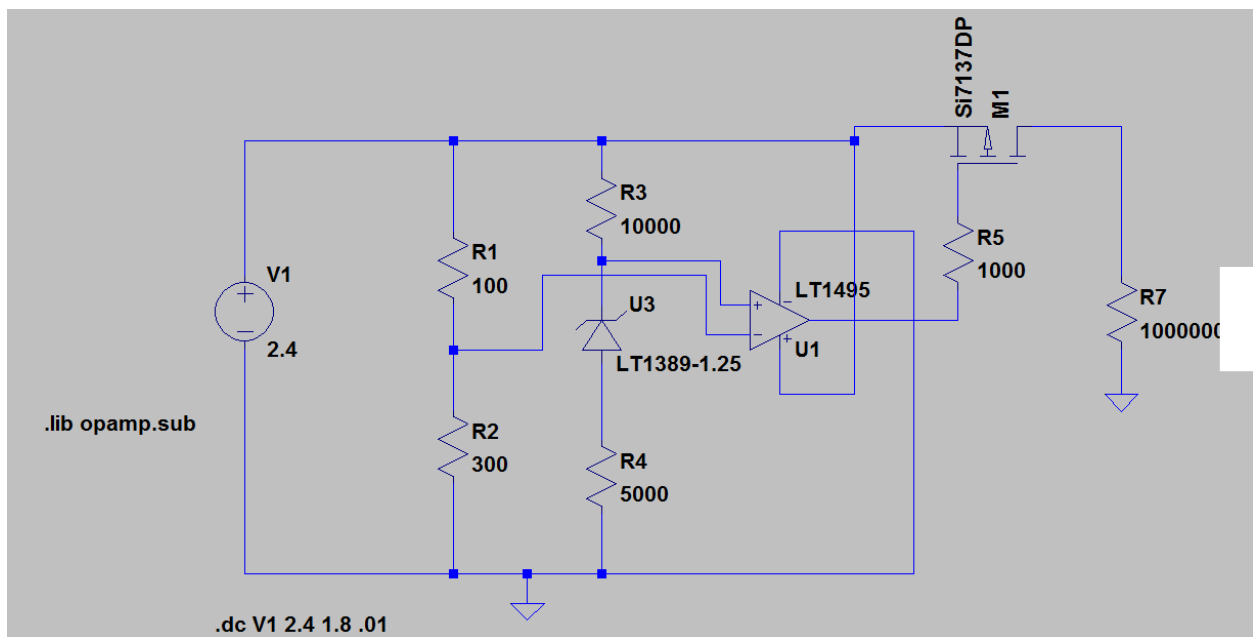


Figure 5. Working UVLO simulation circuit

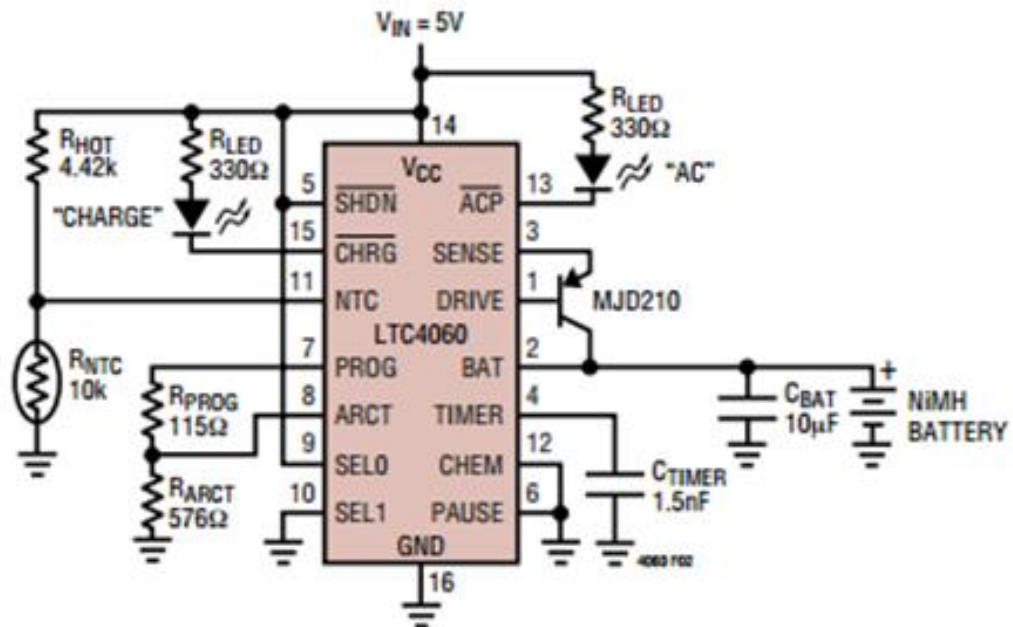


Figure 6. Manufacturer suggested circuit from charger [10]

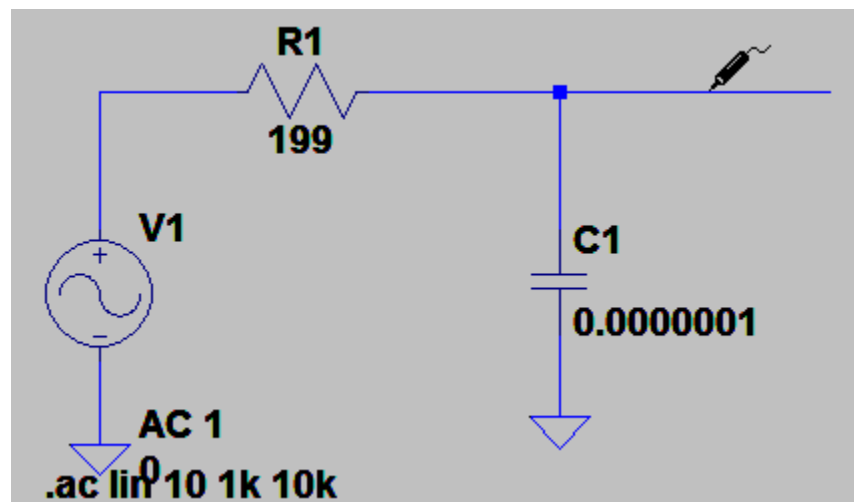


Figure 7. Low pass filter simulation circuit

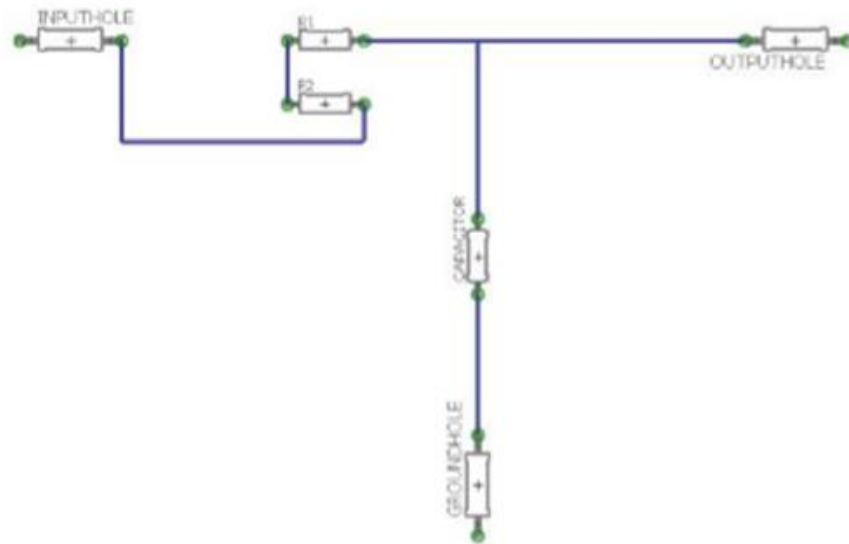


Figure 8. Low-pass filter PCB design

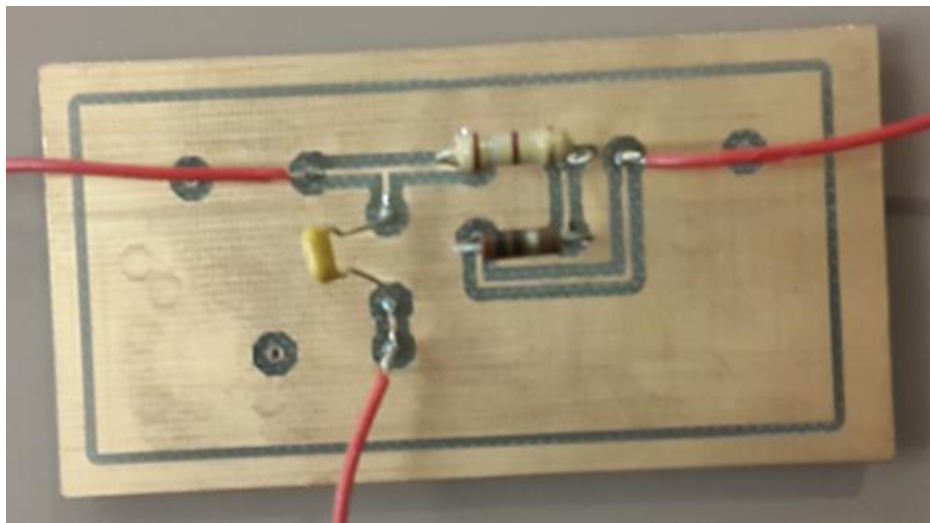


Figure 9. Low-pass filter PCB

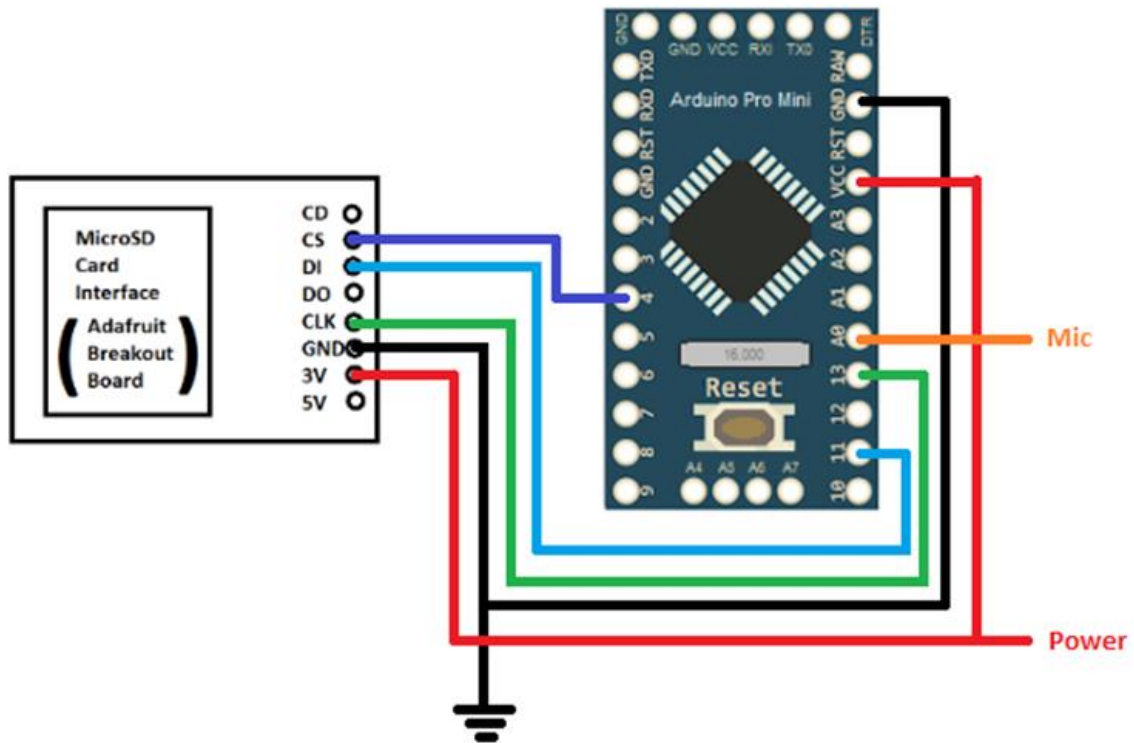


Figure 10. Arduino Mini Pro and Adafruit SD breakout interface [4][5]

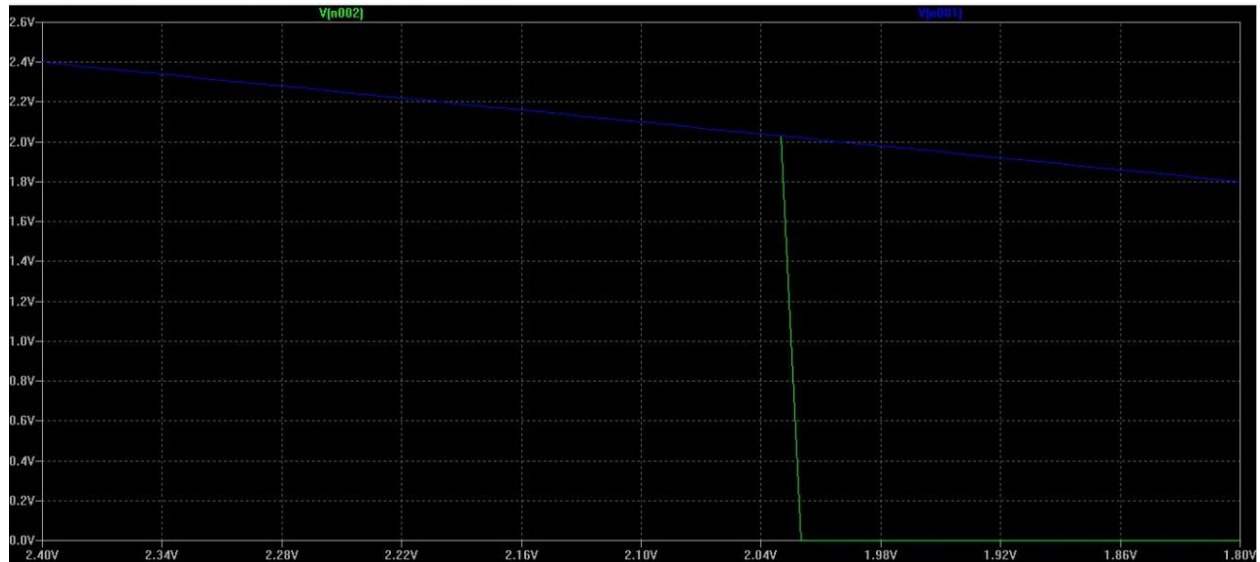


Figure 11. UVLO simulation

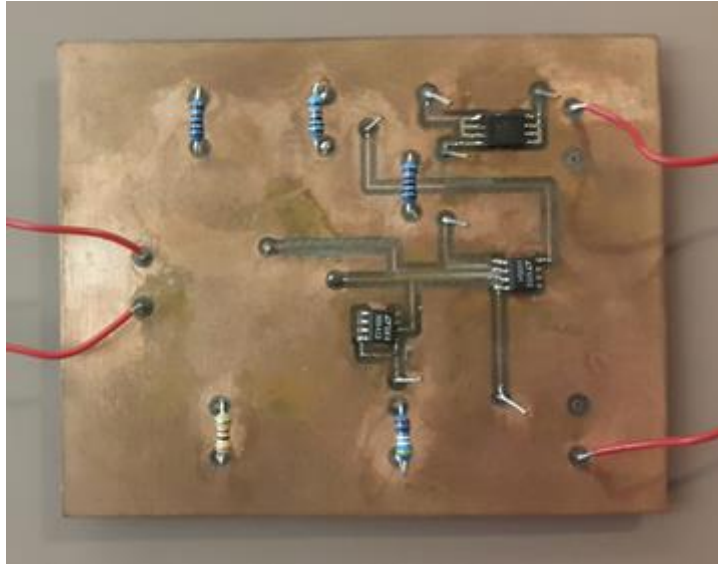


Figure 12. UVLO PCB

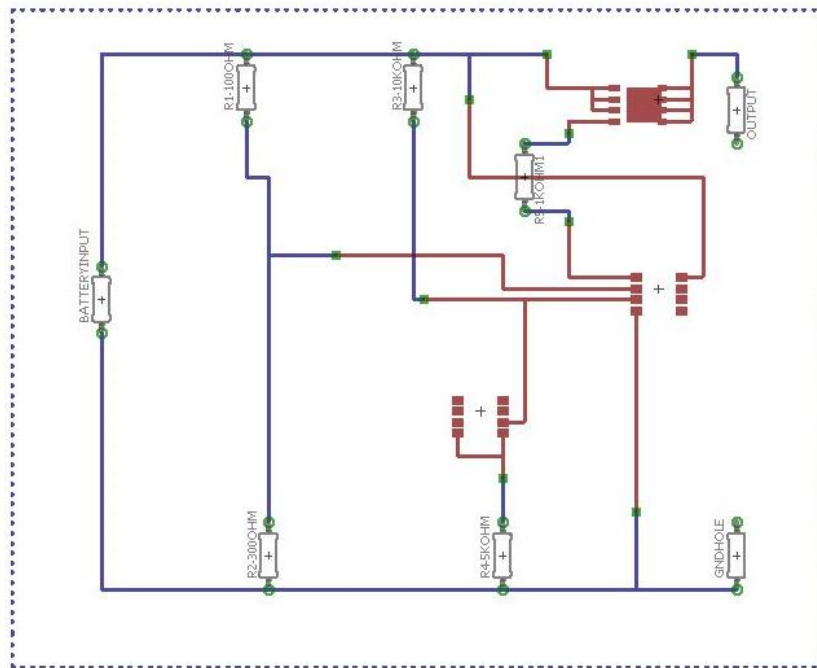


Figure 13. UVLO PCB design

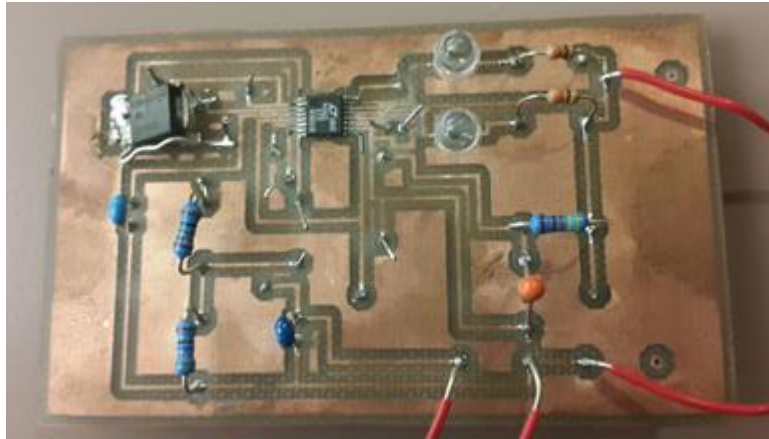


Figure 14. Charger PCB

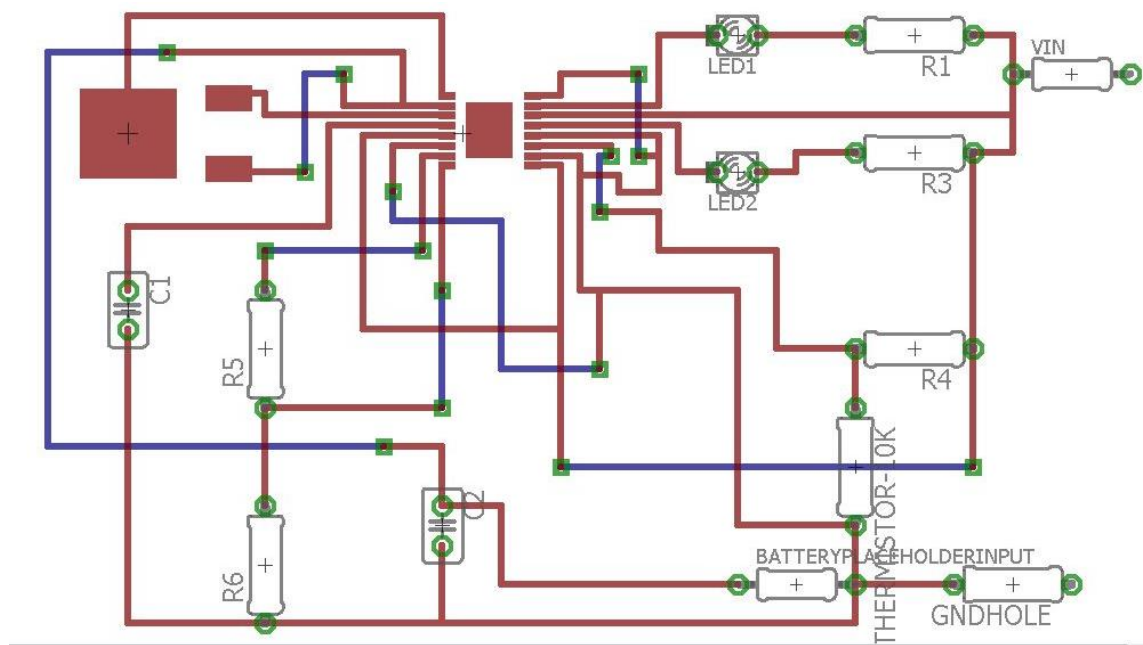


Figure 15. Charger PCB design



Figure 16. Low-pass filter bench test result

Appendix B Table

Table 1. Mentor's Program Task Probability [11]

Event detection	10%
Event tracking	5%
Logging / transmitting of audio events	85%

Table 2. Power Consumption [11]

Parts	Power Consumption	Symbol
audio processing		
MIC	0.2 - 0.5 mA	T
OPA344 (Preamp)	0.3 mA	
12-bit ADC (on Microprocessor)	0.5 mA	
Total	1.0 mA	
uC module		
Arduino Pro Mini (active)	5 mA	A
Arduino Pro Mini (idle)	0.9 mA	I
other		
Writing to SD card	40 mA	W

Table 3. Microphone Test Result

Sound Frequency			Sound Frequency			Sound Frequency		
<i>Generated</i>	Measured	Percent Difference	<i>Generated</i>	Measured	Percent Difference	<i>Generated</i>	Measured	Percent Difference
100	200.1	100.1	3100	3100.01	0.000323	6100	6100	0
200	199.3	0.35	3200	3199.9	0.003125	6200	6200.01	0.000161
300	299.8	0.066667	3300	3300.01	0.000303	6300	6301	0.015873
400	399.9	0.025	3400	3400	0	6400	6400.03	0.000469
500	500.1	0.02	3500	3500.03	0.000857	6500	6500.01	0.000154
600	599.9	0.016667	3600	3600.01	0.000278	6600	6599.98	0.000303
700	700.01	0.001429	3700	3700.01	0.00027	6700	6700.01	0.000149
800	801.9	0.2375	3800	3800	0	6800	6800	0
900	901.9	0.211111	3900	3899.9	0.002564	6900	6900.2	0.002899
1000	999.98	0.002	4000	4000.01	0.00025	7000	7000.01	0.000143
1100	1101.1	0.1	4100	4100.2	0.004878	7100	7100.1	0.001408
1200	1200	0	4200	4200.02	0.000476	7200	7200	0
1300	1300.1	0.007692	4300	4300.3	0.006977	7300	7300.3	0.00411
1400	1399	0.071429	4400	4400.2	0.004545	7400	7400.1	0.001351
1500	1501	0.066667	4500	4500.02	0.000444	7500	7500.01	0.000133
1600	1600.2	0.0125	4600	4599.8	0.004348	7600	7600.02	0.000263
1700	1699.9	0.005882	4700	4700.1	0.002128	7700	7700	0
1800	1799.9	0.005556	4800	4800.01	0.000208	7800	7801	0.012821
1900	1900.01	0.000526	4900	4900	0	7900	7899.8	0.002532
2000	2000.02	0.001	5000	5000	0	8000	8000.04	0.0005
2100	2100	0	5100	5100	0	8100	8099.93	0.000864
2200	2200.1	0.004545	5200	5200.02	0.000385	8200	8200.1	0.00122
2300	2300.1	0.004348	5300	5299.7	0.00566	8300	8300	0
2400	2400.05	0.002083	5400	5400.1	0.001852	8400	8400.2	0.002381
2500	2499.9	0.004	5500	5500.1	0.001818	8500	8500.2	0.002353
2600	2600.01	0.000385	5600	5600.2	0.003571	8600	8600.01	0.000116
2700	2700.01	0.00037	5700	5700	0	8700	8700.1	0.001149
2800	2800.04	0.001429	5800	5800.1	0.001724	8800	8800.03	0.000341
2900	2900.8	0.027586	5900	5900.1	0.001695	8900	8900.02	0.000225
3000	3000.04	0.001333	6000	5999.99	0.000167	9000	9000.1	0.001111

Table 4. Low-Pass Filter Test Result

Freq (Hz)	Vi (V)	Vo (V)	Db	Freq (Hz)	Vi (V)	Vo (V)	Db	Freq (Hz)	Vi (V)	Vo (V)	Db
200	0.91	0.91	0.0000	3200	2.89	2.70	-0.5907	6200	2.74	2.21	-1.8672
400	1.72	1.79	0.3465	3400	2.88	2.67	-0.6576	6400	2.73	2.18	-1.9541
600	2.35	2.38	0.1102	3600	2.87	2.64	-0.7256	6600	2.72	2.14	-2.0831
800	2.75	2.79	0.1254	3800	2.86	2.61	-0.7945	6800	2.71	2.11	-2.1737
1000	2.93	2.95	0.0591	4000	2.85	2.57	-0.8982	7000	2.70	2.09	-2.2243
1200	2.98	2.96	-0.0585	4200	2.84	2.54	-0.9697	7200	2.69	2.05	-2.3600
1400	2.97	2.94	-0.0882	4400	2.83	2.51	-1.0423	7400	2.68	2.02	-2.4557
1600	2.97	2.92	-0.1475	4600	2.82	2.47	-1.1510	7600	2.68	2.00	-2.5421
1800	2.96	2.90	-0.1779	4800	2.81	2.44	-1.2263	7800	2.67	1.97	-2.6409
2000	2.95	2.87	-0.2388	5000	2.80	2.40	-1.3389	8000	2.66	1.93	-2.7865
2200	2.94	2.85	-0.2700	5200	2.79	2.37	-1.4171	8200	2.66	1.88	-3.0145
2400	2.93	2.82	-0.3324	5400	2.78	2.34	-1.4966	8400	2.65	1.86	-3.0747
2600	2.92	2.79	-0.3956	5600	2.77	2.31	-1.5774	8600	2.64	1.84	-3.1357
2800	2.91	2.76	-0.4597	5800	2.76	2.27	-1.6977	8800	2.64	1.83	-3.1831
3000	2.90	2.73	-0.5247	6000	2.75	2.24	-1.7817	9000	2.63	1.80	-3.2937

Table 5. Sensor Module RVA

Requirements	Verification	Points 15
Microphone Must record frequencies 0 to 8k Hz to capture animal sounds which range in frequency up to 8k Hz as stated by Mentor.	- Connect microphone to multimeter - Emit different sound frequencies from device such as cellphone using an app. - Test by playing sounds into microphone 10 times for each frequency range: 0-2k, 2k-4k, 4k-6k, 6k-8k Hz. - Record on multimeter to check the frequencies recorded. - Graph results, and make sure at least 90% of attempts from each range were recorded. Perform more trials for each range if necessary.	5 Points if all four ranges record 90+% of time -----Partial----- 4 pts if 3 of 4 ranges 90+% 2 pts if 2 of 4 ranges 90+% 1 pts if 1 of 4 ranges 90+%
Passive Low Pass Filter -3dB cut-off must block out frequencies greater than 8k Hz, +/- 5%, as this is outside the frequency range of animal sounds as stated by Mentor. Mentor suggests this is optional, not critical as not many frequencies above 8k Hz will be encountered.	- Connect Passive Low Pass Filter to oscilloscope and function generator, input will receive various signals, and output will send filtered signal to oscilloscope. - Pass signals at various frequencies. - Test by sending input frequencies 10 times for each range, 0-2k, 2k-4k, 4k-6k, 6k-8k, 8k-9k, 9k-10k Hz. - Record and display results on computer to see which frequencies were passed, and which were blocked. - Graph results, and make sure filter passes 90+% of frequencies up to 8k, and make sure filter blocks 8k+ Hz 90% of time.	10 points if only passes 0-8k Hz 90+% of time -----Partial----- 9 pts if passes up to 9k Hz 90+% of time 8 pts if only 0-6k Hz pass 90+% of time 5 pts if only 0-4k Hz pass 90+% of time

Table 6. MCU RVA

Requirements	Verification	Points 15
Microcontroller • ADC input must convert analog signal to digital signal/data. • Serial Data Output must send out data correctly.	1. Connect 3.3 V power supply and Ground 2. Connect to SD card interface 3. Write basic program to save file onto SD card 4. Check on computer if file recorded correctly 5. Connect microphone to ADC 6. Write program to detect and record audio file to SD card 7. Speak into microphone 8. Check contents of SD card on computer to see if spoken words recorded correctly 9. Repeat trials as needed	10 points total if ADC converts sound correctly and Serial Data Output sends correct data, recorded audio file on SD card is same as words spoken into mic -----Partial----- • 8 pts if ADC records with a lot of noise • 5 pts if ADC doesn't work but can still send to SD card
SD Interface • Must write data received to be effective and useful for wildlife research.	1. Connect to microcontroller 2. Connect 3.3 V power supply and Ground to interface. 3. Insert SD card into interface. 4. Write Test File from microcontroller to SD card, so file is recorded onto SD card. 5. Remove SD card and check on computer to verify correct file 6. Repeat test to check works correctly	5 points if file record correctly -----Partial----- • 3 points if file not correct in all trials

Table 7. Voltage Regulator Test Result

Input Voltage (V)	Output Voltage (V)	Output Current (mA)
2.4	3.348	109.1
2.3	3.345	107.9
2.2	3.342	106.5
2.1	3.341	104.8
2.0	3.337	102.3
1.9	3.337	101.6

Table 8. UVLO Test Result

Input (V)	Output (V)
2.40	2.399
2.35	2.350
2.30	2.299
2.25	2.250
2.20	2.200
2.15	2.149
2.10	2.100
2.05	2.049
2.00	2.000
1.99	0.036
1.95	0.036
1.90	0.036
1.85	0.036
1.80	0.038

Table 9. Charger Test Result

Condition	Current through battery (A)
‘off’	2.364
‘on’	2.405
Differences	0.041

Table 10. Power Module RVA

Requirements	Verification	Points 20
Boost Converter Circuit - Must boost input voltage of 2.4-1.9 Volts to output Voltage of 3.3 Volts - Output at least 45.8 mA to power MCU and Sensor Modules	- Connect Input to DC power supply - Measure Output Voltage with multimeter - Turn DC power to 1.2 Volts - Check to that output is 3.3 volts on multimeter - Measure output current on multimeter when attached to load - Check that current is at least 45.8 mA	5 Pts total ----- 3 points if boost to output of 3.3 volts -- ----Partial----- 2 pt if less 2 points if outputs at least 45.8 mA current -----Partial----- 1 pt if less than 45 mA
UVLO Circuit Must cutoff voltage output when input voltage (Battery Voltage) falls below 2 Volts	- Connect input to DC power Supply - Measure Output Voltage with Voltmeter - Sweep input voltage from 2.4 to 1.9 Volts - Record output voltages for the input range of voltages - Check that voltage output is cutoff at 2.0 V input and below, i.e. output voltage = 0	10 Pts total if 9/10+ times cuts off output voltage at 2 volt -----Partial----- 8 pts if cutoff at 1.9 6 pts if cutoff at 2.1 4 pts if cutoff at 2.2
Charger Circuit Must output at least 10mA to battery when receive 5 Volt input to ensure charge battery given worst case scenario of average 9 mA current drain from system	- Connect 5 Volt Supply to Charger Input - Connect charger to battery - Measure current going into battery on multimeter - Check that min current of 10mA is met - Record results	5 pts if at least 10mA output -----Partial----- 4 pts if only 8 mA 3 pts if only 6 mA 2 pts if only 4 mA

Table 11. Components Cost

Part	Purpose	Cost
Arduino Pro Mini	MCU Microcontroller	\$10.00
Sparkfun FTDI Basic Breakout	Program MCU	\$7.50
32 GB microSD card	Store audio files	\$10.00
Sparkfun Electret Microphone	Capture Sound	\$6.00
(EBL) NiMH 10,000mAh D Cell Batteries	Power Source	\$16.00
(Adafruit) MicroSD card breakout board	MCU Record Data	\$7.50
(Linear Technology) LTC4060 - Standalone Linear NiMH Fast Battery Charger	Charger Component	\$4.40
Microchip Technology ADM00458	Voltage Regulator	\$15.00
Si7137DP PMOS	UVLO	\$3.00
LT1495 OPAMP	UVLO	\$3.00
Lt1389 Zener Diode	UVLO	\$3.00
MJD210 BJT	Charger Component	\$5.00
Thermistor	Charger Component	\$1.00
Resistors	UVLO, Charger, Filter Components	\$5.00
Capacitors	UVLO, Charger, Filter Components	\$2.00
F-F Cables	MCU Connect	\$5.00
Box	System Package	\$7.50
Belt	System Package Component	Free
Total		\$110.90

Table 12. Service Cost

Service	Hours	Cost (\$15/Hour)
Machine Shop	1	\$30
PCB Shop	2	\$15
Total	3	\$45

Table 13. Labor Hours

Job	Hours
Design Filter	3
Build Filter	2
Write code	21
Test and Debug Code	15
Connect SD Interface to MCU	3
Connect Sensors to MCU	1
Design UVLO	10
Assemble UVLO	5
Assemble Linear Charger Circuit	4
Wire Power Supply	3
Wire up system	2
Test Power Supply	4
Test MCU	10
Test Sensors	2
Calculations	6
Assemble product	1
Design PCB's	11
Debug System	10
Total	113

Table 14. Labor Cost

Hours	Labor Cost (\$30/Hour)
113	\$3,390
X 2.5	\$8,475

Appendix C Abbreviations

Unit or Term	Symbol or Abbreviation
32 bit File Allocation Table	FAT32
Alternating Current	AC
Analog to Digital Converter	ADC
Card Detect	CD
Clock	CLK
Chip Select	CS
Data In	DI
Data Out	DO
Decibel	dB
Direct Current	DC
Dollar	\$
Gigabyte	Gb
Ground	Gnd
Hertz	Hz
Light Emitting Diode	LED
MilliAmpere	mA
MilliAmpere-Hour	mAh
Master Output, Slave Input	MOSI
MicroFarad	μ F
Nickel Cadmium	NiCD
Nickel Metal Hydrate	NiMH
Ohm	Ω
Positive-Channel Metal Oxide Semiconductor	PMOS
Printed Circuit Board	PCB
Serial Clock	SCK
Secure Digital	SD
Under Voltage Lockout	UVLO
Volt	V
Windows Wave	wav

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