Early Automobile Reminder System (EARS)

A Major Qualifying Project Report:
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Abstract

The purpose of this project was to design a safety device which pedestrians wear capable of detecting a car driving on the road and alerting the driver and the pedestrian to the potential hazards. The signal from a microphone was passed through a set of resonators and a band pass filter designed to target the frequencies produced by tires, then sampled by a microcontroller which calculated the energy of the signal. If the energy was above a hardcoded threshold, the microcontroller outputted a pulse signal to the vibrating motor and an LED. Initial tests show that we are able to isolate the frequencies that we wanted, which were a good indicator of a cars presence and that the microcontroller was able to output a warning when there is a spike in the input. We conclude that monitoring the frequency of tires is an effective strategy of car detection. Further work is necessary to determine the effective distances of this device for different environments and cars.

Executive Summary

Hard of hearing individuals are not able to listen for a car coming up behind them the same way that an average pedestrian can. This could lead to a hazardous situation where a hard of hearing pedestrian cannot hear a car approaching from behind them with enough time to react to the situation. The EARS product is designed to be able to listen to a car approaching a pedestrian along a road and alert the user as well as the driver to the situation, giving the user more time to react. In a survey conducted between 2004 and 2008, when asked "Without the use of hearing aids or other listening devices, is your hearing excellent, good, a little trouble hearing, moderate trouble, a lot of trouble, or are you deaf?" approximately 2.8% of adults older than 18 indicated that they had a lot of trouble hearing or were deaf (Centers for Disease Control and Prevention, 2010). That data combined with the closest population estimates from the U.S. census bureau yields that there are approximately 6.5 million people in the United States that this product would be applicable to (U.S. Census Bureau, 2012).

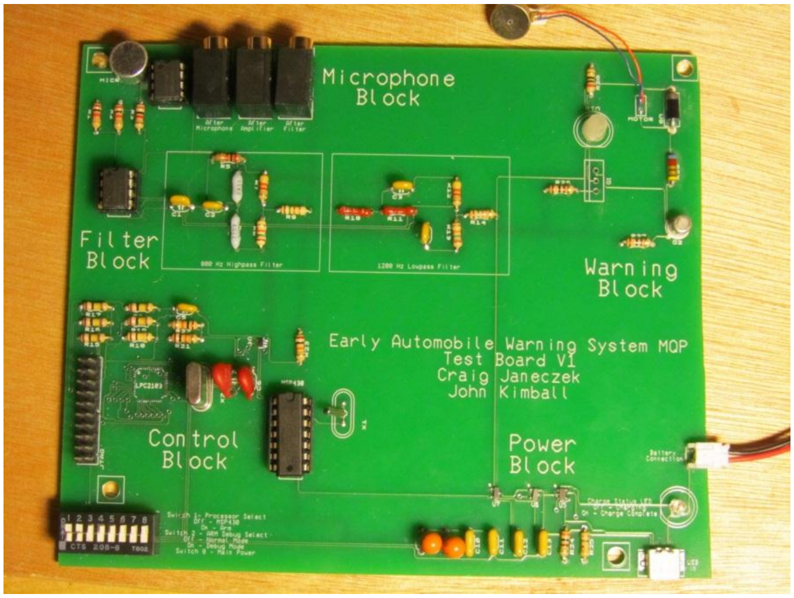


Figure 1: Testing Version of the Final Board

While researching how to detect a car approaching an individual, we needed to determine both what to pick up on as well as how to detect it. We made the determination to attempt to detect the tires on the vehicle which would have the least amount of changes between different vehicles. After some research we found that the target frequency would be between 800 and 1200 Hz. To isolate these frequencies from the rest of the ambient noise, we utilized a combination of physical resonators as well as an analog filter. The physical resonators design that we implemented was that of a tube resonator, which changes its resonance based upon its length. To implement this approach for multiple frequencies, we used multiple single frequency resonators in parallel. Once the signal has passed through the resonators, it passes through a dual pole Sallen-Key filter in a band pass configuration. This attenuates the frequencies outside of our target range while adding a slight gain to our target range. At this point the signal is sampled at a rate of 3 KHz by our microcontroller in order to satisfy the Nyquist theorem for our maximum frequency of 1.2 KHz. The microcontroller then calculates the energy of the last 0.1 seconds worth of data and compares it to a threshold which we programmed in. If the energy of the signal is above the threshold, the microcontroller outputs a pulse width modulated wave with three on cycles. This acts as a trigger wave to the warning block which consists of both a vibrating motor for the user and a flashing LED for the driver. The final testing version of this system is pictured in Figure 1.

Through testing this device we have been able to prove most of our design. Through testing of the microphone and filter parts of the circuit, we have seen data confirming our research of detecting a car through the frequencies of 800 to 1200 Hz. We have also proven that our filter design, which was altered to run on a single supply, provides the proper magnitude response. Testing of the microcontroller circuit confirmed that the code works properly and that when given a spike in the input, the microcontroller will produce the proper trigger waveform. There was also a lot of testing done to the physical resonators and we have decided that the best configuration of resonators would be multiple single frequency resonators with their ends capped by microphones.

From this project we are able to conclude that this is a viable idea and that there would be a sizeable target market of people in the United States. The individual blocks of the design have been proven to work individually, but we were unable to completely integrate the blocks together. Further work is necessary on the design of the printed circuit board to ensure that the blocks will properly interface with each other. Studies for determining the effective distances for this device for different environments and cars would provide more of an idea of how much extra time this device would give the end user. Overall, we have proven the functionality of the individual blocks within this system as well as the viability of the idea behind this device.

Introduction

This report details the design of the Early Automobile Reminder System (EARS). This product is designed to increase the safety of hard of hearing individuals while they are walking alongside a street. Most people are able to detect a car coming up from behind them by utilizing their hearing, but a hard of hearing individual does not have the ability to do this. The EARS device performs the task of listening for the approaching vehicle and warning the user as well as the driver to the potentially hazardous situation.

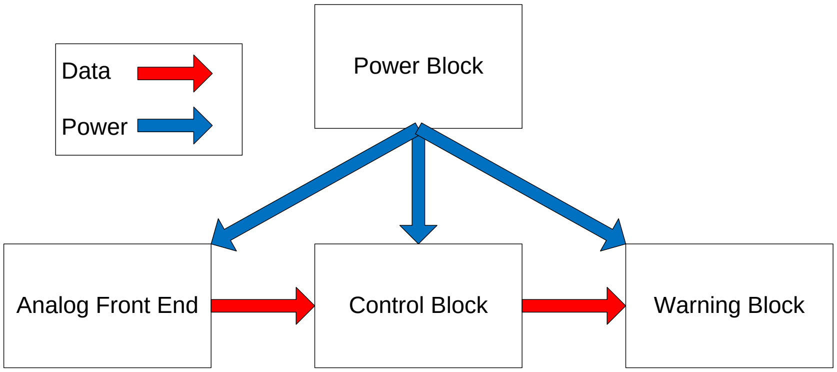


Figure 2: Overall System Block Diagram

Figure 2 shows the block diagram of our system with data and power flow lines. The system is divided into three main blocks, the analog front end, control block and the warning block. The analog front end consists of the microphone and bias circuitry as well as the analog filters. At the center of the control block is a microcontroller which takes in data from the analog front end and determines whether or not a warning is necessary. The warning block takes the trigger from the control block and consists of both a vibrating motor for the pedestrian and flashing LEDs for the driver of the car.

Requirements

In the planning stage in our project, it was necessary to declare how we envisioned our project. In order to do this, we needed to define implicit and explicit requirements for the product. From these implicit and explicit requirements, we derive our specific product requirements. We also wanted to have an idea of what our product will look like; therefore we shall detail our product through an artist's rendition.

Implicit Requirements

When thinking about this product, we needed to define the implicit requirements that apply to it. The implicit requirements are requirements that the consumer would not necessarily ask for but would assume that the product had. The major one that we could think of for this product is the ability to detect a hazard and warn the consumer. This is the basis of the project and if this was not met the product would not perform its primary task. Another implicit requirement stems from the first one; this is to warn the user with reasonable amount of time to react. The term reasonable will be defined from further experimentation into the speed in which we can make the product detect a car and process the information as well as how long an average person needs to react. Since this product is being marketed to people that are riding a bike or walking alongside the road they will not need a lot of time to react, this warning serves more of a heads up to keep them aware of their surroundings. Along the same lines, the consumer will assume that this product should be accurate. It should be able to detect the oncoming car and not miss many instances of a potential hazard. Due to the differences in cars and the possibility of them emanating different frequencies it may not be possible to guarantee that this product will warn on every car that passes by, but we designed this product to err on the side of caution and warn more often than not.

Other than implicit requirements that apply to the functionality of this product, there are requirements that apply to the physical product as well. The first one comes from the fact that this product will be used outside and therefore needs to be durable enough to withstand differing weather conditions. Another requirement which applies to the physical device is its size. If this product is too bulky, the consumer will not want to wear it and therefore will defeat its purpose. Stemming from the same issue of the consumer not wanting to wear this product is the aesthetics of it. If the product is not aesthetically pleasing it will not be worn outside and therefore will not help the consumer. A final implicit requirement is a fairly shallow learning curve. By this we mean that the consumer should be able to perform the basic operations of this product with only a small amount of consulting a manual.

Explicit Requirements

Many of the implicit requirements overlapped with later explicit requirements. This is not seen as problematic, as the two can work side-by-side to help provide more accurate and feasible product specifications. Although some of these requirements are derived from examples found in the market research, we felt that the best source of information on "what the user wants," would come from the users themselves. After a series of emails, the basic contacts referred to in Appendix A were consulted, and a survey was drafted (see Appendix B) to provide a general idea of what hard of hearing people would expect in a product. This research was performed in March and April of 2011.

When performing market research, the topics that we queried our target market on were split into logistical questions and functionality questions. The logistical questions asked about qualities such as the size, placement, and cost of the product. Our results yielded that the size of the product, as seen by the consumer, should be approximately the size of a cell phone. When asked about the placement of this product on a consumer's body; the consumers were open to armbands, wristbands, and glasses. With the product having only basic functionalities, the maximum cost that a consumer would be willing to pay was $100.

The functionality questions about the product asked more about the explicit functionalities of the product than implicit assumptions. When asked about the hazards that the consumer wanted this product to detect, vehicular traffic was the main response. Along with the flashing LEDs used to alert the consumers, vibrations were requested as an alternate form of alerting. This functionality could be implemented in either the armband or wrist strap configuration of the product, but would not be a feasible idea to be implemented in the glasses configuration of this product. Another functionality that was deemed very important by the consumer was the ability to discern from what direction the hazard is coming from. If this functionality was implemented, it would either require the consumer to utilize the glasses configuration of the product, or a wristband or armband on each arm. This would be the only way with the current configuration options to allow the consumer for an adequate amount of time to react to the hazard.

Product Requirements

Examination of the implicit and explicit requirements begins to yield the product requirements. We will first look at the implicit requirements. The first product requirement to come from the implicit requirements is that the device needs to accurately detect a hazard. This is part of the core functionality of the product and is directly taken from a customer requirement. Warning the consumer is the second part of the core functionality of this device and is also taken directly from an implicit requirement. The packaging for this product needs to be made from a durable set of materials that would be able to withstand weather such as rain as well as a wide array of temperatures. This will ensure the longevity of the device as well as the safety of the consumer. The device must alert the consumer every time there is a hazard with an acceptable amount of false alarms. This is important because this insures that the device is designed with wide enough tolerances that it will not miss many warnings if necessary. Although the consumer wanted the device to not be overly sensitive, they also wanted it to not cause any other safety concerns. We would rather have this product warn more than miss a warning. The device should be intuitive enough that the consumer will easily be able to determine what the warning means and how to react to it. This also will take into the consideration of the requirement of having a shallow learning curve. The device should be able to be attached to the body in a comfortable and non-descript way. This is important to the consumer and if the device does not fit this description there is a chance that the consumer will not utilize the device. This product requirement comes from the customer's requirement of not having a large burden and being aesthetically pleasing.

After implicit requirements we focused on explicit requirements. The first explicit requirement was that the product needs to be reliable, since the device's failure might lead to life-threatening consequences for a user. This loops back into our wanting to give an extra warning over missing a warning. If a device gives warnings when there is no threat, it is much better than if it does not give a warning when there is a threat. Our product will be controlled in such a way that it should not fail to inform a user about many threats from average automobiles. The second explicit requirement was the ability to tell from which direction a vehicle is approaching. Since this product is being marketed towards users that are walking or biking along the side of a road, not in the middle of it we are assuming that all of the traffic will be on one side of the user. This will simplify things for the user because it will remove the time needed to decode what the warning means and then react, they will simply need to react. The third requirement was cost. In order for this product to be successful on the market, it needs to be available to everybody and to be relatively cheap. Therefore, we will need to create a design of the circuitry which would minimize the cost. The product also needs to have a reasonable size. This is very important, since devices that are easily noticeable and heavy tend to be avoided by customers. Hence, we will design our product to be similar in size and weight to products currently on the market which are taken while jogging such as a cell phone. One of the explicit requirements was an additional warning system, like a vibrating pulse. This is important for the user, since many people will not be able to see the LEDs all of the time. Therefore, a vibrating pulse might be a more efficient way of informing a user of a possible threat. The last two explicit requirements included location of the product and detecting different types of threats. Location is important for the user, since each user has their own preferences on which location on their body they would put the product. This will depend on the technical requirements and where it is feasible to place a product. The last explicit requirement about detecting different types of threats can be important for the user, but the more signals that are involved, the more complicated the product will become. Therefore, people's interest in the product could decline. In addition, the communication between the user and the product is limited to visual and vibrating signals, which are very limited in providing many details about the information. Therefore we will design this product around the average automobile therefore giving the user a warning for most of the cars that pass by.

Artists Rendition

Figure 3: Artist's Rendition of the Product

As shown in Figure 3 the artist's rendition of this product is a simple easy to understand design. There would be microphones on the sides of the unit which would allow for the unit to be worn on either arm or hip and still be effective at determining if an automobile was approaching from behind the user. The input from the user would be limited to a power button which is located on the bottom of the front of the unit. The LED that is located in the bottom right of the front of the unit would be a low battery LED that would alert the user when the battery for the product was approaching its lower limit of functioning. The main warnings would include multiple LEDs located on the front of the unit that would flash to alert the user as well as possibly alerting the driver. There would also be a vibrating motor in the unit but this would not be visible to the user. This product would be self-contained and would be able to fit into adapters that attach to the users hip or around the users arm

Figure 4: Artist's Rendition of possible external warning system

Figure 4 shows another possible configuration of a warning system. This wristband could attach to the main unit and would be an accessory to the main unit. It could be warn around the user’s wrist like a watch and would provide another set of flashing LEDs and vibrations to warn the user.

Overall this product is mainly a simple to use main unit which has the flexibility to be worn in multiple places on the user. This allows for the same unit to be marketed and sold to a wide array of people. There could also be accessories such as a wristband that would serve as another warning system to back up the main one.

Looking at the product requirements that we defined earlier there are a couple of conclusions that we can derive for this product. The first is that the minimum number of LEDs that this product will have is 2, one for warning and one for a low battery. The maximum number of LEDs used will be calculated once we perform a cost benefit analysis on the amount of current used versus the amount of warning light created. We also can determine rough dimensions for the unit. By analyzing common smartphones in their respective cases we can see that there is an average form factor of 5”x2”x.75”. We will aim for this product to fall inside this range in order to be comparable to products that are currently taken around while walking or riding a bike. The weight of the product is not high on our priority list at this time, but in keeping with the theme of being comparable to modern smart phones, a target of 200g should be set. There should also be a target price of $100. This was set by the market research performed and is the price that was most commonly selected as the highest price that was willing to be paid for this unit.

System Overview

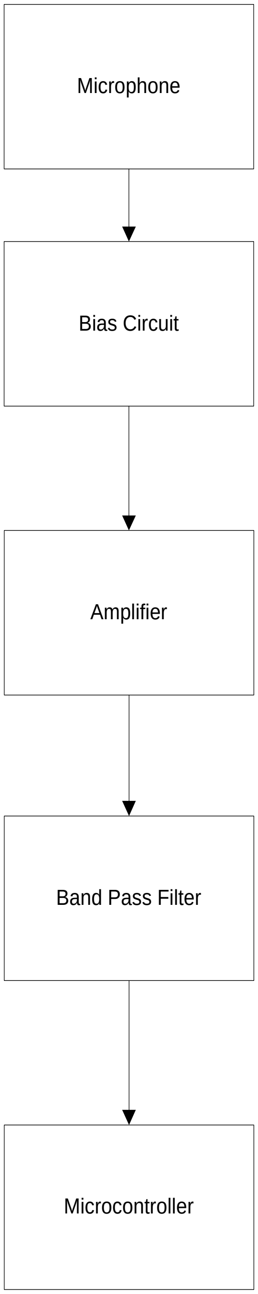


Figure 5: System Flow Chart

Displayed in Figure 5 is the flow chart for our system. The microphone will act as a varying resistance when struck with the noise from its surroundings. Through the use of a bias circuit acting as a voltage divider, this varying resistance can be changed into a varying voltage which will mimic the sound. The center of this varying voltage is set by the positive and negative rails that are inputted to the bias circuit. Although the changing voltage will mimic the sound, the amplitude will be very small. Therefore the next block will need to be some form of amplification circuit.

The amplification circuit will amplify the changing voltage in order to take full advantage of the microcontroller’s input dynamic range. The greater the dynamic range, the higher the resolution will result from the ADC. By amplifying the signal and a greater resolution at the microcontroller, our warnings will be more accurately aligned with when we want them.

Once the signal has been amplified, it will be fed through a band pass filter network. This will reduce the magnitude of frequencies in the input signal that are not in our desired pass band. For our purposes, the pass band is 800-1200 Hertz. Once the signal has been filtered it will be fed into the microcontroller which would make a decision on whether or not the warning needs to be produced. If a warning was necessary, the microcontroller would send trigger waves to the warning block of the system.

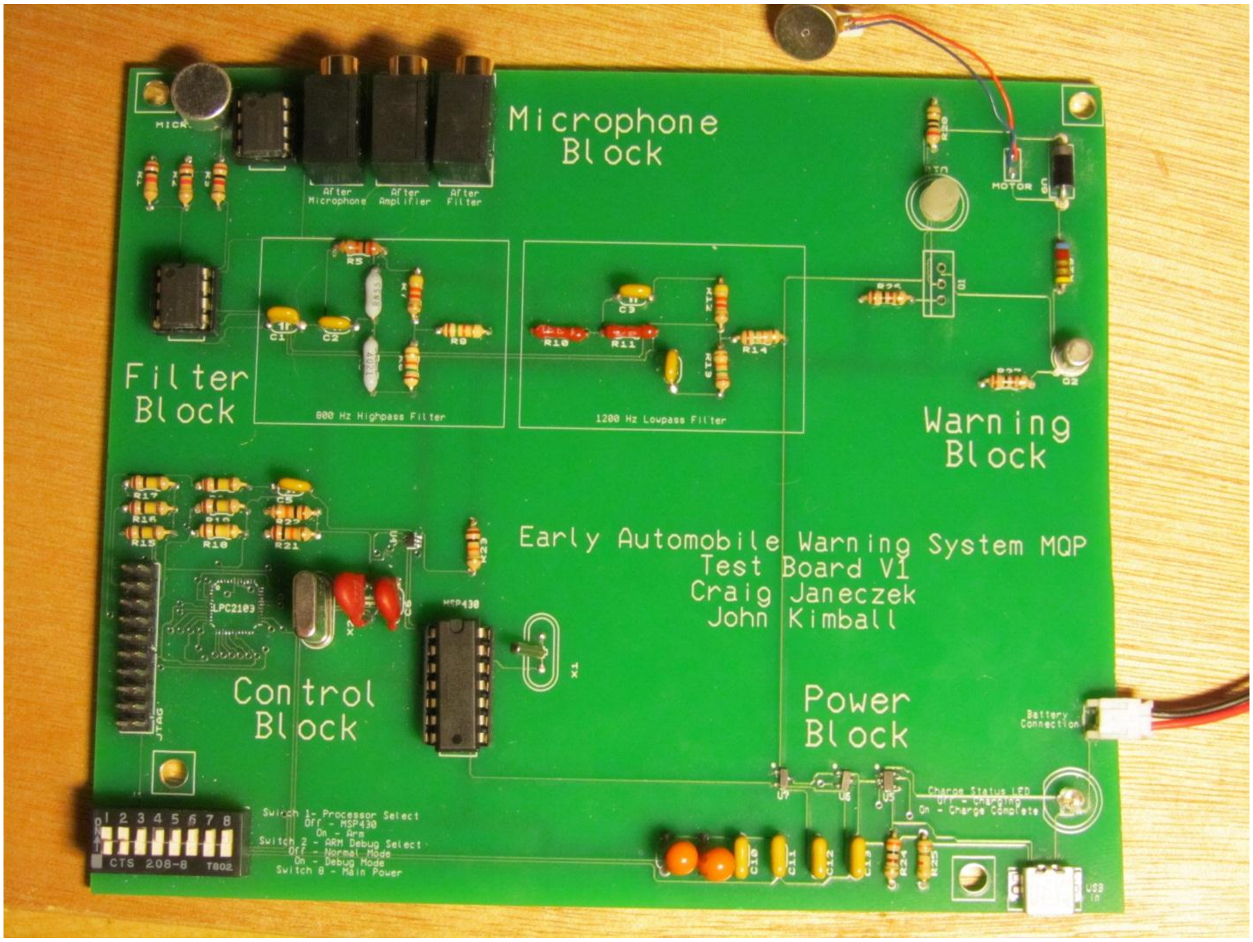


Figure 6: Testing Board

In Figure 6 we can see the testing version of the board design. This board was designed with ease of understandably as well as testing in mind. We can see the microphone, filter, control, warning and power blocks labeled as well as separated from each other on the board. One main difference between this board and the smaller production version of this board is the audio jacks which tap into the data after the microphone, the amplifier and the filter. This allowed for a greater ability to test and to record the actual data from inside our system.

Microphone Block

The main task performed by the microphone block is to bias the microphone to allow for it to successfully capture the data. The first stage of this is a bias circuit to allow the microphone to work properly. Since an electret microphone can be modeled as a variable resistance, we created a bias circuit by creating a voltage divider with the microphone as one of the resistances. The voltage being pulled from the divider will have both a dc and an ac component. The dc components value will be chosen by the other resistance in the divider. We selected a resistance that is equal to the resistance of the microphone with no stimulus, this will set the dc bias to be one half of our positive voltage supply and therefore provide us with the greatest dynamic range. The ac part of the output will be the signal which we are after. This is a voltage representation of the sound that the microphone is experiencing.

The other component of the microphone block is an amplifier. This is where we can set the gain of the signal before it goes to the filtering block. In Figure 7 the gain of the amplifier is set to 1 and therefore acts as a buffer. We can adjust the gain of this circuit depending on the signal coming into this block. This will make it so that we can control the voltage levels into the filtering block and therefore not cause any clipping due to hitting the rail.

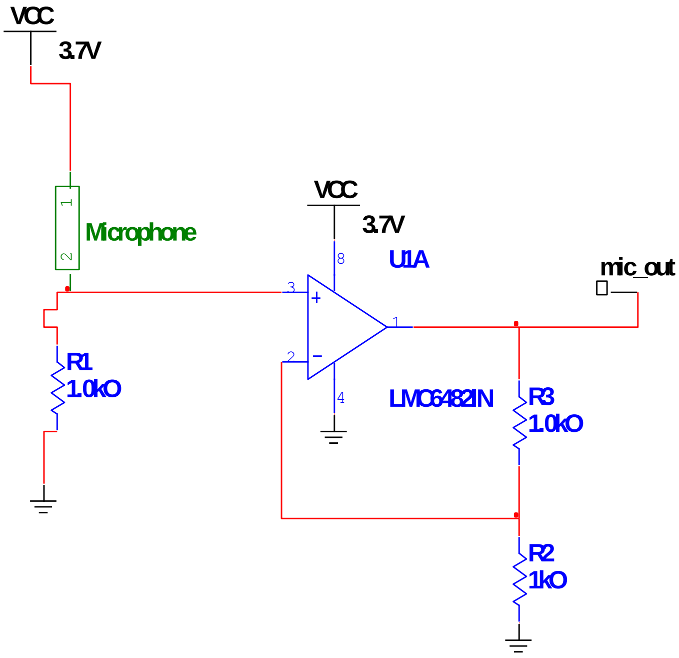


Figure 7: Microphone Bias Circuit

Filtering Block

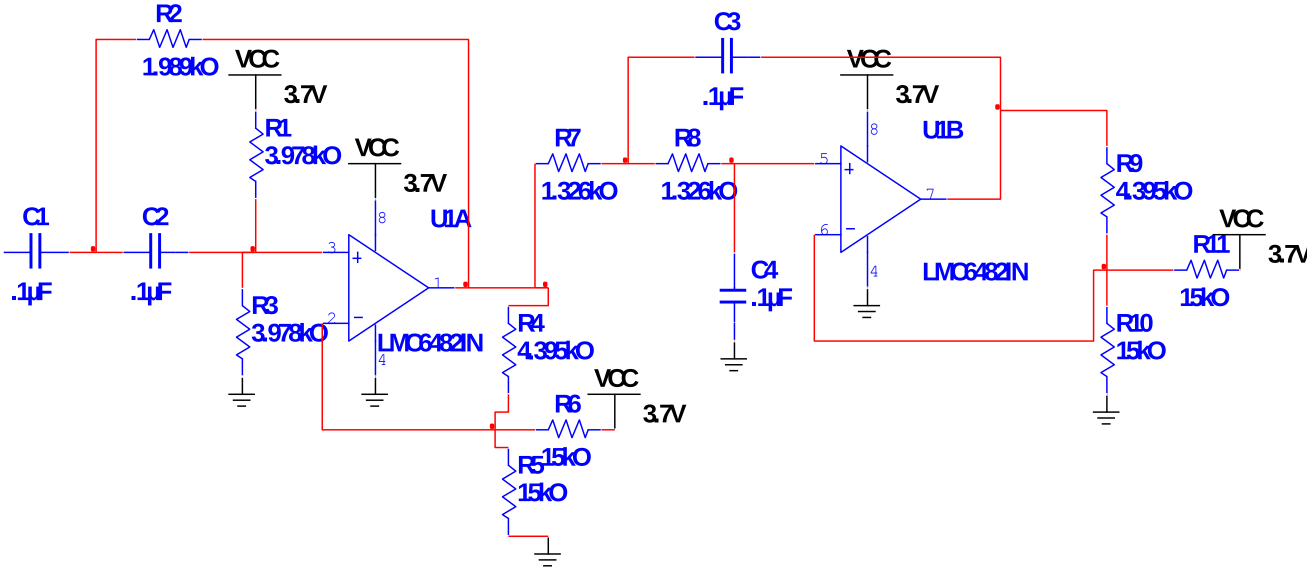


Figure 8: Filter Block Circuit

For the filtering block of our system, we decided to implement a Sallen-Key Filter. Our justification for this filter choice begins with the fact that it is a 2-pole active filter built into one circuit. This will give us the appropriate high and low pass bands for our 800-1200Hz range we are trying to achieve. This will allow us to create a good quality magnitude response with the use of resistors capacitors and op amps, no inductors will have to be used which will save us space. Another benefit is that the filter will double as a buffer which will also help with maintaining the desired magnitude response with varying surrounding electrical conditions.

Within the Sallen-Key filter, we had the option to choose between a Chebyshev response and a Butterworth response. When considering the respective gain plots in Decibels of each, we noticed that the filters are similar however, the Butterworth filter has a smooth line in the pass-band and the Chebyshev filter has a ripple in the pass-band but a steeper drop off. We determined that we cared more about the consistency in the pass band than a higher drop off in the stop band. Due to the smooth characteristic of the Butterworth, we opted to use this filter to feed a constant frequency of 800-1200Hz from the respective high and low-pass ends of the filter.

Figure 8 is the implementation of this filter which we plan on using. The resistor values are the ideal ones from our calculations and will slightly differ from the final values used. By utilizing voltage dividers we are able implement this filter by using only one supply.

We also attempted to derive the transfer function and gain of this Sallen-Key Filter from our low pass portion of the band pass filter. From the left hand side, our Vin is fed from the top block into R7. For our purposes of simplification, we will call R7 as R1 in our derivation. We will have the point between R7 and R8 referred to as node 1 such that the voltage at that point will be V1. The point on the other side of R8 will be addressed in a similar fashion as V2 and Vout at pin 7 of the op amp. After we have detailed these parameters, we set up our respective KCL loops such that the current at each node is 0. Using this fact along with the reminder that the impedance of a capacitor is:

$$Z = \frac{1}{j\omega c}$$

We also have to keep in mind that our Op-Amp chip has gain to it as well such that

$$V_{out} = GV_2$$

Detailed below is our derivation of the Transfer function for a Sallen-Key filter which works through the systems of KCL equations. After we have solved for the output/input, we go on to re-arrange to solve for the gain of our Sallen-Key Filter.

Solving for $V_{\text{out}}/V_{\text{in}}$ of Sallen-Key Filter using nodal analysis:

$$\frac{(V_{in} - V_1)}{R} + \frac{(V_{out} - V_1)}{\frac{1}{j\omega c}} + \frac{(V_2 - V_1)}{R} = 0$$

$$\frac{(V_1 - V_2)}{R} + \frac{(0 - V_2)}{\frac{1}{j\omega c}} = 0$$

$$V_{out} = GV_2$$

We rearrange to solve for a value of V_2:

$$\frac{V_{out}}{G} = V_2$$

We then substitute our new value of V_2 into our nodal analysis equations:

$$\frac{(V_{in} - V_1)}{R} + \frac{(V_{out} - V_1)}{\frac{1}{j\omega c}} + \frac{(\frac{V_{out}}{G} - V_1)}{R} = 0$$

$$\frac{\left(V_1 - \frac{V_{out}}{G}\right)}{R} + \frac{(0 - \frac{V_{out}}{G})}{\frac{1}{j\omega c}} = 0$$

Rearranging to solve for the value of V_1:

$$V_1 = \frac{V_{out}}{G}\,(Rj\omega c + 1)$$

We can then substitute this into the nodal analysis equation:

$$\frac{V_{in} - \frac{V_{out}}{G}(Rj\omega c + 1)}{R} + \frac{V_{out} - \frac{V_{out}}{G}(Rj\omega c + 1)}{j\omega c} + \frac{\frac{V_{out}}{G} - \frac{V_{out}}{G}(Rj\omega c + 1)}{R} = 0$$

Solving for $V_{\text{out}}/V_{\text{in}}$:

$$\frac{V_{out}}{V_{in}} = \frac{1}{\frac{1}{G} - (\omega RC)^2 + j\omega RC\left(\frac{3}{G} - 1\right)}$$

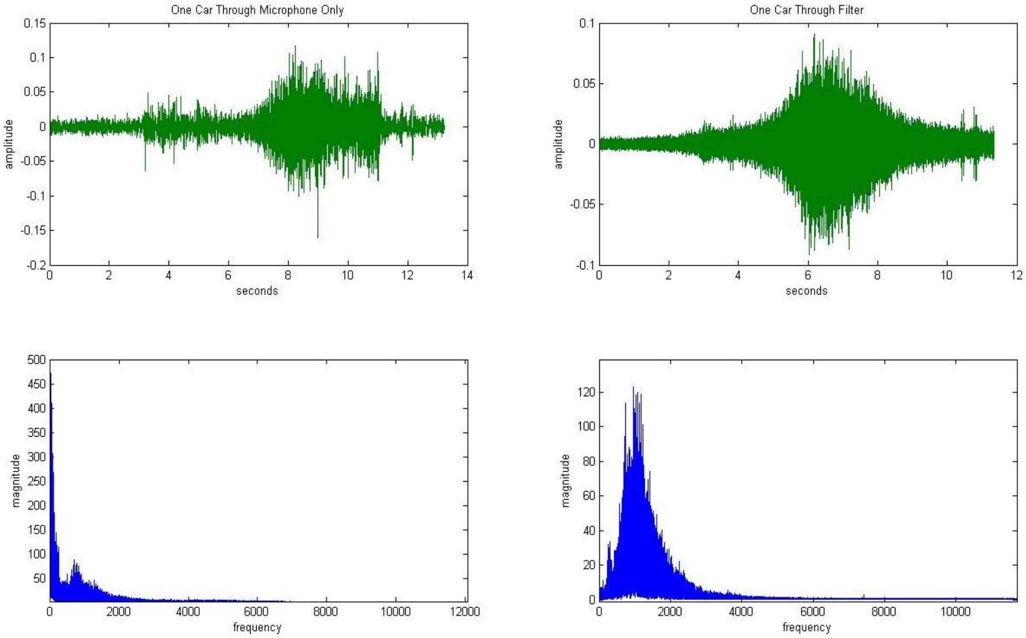
Rearranging to solve for Gain:

$$G = \frac{V_2 Rj\omega C + V_1 - V_{in} + V_1 j\omega CR}{V_2 j\omega CR}$$

Equation 1: Gain of Our Filter

From Equation 1, we now know the transfer function and gain of our filtering block. This allows us to see how much gain we are adding into this system from this block. This is critical information since we are dealing with our signals which react in accordance to the respective gain in our filter block.

To test the filters within our design we wanted to record data from cars driving by the device with the built in audio jacks. By comparing the data from directly after the microphone to the data from directly after the filter we could determine whether or not the filters were working properly.


One Car Through Microphone Only

One Car Through Filter

Figure 9: Filter Test Results for One Car

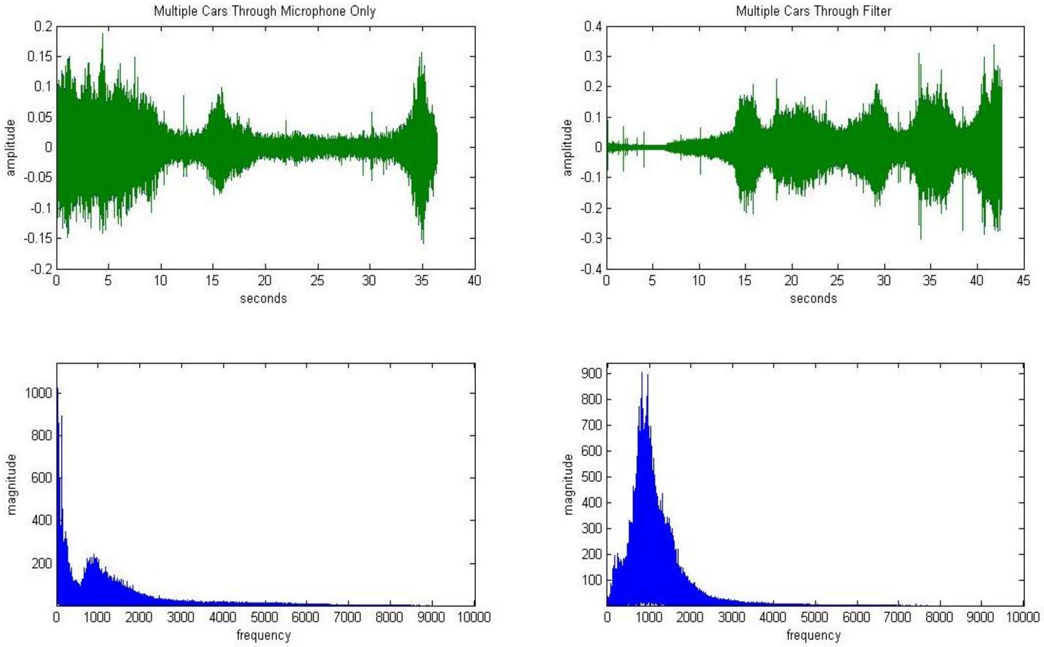


Figure 10: Filter Test Results for Multiple Cars

We first recorded one car passing by the device directly after the microphone as well as directly after the filter; this result is shown in Figure 9. Comparing the magnitude response in both the microphone and filter tests we can see that there is a peak at around 1 KHz. This backs up our original thoughts that we can detect a car by keying on those frequencies. Also comparing the two magnitude responses shown that in the microphone only test there is a lot of noise near 0 Hz, and in the filtered test that noise in eliminated. This shows that the filter is working correctly and provides the response that we are looking for. Looking at the test for multiple cars in Figure 10 we see similar results. This confirms the results from the one car test and shows that it was not a positive result because of the specific car chosen for the test.

Microcontroller Block

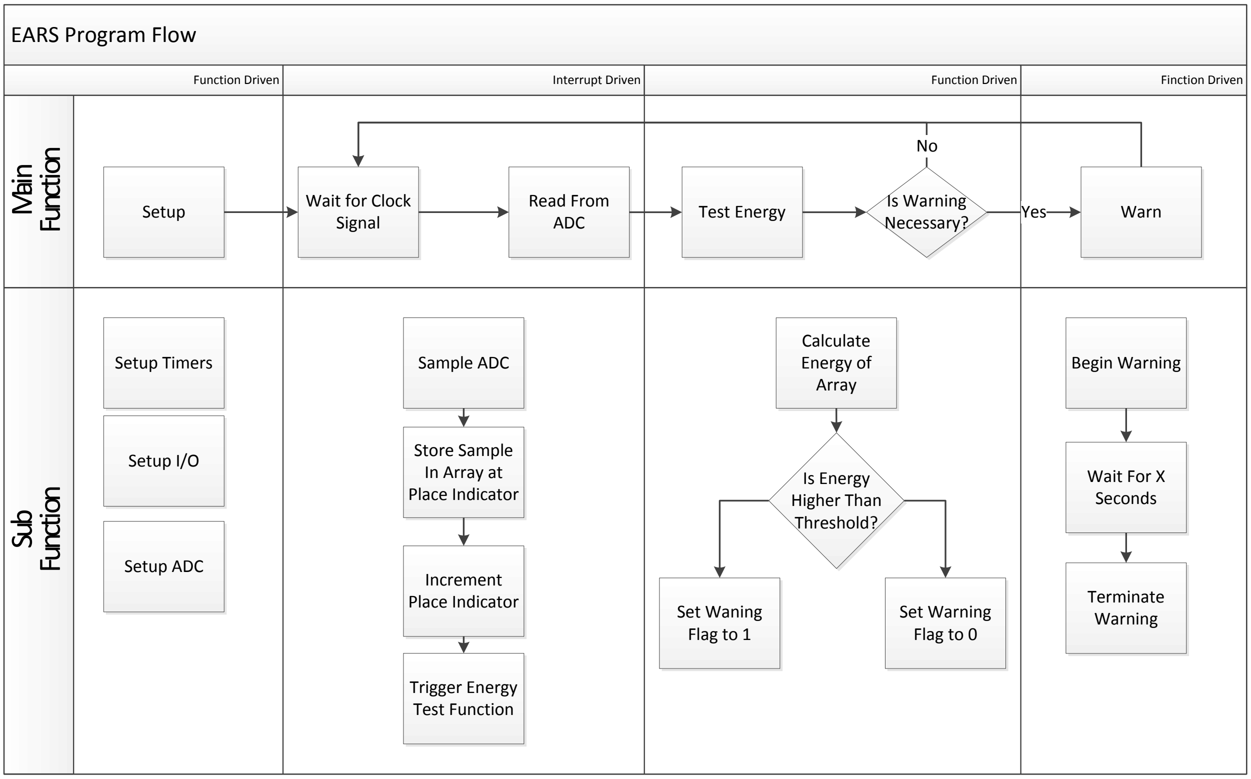


Figure 11: Code Flow Diagram

Along with a block diagram of the physical connections to the microcontroller, there is also a block diagram for the code inside the microcontroller. The design of the code for this product will perform the functions of initializing the microcontroller, taking in the filtered voltage signal, testing to see if a warning is necessary, and if so providing a warning. We feel that this is the minimum that this code will need to do. There are additional features that could be added on near the end of the project, such as determining direction of the warning or performing some digital filtering.

The first main block of the code will be all of the configuration steps. This code will only occur once and once performed the code will loop continuously. The main things that this will setup will be the internal timers, input and output, and the analog to digital converter. We will drive the ADC off of a timer signal, which means that we will need to configure one of the timers to interrupt at the frequency that we would like the ADC to sample at. Our preliminary calculations show that we will set the timer to interrupt at a rate of 3 kHz, which will account for the Nyquist rate of 2.4 kHz as well as some headroom. The main input to the microcontroller will be the filtered voltage signal and the main output will be the warning triggering pulses. Due to this, there will need to be one ADC input pin and at least one warning output pin. Finally this portion of the code will need to setup the ADC. This setup will ensure that the ADC will trigger when we want it to and that it will perform the proper functionalities when it is triggered.

The second block of the code will perform the task of reading in a sample of the signal. When triggered by an interrupt, the ADC will read the voltage that is inputted at the designated pin. This will be converted to a digital value and then will be stored in an array in memory. The length of this array will determine how long into the past we look to test the energy of the signal. The spot that the value is placed in the array is determined by a pointer value which is incremented once the value in placed so that the next value read in is in the correct spot. Once this is complete the function calls the next block of code which tests the energy of the signal.

Once the value is properly stored in the array, the code tests the energy of the signal. Since the energy of a signal does not depend on the order of the samples, the code will sum the squares of the samples in the array. The code will then compare this energy value to a threshold value that we had defined earlier in the code. If this comparison determines that the energy is higher than the threshold it will then call the function which sets off the warning. If it is determined that the energy is lower than the threshold it will pass over the warning function and wait for the next sample.

If the program determines that there is a warning necessary, it will call the final block which will perform the warning. Since we will be using the output signal from the microcontroller as a trigger signal, simply setting the pin output high and low will suffice as turning the warning on and off. We used a duty cycle of 66% with the warning being on for one second and then off for a half second. We took this idea from current warning mechanisms on the market such as the vibrate signal on your phone when a message is received. We believe that someone will react better to an alternating signal than a single long pulse. Once the warning is complete the code will wait for the next interrupt to occur which will start the whole sequence again.

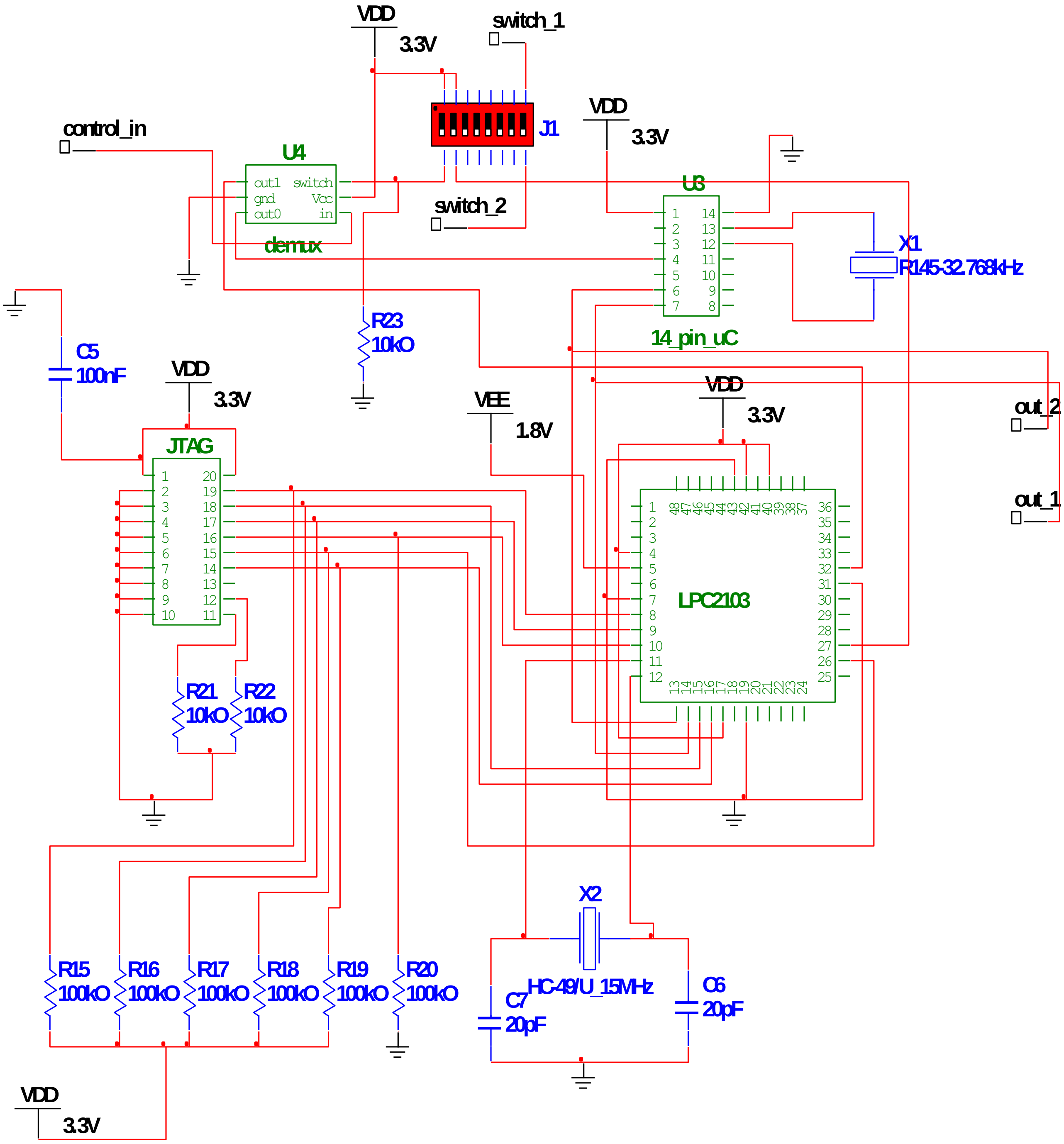
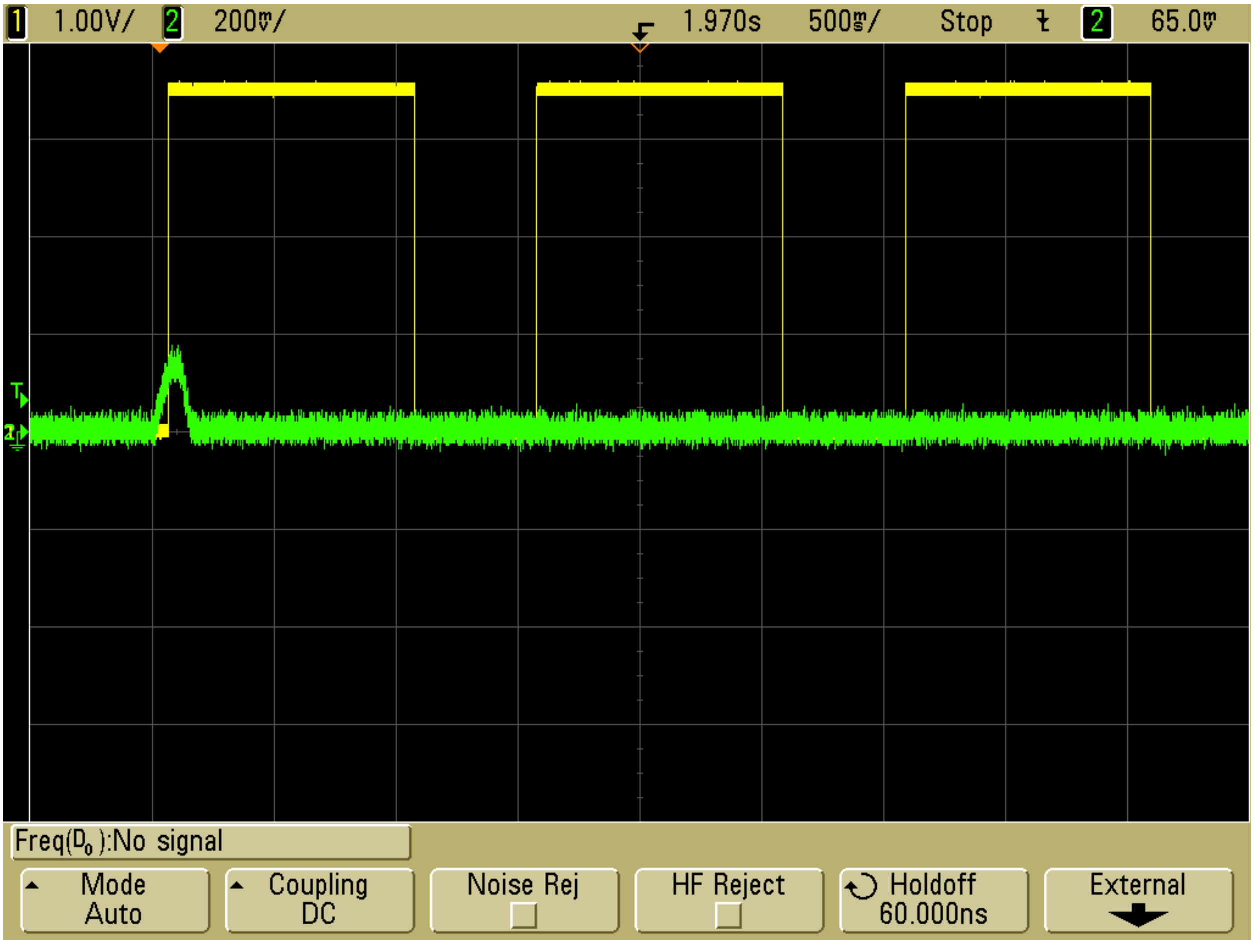


Figure 12: Microcontroller Block Circuit

Figure 12 is the schematic for the circuit we are using to implement this block. This design is going on a testing board where we will be able to work with both a MSP430 as well as the LPC2103 which is an ARM7 variant. Since we are using the ARM 7 we need to include a JTAG to allow for programming and debugging, as well as a switch for setting the debug mode. We use a demultiplexer and a switch to choose one microcontroller to use at a time.

In order to test this block we isolated it from the system and provided a test input. This test was meant to simulate a wave passing through the filter and arriving at the microcontroller. By monitoring the output pins we can see if the microcontroller triggers the output when it was necessary.



Freq(D$_0$):No signal

Mode Auto

Coupling DC

Holdoff 60.000ns

Figure 13 : Results of Microcontroller Test

In Figure 13 we see the input to the microcontroller in green and the output of the microcontroller in yellow. The input was created by using a power supply which we increased the voltage on to simulate a signal in the target frequency range. We can see that when there is a spike in the input, the output is a set of three square wave pulses. This is the correct result since we want to create a vibrating pulse even if the input is only for one portion of the entire warning.

Warning Block

One of the most crucial aspects of the system is the warning block. The purpose of the warning block is to alert the user of an incoming threat. The warning block will communicate with its surroundings in two different ways. First is through an LED that will be bright enough to alert the driver of the threat. Secondly, there will be a vibrating motor in the object itself so that the user will be warned. This will result in a simple, yet effect design which emphasizes high reliability and low cost.

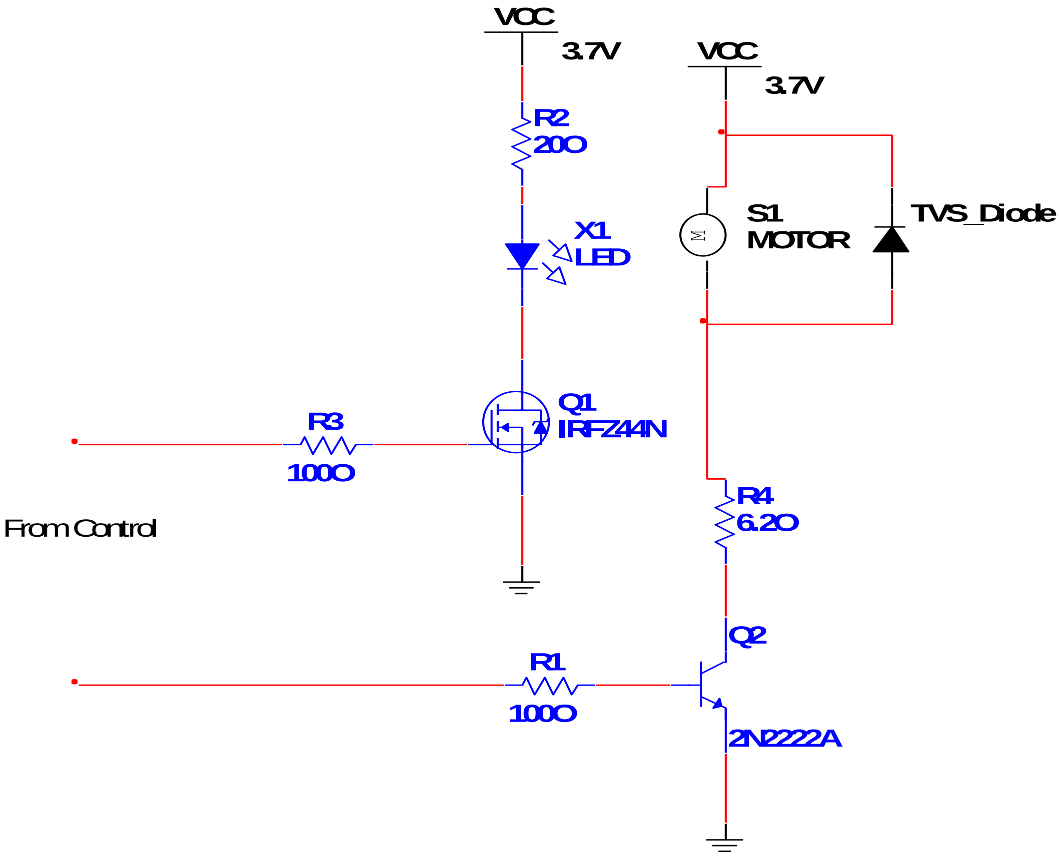


Figure 14: Warning Block Circuit

Figure 14 is the schematic of the warning block which we plan on using. We are utilizing the two forms of warning that we determined necessary during the research phase. These are each driven separately by two signals from the control block. The led and the motor will pulse when a warning is triggered to hopefully gain more attention from both the drivers and the pedestrian.

As an input to this block, we have the three warning pulses from the MSP430. The input power for this circuit is modeled as a voltage source of 3.7V. Since the voltage is greater than the voltages of the power MOSFETs, we decided to use a special model of FET called the IRFZ44N, which will in turn, turn the LEDs on. We are planning on using a resistor of 100Ω at the gate of the MOSFETs so that the current does not damage the NMOS transistors. Since this voltage turns on the MOSFET, the current will then drain to the source. One of the good aspects of the IRFZ44N NMOSs is that it has an integrated protection diode which goes from source to drain, which saves us from having to include an external diode. Since the FET is turned on, the drain current flows from the rails to ground. This will help prevent any backflow current in the circuit. We also had to place a small resistor of 20 Ω from Vcc to our LED for current flow.

On our motor side of the figure, we have placed in a transient voltage suppressing diode in series to prevent any voltage spikes from occurring in this side of the circuit and from damaging the motor. Another highlight of this circuit is the 2N2222A NPN Bipolar Junction Transistor. The purpose of this component is to drive extra current to the motor to help run at very high speeds to alert the user.

Power Block

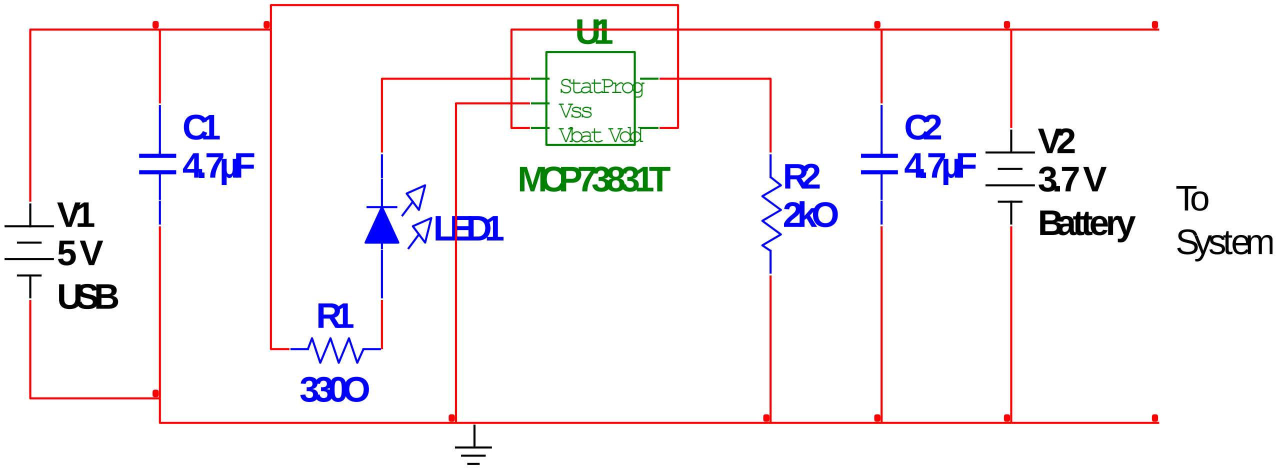


Figure 15: Power Block Circuit

In Figure 15, we have displayed our charging circuit. From the figure, we can see that the voltage is supplied to our chosen charging chip through a 5V USB charging cable in through pin Vdd, or battery charging management port. Also, it is also recommended that we bypass the 5V input supply with a 4.7uF capacitor. The Vss port is tied to ground. Our VBat port is connect to the positive terminal of our battery and ground which will charge the battery with a desired charge, the negative terminal of the battery is tied to the Vss terminal of ground. The positive terminal of the VBat is also connected to a 4.7uF capacitor which is designed to act as a bypass for the battery and ensure stability when the battery is disconnected. The PROG pin is where we are able to set the charge current on our battery. We are able to do so by connecting a certain resistance to Vss ground to acquire our desired charge current. Our STAT pin is to show us the condition of the charging circuit. The LED which is wired in series with the pin is lit up while the battery is charging and turns off when the battery is charged.

Examining this circuit brings forward a new point, why we chose the elements which we did. We chose a cell-phone battery because it is light weight. Furthermore, we are using a Lithium-ion polymer battery, one of the lightest batteries on the market. This battery can hold 850mAh of charge. This will give us ample usage time and minimal current draw from our circuit. We chose the 5V USB charger because it has the ability to charge our battery while regulating the current and shutting down operation once full charge is reached.

Physical Amplifier

The goal of this section of the project is to filter the signal by increasing the amplitude of the desired frequencies while leaving the other frequencies alone. To accomplish this, research on different mechanical methods of how this could be done was necessary. For this application, resonance was the theory which seemed like it would work the best. Resonance occurs when the source of the energy alternates at approximately the natural frequency of the oscillator (Hall, 2002). By examining different configurations of oscillators, an acceptable attachment for the microphone could be designed.

One of the simplest forms of a resonator is a cylindrical tube. The ends of this tube can either be open or closed which will determine the form of the equation necessary to describe the length of the tube. A tube that is open at both ends will have antinodes at each of the openings and will produce a complete series of harmonics including the even and odd modes of resonance. A tube that is closed at one end and open at the other will have a node at the closed end and an antinode at the open end; this will produce a series of harmonics including only the odd modes of resonance. The length of an open at both ends tube resonator is two times the length of the closed at one end tube resonator of the same frequency. A caveat of the open ends of a tube is that there will not be a true antinode there and some energy will escape. To account for this there needs to be an end correction factor in our calculations. The result of the end correction phenomenon is that the resonant frequency of a tube is lowered (Wood, 1930).

A Helmholtz air cavity resonator is another type of resonator. This device is a cavity which is almost completely enclosed with a neck for an entrance and a small pinhole for the exit. The fundamental resonant frequency of this device is dependent upon the nature of the air in the neck and not in the cavity. The main dimensions that change the fundamental frequency are the length and the cross sectional area of the neck (Wood, 1930). Since the goal of this device is only to selectively amplify selected frequencies, resonance is a good choice for a design basis. As shown, there are multiple ways that this device can be designed to take advantage of the theory of resonance to achieve this goal.

Proposed Implementation

After researching the topic of resonance, we decided upon using tubes as resonators for this project. The first reason that we selected tubes over Helmholtz resonators is the size constraints. By utilizing a tube that is closed at one end that resonates between the frequencies of 800 and 1200 Hz, we were able to stay within the size constraints we had proposed from our customer research. These size constraints consisted of a footprint of approximately 5 inches by 2 inches. The longest tube was approximately 10.5 cm in length which was shorter than our proposed length of 12.7 cm. Another reason we selected the tube resonators is the ease of manufacturing and testing. This gave us the ability to create multiple different configurations of these resonators and test them while not spending a lot of time or money. The ease of cutting and capping a new tube is much less complex than having to re-create a Helmholtz resonator to achieve the same results.

Once we had decided upon the tube resonators, we then had to determine the number of resonant frequencies to utilize. Upon first approach we decided to utilize five resonant frequencies starting at 800 Hz and increasing by 100 Hz until 1200 Hz is reached. We believed that this will give us a wide enough range of frequencies for this device to successfully determine the presence of a car behind it.

Now that we had determined the number of frequencies, we needed to determine how the resonators will be positioned inside the device. We planned on having these resonators lined up parallel to each other with their sides touching. This performs the main task of placing these resonators in a fashion that will allow them to fit inside the device. By lining the tubes up, the depth of the device will be minimized since the length is constrained by the length of the tubes and the width of the device is constrained by the printed circuit board.

This is a baseline design for this attachment. By starting with a base design we had something to compare our tests to and make improvements on. This process has also allowed us to make some preliminary observations and decisions which helped to speed up the testing process.

Proposed Testing

Now that we had a proposed design of this resonator, we came up with some proposed testing to improve upon our design. The main parts of the design that we tested are the proper frequency choices, the correctness of the tubes and the ability to resonate as a group. We came up with one main test for each of these three areas.

First, we needed to determine which frequencies we should select for the tubes. Since our research had shown that most tires on most road conditions give off frequencies between 800 and 1200 Hz, we have our boundary frequencies. We now needed to determine where and how in this range the frequencies should be divided. One possible approach was to have 5 different tubes, each spaced 100 Hz from each other. Assuming a linear spread of frequencies throughout the region of interest, this will give us maximum coverage. In order to test this approach we decided to record one car passing by on the street and observing the frequency spectrum given off. If there was semi constant amplitude of the frequencies across our region of interest, we decided to implement the 100 Hz gap approach. Another possible approach was if there is something resembling a normal distribution in the frequency spectrum. In this case we decided to apply a normal distribution fit to the data and place the resonant frequencies in a way that agrees with the statistical analysis of the data.

The next thing to test was the correctness of the tubes. This test was designed to prove that the tubes will in fact resonate at the frequencies desired. This also gave us an idea of the typical amplitudes that we would be looking at pulling from this resonator. In order to test this, we first needed to perform the calculations that will determine the length of the tubes.

$$F = \frac{nv}{4(L + 0.4d)}$$

Equation 2: Length of a Closed End Tube Resonator

Equation 2 shows the relationship between the length of the tube (L) and the frequency which it resonates at (F). The other variables in the equation are the diameter of the tube (d), the speed of sound in air (v) and an integer representing the resonance mode. By using an n value of 1, we calculated the length with a node at the closed end of the tube and an antinode at the open end of the tube. This gave us the shortest lengths while still achieving resonance at the required frequencies.

Once we had tubes at the proper lengths we needed to cap them. For this we used small pieces of acrylic and a silicone sealant. Since the sealant filled in the gaps between the acrylic and the tubes, this created a tighter seal than if we were to purchase small caps to press fit over the end of the tubes. This setup also allowed us to connect multiple tubes to one backplane and create a setup to test if the resonator will resonate at multiple frequencies.

The main test to determine the resonant frequency of a single tube was to blow over the top of the tubes and record the noise created. Each tube gave off a specific pitch when this is done and by recording the sound and doing a frequency analysis of what the sound is made up of, we determined if the tube was at the proper frequency. If the tube gave off a frequency that is too low, we sanded down the open end a small amount and tried the test again until we achieved the desired results.

The next step was to test if the group of resonators would work correctly. We could once again perform the single tube tests on the individual tubes in the group to ensure that they were working properly. Once we had confirmed that they work individually, we could begin to test the group as a whole.

Implementation

While working on the proposed tests for determining which frequencies to place in the resonator, we determined to go with a linear spread of 100 Hz between each frequency. We had come to this determination because our research had shown that there are tires and conditions that will still produce the frequencies near the outer boundaries of our regions. Since we wanted to be able to detect all vehicles equally, we needed to use a linear setup instead of biasing our design to a small subset of conditions.

Once we decided on how to divide up the resonant frequencies, we needed to decide how to group the resonators together. We experimented with different configurations, the two main ones being a group of single resonators on a plate as well as one resonator with multiple holes to create multiple resonances. The group of resonators on a plate would be able to give the cleanest responses for each of the frequencies, but would be bulkier and take up more space. The single resonator would be smaller and may not give as clean of a response. We attempted to use a single resonator and have the group of resonators as a backup.

Test Results

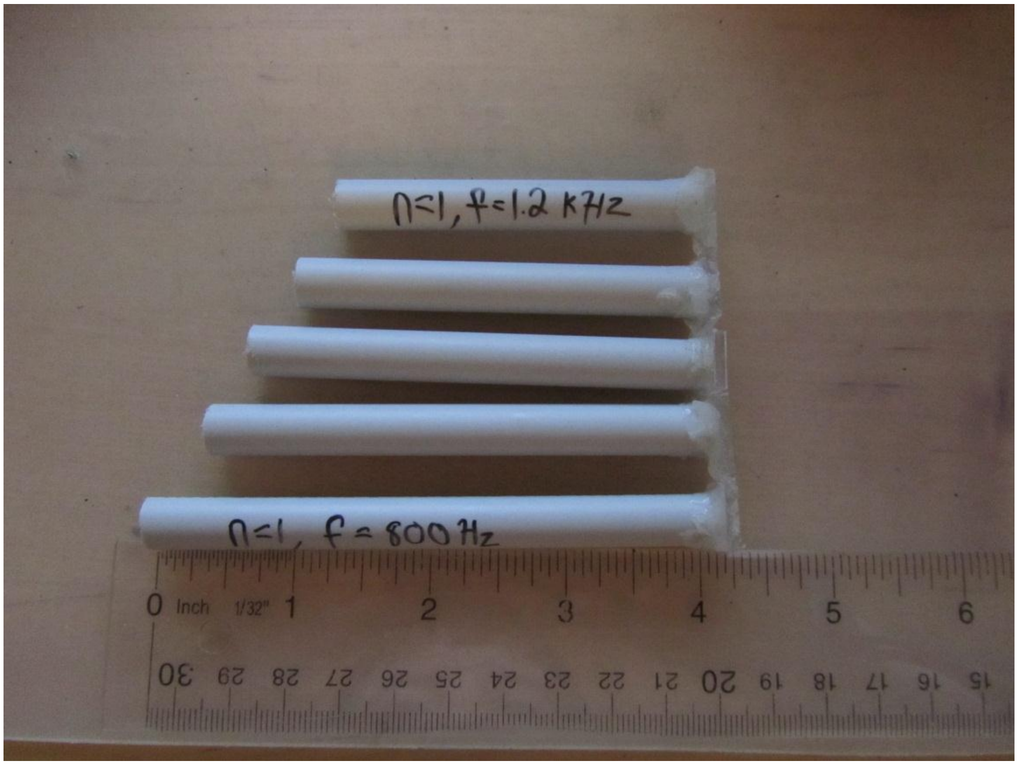


Figure 16: Single Frequency Resonator Tubes

Once we determined our testing approach, we began testing data. The first major test was to cut one tube and record the frequency it gave off while resonating. Examples of the single frequency resonators are found in Figure 16. We were unable to get any acceptable data by just placing the microphone near the resonating tube; therefore, we had to alter the test. Since the resonance we hear is the air inside the tube resonating, we decided to use the microphone as the cap in order to easily record the sound inside the tube.

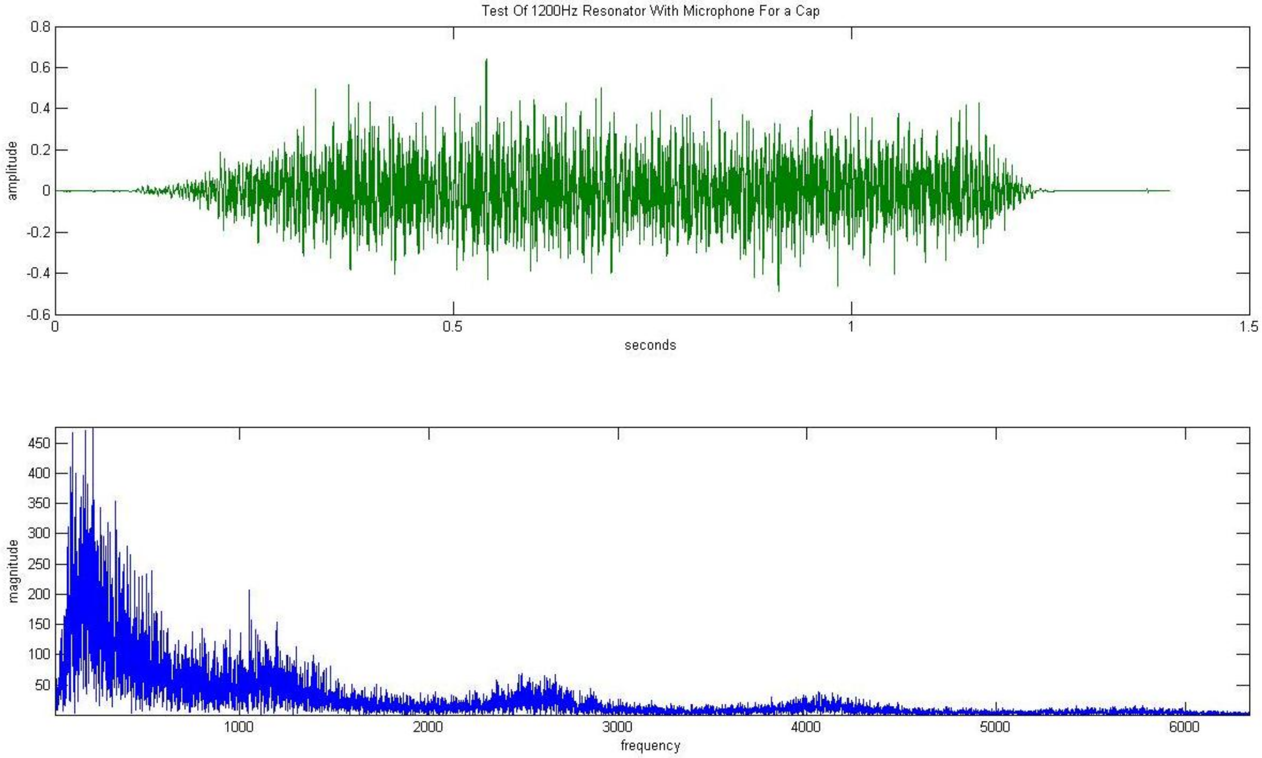


Figure 17: Amplitude and Magnitude Response of a 1.2 KHz Tube

Figure 17 shows the test results for a tube cut to resonate at 1.2 KHz with a microphone as its cap. We can see the primary resonance around 1.2 KHz and we can also see three other modes of resonance. This test shows that if we were to use a microphone as a cap for a resonant tube we would successfully be able to record the resonance inside the tube.

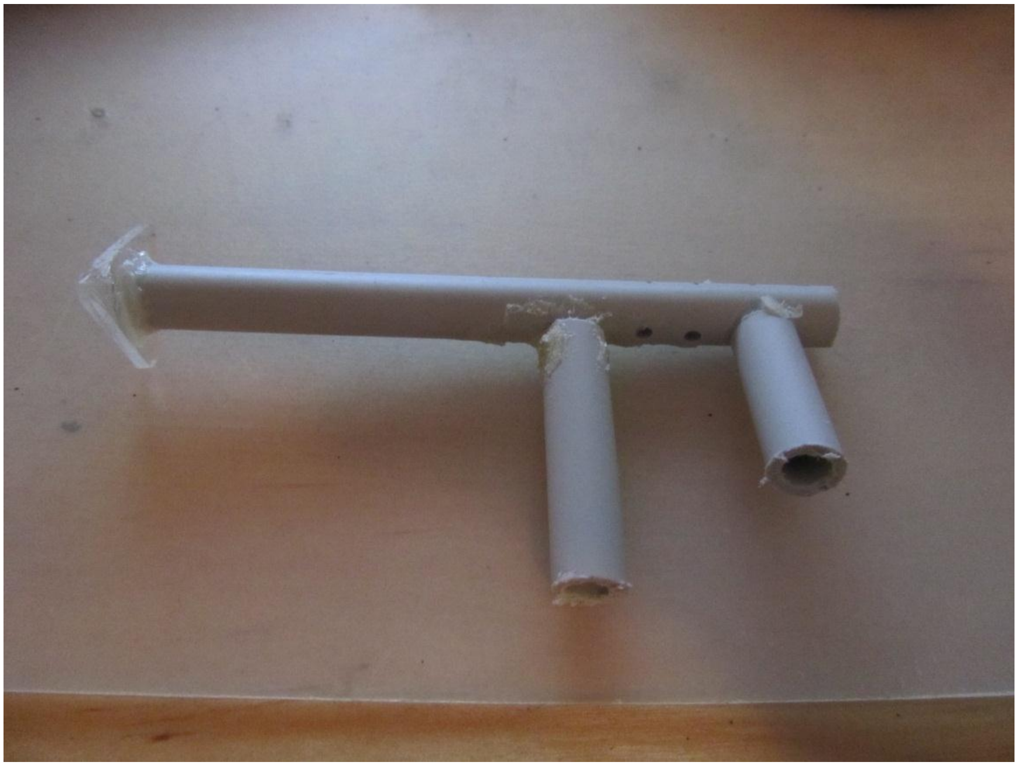


Figure 18: Multiple Resonances in one Tube

Next we looked at a single resonator with multiple holes cut into it to attempt to create resonance at multiple different frequencies. To make this resonator we started with an 800 Hz resonator, which is the longest length tube that we use. We then capped one end and measured the lengths from the capped end that would correspond to the frequencies we want to resonate at. To simulate the end of a tube, we drilled holes at those measurements. This setup is shown in Figure 18 with the output tubes attached for 900 and 1200 Hz. Using the results of the last test, we knew that it would be easiest to record the data by making another tube off of the first. To solve this issue we cut smaller tubes and attached them off of the holes drilled in to the main tube. To get a measurement we placed a microphone on the end of the tube off of the first and recorded the data.

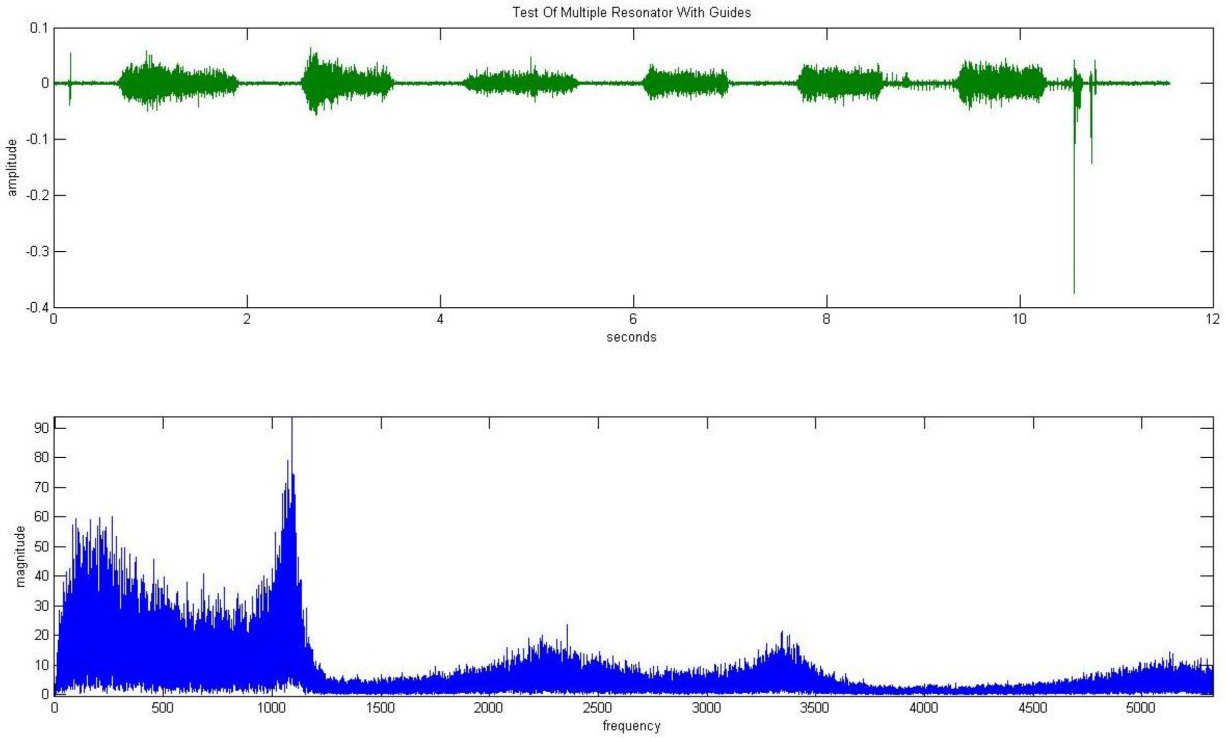


Figure 19: Amplitude and Magnitude Response of 1.2 KHz Slot on the Multiple Frequency Resonator

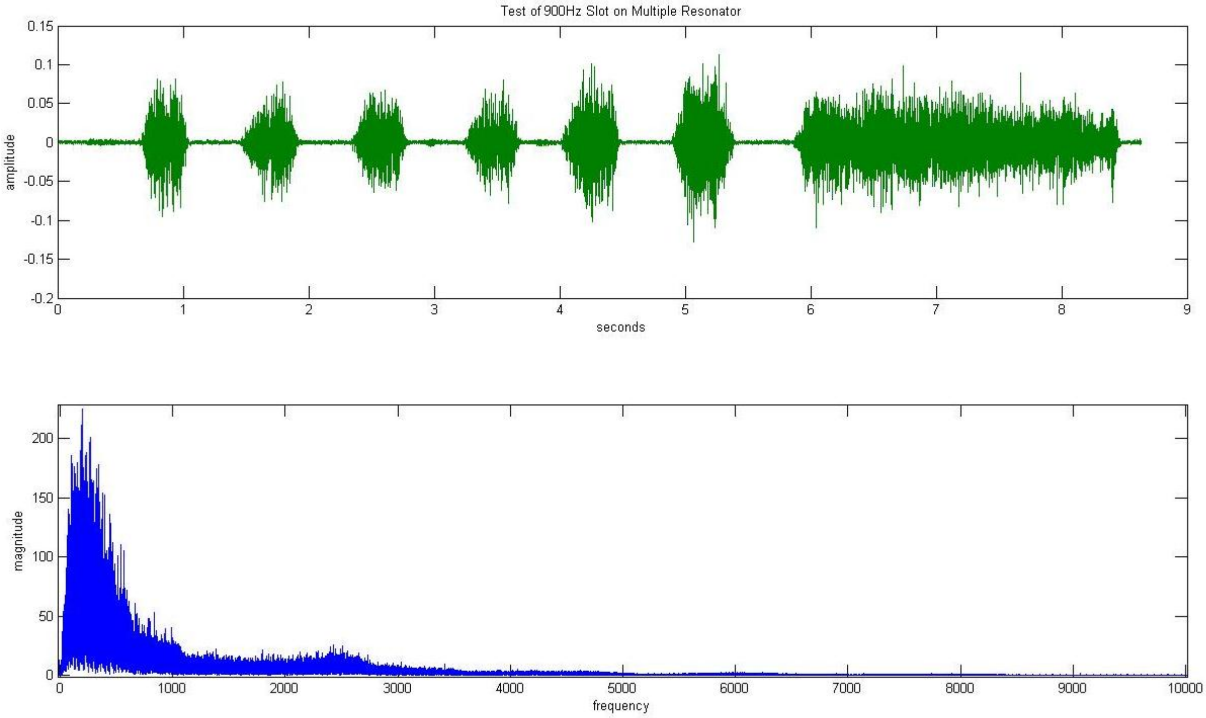


Figure 20: Amplitude and Magnitude Response of 900 Hz Slot on the Multiple Frequency Resonator

Figure 19 shows the results of recording data from the 1.2 KHz hole on the setup described earlier. We can see that there is a spike at the 1.2 KHz frequency with an odd drop off of magnitude directly after that. Figure 20 shows a similar test but on the 900 Hz hole on the device. Unlike the first test on this device, this test does not show any noticeable spike at the frequency it is designed to resonate at and therefore does not show positive results. Looking more into this we could see that the only test that returned a positive result was the test on the 1.2 KHz hole. This is also the shortest tube and therefore the closest hole to the cap. Therefore in a setup like this the only mode of resonance will be the one achieved by the closest hole to the tube. Due to this, the setup that we had planned on using is not a valid option. This means that in order to get multiple resonances, we needed to make multiple single tube resonators with microphones for caps. Although this will be larger than we had originally planned on having, it will create the resonances that we want.

Future Improvements

The main improvement to target would be the overall size of the group of resonators. Since the current size is dictated by the number of resonators and the size of the tube, these are the two areas to improve upon. Either adjusting the number of resonators or the diameter of the tubes would alter the size of the group of resonators. Another way to alter the size of the resonators is to implement the multiple resonances in one tube idea differently. Since the hole closest to the cap is the only one that resonates, one way to make the system work would be to cover up the holes in a pattern.

Conclusions

The goal of this section was to create a device that would improve the sensitivity of a microphone to a band of frequencies. We planned on achieving this by utilizing resonators to increase the amplitude of the desired frequencies. Since we wanted multiple resonant frequencies and a small form factor, we chose to use tube resonators. We performed successful tests on the design of a tube resonator with a microphone as a cap to record the data. Overall, we were able to come up with a design that would successfully resonate at multiple frequencies while still allowing for data to be pulled from it.

Enclosure

When designing our enclosure for our device, we needed to keep a few things in mind. This needed to be made from a fairly light-weight material and be able to be worn on the arm. For this reason, we decided to construct it out of acrylic. The acrylic we used is ¼ inch thick or 250 mils. Working with acrylic gave us the ability to use WPI’s laser cutter. In order to use the laser cutter, we constructed our desired shape of our enclosure in AUTOCAD. We were able to load the AUTOCAD files into the laser cutter to cut out the six sides of our enclosure.

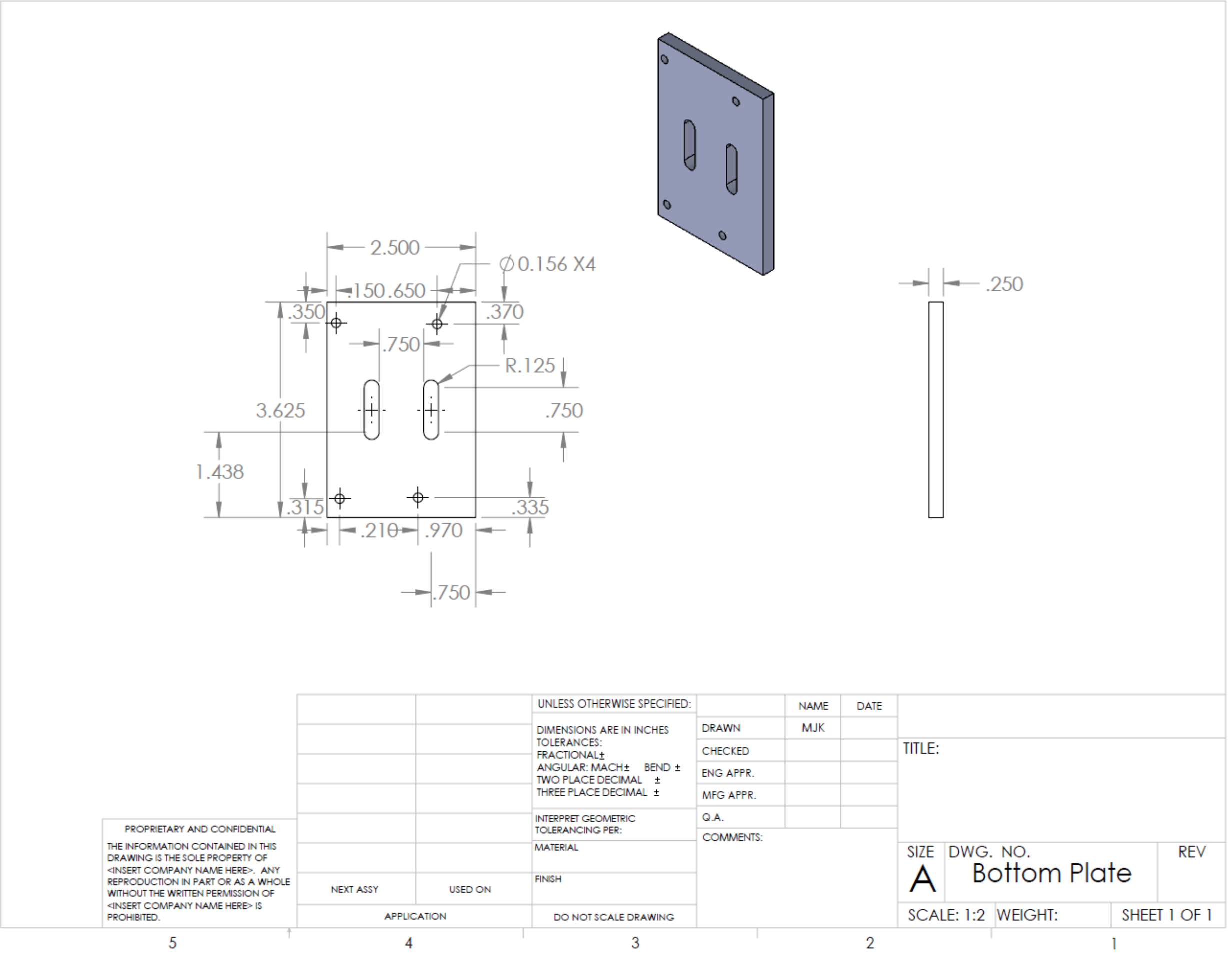


Figure 21: Base Plate

Our base plate is dimensioned at 2500 mils by 3625 mils and has a thickness of 250 mils. On the base plate of the enclosure, we left four screw holes based upon the dimensions of the locations of the screws. These holes have a diameter of 156 mils. We made the first screw-hole located at an X-Y Coordinate of (0, 0) in the upper-left hand corner of the board. All of our dimensions are measured in distance from this point in mils. The upper right screw-hole is located at (1700, 20) and the lower right-hand corner is located at (1380, 2940). The bottom left-hand corner screw hole is located at (60, 2960). We also wanted to have room to mount this on the arm by Velcro. We placed two oval holes as well with a 750 mil length each.

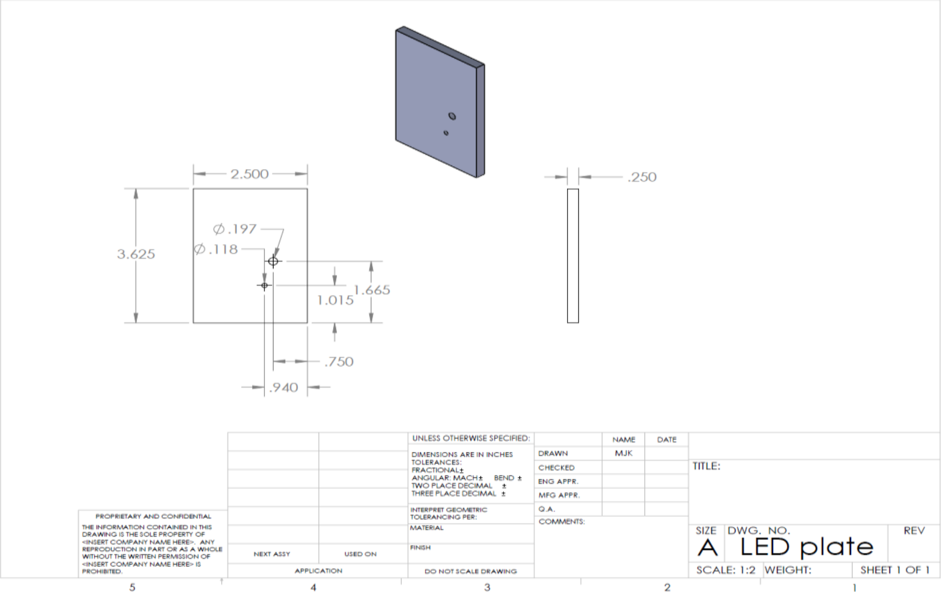


Figure 22: Top Plate

The top plate has 2 holes for the LEDs in our unit each measured at 197 mils and 118 mils respectively. Using the top left hole again as our (0, 0) reference, we have holes placed at (1600, 1610) and also at (1410, 2260). Our top plate also holds the same 2500 mils by 3625 mils.

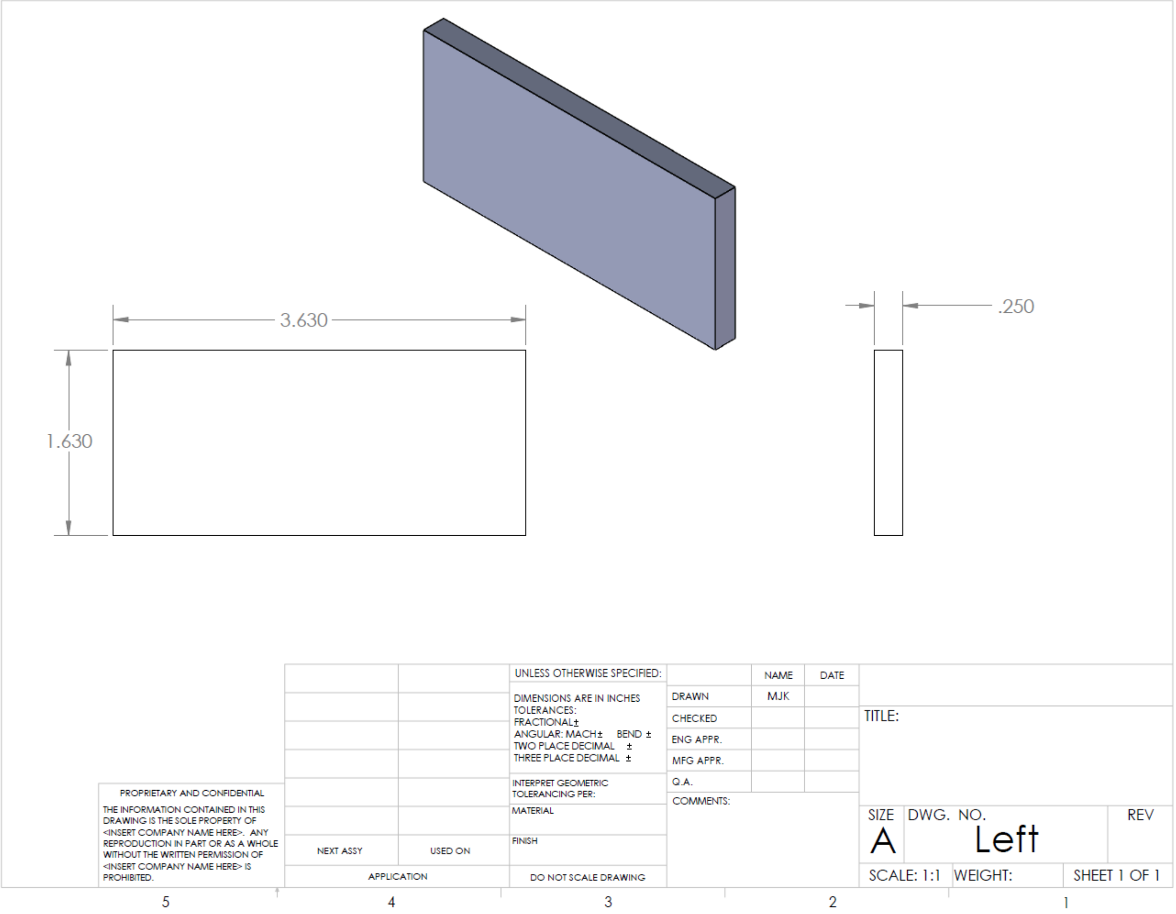


Figure 23: Left Side

Our left hand side piece is a simple 3630 by 1630 mil rectangle.

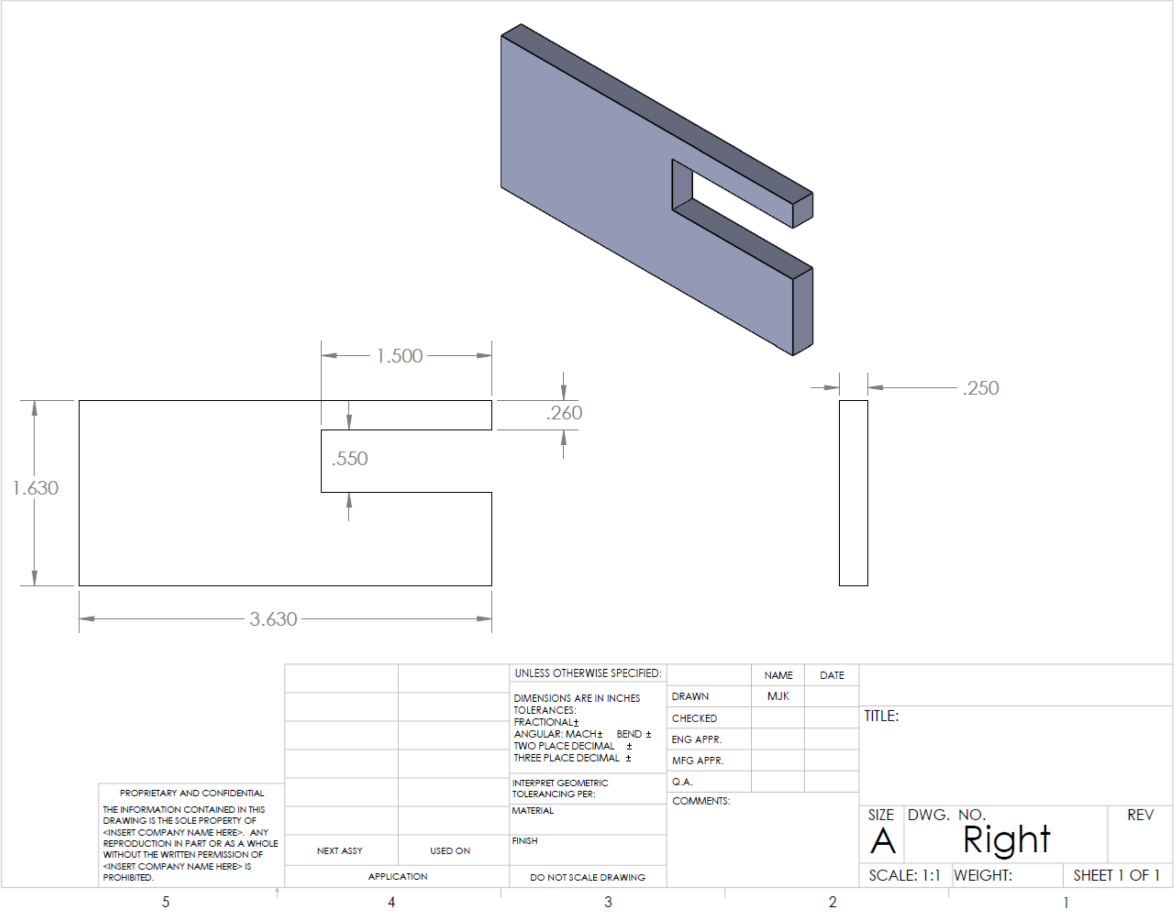


Figure 24: Right Side

Our right hand side piece was a bit more complicated due to our board’s need for a charging port. We left one hole 550 mils wide for the charging port. Otherwise, it is a simple rectangular cut out.

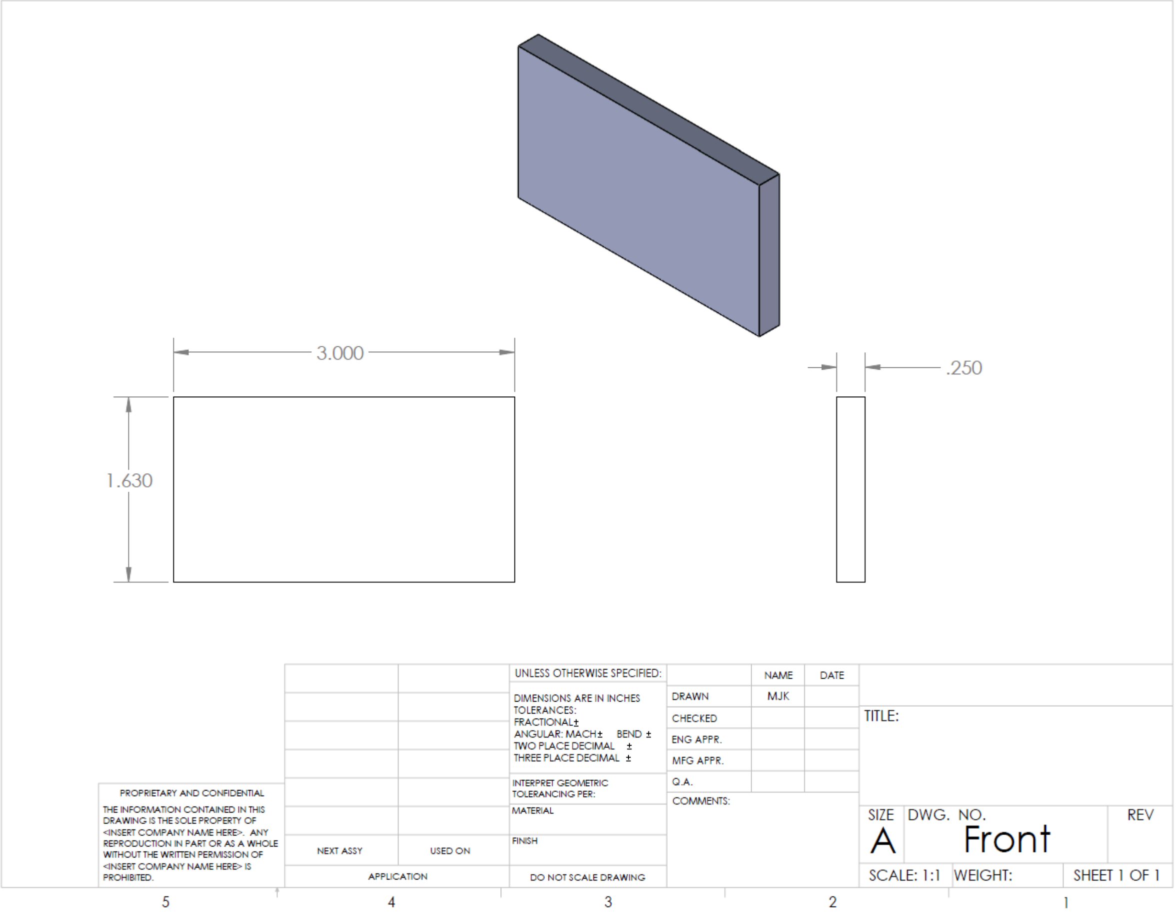


Figure 25: Front and Back

This piece was duplicated for our front and back pieces because of exact matching dimensions. It is also a completely rectangular figure with a measurement of 1630 mils by 3000 mils.

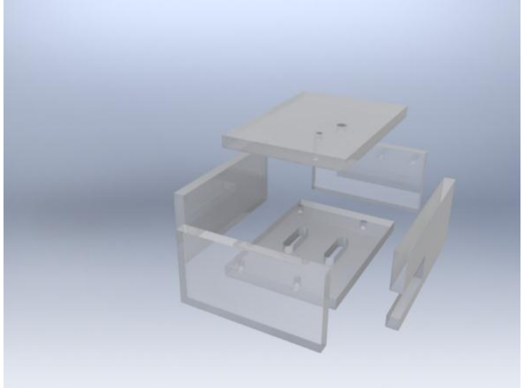


Figure 26: Isometric Exploded View

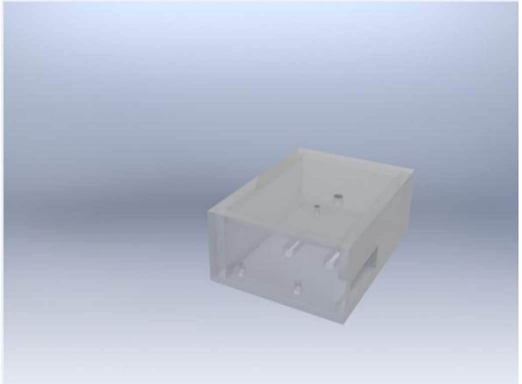


Figure 27: Isometric Assembled Completed

Once we cut out all of our pieces, we were able to produce what appears in Figure 26. After we obtained super glue and screws to hold our board in place, we were able to construct our pieces into an enclosure very similar to the Figure 27.

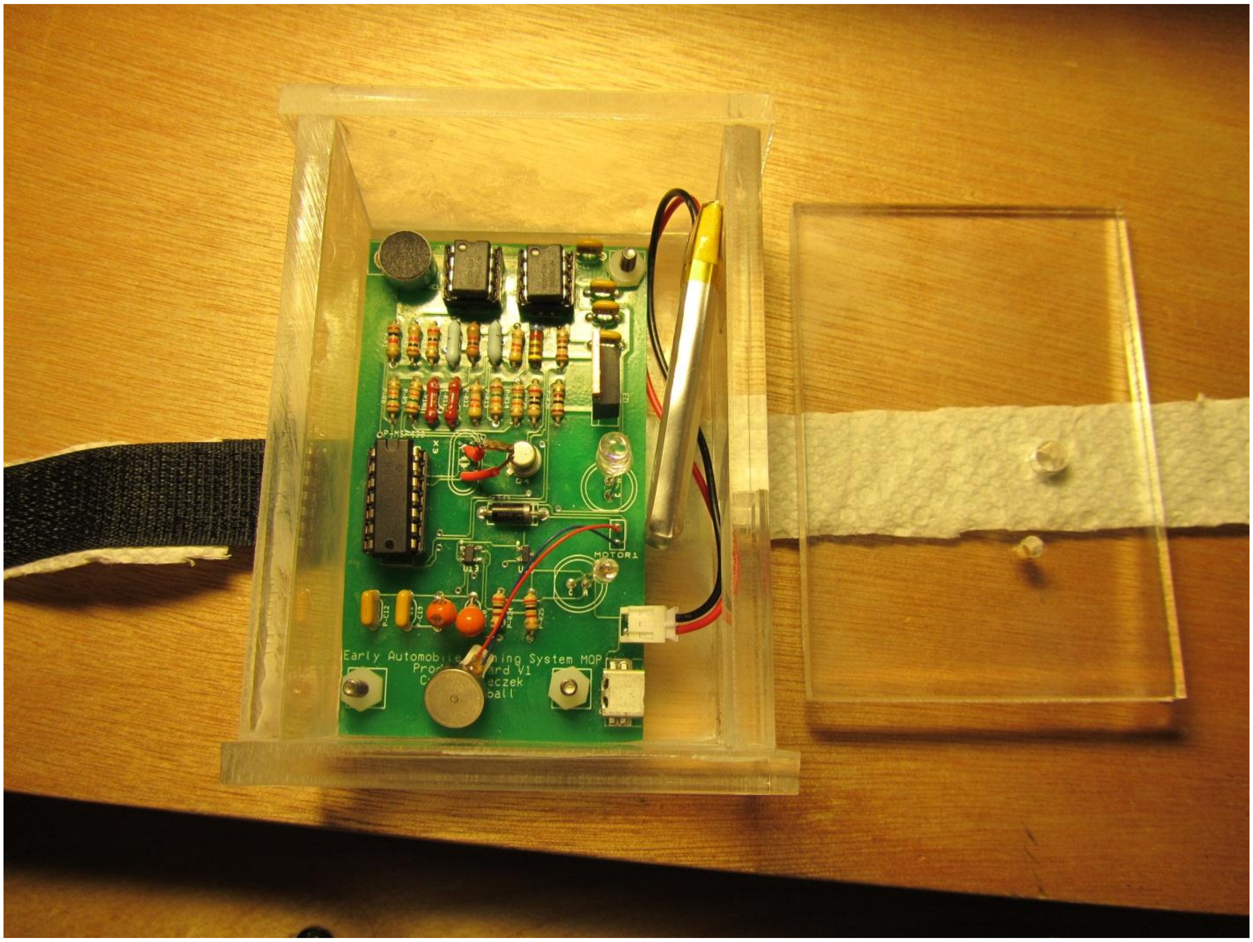


Figure 28: Production Board in the Assembled Enclosure

In Figure 28 we can see the enclosure assembled with the production size board inside of it. The cover of the enclosure has been left off in order to allow for ease of access to the board. In this picture we can also see the Velcro strap attached to the back of the enclosure.

Conclusions

The goal of this project was to design and implement a device which would increase the safety of hard of hearing individuals walking along a road. We determined that by listening for the frequency given off by tires we would be able to accurately detect cars. We implemented a band pass filter to only let through 800 to 1200 Hz, which was the target frequency spectrum determined by the tires. We also designed and implemented an attachment for the microphone which would resonate at a linear spread of frequencies within our target range. This added another layer of filtering and therefore we were able to decrease the overall sensitivity of the device with the same results. Once the signal was filtered we sampled it with a MSP430 microcontroller a rate of 3000 Hz. By testing the energy of the past 0.1 seconds, the microcontroller was able to determine if a warning was necessary and if so create a trigger pulse. The trigger pulse alternated a vibrating motor for the pedestrian as well as a LED for the driver. Overall the system determined if there was a car behind it and set off the proper warnings.

Appendices

The following appendices contain information deemed pertinent to this initial report, but too cumbersome to include within the body text. These include resources that were used and that are currently available, proving the feasibility of future progress on this project.

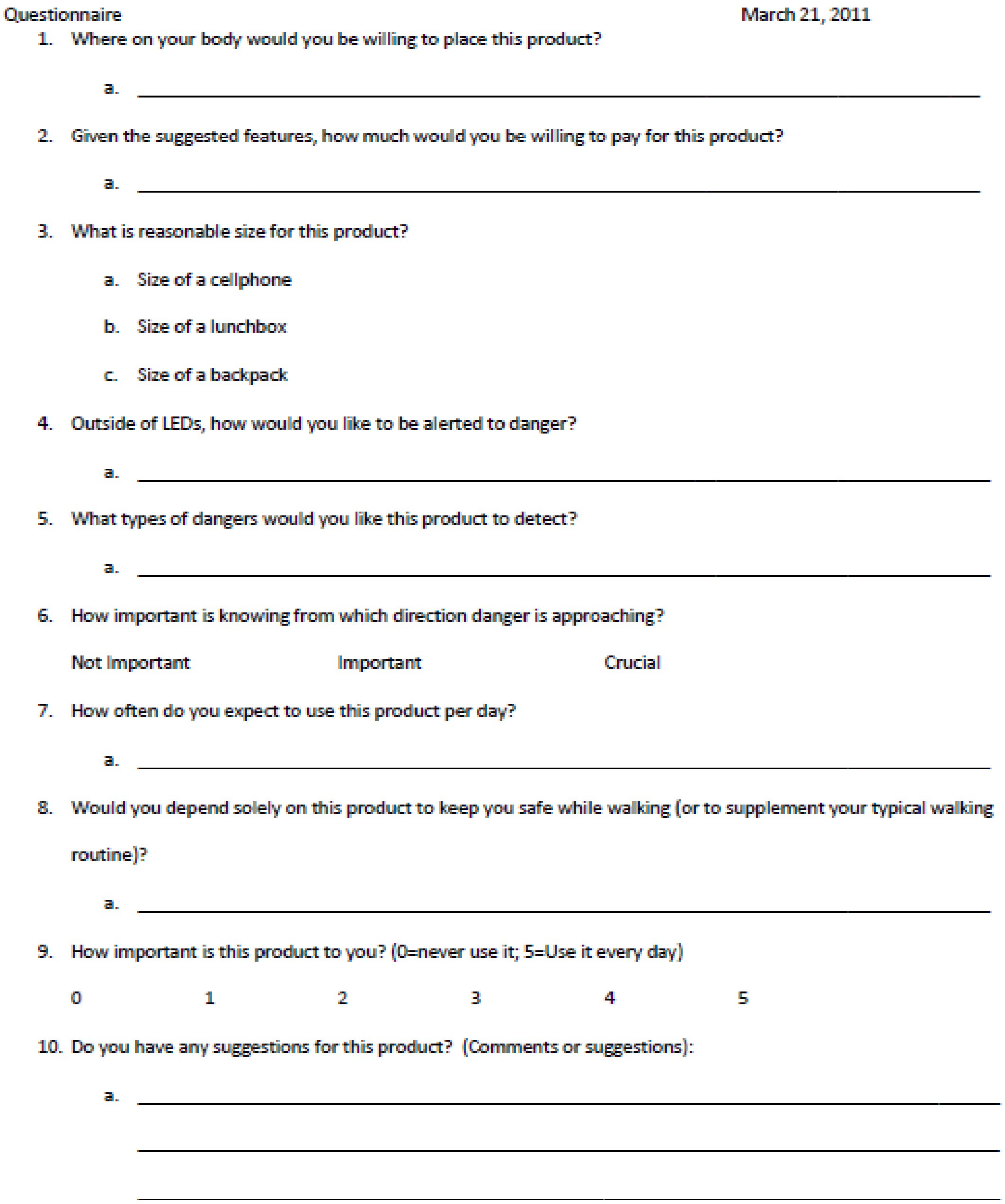
Appendix A

In addition to professors at WPI, we wanted to find local experts in our subject as well as contacts who would associate with the target market. Establishing these contacts now will greatly aid in both the design and testing phases of the project, as we can find advice regarding a particular technical aspect very quickly, and several users who may be willing to test the product.

Name	Email	Affiliation	Comments
Aleshia Carlsen	bryanacarlsen@wpi.edu	WPI DSO	Willing to meet with group and potentially provide a local contact/volunteer a WPI
Christine Thompson	cthom27062@aol.com	Hearing Loss Association of America	Will provide a HoH perspective on the project as well as provide other useful contacts.
Paul Ingemi	pingemi@gmail.com	Hearing Loss Association of America	Will forward survey to our target market.
Beth Wilson	wilsondrbeth@aol.com	Raytheon	ECE PH.D specializing in signals processing who is willing to give a HoH perspective on our project as well.

Appendix B

The following is a questionnaire that is currently (at the time of writing) being distributed to several Hard of Hearing people and other volunteers. This input will greatly help focus the product specification to fit the most common needs and concerns.



Questionnaire March 21, 2011

1. Where on your body would you be willing to place this product?
    a. ______________________________
2. Given the suggested features, how much would you be willing to pay for this product?
    a. ______________________________
3. What is reasonable size for this product?
    a. Size of a cellphone
    b. Size of a lunchbox
    c. Size of a backpack
4. Outside of LEDs, how would you like to be alerted to danger?
    a. ______________________________
5. What types of dangers would you like this product to detect?
    a. ______________________________
6. How important is knowing from which direction danger is approaching?

    Not Important Important Crucial
7. How often do you expect to use this product per day?
    a. ______________________________
8. Would you depend solely on this product to keep you safe while walking (or to supplement your typical walking routine)?
    a. ______________________________
9. How important is this product to you? (0=never use it; 5=Use it every day)

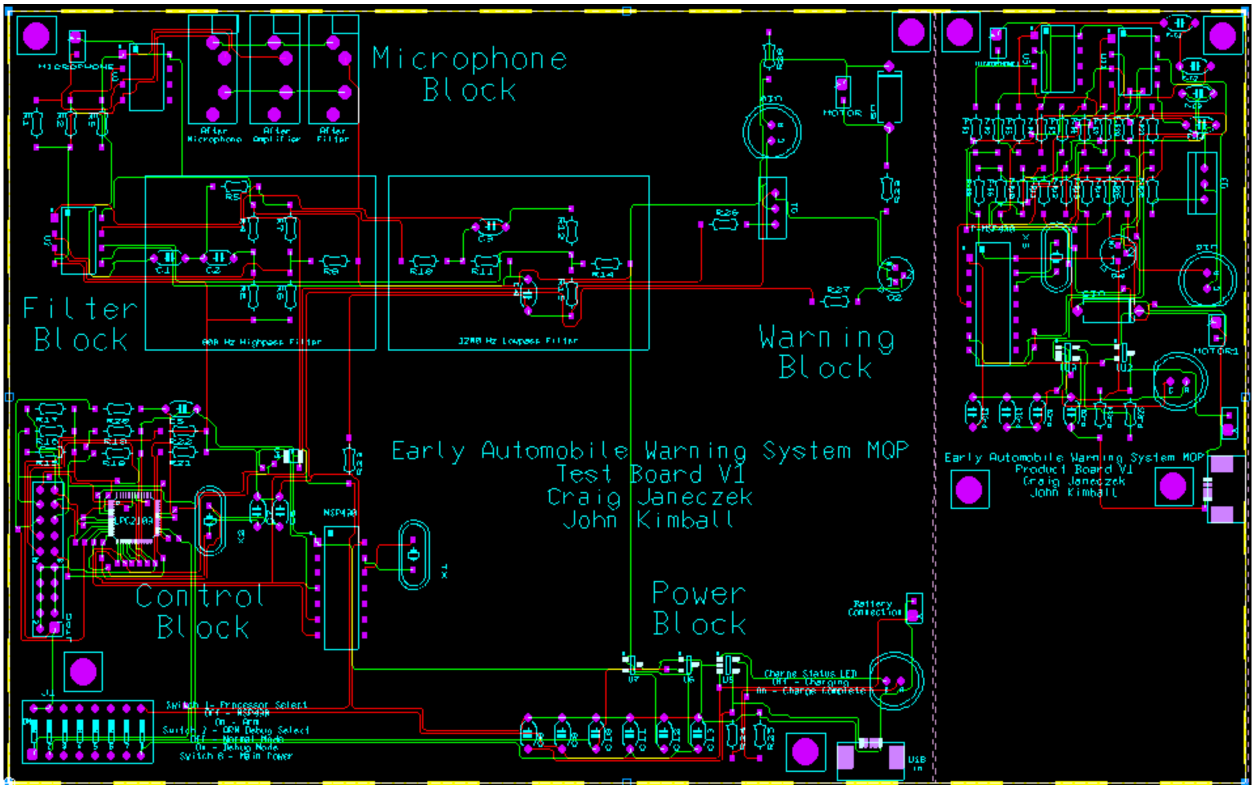
    0 1 2 3 4 5
10. Do you have any suggestions for this product? (Comments or suggestions):
    a. ______________________________

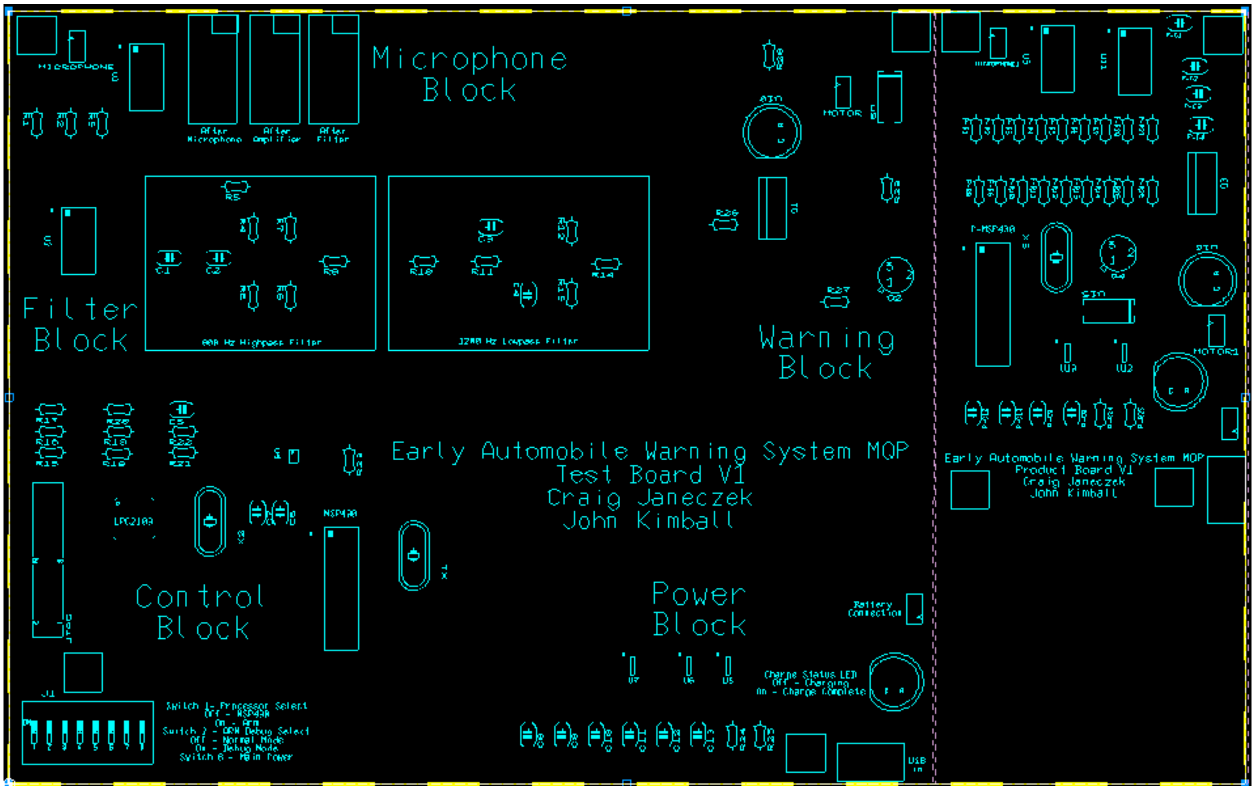
    ____

    ____

Appendix C

The following are some screen captures of the first version of the PCB design. This has the testing board on one side and a more compact production version on the other. The total dimensions of the board are 8” wide and 5” tall.





Appendix D

This is the code which we programmed onto the MSP340 in the control block of this device.

```
//Written by Craig Janeczek

#include <msp430g2231.h>
#include <math.h>
#define window 30          // 30 samples at 3kHz is 0.01 seconds
#define threshold 6000     // threshold energy
volatile long reading;
int i=0;
int timer=0;                //timer variable to keep track of warning
long unsigned int energy;   // total energy of the data array
int pointer=0;              // array pointer variable
unsignedint data [window]; //array of window data


voidFaultRoutine(void);
voidConfigClocks(void);
void ConfigTimerA2(void);
void ConfigADC10(void);
voidConfigPins(void);
void Warn(void);

void main(void)
 {
  WDTCTL = WDTPW + WDTHOLD;               // Stop watchdog timer
  _BIS_SR(GIE);                           // Global Interrupt Enable
ConfigPins();                           // Configure the input and
output pins
ConfigClocks();                         // Configure internal clocks
ConfigTimerA2();                        // Configure TimerA to
interrupt at 3kHz
ConfigADC10();



while(1)
 {
energy=0;                               //initalize the energy to 0
for(i=0;i<30;i++)
  {
energy= energy + pow(data[i],2);      //add all of the energy values
  }

if(energy > threshold)
Warn();




 }
 }
voidFaultRoutine(void)
 {
   P1OUT = 0x01;                          // red LED on
```

```
while(1);                              // TRAP
 }

voidConfigClocks(void)
 {
if (CALBC1_1MHZ ==0xFF || CALDCO_1MHZ == 0xFF)
FaultRoutine();                           // If calibration data is
erased
                                                  // run FaultRoutine()
  BCSCTL1 = CALBC1_1MHZ;                          // Set range
  DCOCTL = CALDCO_1MHZ;                      // Set DCO step +
modulation
  BCSCTL3 |= LFXT1S_0;                      // LFXT1 =
cryatal32.768kHz
  IFG1 &= ~OFIFG;                           // Clear OSCFault flag
  BCSCTL2 |= SELM_0 + DIVM_0 + DIVS_0;      // MCLK = DCO, SMCLK = DCO
 }

void ConfigADC10(void)
 {
   ADC10CTL0 = SREF_1 + ADC10SHT_0 + REFON + REF2_5V + ADC10ON +
ADC10IE;  // Vref+ and Vss
   ADC10CTL1 = INCH_2 + ADC10DIV_0;        // A2 ADC10CLK
 }

void ConfigTimerA2(void)
 {
     CCTL0 = CCIE;                            // interupt enable
     CCR0 = 10;                               // interrupt at 3kHz
     TACTL = TASSEL_1 + MC_1;                 // ACLK, operate in up
mode
 }

voidConfigPins(void)
{
  P1DIR = BIT2;                                //set P1.2 to be input
  P1SEL = BIT2;                                //set P1.2 to be ADC
input
  P1DIR |= BIT4 + BIT5;                        //set P1.4 and P1.5 to
be output
  P1OUT &= ~BIT4 + ~BIT5;                      //set P1.4 and P1.5 low
}

void Warn(void)
{
for(i=0;i<3;i++)                           //repeat 3 times
  {
  P1OUT |= BIT4 + BIT5;                      //set P1.4 and P1.5 high
timer=0;                                   //reset the warning timer
while(1)
  {
if(timer>3000)                           //wait 1 second
```

```
break;
  }
  P1OUT &= ~BIT4 + ~BIT5;                       //set P1.4 and P1.5 low
timer=0;                                   //reset the warning timer
while(1)
  {
if(timer>1500)                           //wait .5 second
break;
  }
  }
}


 #pragma vector=TIMERA0_VECTOR
__interrupt void Timer_A (void)
{
timer++;                               //increment the warning timer
 ADC10CTL0 |= ENC + ADC10SC;             // Samp and convert start

}

 #pragma vector=ADC10_VECTOR
__interrupt void ADC10 (void)
{

reading = ADC10MEM;                   // Read conversion value
data[pointer]=reading;                // transfer reading to the array
pointer++;                            //increment pointer variable
pointer=pointer%window;               //loop through the array and
replace oldest value

}
```

Works Cited

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