

# **QuietCom Noise-Cancelling Communication System**

## **Final Report EE198B-Senior Design II**

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**May 10, 2008**

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## **1 Introduction**

This section will introduce the purpose of our project and explain to our intended audience the significance of using the combination of passive noise reduction ear plugs with an active noise reduction system. Our intention is to minimize loud noise and ambient noise. Loud noise is experienced when riding in a fast-moving car or motorcycle. Loud ambient noise can also be experienced when operators are working in data centers with hundreds of servers running, construction sites, or working in clean rooms. Designing an active noise reduction system can certainly make working more comfortable in such areas and help prevent any additional hearing loss. Furthermore, since communication is frequently required in loud areas, we decided to implement communication capabilities into our design. This is so that operators can still comfortably communicate with others.

### **1.1 Abstract**

Permanent hearing loss is an inherent problem in many occupations. By adding an active noise reduction system to passive noise reduction earphones, wind noise can be reduced to safer and more comfortable levels. A communication system with noise cancellation will allow operators to function comfortably without sacrificing the ability to communicate with others.

### **1.2 Executive Summary**

Permanent hearing loss is serious problem for motorcycle riders. The louder the noise a person is exposed to, the lower the exposure time until permanent hearing loss is sustained. When sound levels exceed 100 dB, maximum safe exposure time is reduced to approximately 2 hours. At 115 dB, safe exposure time is reduced drastically to about 15 minutes (FreeHearingTests.Com).

Unfortunately, even with a full face helmet, a motorcycle rider can experience over 115 dB of wind noise at freeway speeds. Currently, passive noise reduction (earplugs), are encouraged for motorcycle riders who expect to ride over 35 mph. However, passive noise reduction will only reduce about 20 dB of noise.

We wish to combine active noise reduction with passive noise reduction by adding active noise reducing speakers to earplugs. This small device will be small enough to fit under a motorcycle helmet and when used in conjunction with passive noise reduction - will provide an optimum amount of noise reduction.

Furthermore, verbal communication is impossible when exposed to noise levels equivalent to wind noise at freeway speeds. By implementing additional microphones to and a push-to-talk button, operators will be able to hear and speak to those nearby.



**Figure 1. Active Noise Cancellation Combination**

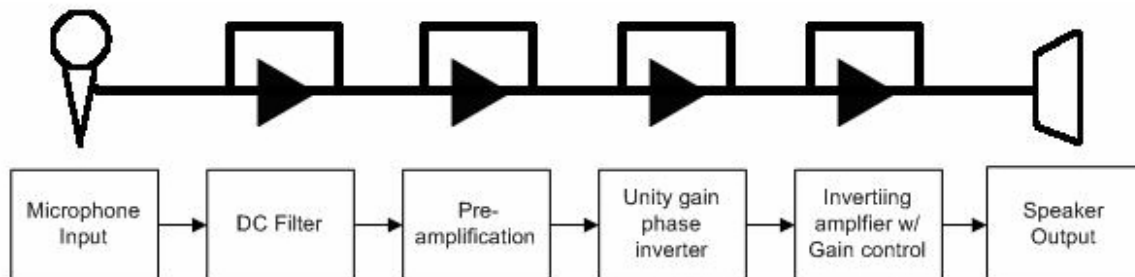
Active noise cancellation works by combining a sound with the same sound in inverting the phase. In an ideal situation (a perfectly sinusoidal input), the two will add and cancel each other out.

## 2 Design Phase

The most difficult aspect of our communications system is achieving effective noise cancellation. There are two possible approaches in implementing active noise reduction: analog and digital. Due to time constraints and the analog nature of audio, we decided to go with an analog circuit implementation for our noise reduction.

### 2.1 Design Description

Our design is intended to bring in a low-frequency signal using some source of audio such as a tone generator. The signal will enter the circuit using a microphone attached to the input jack of our circuit. This sinusoidal signal will enter our circuit, pass a DC filter stage, and traverse 3 dual-audio operational amplifiers where each operational amplifier will serve to perform a specific purpose. The DC filter stage, operational amplifiers, microphone input, and speaker output are shown below in Figure 2.



## Figure 2. Single Channel Analog Noise Cancellation Block Diagram

Our Analog Noise Reduction System will be implemented with 3 dual-audio op-amps and a DC filter stage featured on two channels: a DC filter, a preamplifier, a unity-gain phase inverter, and finally a gain-controlled inverting amplifier for the speakers. The block diagram portrays a single channel layout. The second channel is an exact mirror image of the first channel and will be implemented to meet our requirements in producing noise reduction in two-channel stereo audio (Refer to Figure 10).

### 2.2 Design Details

The following sections will go into detail in explaining each stage shown in the block diagram of Figure 2, starting with the microphone input stage and ending with the speaker output stage.

#### 2.2.1 Microphone Input

After researching some microphones on the internet, the team decided to choose a set of omni-directional condenser microphones from Radio Shack (Refer to Appendix A). Cost and availability were the underlying factors for choosing this microphone. We used a 9 volt DC supply voltage to power our circuit so the microphone supply voltage range of up to 10 volts fits our requirement. Figure 3 below shows the microphone internal circuitry.

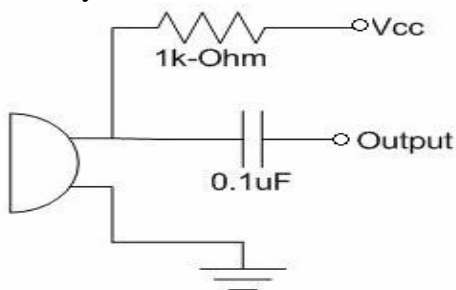


Figure 3. Microphone Internal Circuitry

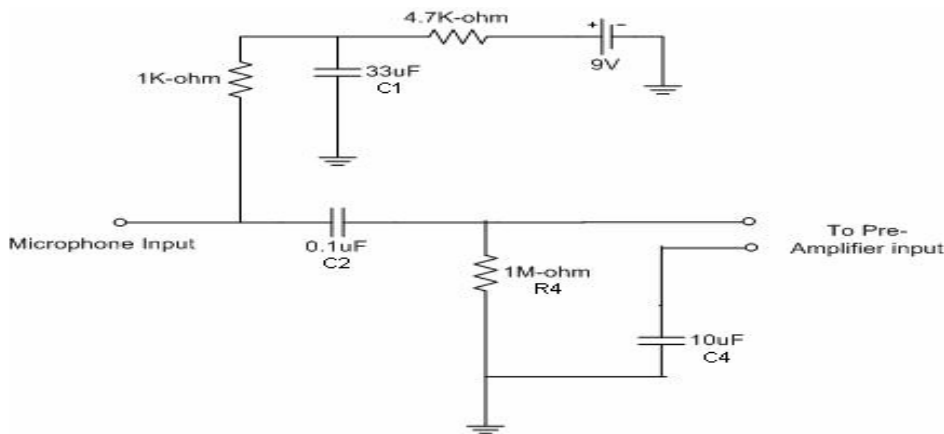
#### 2.2.2 DC Filter

When working with audio, fidelity and noise are two very important considerations in design. Initial testing of our microphone revealed that we would not be able to directly connect a microphone to an inverting op amp and expect an output. After some research and speaking to audio experts on the Headwize.com forums, it was revealed that we would need a DC Filter and Preamplifier.

The DC-Filter section of the noise cancellation circuit was intended for two reasons: to minimize parasitic capacitive coupling and to block the DC bias settings from our AC signal.

Parasitic capacitive coupling is otherwise known as noise interference and is often unintended when designing analog circuits on breadboards (Wikipedia). One of our requirements is to design a two-channel noise reduction system and the crossing of wires and capacitance among both channels introduces capacitive coupling which appears as noise to the human ear. Our DC filter section of our circuit will work to minimize this effect.

The primary function of the network composed of capacitors C1, C2, C4, and the 1M $\Omega$  resistor R4, is to block the DC signal from entering the pre-amplification stage. The capacitor and resistor values were chosen to block the DC signal but the secondary function is to allow the frequency range intended to enter the pre-amplification stage. Shown below in Figure 4 is the DC filter stage.



**Figure 4. DC Filter**

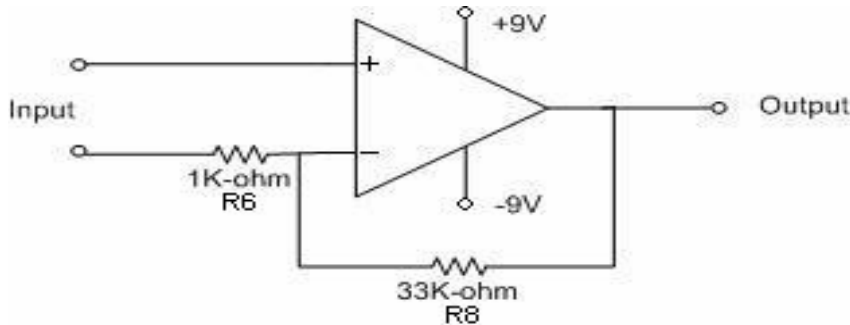
### 2.2.3 Pre-amplification

As mentioned with the DC-Filter we were also able to obtain an electrets condenser pre-amplifier design from audio experts at the Headwize.com Forum, in this pre-amplification section, we amplify the incoming signal after passing the DC filter stage. We chose to use the NE5532 audio operational amplifier for a few reasons: the capability of achieving a high dc voltage gain (~100V/mv), its low noise characteristics, its low power consumption (3V to 20V), and high bandwidth frequency range (up to 10 Mhz). Also, this was the only audio amplifier available at our local electronics store. The first three NE5532 audio operational amplifiers were used to design the first channel (refer to Figure 10) and three others were used to construct the second channel.

The non-inverting amplifier shown in Figure 5 accompanied by resistors R8 and R6 allowed us to achieve a gain of 30.6 dB given the chosen resistor values:

Non-Inverting Configuration:  $(1 + R8/R6) \Rightarrow (1 + 33K\Omega/1K\Omega) = 34$

Gain =  $20 * \text{Log}(34) = 30.6 \text{ dB}$



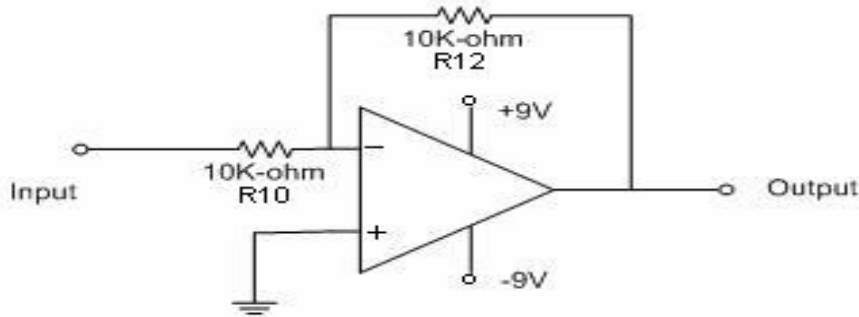
**Figure 5. Pre-amplification**

### 2.2.4 Unity Gain Phase Inverter

In order to obtain noise cancellation, it is critical that the phase of the output is close to a 180 degree inversion of the input. Since it was impossible to tell what the propagation delay of our microphone or selected speakers would be, we decided to implement a unity gain phase inverter to help us tweak our phasing. By having this stage, we have the option of inverting the signal in addition changing the distances of the microphones and speakers.

The function of the unity gain phase inverter is to primarily invert the phase of the signal coming from the pre-amplification section of our design. It is for this reason an inverting NE5532 amplifier with accompanying resistors were chosen. The value for the two resistors are of equal value in order to achieve unity gain from the NE5532 op-amp output, that is  $R10 = R12 = 10 \text{ K}\Omega$ . The group decided in designing a unity-gain inverting operational amplifier rather than a voltage follower to ensure unity gain at this stage despite resistance differences in the wires.

At this point in the circuit, the signal coming from the microphone has been amplified from the pre-amplification stage, and the signal can be inverted one hundred and eighty degrees. Figure 6 below displays the unity gain phase inverter.

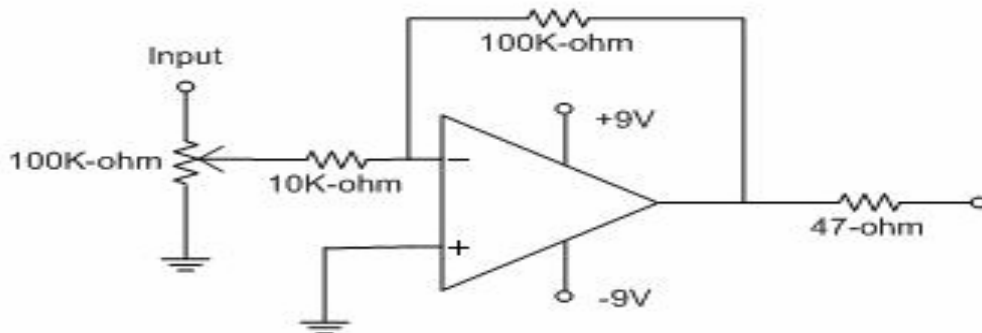


**Figure 6. Unity Gain Phase Inverter**

### 2.2.5 Inverting Amplifier Gain Control

The inverting amplifier gain control stage allows the user to change the gain so the signal can be amplified and adjusted so quality hearing can be heard from the output speakers (or headphones). At the input of the inverting stage shown in Figure 7, there is a potentiometer in parallel with the input resistor to the inverting operational amplifier.

This potentiometer is used to vary the input resistance so the gain can be adjustable at the speaker side where the range of the potentiometer varies from  $\sim 60\Omega$  to  $100K\Omega$ . The  $100K\Omega$  ( $R_f$ ) resistor was used so a gain of at least 10dB can be achieved.



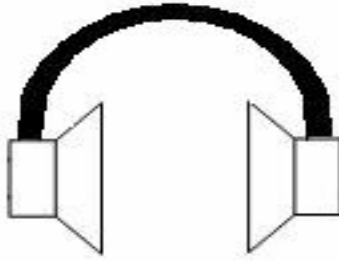
**Figure 7. Inverting Amplifier Gain Control**

### 2.2.6 Speaker Output

The block diagram shown in Figure 2 is terminated with a speaker output so the inverted (one hundred and eighty degrees) sound can be heard from the initial sound taken in from the microphone. Because of the inability of locating and purchasing high cost, high fidelity-speakers, the team decided to use a set of good-quality headphones to listen to the output sound. The headphones were glued to the microphones so they could easily be mounted to the user's ears. This attempt to use a set of headphones and glue the microphones enhanced the ability to hear the noise reduction coming from the user's



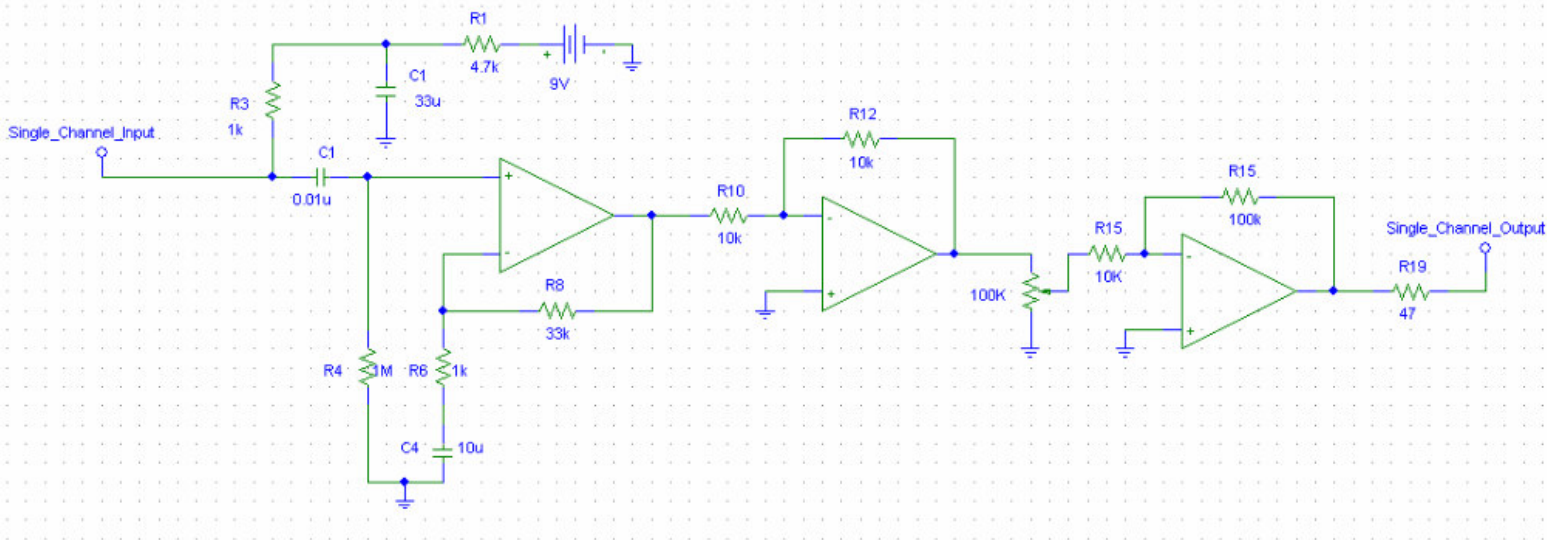
surroundings. Figure 8 displays a set of headphones similar to the actual headphones the team used in the design.



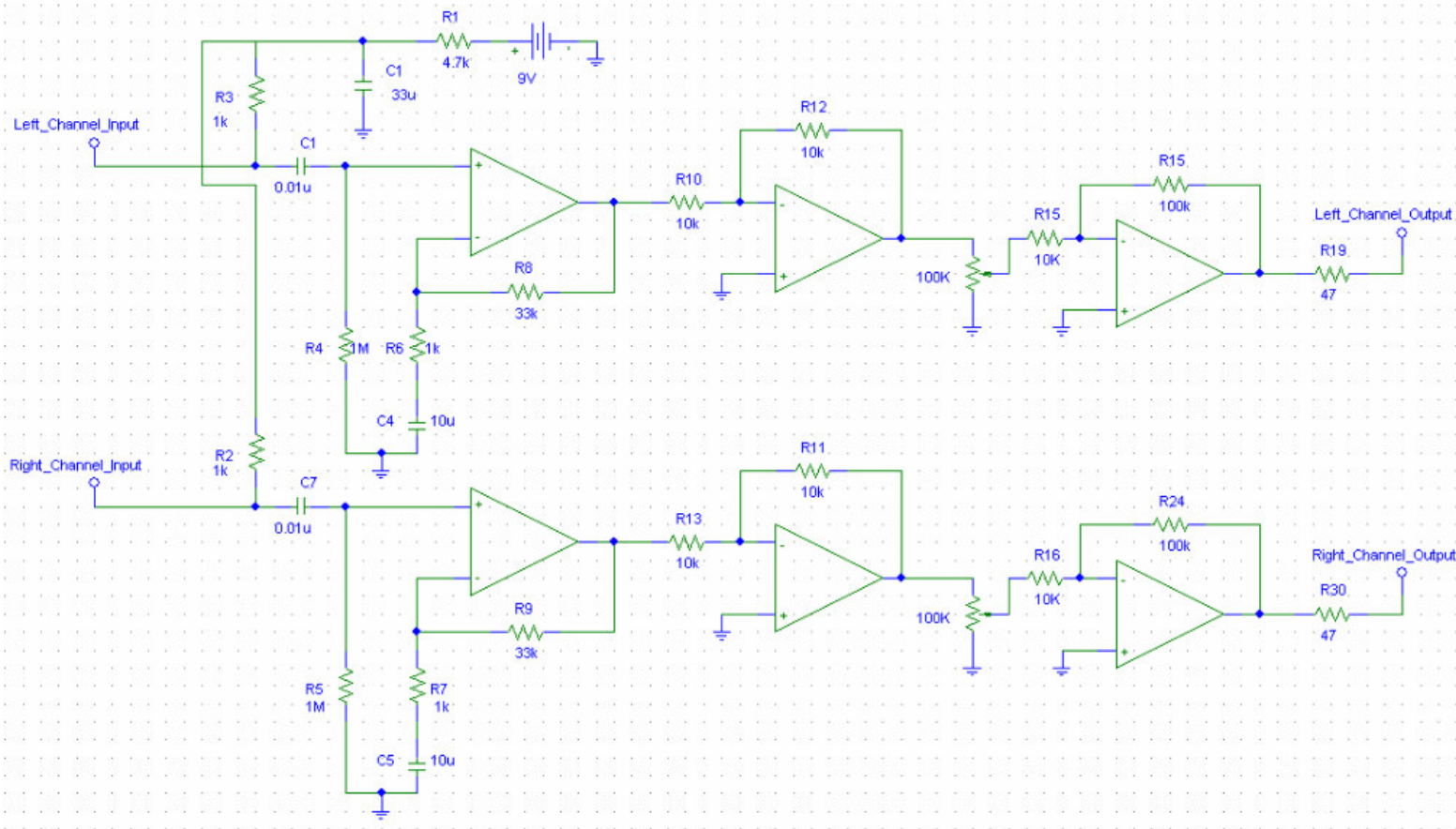
**Figure 8. Headphone Output**

### 2.3 Noise Cancellation Circuit Layout

The block diagram from Figure 2 is a simplified single-channel layout of the team's circuit. The final circuit layout composed of all the stages described above are shown below using PSPICE, with resistor and capacitor values, along with the microphone input and headphone output jacks. Figure 9 displays a single-channel, mono audio diagram. Figure 10 displays a dual channel-stereo audio diagram of our final circuit implementation.



**Figure 9. Single-Channel, Mono Audio**



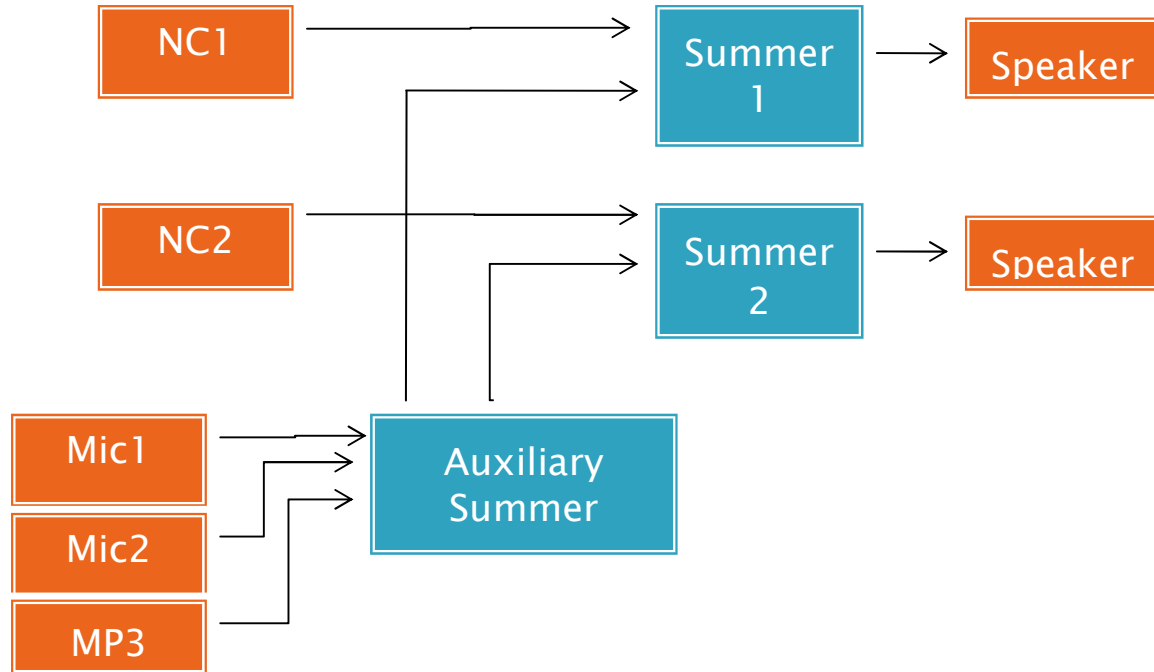
**Figure 10. Dual-Channel, Stereo Audio**

### 3 Communications System

This section will include the implementation of our communication system and an enhanced version of the team's noise reduction design (See Figure 2 block diagram). A variety of modifications were made for a more practical application and to design for a user-friendly system.

#### 3.1 Design

Our Communication System was designed as follows:



**Figure 11. Communication System Block Diagram**

Utilizing the noise cancellation circuit, we expanded our project into a communication system using additional audio operational amplifiers. By using our previous gain control stage as also a summer, we were able to add additional inputs to our system. A push button switch was placed before each auxiliary communication microphone for practical usage. An mp3 auxiliary port was also added for additional functionality.

## 6.2 Communication System Implementation

The implementation of Figure 11 above is shown below using PSPICE (Figure 12) and as a breadboard implementation (Picture 2).

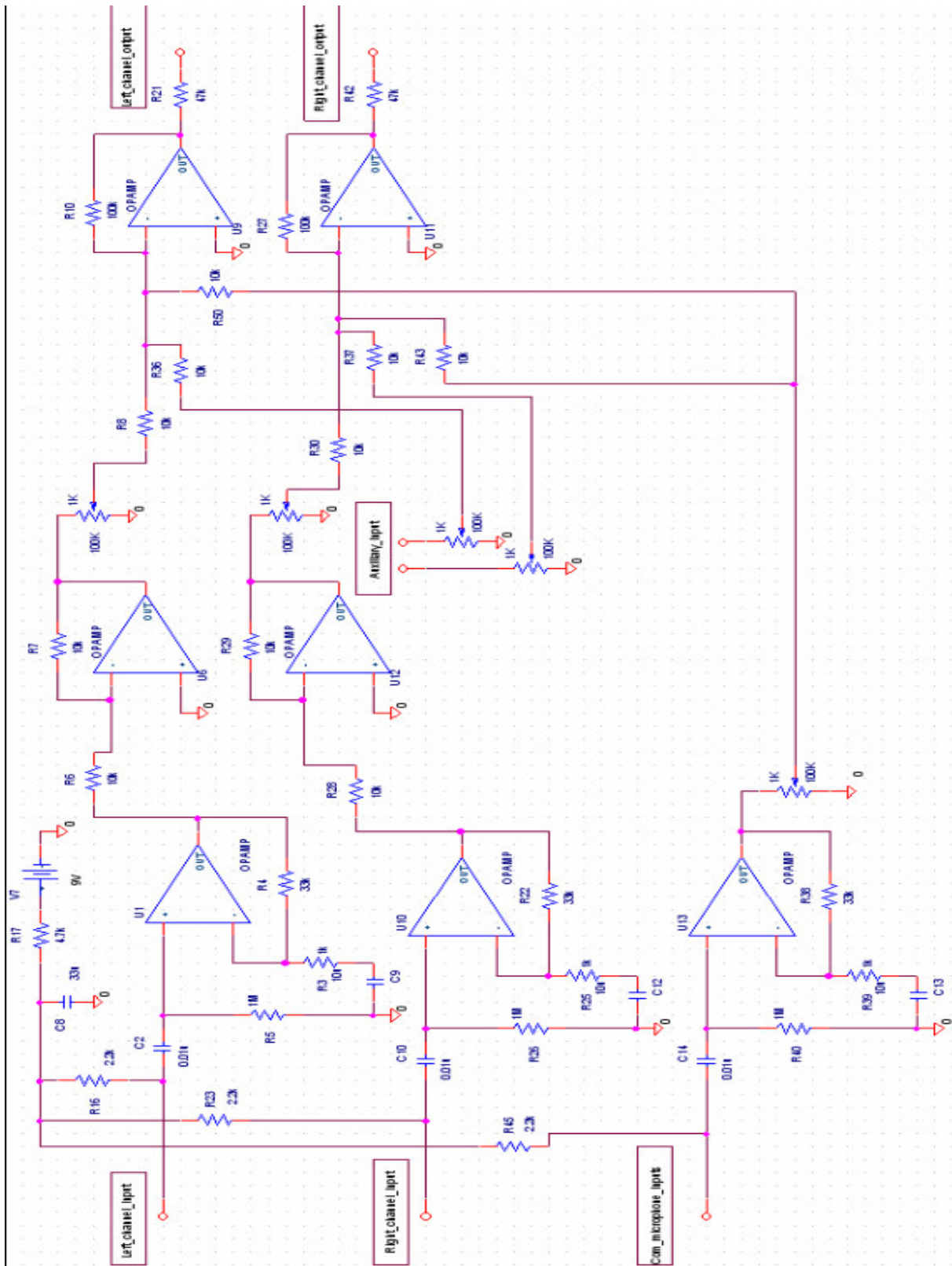


Figure 12. Communication system



**Picture 1. Communication System Breadboard Implementation**

### **6.3 Future Considerations**

The Noise-Cancellation aspect of our project works. In conjunction with passive earplug elements, the results are quite good. However, for communication in extremely loud environments to be truly effective, further research and additions must be made to the current project. Additions must also be made to make the product more useful and marketable.

Future additions to the Communication System would include:

1. Wind-Resistant Microphones – A pressure microphone, such as a throat-microphone could be utilized so ambient noises are not also picked up when using the communication feature. Further research into throat microphones is required before implementation.
2. Music Cut-Out – Currently, our auxiliary mp3 output remains on when the push-to-talk feature is engaged. This mixing of music and communication is not ideal. A music cut-out feature should be added to the circuit.
3. Automatic Gain Control – It may be advantageous to implement automatic gain control features to the circuit so the gain of the noise-cancellation circuit will automatically adjust to the ambient noise.
4. Wireless Communication – Implementing Wireless Communication between cell phones and other QuietCom units would be a required feature.

Finally, a digital implementation of our circuit might also be considered. As our project grows more complicated, a fast DSP may be used to create a more effective noise cancellation and also a more robust communication system.

### **3 Implementation Phase**

This section will describe our actual circuit implementation and the construction of our breadboard with all of the stages described in the block diagram of Figure 1.

#### **3.1 Considerations**

The team brainstormed on circuit implementation elements and came up with the following list of external and internal circuit elements:

- Dual-gang potentiometers for controlling stereo amplifier gain
- High dc voltage-gain, low-noise, NE5532 operational amplifiers
- Omni-directional condenser microphones
- Auxiliary Stereo Jacks
- Toggle Switches
- A set of EE 118 Breadboards
- Sound recorder, Tone Generator
- Several pairs of speakers and head phones
- Mp3 player

#### **3.2 Different Input/Output Device Attempts**

During testing of the noise cancellation stages, individual team members spoke into the microphone to produce a sound signal to the input of the circuit. Later the team searched for a tone generator on the internet where low and high frequency values were set and a constant tone could be tested.

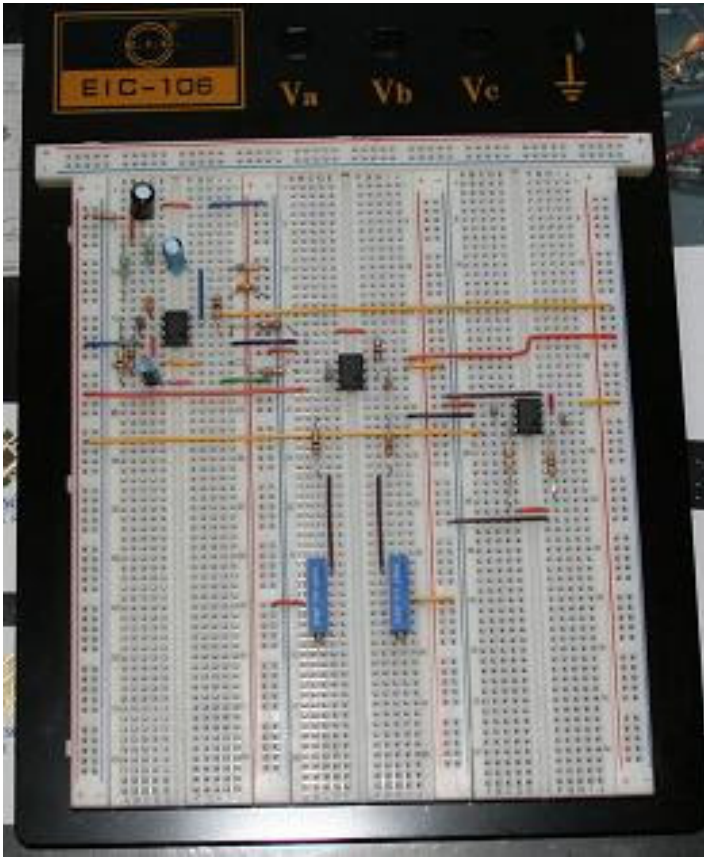
For the output sound wave, the team initially wired computer speakers to the output of the circuit so all the team members could attempt to hear the input noise inverted at the speaker output. From using low-quality computer speakers, the team noticed the fidelity of the sound being played back was of importance. Being in a small room where noise is constantly being reflected off the walls would also affect the results. Later the team decided to use headphones to minimize any external noise and so the focus on the input signal and the inverted signal could be analyzed more accurately.

In the end, the team decided to glue together a set of headphones and microphones. This is where our unity-gain inverting stage was most helpful. Depending on the distance of the microphone to the output, the phasing of signals was changed.

#### **3.3 Breadboard Implementation**

The team's breadboard implementation can be viewed in Picture 1 below. The breadboard was acquired from the team's past EE118 lab and the circuit elements are briefly described in section 3.1 above and in the following section.





**Picture 2. Breadboard Implementation of Noise Cancellation**

#### **4 Testing Phase**

There were two steps for the testing phase - testing under ideal conditions and actually real world noise reduction. The first stage of our testing was to use a function generator and an oscilloscope to check input and output parameters to ensure that the circuit truly inverted an audio input. The second stage was to hook up the circuit with microphones and speakers and use a tone generator to see if there was an actual reduction using human ears.

##### **4.1 Testing Requirements**

In order to properly test our circuit, we determined that we needed the following:

- Function Generator – used to generate a test signal
- Oscilloscope – used in conjunction with function generator to test circuit
- Digital Multimeter – indispensable troubleshooting tool
- Test Tone Generator – Test tone for real-time testing
- Microphone – used to make real-time measurements and analysis
- Recorder – used to record wind noise.
- Audio Spectrum Analyzer – Used in conjunction with microphone and recorder to make an analysis.

- Human listener

## 4.2 Noise Cancellation Lab Testing

In our initial testing, we had to verify that our circuit was finally working. In order to do this, we used a function generator and oscilloscope. By generating a waveform using the function generator, both the input and output can be monitored using an oscilloscope.

In Figure 13, we can see how the circuit responded to a 1kHz sinusoidal input (top) and the output (bottom).

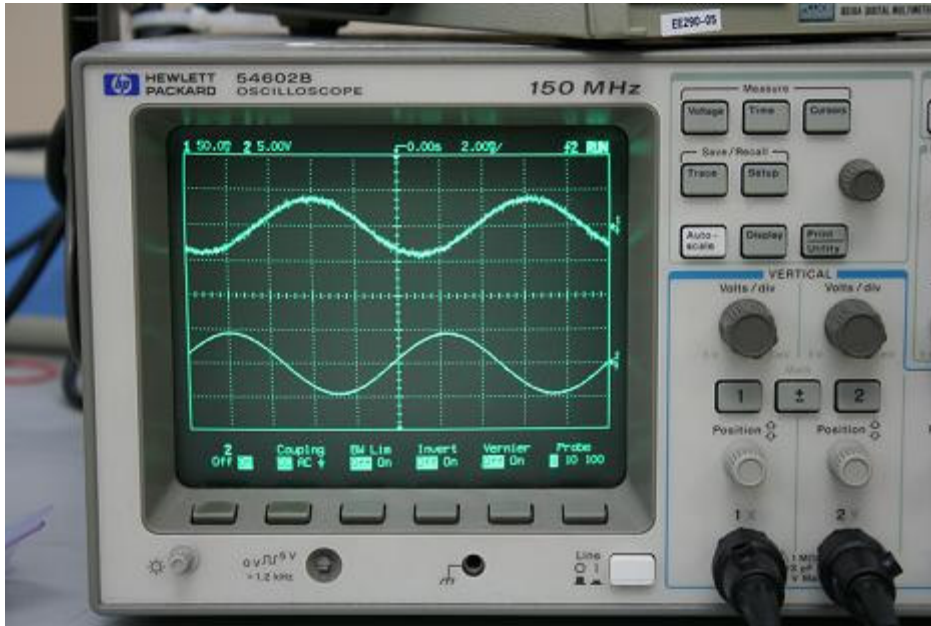


Figure 13. Noise Cancellation Oscilloscope Testing

What we found was that despite a little bit of noise, the signal was inverted pretty well. From this test, we could see that the circuit delay remained constant. It also affects high frequencies much more than low frequencies by changing the phase. At 1kHz, we can see that cancellation will result, but the phase is starting to move away from a perfect 180 degree inversion.

## 4.3 Real-Time Testing

When we were finally able to verify that the noise-cancellation portion of the circuit worked, we moved on to testing with a real audio input and output. Of course, in adding a microphone and speaker into our design, we were introducing quite a bit of delay to our system.

In the end, the team decided to glue together a set of headphones and microphones. But due to our increased delay and changed phasing, our unity-gain inverting stage was most helpful during this phase of testing. Depending on the distance of the microphone to the output, the phasing of signals was changed. We were able to find the configuration and



find the least amount of distance that we would need between the speaker and microphone.

By now, we were able to physically hear that our circuit worked. However, it was unclear exactly how much noise was being cancelled.

In order to get an idea of how well our system would cancel wind noise, we used a spectrum analyzer to find a few prevalent frequencies of our wind noise. By making a recording of freeway riding and analyzing it, we determined 300 and 600 Hz were appropriate testing frequencies.

In order to get an idea of how much noise was truly being cancelled we placed a small microphone in our ear in between our ear drum and speaker and took measurements at both 300Hz and 600Hz. We realize the most realistic method of measuring loss would be to use a simulated ear-drum, but we were not able to obtain one soon enough. Through our conservative measurements, we were able to determine that we obtained about a 9dB loss at 300Hz (Figure 14) and 6dB at 600Hz (Figure 15). At about 1.2kHz, it seems that our system delay is too great to result in any additional cancellation.

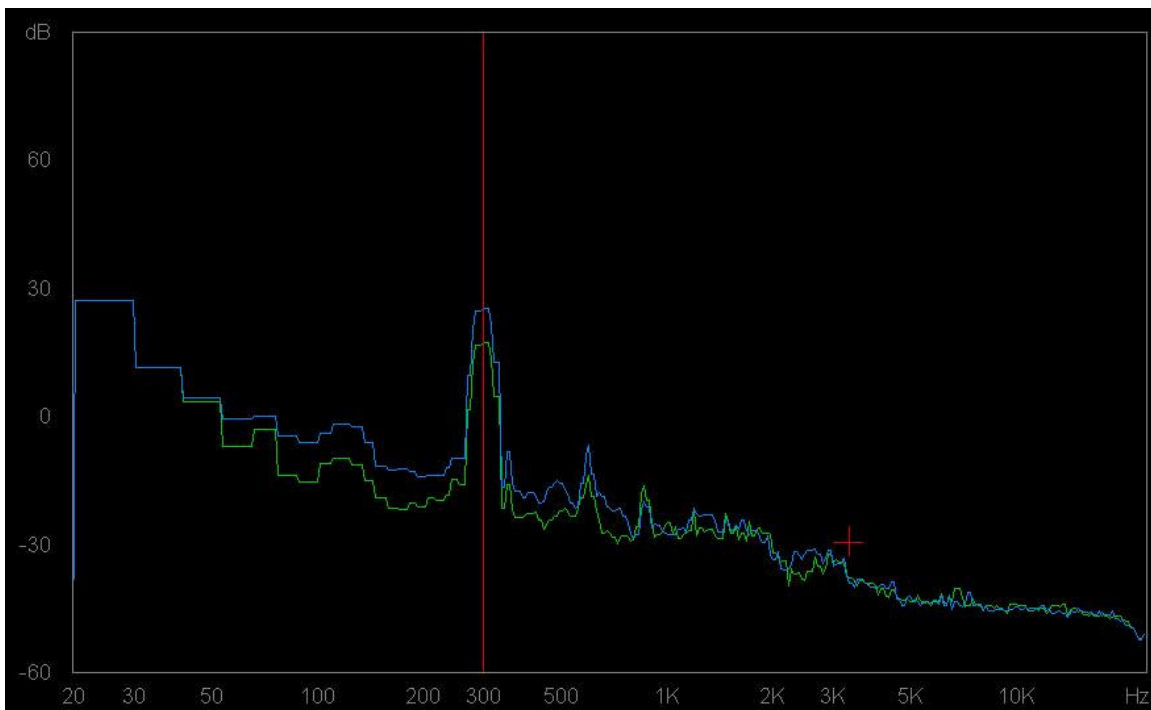


Figure 14 – 9dB Loss at 300Hz

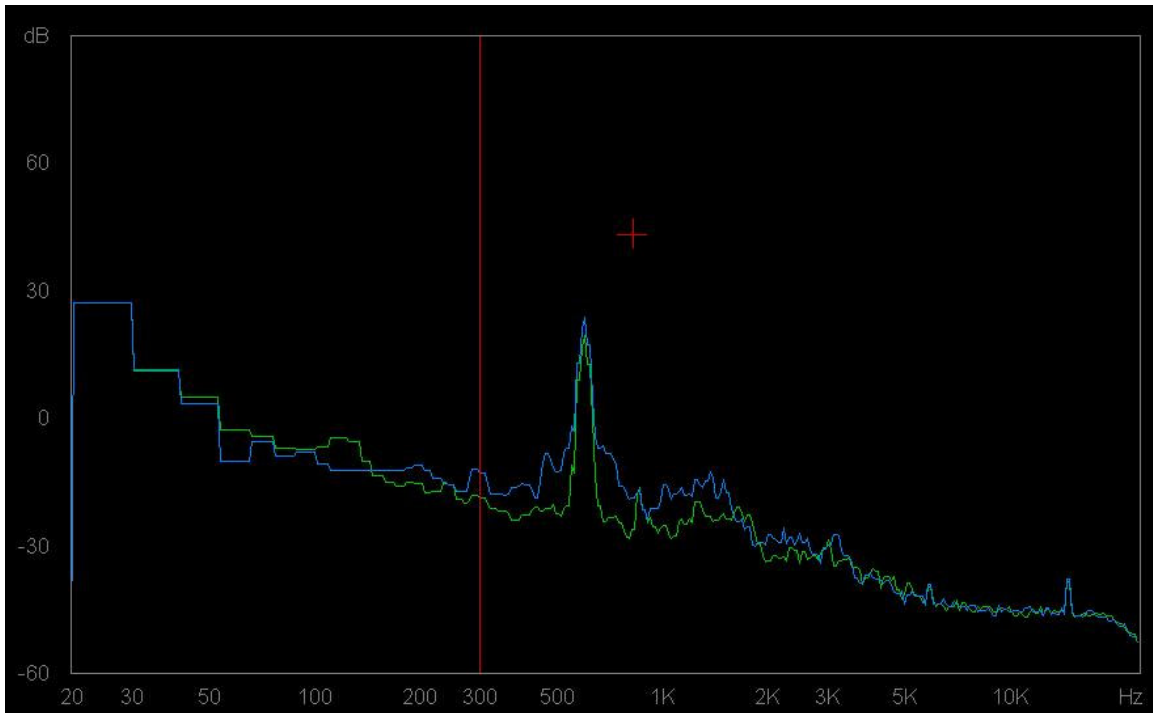


Figure 15 – 6dB Loss at 600Hz

## 5 Resources and Costs

This section will include the various resources used throughout the course of designing, implementing, testing, and making modifications to the team's noise reduction system. The resources section will include the equipment used to test the system. The costs section will illustrate the expenditures for all the parts used.

### 5.1 Resources

The team's senior project advisor was very helpful in keeping the team on track by asking for updates on the team's progress. Dr. Raymond Kwok took the time to approach the team and ask questions and for demonstrations throughout the semester. His advice was always helpful and intuitive to the project.

Two teammates from the team are motorcycle riders. They were able to provide some of the needed resources for testing the noise reduction system. This was a real practical application in testing out the circuit since the team's vision was to reduce high wind noise to motorcycle riders.

A valuable resource was the IEEE lab equipment where an oscilloscope, logic analyzer, probes, and a function generator were provided.

Below is a list of the resources used throughout the semester:

- Dr. Raymond Kwok
- Motorcycle Helmets

- Motorcycles
- IEEE Computers - Test Tone Generators
- IEEE Test labs (Oscilloscope, Logic Analyzer, Function Generator, Probes)
- PSPICE

## 5.2 Costs

The team was very fortunate in acquiring IEEE lab equipment to test the noise reduction system. However, many parts were purchased from a variety of stores including Radio Shack and Best Buy.

Table 1. below is composed of the implementation costs. This includes all of the circuit elements where the only item that was free was the breadboard. Everything else was purchased at a local store for the prices indicated in the table.

Table 2. below is composed of the external costs. The majority of these items were free since the resources were mostly owned or borrowed from the IEEE laboratory. The only external item purchased was the sound recorder which was quite expensive.

**Table 1. Implementation Costs**

<b>Materials</b>	<b>Unit cost</b>	<b>Units</b>	<b>Total cost</b>
<b>Resistors</b>	<b>\$13</b>	<b>20 (Pack of 500)</b>	<b>\$13</b>
<b>Capacitors</b>	<b>\$2</b>	<b>8</b>	<b>\$1</b>
<b>Headphones</b>	<b>\$20</b>	<b>1</b>	<b>\$20</b>
<b>Potentiometers</b>	<b>\$2</b>	<b>3</b>	<b>\$4</b>
<b>Auxiliary Connectors</b>	<b>\$3</b>	<b>3</b>	<b>\$9</b>
<b>Breadboard</b>	<b>Free</b>	<b>1</b>	<b>Free</b>
<b>NE5532 Op-amps</b>	<b>\$3</b>	<b>7</b>	<b>\$21</b>
<b>Toggle switches</b>	<b>\$2</b>	<b>4</b>	<b>\$9</b>
<b>Microphones</b>	<b>\$.50</b>	<b>4</b>	<b>\$2</b>
<b>TOTAL</b>	<b>\$45</b>	<b>50</b>	<b>\$90</b>

**Table 2. External Costs**

<b>Materials</b>	<b>Unit cost</b>	<b>Units</b>	<b>Total cost</b>
<b>Sound recorder</b>	<b>\$50</b>	<b>1</b>	<b>\$50</b>
<b>Motorcycle</b>	<b>Free</b>	<b>1</b>	<b>Free</b>
<b>Motorcycle Helmet</b>	<b>Free</b>	<b>1</b>	<b>Free</b>
<b>Computer</b>	<b>Free</b>	<b>1</b>	<b>Free</b>
<b>Oscilloscope</b>	<b>Free</b>	<b>1</b>	<b>Free</b>
<b>Power supply</b>	<b>Free</b>	<b>1</b>	<b>Free</b>
<b>Function generator</b>	<b>Free</b>	<b>1</b>	<b>Free</b>
<b>Soldering Equipment</b>	<b>Free</b>	<b>1</b>	<b>Free</b>
<b>TOTAL</b>	<b>\$50</b>	<b>8</b>	<b>\$50</b>

## **6 Conclusion**

The team was successful in completing the noise reduction communication system. Over the course of the semester, the team was able to design, implement, test, and make modifications to the circuit to meet the team's desired goals and accomplish a working product to present to our advisor and the senior project panel. In addition, the team was able to produce a low-cost, working product which was an achievable requirement from the beginning of the semester. The product was demonstrated to Dr. Raymond Kwok, the senior project panel including Professor David Parent.

The team's project works much better at low frequencies than high frequencies. As discussed in the testing section of this report, the team achieved -9dB at 300 Hz and -6dB at 600 Hz. In conjunction with passive earplugs, we obtain up to ~30dB of attenuation. The communication additions to the project also work. Utilizing a push-switch, a user can use the Push-to-talk function in order to hear and communicate with others more effectively.

The initial problem stated in the introduction section of this report will be reduced for motorcycle cycle riders, and possibly solved for communication operators, data center technicians, and construction workers. Our product will reduce wind noise levels and noisy uncomfortable environments for safe and comfortable operation.

This project has been a great learning experience for the entire team. Cohesive working and constant collaboration enabled this project to be a success. This project was a learning experience on many aspects. On the technical aspect, the team gained great experience in working with audio devices, noise controlling, reading schematics, and understanding analog circuitry. On the non-technical side, the team gained great

experience in terms of locating available resources on and off campus, time management, and project management.

## **7 Team Members**

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## **Appendix A – Device Specifications**

### **NE5532 Dual Operational Amplifier Specifications:**

Wide Supply Voltage Range:  $\pm 3\text{V}$  to  $\pm 20\text{V}$

High dc Voltage Gain:  $100\text{ V/mV}$

Unity-Gain Bandwidth:  $10\text{ MHz}$

Common-Mode Rejection Ratio:  $100\text{ dB}$

High Slew Rate:  $9\text{V}/\mu\text{s}$

Equivalent Input Noise Voltage:  $5\text{ nV}/\sqrt{\text{Hz}}$  Typ at  $1\text{ kHz}$

Peak-to-Peak Output Voltage Swing:  $32\text{V}$ , with  $V_{CC\pm} = \pm 18\text{V}$  and  $R_L = 600\Omega$

### **Microphone Electrical Characteristics:**

Supply Voltage: (V+)  $1.5$  to  $10\text{ VDC}$

Nominal Supply:  $4.5\text{ VDC}$

Current Drain:  $.5\text{ ma}$  (max.)

Signal/noise:  $40\text{Db}$  (min.)

Sensitivity:  $-65\text{dB}$   $\pm 4\text{dB}$

VCC:  $+4.5\text{ V}$ ,  $R_L: 1\text{K}\Omega$

Outer Dimensions:

Diameter:  $9.83\text{mm}$   $\pm .1$

Depth:  $7.00\text{ mm}$   $\pm .3$

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Headwize:

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Hearing Tests:

[Freehearingtest.com](http://Freehearingtest.com)