# Energy Efficiency & Audio Quality in Mobile Devices & Intercom Systems

## An Illinois Institute of Technology Interprofessional Project


**IPRO 344 Team, Fall 2009**
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Woochan Kim, Electrical Engineering
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**12/7/2009**

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## I. Executive Summary

IPRO 344 focuses on improving audio quality and energy efficiency for mobile devices and intercoms. An increasing demand for faster, more reliable commercial service is the current trend. On the other hand, customers' satisfaction is the most important factor for any business in the service industry. However, drive-thru systems do not provide high-quality service for customers. In fact, more than 50% of order accuracy problems occur at the point of communication in drive-thru systems, particularly, during order capture. It causes several negative effects, such as frustration at the repetition of an order, receiving incorrect items, and the wait associated with long lines.

This problem happens mainly because of the low sound quality of the communication system between customers and order takers. Recently, steps have been taken to alleviate order capture error. However, the addition of display screens at drive-thru kiosks does not solve the trouble with the clarity of the communication system. Many rounds of communication are still exchanged in correcting an order that is misheard. This problem lies fundamentally with the audio quality. If time can be saved and order capture error prevented, then the throughput of drive-thru businesses can increase as well as customer satisfaction, translating to greater market success.

With the efforts from previous semesters, we now have a prototype of our kiosk system build with energy efficient electronics and high quality audio. The focus of the IPRO 344 iFidelity team for the Fall 2009 semester is to gather and analyze data from our audio system and further refine and improve upon the hardware and procedures from the efforts of previous semesters. The team has set objectives of improving the audio performance of our kiosk, experimenting, testing and demonstrating the improvement empirically, establishing a frame of reference to compare our design to currently used intercom systems, and refining the kiosk circuitry and enclosure.

## II. Purpose & Objectives

The fast food industry is a 120-billion dollar commodity. McDonald's alone makes up 22.8 billion of this market. 60% of McDonald's business comes from drive-thrus, and annually there has been a 6-7% increase in drive-through business. Order capture in the drive-through systems experience an error of more than 50% and can lead to customer dissatisfaction and loss of business. In order to tap into the rising drive-through service market, our goal is to improve upon the process of intercom systems and solve these audio quality problems. However, there is a lack of standardized test data and a methodology for the evaluation of audio quality and performance in noisy environments.

In past semesters, Class D amplifiers have been found to be energy efficient and a viable component in two-way communication devices. The focus has shifted toward audio performance and the development of a kiosk. Pre-amplifiers for microphones and headsets were designed as well. This semester, our objective is to further improve the audio performance and the development of a kiosk and other components from previous years' work. The focus of the IPRO 344 iFidelity team for the Fall 2009 semester is to gather and analyze data from the audio system constructed from previous semester's endeavors and further refine and improve upon the hardware and procedures developed in previous semesters. The team has set objectives of improving the audio performance of our kiosk, experimenting, testing and demonstrating the improvement empirically, establishing a frame of reference to compare our design to currently used intercom systems, and refining the kiosk circuitry and enclosure. To increase our level of teamwork and efficiency, we have established different teams with their own underlying objective within the project. The team aims to offer the service of audio system analysis and an array of solutions in order to improve the performance of intercommunication devices.

## III. Organization & Approach

Research is conducted mostly on the internet by reviewing information relevant to the project. This includes reading on acoustic properties, the review of speech quality test standards, and the assessment of potential software that can be used for sound quality analysis in this project. This form of research method is chosen mainly because information on the internet is easily accessible, and the most updated information can be retrieved.

The efforts of the team were focused into multiple, overlapping subteams for meeting minutes, documentation, presentation, research, economics, purchasing, website, kiosk refinement, circuits & signal processing, tools & media, and project coordination. Through this division, each meeting would have well-documented minutes and any pressing project work would be discussed. Information would be disseminated by and recorded for each team and their findings each week, as the group progressed toward the semester's goal. Several additional working and testing sessions occurred outside of the designated classroom time as well. The Coordination subteam has generated a timeline which the group adhered to for the work done in the interprofessional project.


Figure 1—Division of Labor, IPRO 344 Subteams

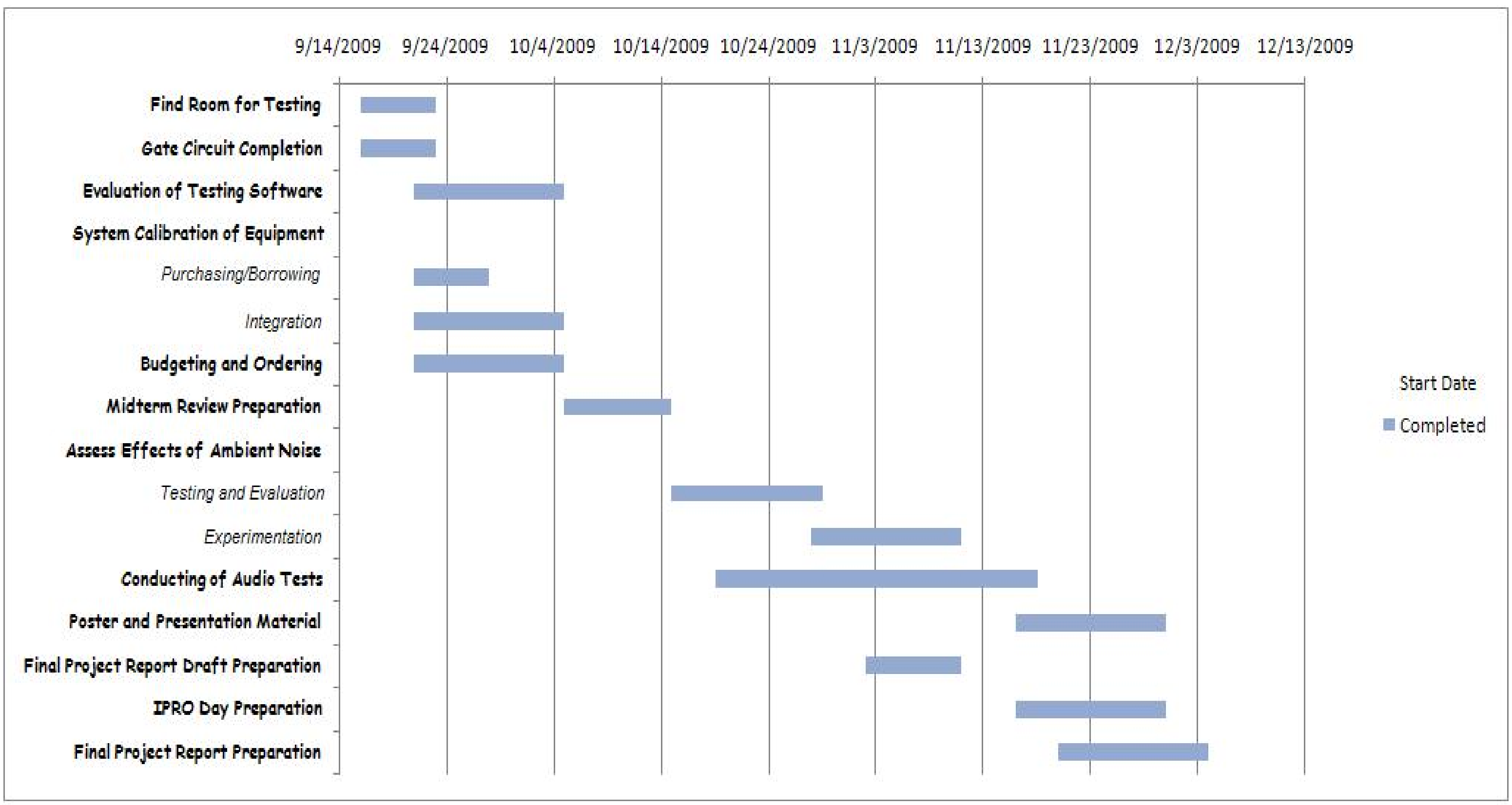



Figure 2—Project Coordination Timeline

## IV. Analysis & Findings

The high efficiency and audio quality intercom system is comprised of several physical parts. The client side module (CSM) is the kiosk enclosure which contains the microphone, pre-amplifier, class D amplifier, and loudspeaker. The server side module (SSM) contains a mixer, equalizer, and headset pre-amplifier within. The client priority gate (CPG) is a separate entity that is enclosed inside the SSM. The interconnection can be seen in the figure below.

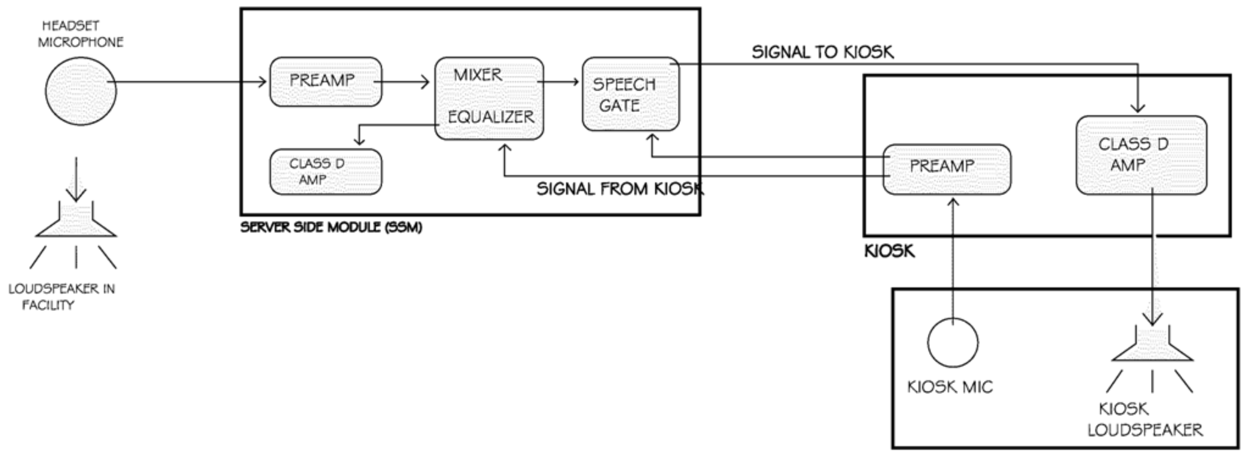



Figure 2—iFidelity System Block Diagram

### i. Research Team

The economics part of the research has focused on the importance of two-way communication systems at businesses that feature drive-thru components. Such businesses are dominated by fast food restaurants which represent one of the largest segments of the food industry with over 200,000 restaurants and $120B in sales in the U.S. alone. Fast food restaurants, also known as quick service restaurants (QSRs), are noted for their short food preparation time. Some of the largest players in this category include international giants like McDonald's and Yum!Brands, national chains such as Wendy's and Burger King and regional players like Jack In The Box and Sonic.

Although in 2008 the food industry has been hardly hit by the economic downturn, in 2009 the leading 10 fast food chains overall enjoyed their greatest collective sales gain since 1987. According to QSR magazine, the leading industry analyzer, the main factors responsible for the increase in revenue are low prices, menu innovation and quick service and increased accuracy of orders.

A recent report issued by QSR magazine states that McDonald's leads the industry with $30 B. At a typical McDonald's restaurant drive-thru sales account for more than 60 percent of the overall revenue and more than 80 percent of the lunch revenue. The report also points out to the importance of communication accuracy in the ordering process making it clear that saving a few seconds at the kiosk can significantly increase sales and customer satisfaction.

Compared to 2008 when all but seven chains had accuracy rates of 90 percent or better, this year's study found that 12 chains hit accuracy rates of 90 percent or higher. Chick-fil-A had the best communications, with 99.5 percent of interactions rated as "clear and understandable." White Castle's 2009 accomplishment of 97.6 percent would have been good enough for first place just about any other year but landed it in second this year. Rounding out the top five were McDonald's, Hardee's, and Rally's (the latter two tied). Overall the 2009 average was 93.6 percent clear communication compared to 91.5 percent in 2008.

As the traffic and business volume at quick service restaurants increases it becomes clear that in order to meet the demands of a highly lucrative trade there is room for improvement in the communications area. The key equipment component that facilitates the exchange of information between the customer and the sales person is the kiosk. Investigating the factors that alter the communication process and looking into ways to improve this process are the main purposes of the IPRO 344 project and we hope to develop a viable and affordable solution that will address this issue.

## ii. Tools and Media Team

The Tools & Media Team worked with the Research Team to research standards, evaluate software packages, and design tests to quantify the performance of our audio kiosk. A wide set of real life scenarios were introduced as a part of the test methodology. In addition to the special features of setup, relevant sound situations with variable frequency characteristics and noise levels were considered as factors to improving the data obtained from testing.

Significant progress has been made on the strategies and programs for executing tests on our Kiosk intercom system. Earlier in the semester, we decided to go back to using the Speech Transmission Index (STI) instead of the Speech Intelligibility Index (SII). This decision was made because STI is better suited for measuring actual response of an audio system, and SII is more intended for prediction and simulation of sound quality in an environment.

The previous software used - LexSTI - was difficult to set up in testing sessions because of difficulties with calibration. One of the goals of this semester was to produce a repeatable, rapid, and simple test procedure that could be applied to any intercom system to develop comparative performance metrics. Jeff Chiles developed a MATLAB script to automate the collection of acoustic data through the sound system. The test procedure was further quickened by the discovery that sound-pressure-level (SPL) calibration, which allows the computer to "know" how loud a sound coming into it really is, is not necessary to perform an accurate analysis of the STI. As such, the headphone-level sound output was taken directly from the kiosk into a high-quality sound card and recorded using the MATLAB script.

STI tests were conducted for a wide range of system configurations, including microphone types, microphone depths, and acoustic foam presence. In addition, the STI was analyzed while a strong source of ambient noise was present. The last series of STI tests were conducted with the intent to develop a visual map of the optimal speaking position for customers communicating in a drive-thru intercom system. The kiosk was moved in incremental distances and rotated in various angles to simulate a customer talking in from different positions, and the STI was recorded for each case.

Although the STI is an excellent measure for one aspect, the speech intelligibility, it does not assess nearly everything relevant to quality audio in a drive-thru environment. The Ambient Noise Acquisition and Analysis test (ANAA) was designed by the *Tools and Media Team* and the *Circuits and Signal Processing Team*. The purpose of ANAA is to examine the intensity of ambient noise in the drive-thru environment, and to discover means of minimizing it.

The test involved placing a source of ambient noise from an angle and some distance, and recording the total amount of sound energy delivered to the microphone over a 20-second interval. Lower relative sound energy indicates better minimization of ambient noise. Various sound clips were used with the intent of analyzing the effect of various types of sound, including street noise, rain, wind, and a diesel engine. Various system parameters were modified for tests, including the presence of acoustic foam, microphone type, and microphone depth in the sound chamber.

The interaction between our hardware and software packages can be seen in the figure below.

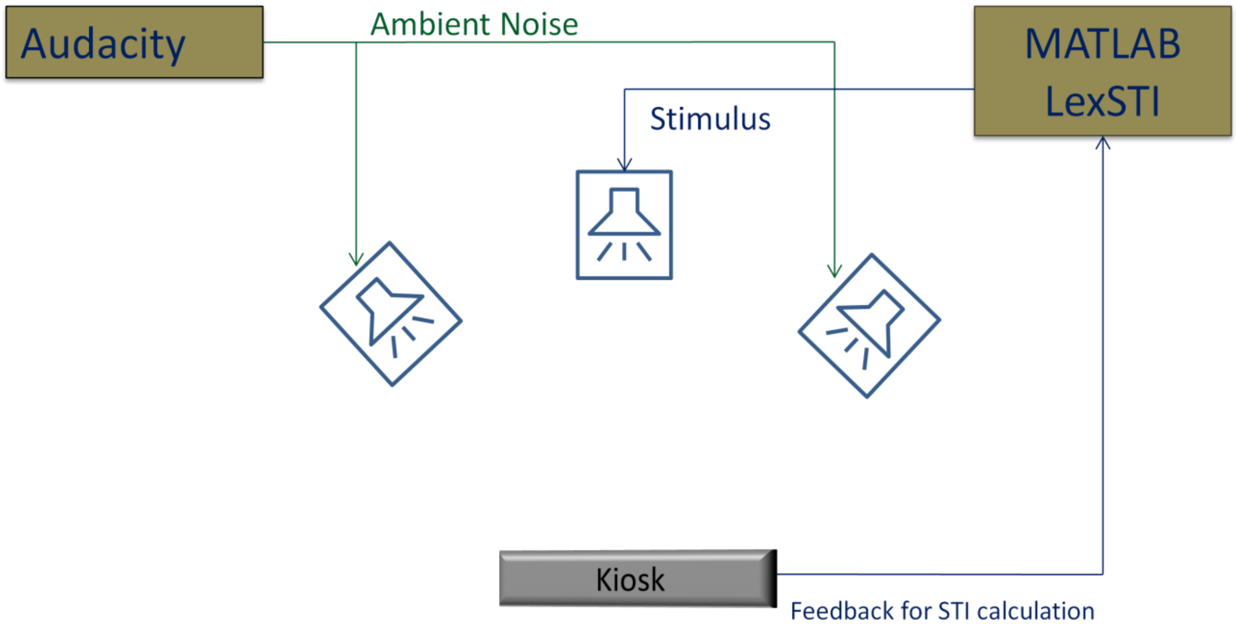


Figure 3—Overview of Test Configuration

### iii. Circuits and Signal Processing Team

The Circuits & Signal Processing Team worked to understand, improve upon and repackage the server side module and verify its operation when complete. The server side module (SSM) has been the major task at hand for this team. The SSM is a sound-processing device (about 1 square foot in size) that is placed inside the drive-thru building. The server can vary certain characteristics of the incoming sound by using this device. With little training, this can be used to effectively increase the quality of the customer's voice and improve intelligibility.

Although a working prototype was developed in the previous semester of this IPRO, the prototype had some functional deficiencies and was difficult to operate without instruction. As such, a focal point in the design of the new SSM was creating a user-friendly interface. The team made the decision to follow the conventions set by audio equipment with the placement of volume, gain, and frequency adjustment hardware. The new enclosure has been machined and populated with the devices, and each component has been interconnected and powered.

The SSM has the ability to mix in 4 channel inputs, adjust the gain and pan the directionality of each, and adjust the high, middle, and low frequencies for two output sources as well as the directionality there. Also within the SSM is the Client Priority Gate (CPG) which ensures proper etiquette between the client and server. Implemented on an

Arduino microcontroller, the algorithm mutes the server when the client is speaking. This feature can be bypassed if elected.

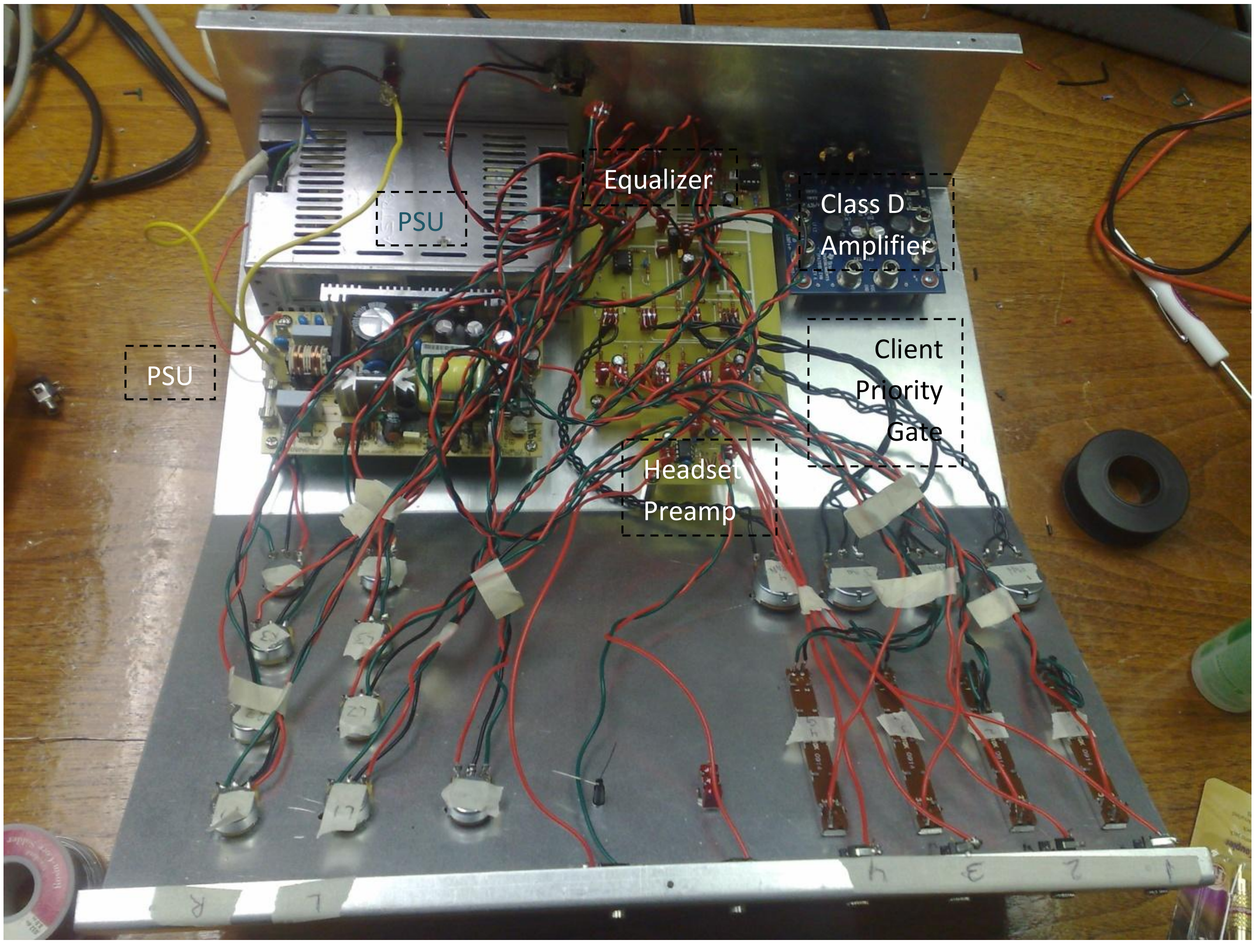



Figure 4—Internal View of Server Side Module

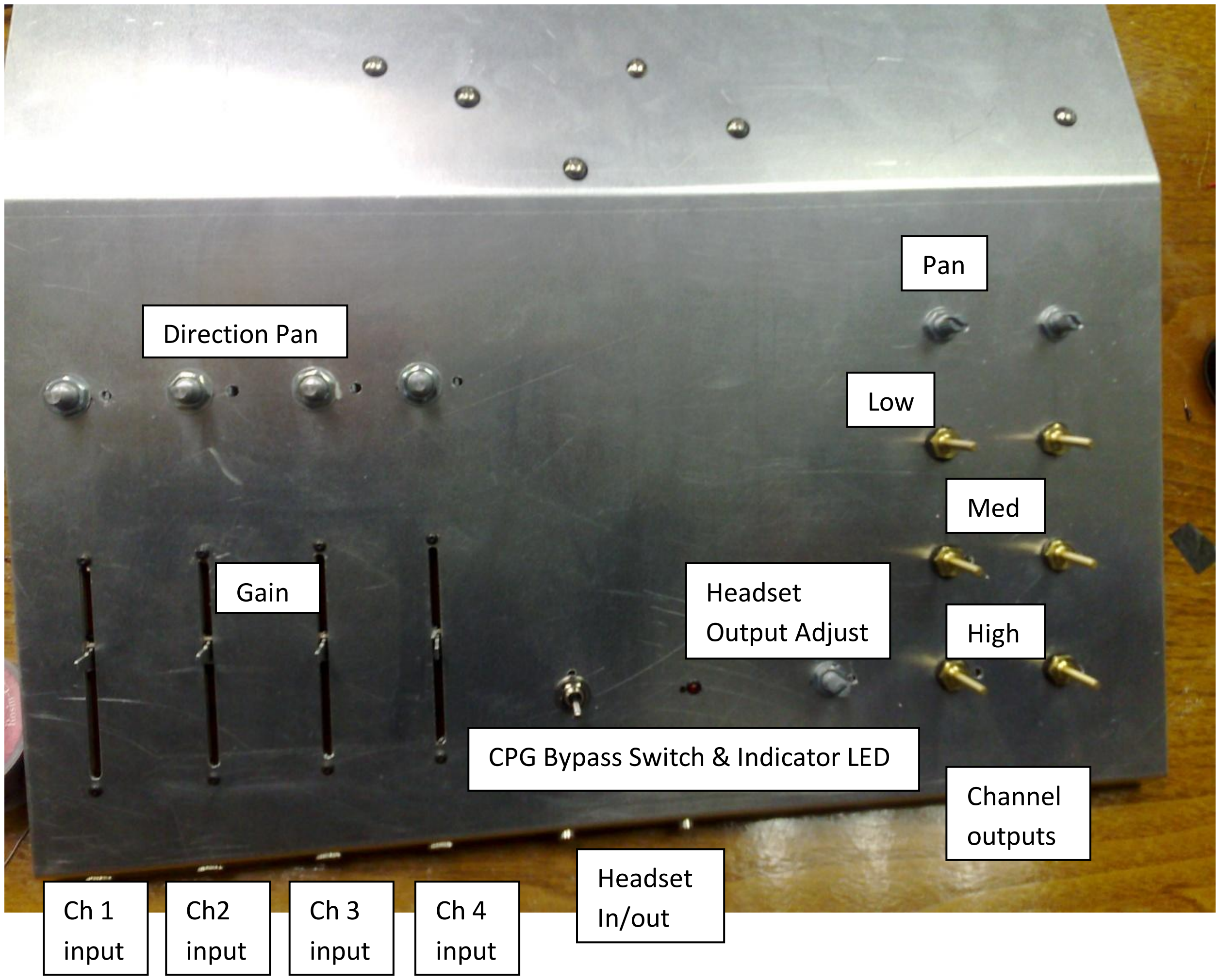



Figure 5—Front View of Server Side Module

## iv. Kiosk Team

One of the problems carried over from last semester was the difficulty in accessing the equipment within the kiosk. The main access consists of two sliding panels that stack on each other. These panels were made to fit within grooves along the backside of the kiosk. The panels however often became stuck within the grooves. Without any handle or even an appropriate makeshift grip, it was always a great task in opening the kiosk. The purpose of the kiosk team was to modify the existing kiosk for further accessibility to electronics inside while maintaining the integrity of the acoustically designed microphone chamber. Throughout the course of the semester, several improvements were made on the kiosk. The sliding back panels that act as the access point for the system inside were sanded along the edges. This alleviated the difficulty caused from how tight the panels fit into the grooves of the kiosk backing. Handles were affixed to the back panels of the kiosk which greatly reduced the amount of time and effort needed to remove the panels from the back of the kiosk. The client side module was affixed securely to the inner walls of its chamber inside the kiosk to ensure the safety of the equipment. Finally, the kiosk was repainted to increase its aesthetic appeal for the presentation.

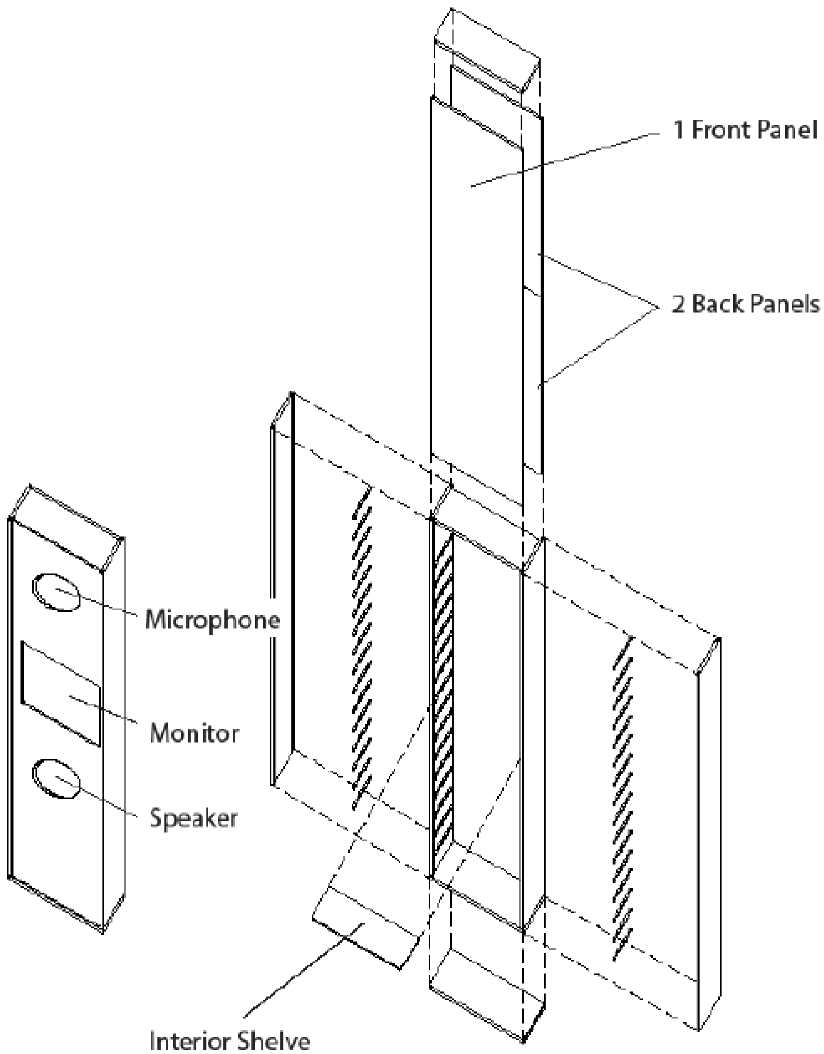
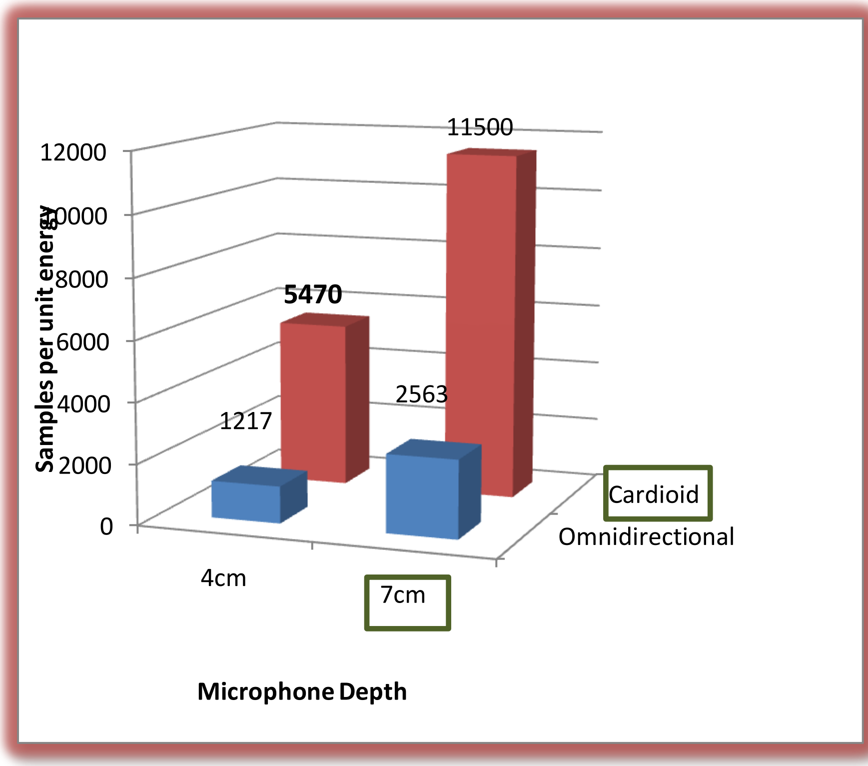


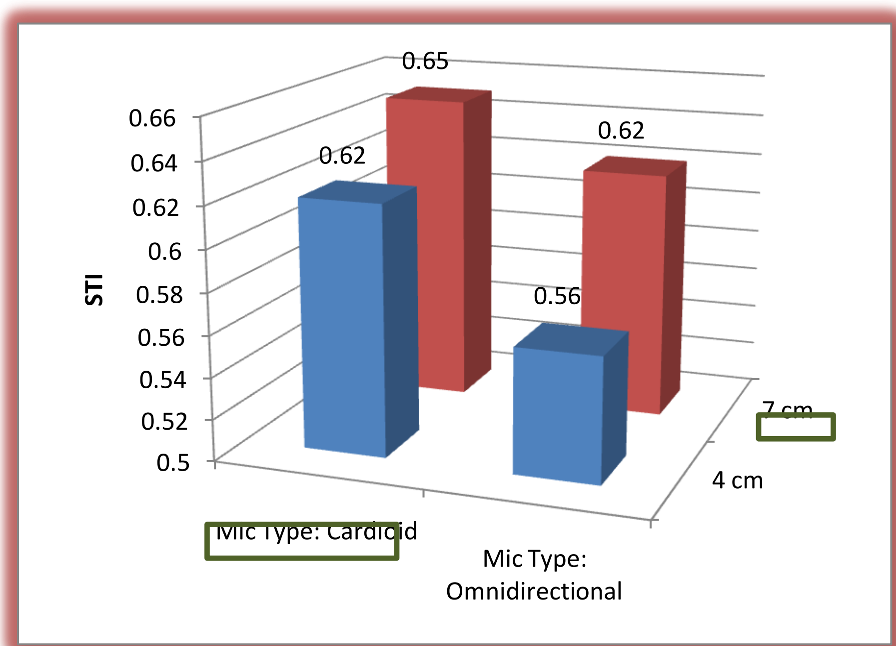

Figure 6—Client Side Module Compartments

## v. Test Results & Analysis

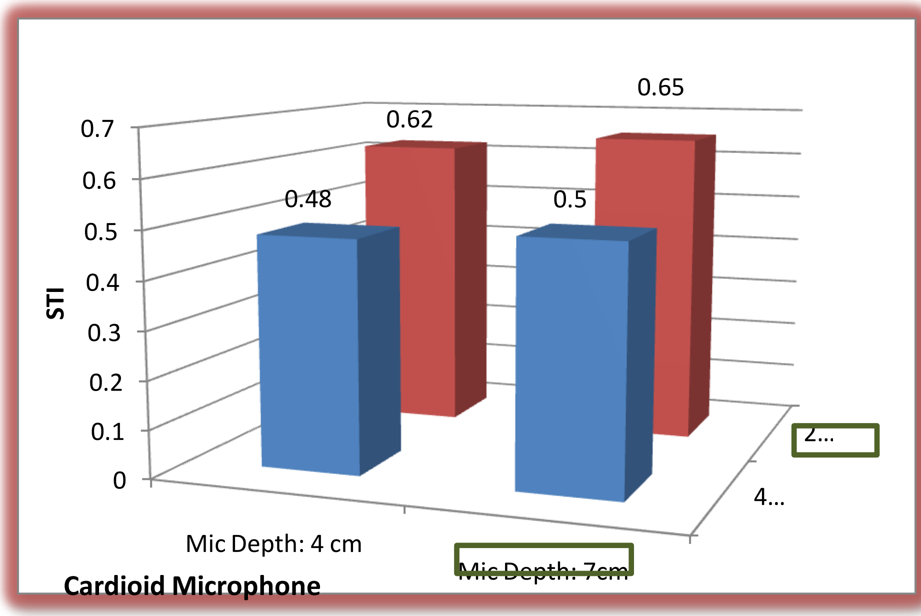
Our ambient noise, STI, and foam tests were performed in the testing environment. Conclusively, the optimal microphone depth was seen to be 7 cm, the optimal distance from the stimulus was 1 foot, and the best microphone directionality pattern to use was cardioid. Also, it was found that the presence of acoustic foam in the microphone chamber improves ambient noise rejection. In the ambient noise acquisition and analysis (ANAA) test, the system was subject to several different noise sources, including diesel engine, rain, wind, traffic, and human speech.




Graph 1—Ambient Noise Rejection vs. Microphone Type and Depth




Graph 2—Microphone Type and Depth vs STI




Graph 3—Relationship Between Distance from Stimulus Source and STI

## V. Conclusions & Recommendations

The IPRO 344 iFidelity team met its goals for the semester through the extensive testing conducted, reconstruction of the server side module, and preliminary evaluation of the economic feasibility of the project and components developed. International testing standards as well as our own designs were used to test the client side module's performance. Verification, reorganization, resoldering, and rewiring of the electronics in the server side module allowed for all inputs and outputs to be utilized. Through our analysis, we saw that cardioids microphone directionality performed better than omnidirectional microphones, achieving higher STI values. The optimal depth of the microphone in the chamber was found to be 7 cm, and the ideal distance from the microphone outside of the kiosk was 1 foot away. With our ambient noise analysis, we determined that the use of acoustic foam improves ambient noise rejection.

## VI. Acknowledgements

We would like to thank Shure, Inc for their support through the donation of high quality microphones for our audio system and Professor Muehleisen for the use of calibration microphones and SPL equipment.

# VII. Appendices

## i. Budget

### www.Mouser.com

| Index | Quantity | Part number | Description | Price (USD) | Ext. (USD) |
|---|---|---|---|---|---|
| 1 | 10 | 652-PTA6432015CPB103 | Slide Potentiometers 10K LINEAR | $1.76 | $17.60 |
| 2 | 10 | 450-3051 | Knobs & Dials SLIDE CONTROL BLACK | $0.33 | $3.30 |
| 3 | 5 | 696-SSI-LXH312ID | LED Panel Mount Indicators 3mm Red | $0.55 | $2.75 |
| 4 | 5 | 108-0001-EVX | Miniature Toggle Switches SPST OFF-ON | $1.70 | $8.50 |
| 5 | 3 | 571-1-390261-9 | IC Sockets 28P ECONOMY TIN SKT | $0.30 | $0.90 |
| 6 | 15 | 649-DILB8P223TLF | DIP Sockets 8P IC SOCKET | $0.12 | $1.80 |
| 7 | 2 | 571-2-1571552-3 | IC Sockets DIP .3CL 14P S&R OFRM AU/SN | $0.85 | $1.70 |
| 8 | 2 | 571-26416101 | IC Sockets 16C SOCKET | $0.46 | $0.92 |
| 9 | 5 | 539-CK05270K | Monolithic Ceramic Capacitors MONO CAP | $0.35 | $1.75 |
| 10 | 6 | 313-2441F-25K | 24mm Carbon Potentiometers Linear D-Shaft 25K | $1.40 | $8.40 |
| 11 | 10 | 660-MF1/4DC3302F | 1/4Watt Metal Film Resistors 33K 1% 100PPM | $0.06 | $0.60 |
| 12 | 100 | 71- | 1/4WATT Metal Film Resistors 1/4watt | $0.03 | $2.80 |

| | | | | | |
|---|---|---|---|---|---|
| | | CCF5510K0FKE36 | 10Kohms 1% Rated to 1/2watt | | |
| 13 | 10 | 660-MF1/4DC3301F | 1/4Watt Metal Film Resistors 3.3K 1% 100PPM | $0.06 | $0.60 |
| 14 | 10 | 660-MF1/4DCT52R1801F | 1/4Watt Metal Film Resistors 1/4W 1.8K ohm 1% | $0.05 | $0.50 |
| 15 | 10 | 660-MF1/4DCT52R2700F | 1/4Watt Metal Film Resistors 1/4W 270 ohm 1% | $0.05 | $0.50 |
| 16 | 10 | 81-RPE5C2A471J2P1A3B | Monolithic Radial Lead Capacitors 0.1LS 470pF 100volts 5% | $0.18 | $1.80 |
| 17 | 10 | 81-RPEE42472M2P1B03B | Monolithic Radial Lead Capacitors 4700pF 100volts Z5U 20% 2.5mm L/S | $0.26 | $2.60 |
| 18 | 3 | 581-SR595C223KARTR2 | Radial Monolithic Capacitors 50volts 0.022uF 10% X7R | $0.28 | $0.84 |
| 19 | 5 | 75-1C25Z5U223M050B | Monolythic Ceramic Radial Capacitors 0.022uF 50volts Z5U 20% 6.4mm L/S | $0.17 | $0.85 |
| 20 | 5 | 581-SR205C473KAR | Radial Monolithic Capacitors 50volts 0.047uF 10% X7R | $0.28 | $1.40 |
| 21 | 3 | 581-AR155C102K4R | Automotive Radial Monolithic Capacitors 50volts 1000pF 10% X7R | $0.22 | $0.66 |
| 22 | 10 | 81-RPE5C1H220J2P1Z03 | Monolithic Radial Lead Capacitors 22pF 50volts C0G 5% 2.5mm L/S | $0.18 | $1.80 |
| **Total** | | | | | $62.57 |

**www.Digikey.com**

| Index | Quantity | Part Number | Description | Unit Price USD | Extended Price USD |
|---|---|---|---|---|---|
| 1 | 10 | 1N752A-ND | DIODE ZENER 5.6V 500MW 5% DO-35 | 0.059 | $0.59 |
| 2 | 8 | LM837N-ND | IC OP AMP QUAD LOW NOISE 14-DIP | 1.71 | $13.68 |
| 3 | 3 | ATMEGA168-20PU-ND | IC AVR MCU 16K 20MHZ 28DIP | 4.11 | $12.33 |
| 4 | 10 | P3471-ND | .00047 UFD POLYPROPYLENE CAP | 0.199 | $1.99 |
| 5 | 10 | P4725-ND | CAP .1UF 100V STACK METAL FILM | 0.125 | $1.25 |
| 6 | 10 | P833-ND | 100UF 16V MINI ALUM ELECT (KA) | 0.102 | $1.02 |
| 7 | 10 | P807-ND | 10UF 16V MINI ALUM ELECT (KA) | 0.091 | $0.91 |
| 8 | 4 | P3102-ND | .001 UFD POLYPROPYLENE CAP | 0.46 | $1.84 |
| 9 | 10 | P3271-ND | .00027 UFD POLYPROPYLENE CAP | 0.199 | $1.99 |
| 10 | 10 | P4556-ND | CAP .0027UF 50V POLYESTER | 0.072 | $0.72 |
| 11 | 5 | P3821-ND | .00082 UFD POLYPROPYLENE CAP | 0.23 | $1.15 |
| 12 | 10 | P4719-ND | CAP.033UF 100V STACK METAL FILM | 0.151 | $1.51 |
| 13 | 10 | P4713-ND | CAP .01UF 100V STACK METAL FILM | 0.128 | $1.28 |
| 14 | 10 | P4518-ND | CAP .027UF 50V STACK METAL FILM | 0.128 | $1.28 |
| 15 | 10 | P4731-ND | CAP .33UF 100V STACK METAL FILM | 0.179 | $1.79 |
| 16 | 3 | P3822-ND | .0082 UFD POLYPROPYLENE CAP | 0.49 | $1.47 |
| 17 | 10 | 1.0KH-ND | RES 1.0K OHM 1/2W 5% CARBON FILM | 0.058 | $0.58 |

| | | | | | |
|---|---|---|---|---|---|
| 18 | 4 | CD4066BCN-ND | IC SWITCH BILATERAL QUAD 14-DIP | 0.45 | $1.80 |
| 19 | 15 | A31120-ND | CONN RECEPT 2POS 22AWG MTA100 | 0.22 | $3.30 |
| 20 | 15 | A1911-ND | CONN HEADER VERT 2POS .100 TIN | 0.21 | $3.15 |
| 21 | 20 | A31089-ND | CONN RECEPT 3POS 22AWG MTA100 | 0.22 | $4.40 |
| 22 | 20 | A31113-ND | CONN HEADER VERT 3POS .100 TIN | 0.22 | $4.40 |
| 23 | 3 | P3C3103-ND | POT 10K OHM 9MM VERT NO BUSHING | 0.99 | $2.97 |
| 24 | 4 | CT2243-ND | POT 500K OHM 1/4W CARB AUD TPR | 2.77 | $11.08 |
| 25 | 5 | CT2241-ND | POT 100K OHM 1/4W CARB AUD TPR | 2.77 | $13.85 |
| 26 | 1 | L131-ND | CONSOLE ALUMINUM: 15"X15"X4.5" | 66.99 | $66.99 |
| 27 | 4 | X056-ND | CRYSTAL 8.000 MHZ SER 49UA | 0.4 | $1.60 |
| 28 | 4 | X077-ND | CRYSTAL 16.000 MHZ SER 49UA | 0.4 | $1.60 |
| 29 | 4 | LM7805CT-ND | IC REG 1A POS 5V TO-220 | 0.45 | $1.80 |
| 30 | 10 | P5165-ND | CAP 100UF 35V ALUM LYTIC RADIAL | 0.102 | $1.02 |
| 31 | 10 | LM833NGOS-ND | IC OPAMP AUDIO DUAL LN 8-DIP | 0.63 | $6.30 |
| | | | **Total Cost:** | | **$169.64** |

www.Amazon.com

| Index | Quantity | Part number | Description | Price (USD) | Ext. (USD) |
|---|---|---|---|---|---|
| 1 | 1 | EMU 0202 | USB 2.0 Audio Interface | 96.59 | $96.59 |
| 2 | 1 | ------------------ ------------------ | XLR male to XLR female Microphone Cable - 15 feet | 5.46 | $5.46 |
| 3 | 1 | ------------------ ------------------ | Belkin 36-Piece Demagnatized Computer Tool Kit with Case (Black) | 29.23 | $29.23 |
| Total | | | | | $131.28 |

www.Astrodyne.com

| **Index** | **Quantity** | **Part Number** | **Description** | **Unit Price USD** | **Ext Price USD** |
|---|---|---|---|---|---|
| 1 | 1 | PT-45C | Power Supply | 40.00 | $ 40.00 |
| **Total** | | | | | **$40.00** |

## ii. Team Roster

| Name | Major, Year | Skills and Strength | Experience and Academic Interest | Team Responsible | Other Team involvements |
|---|---|---|---|---|---|
| Jeffrey Taylor Chiles | Electrical and Computer Engineering, 3rd Year | Enclosure design and assembly, microcontrollers, C/C++, Assembly, optoelectronics, test equipment design, testing software development, soldering, PCB layout<br><br>Strengths: Design, troubleshooting, system integration | Considerable experience in electronic assembly and design<br><br>Academic Interest: Electronic Warfare (RF, EMP), optoelectronics, microcontrollers | Project Coordination, | Implementation - Circuits/Signal Processing |
| Roozbeh Shegarfi | Electrical Engineering, 4th Year | Psim, C++, Auto Cad, Soldering, Pspice, troubleshooting, power supplies, | Power Electronics, motor drives, electronics and signal processing | Purchasing team | Documentation,<br><br>Implementation |
| Iat Ieong | Electrical and Computer Engineering, 3rd year | Programming(Java and C), PSpice, soldering | Electronics, signal processing, wireless communication | None | Tools and Media, Research |
| Teague S. Algie | Computer Science, 3rd year | Programming, hobbyist electronics knowledge | Hobbyist electronics knowledge and desire to learn more | Web Team | None |
| Woochan Kim | Electrical Engineering, 4th year | PSpice, MATLAB_Simulink, 3d Max, MS Offices, JAVA, C++. | IIT Hybrid Formula Team (working in motor drive team), interest in the power electronics and signal processing | Tools & Media | Purchasing |
| Changhan Jun | Mechanical engineering, 3rd year | made by hand / some works of mechanical field(about major | Interested in audio systems | None | Purchasing, Poster |

| | | | | | |
|---|---|---|---|---|---|
| Nathan Miller | Architectural Engineering, 3rd year | AutoCAD<br><br>Micro station | Engineering Intern, two summers. Interest in building systems, acoustics, lighting, etc. | Research | Project Coordination |
| Harry Lee | Electrical Engineering, 4th year | Basic circuit analysis, familiar with software such as MatLab and PSpice | Took IPRO-344 during Fall of '08, Interested in sound electronics | None | Documentation, Poster |
| Calin Gavris | Computer Science, 4th year | Programming: C, Java, SQL | Experience with audio systems and high noise environments | Economics | Web |
| Anthony Bartolomei | Mechanical and Aerospace Engineering, 4th year | Matlab, Autodesk Inventor, ProE Wildfire | xing old analog circuit radios as well as working with mixers | Poster | Project Coordination, Economics |
| Joy Bian | Electrical and Computer Engineering, 4th year | Programming (C/C++, Java), MATLAB, VHDL, Assembly, soldering, circuit analysis | Electronic circuits, signal processing | Documentation | Tools & Media |

## iii. Raw Test Data

See attached document for the raw test data collected this semester.