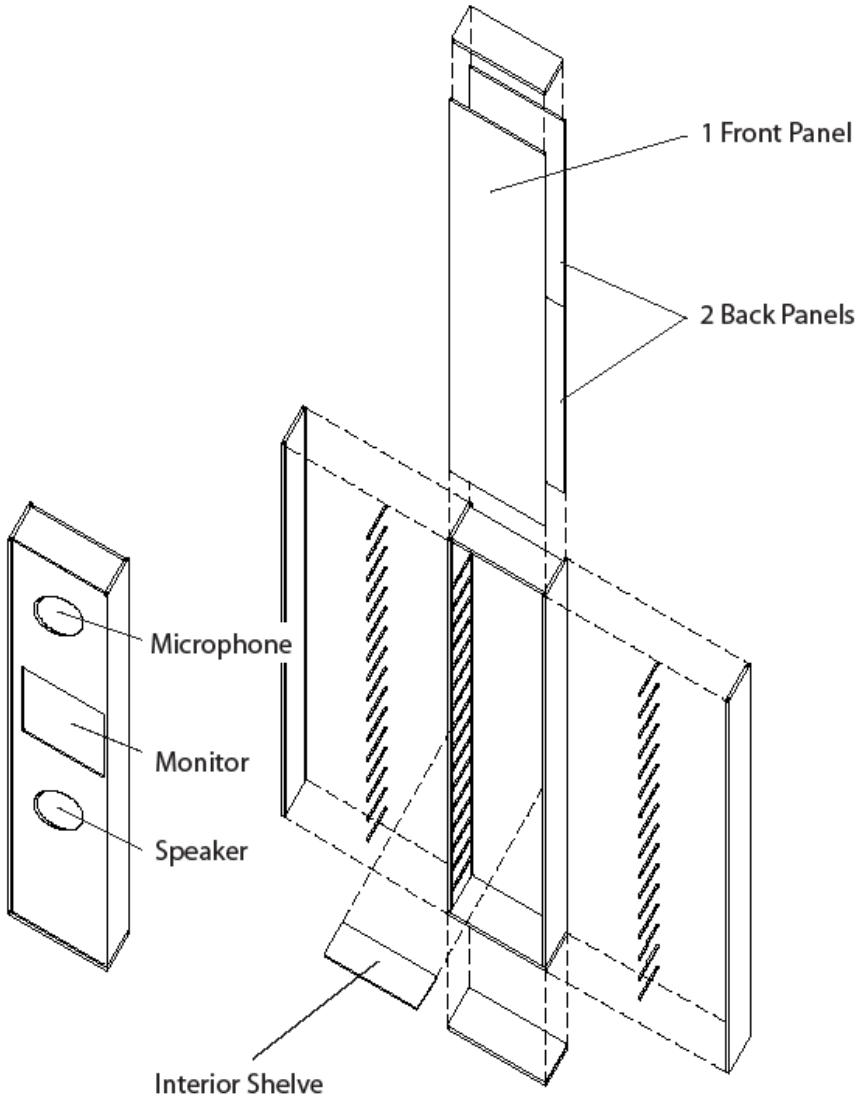
IPRO 344: Improving Audio Quality and Energy Efficiency in Mobile Devices and Intercom Systems.

Instructor: Dr. Thomas Wong

Teaching Assistant: Tao Shen

Sponsor: **Shure Inc.**



I. Team Charter

1. Team Information

A. Roster:

	Name	Contact
Instructor	Thomas Wong	wong@iit.edu
Teaching Assistant	Tao Shen	tshen1@iit.edu
Team Members	Teague Algie	talgie@iit.edu
	Anthony Bartolomei	abartolo@iit.edu
	Joy Bian	jbian1@iit.edu
	Jeffrey Chiles	jchiles@iit.edu
	Calin Gavris	cgavris@iit.edu
	Iat Ieong	iieong@iit.edu
	Chang Han Jun	cjun1@iit.edu
	Woochan Kim	wkim12@iit.edu
	Harry Lee	hlee66@iit.edu
	Nathan Miller	nmiller5@iit.edu
	Roozbeh Shegarfi	rshegarf@iit.edu

B. Team member strengths, needs and expectations

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	Considerable experience in electronic assembly and design 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, 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 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

C. Team identity

- IPRO 344 is the iFidelity team, in pursuit of aural improvement for the drive-through experience.

2. Team Purpose and Objectives

A. 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 developed in previous semesters.

B. 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.

3. Background

A. *Sponsor involved*: Shure Inc. is an audio electronics corporation known for their microphones, in-ear monitors and other audio electronics. Their donation of a high-quality microphone for use in our kiosk has allowed us to reliably capture our audio data.

B. *Information about the user problems that the project is facing*: Within intercom systems, a frame of reference or established system does not exist to evaluate the quality of communication. This has been an issue from previous semesters that we have decided to address by gathering sufficient data to support our implementation of an improved drive-through kiosk and experience. Ambient noise interference is an impediment to the clarity of transmissions in mobile devices and intercom systems as well that can be addressed using filters, equalization or other forms of noise cancellation.

C. *Information about technology/science (potentially) involved in addressing the problems*: Class D amplifiers have been used in our design as a highly power efficient component in the microphone amplifier in our kiosk. Instead of active resistance in low efficiency amplifiers, the switching mode of transistors regulate the power delivery so that energy loss is minimized. Sound quality can be measured by how accurate a device transmits a signal compared to the original sound. In mobile devices and intercom systems, the analog source signal is converted to a digital signal, transmitted to an output device, and the digital signal is converted back to an analog signal that the user hears. In these conversions, data can be lost and the original signal can become inaccurately reproduced.

Undesired ambient noise can also interfere with the relevant sound, making speech unintelligible and interactions unpleasant. Noise control or cancellation for acoustical noise is the practice of reducing or eliminating unwanted sound. There are two types: active and passive where the method of blocking waves differ. Passive noise control is typically accomplished with the use of materials to insulate, absorb, dampen, or isolate the sound. Active noise control makes

use of the wave property of sound, interference, to cancel the undesired portion of sound. Modern technology allows a waveform to be analyzed for background noise. A signal is generated, and destructive interference reduces the perception of unwanted sound.

Technological advancements allow for noise to be blocked selectively as well. Multiple Stimuli with Hidden Reference and Anchor (MUSHRA) is a testing method for subjective evaluation of the perceived quality of audio. With the use of paired tests, a designated reference sample, and several test samples, it takes fewer subjects to obtain statistically relevant results. MUSHRAM is a MATLAB interface for the listening tests that we hope to incorporate in quantifying the human perception of improvement with our design.

D. *Information on the historical success/failure of previous attempts in addressing the problem*: Previous semesters efforts successfully focused on the implementation of the amplifier, construction and refinement of a client side and server side module as an intercom device. Last semester, the IPRO 344 team delved into gathering quantitative and qualitative data from the prototypes. However, there was not enough time to perform testing. We feel that this is an important focus for this semester. Without a frame of reference for the problem, it was difficult to decide how to approach the problem because there was no comparison to how other groups were operating. A previous sponsor, McDonald's, was interested in our findings but was unwilling to provide information about their drive-through intercom devices.

E. *Ethical issues*: IPRO 344 holds each team member to the highest of ethical standards, academic and societal. There will be fair distribution of work in our semester's effort. We will all ensure that each member's abilities are utilized, and no one person is responsible for a disproportionate amount of work. Conversely, no one will be excluded from the project.

We also hold an environmental responsibility to keep the components used ROHS certified and to install environmentally sound and power efficient equipment. We will adhere to copyright and confidentiality matters when testing intercoms and other proprietary equipment. All research sources must be documented and cited, and credit given to sponsors for their support.

F. *Information about the business/societal costs of the problem*: We will formulate an answer to the question of whether the project is worth creating, if it is needed, potentially profitable, and whether a new methodology is imperative. Our efforts will provide a better drive-through consumer experience. Poor order capture and intelligibility has a business and societal cost which can lead to loss of business and customer dissatisfaction toward businesses and drive-through experiences in general.

G. *Implementation details on any practical solutions developed by the project team*: We would like to market our generated testing process, analyze the effect of ambient noise such as diesel engines on the audio quality of communication and the effects of filters, equalization, and noise cancellation in our system. To develop a baseline of information and begin a frame of reference, our proposed solution is to open channels of communication to another fast food restaurant.

H. *Research about similar solutions*: To our knowledge there is no similar solution in existence. A related technology, MUSHRA, is a unified testing method can be of use as a

component of our methodology. As noted earlier, it may be difficult to obtain information from sources about the quality of existing systems due to copyright issues.

I. No attachments.

4. Team Values Statement

A. *List of desired behaviors*: The IPRO 344 team expects all members to arrive to class on time, communicate about time and obligational conflicts in advance, be responsible and accountable for tasks during the semester, ensure a fair distribution of work, and stay on track toward our established goals for the project.

B. *How problems will be addressed*: We will address problems in person as they arise, if needed. Dr. Wong is available as an arbitrator of confidential and private matters. Team members can also bring up problems to the team during our regularly scheduled meetings or call additional meetings as needed.

II. Project Methodology

1. Work Breakdown Structure

A. Problems

Lack of Data

There is currently insufficient data to convincingly demonstrate which major system features are desirable in intercom systems. In order to achieve more certainty, more accessible computer software must be selected. Currently, we are considering interfaces such as MUSHRAM and software such as MATLAB and TrueRTA. We will also obtain the actual reference sound that is local to a typical drive-thru intercom, as well as various kinds of engine sound, background conversation noise, and environmental noise. By cooperating with the implementation teams, tests will be conducted to try to determine the optimum position of the client relative to the kiosk by measuring the signal to noise ratio for various positions and angles. To verify the performance of the kiosk, graphical results may be used to analyze the effectiveness of noise cancellation. Other test data will also be collected on many other acoustic and electrical variables.

Lack of frame of reference for quality of intercom systems

A large underlying issue from previous semesters has been the lack of data on existing intercom systems. In order to evaluate any possible benefits from the work done so far, tests need to be performed on an existing system and compared to the experimental system. This requires access to intercom systems, preferably at a fast-food franchise.

The appropriate solution to this problem is to open up channels of communication with various prospective fast food companies who use drive-thru intercom systems. It is hopeful that with enough contact, one company will grant the team permission to perform tests on their system. The process of contacting these companies will begin immediately. It is reasonable to estimate that a green light to perform tests would be given within a few weeks if given at all. Given that time frame, actual testing would occur around mid-semester.

Incomplete projects/problems from previous semesters

Some technical endeavors from last semester have been left unfinished. This includes the assembly and integration of the Client Priority Gate (CPG), the proper construction of the Server Side Module (SSM), and easier access to the kiosk back panel. First, the resources needed to complete each project must be identified. Next, the importance of each unfinished task must be weighed against the current direction of the IPRO, as it differs from the previous semester. Each of these tasks in some way contributes to the goals for this semester, by improving on the modularity and/or robustness of the intercom standard we are developing.

The major tasks will be to finish testing the CPG, repackage the SSM, and modifying the kiosk so that it can be opened up more readily. The completion of the CPG does not demand multiple solutions, since the tasks were already defined from the previous semester; it is only a matter of spending time to complete the physical implementation. The SSM repackage is also defined, as no more design work will be needed. Once the CPG is integrated into the new SSM, it will be tested to see if audio is passed through it without substantial distortion. It will also potentially be used in live human perception tests, to observe the intended reduction of feedback.

The CPG integration and kiosk improvements are certainly feasible within the semester. Since most of the work will be in conducting tests and recording data, one possibility is to allocate a small task force to work on the SSM repackage in parallel with the progress on testing, since there is no dependency between these tasks. A full-scale repackage of the SSM would require a similar cost for re-implementing the SSM from last semester, but would take less time, as the assembly process is now well-understood. An estimate would be 20 man-hours to produce another copy of the SSM. The cost may be substantially lower, even, because components were ordered in great excess for testing purposes in the last iteration.

Ambient noise interference

Ambient noise interference is an important factor on transmitting voice clearly. In this semester, we are going to investigate the different possible solutions such as noise cancellation technology, equalizer, and noise filters. The feasibility and complexity of each solution differs. Before deciding on the mode, each option must be considered with respect to these factors, as well as the anticipated cost and large-scale impact. Noise cancellation has the potential to greatly reduce noise from nearby cars, wind, and the surrounding environment, but it can become mathematically complicated in the case of many microphones in the array. The "balance" of the microphones might not transfer very well to other intercom systems that attempt to implement such arrays. However, analog noise cancellation is fairly inexpensive and electronically simple.

As an alternative, an equalizer can be applied to the sound from the outside microphone, in order to "filter" out different ambient noise by modifying the frequency response. A diesel engine, which has a fairly distinctive frequency response, could be actively filtered through an equalizer in order to maximize the relative loudness of the desired signal: the customer's voice. A three-band equalizer has already been implemented in the current SSM, at little additional cost. Equalizers are typically uncomplicated, and function as analog devices.

A more complicated, but highly powerful solution is to employ digital noise filters. These are generally software-level algorithms that act to reduce characteristic noise levels and isolate human voice. A great many open-source toolkits are widely available for public use, and these could be applied from a small PC in the intercom system to offer greater power and flexibility in reducing unwanted noise in the signal. However, the cost of the system increases somewhat if a personal computer is necessary. The complexity is also increased substantially, as the PC must be monitored to some extent.

Complicated testing procedure

As a part of the testing methodology a wide set of real life scenarios will be introduced. In addition to the spacial features of the setup (relative position to the kiosk) relevant sound situations with variable frequency characteristics and noise levels will help improve the data obtained from testing. These sound instances can be recorded and then monitored for variability using the TrueRTA software. Also, this software can be used to investigate a "clipping" situation resulted from the physical limitations of the system noticed by the team members of the previous IPRO 344 and stated in their final report.

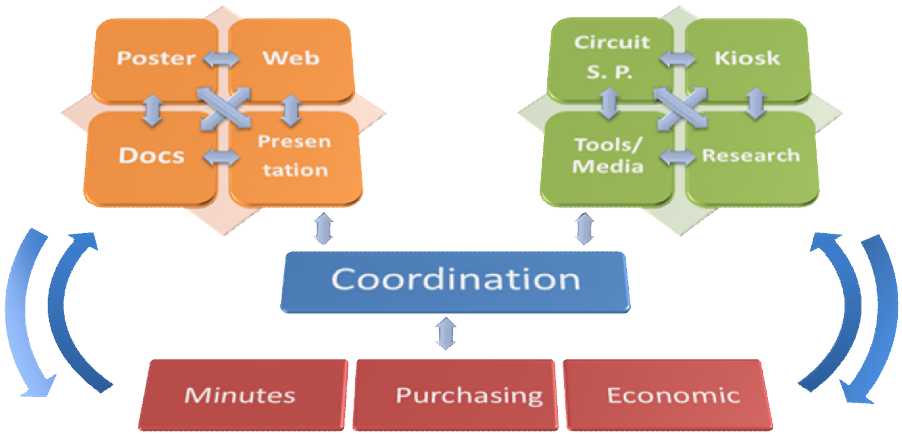
The testing main criteria is The Speech Transmission Index (STI) which is an international standard developed to predict the effects of environmental acoustics on speech recognition ability. The STI method generates a prediction by analysing changes in the Modulation Transfer Function (MTF) when an acoustic stimulus is involved. The evaluation of potential STI variations due to acoustic interference is crucial for the ensurance of the project's success.

The software to be used for the STI measurement is LexSTI 3.1 which is based on an automated system for the calculation of the Modulation Transfer Function. Matlab will be used for interpreting the results. The number of trials will depend on the success of the analysis and the available time but it is expected to be considerably great since the emphasis of this project is on testing and data analysis.

As an alternative method to improve the intelligibility of the system some research will be done in Multiple Stimuli with Hidden Reference and Anchor (MUSHRA) which is a technique that investigates the subjective evaluation of audio quality.

The physical setup of the testing will be roughly based on the original (from last semester) idea with the audio signal to be tested being fed through a microphone provided by SHURE.

B. Team Structure



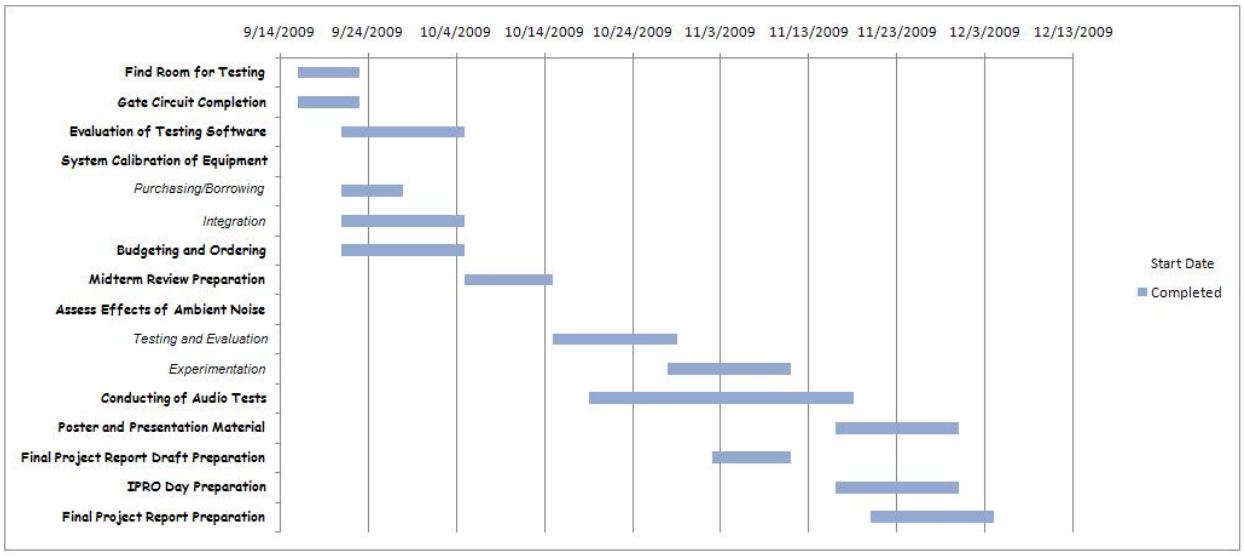
The team structure, as seen in the above diagram, does not indicate a central leader. This is because the efforts are divided into 12 subteams. Each member contributes to more than one team, and most members are leaders of a subteam. The separation of the two upper squares indicates the administrative vs. technical focus of each collection of those teams.

C. Work Breakdown Structure

Timeline:

IPRO Deliverables Schedule (below) + IPRO Task Schedule

Project Plan	September 11, 2009
Midterm Reviews	October 5-15, 2009 (full schedule TBA)
Ethics Reflective Report	November 11, 2009
Final Project Report (first draft)	November 20, 2009
Abstract/Brochure	November 30, 2009 (by 10:00 am)
Poster	November 30, 2009 (by 10:00 am)
Final Presentation	December 2, 2009 (by noon)
Final Project Report (final version)	December 4, 2009 (by 10 am)



The above diagram is the Gannt chart for the various tasks to be performed this semester, as well as the respective phases for each task.

2. Expected results

A. *Provide details on expected activities involved in the project.*

Important activities for this semester include the SSM repackage, the CPG integration, ambient noise reduction implementation, test-suite redesign, and continual testing. The SSM repackage is likely to occupy the most funding, as components are expensive on a one-unit production scale. However, it will offer a great opportunity for applied experience in assembling electronics. The CPG integration will be a relatively small effort that improves the high-end functionality of the system. It will not affect testing very much. The test-suite redesign will concern members of Research and Tools and Media. Most of the work will likely be experimenting with different software packages and determining their usefulness. Finally, testing will be executed for most of the semester, with the intent of reaching useful, distributable conclusions.

B. *Describe expected data from research or testing involved in the project.*

Expected data will concern the effect of various features and their spectral usage. For example, one feature that will be tested is the usage of acoustic foam inside the microphone chamber of the kiosk outside the restaurant. Data will be collected that compares the presence and absence of the foam, as well as the amount and position of the foam. Other important features include internal microphone displacement, microphone aperture size, microphone sensitivity, equalization factors, noise cancellation microphone position, and microphone type. These will be collected with respect to the new kiosk, and may indicate that the presence of these features either improves or degrades the sound quality of the intercom system.

C. *Define potential products resulting from research and testing*.

There are several products which could potentially be created as a result of research and testing of our system. An ambient noise sound library for testing noise suppression will be gathered. An optimum position for a microphone in an enclosed space to diminish ambient noise will also be determined. We will attempt to gather a library of test data on existing intercom systems for later use and analysis. Good testing methods for sound quality in various environments will also be developed.

D. *Define potential outputs to be produced through each of the project tasks*.

Through the completion of our tasks, several outputs will be attained. We will create an ambient noise sound library for testing noise suppression. A client priority gate for supression of server speach during client talking will be created as well. Creation of an intercom server side module (ssm) will be key to the completion of the project. We will develop a basic quality standard for intercom systems. A library of live human perception data on sound clips for later analysis will be gathered. We will also complete development of one of three ambient noise reduction systems (chosen from noise cancelling, equilization, and digital filtering).

E. *Describe the expected results in terms of deliverables that will be produced by the project team, i.e., a working prototype, survey or focus group feedback, grant proposal, etc.*

The major items intended to be produced this semester are: a fully working and durable Server Side Module (SSM), an ambient-noise filtering module, a standardized, streamlined testing procedure, and a set of quality standards to recognize as a minimum for two-way, drive-thru communication systems. The SSM has already been constructed, but as noted earlier in the report, some aspects of it are incomplete. A new testing procedure is sought after in order to increase the portability and reproducibility of the tests for other environments and needs. The new procedure will be exhaustively documented and supported regularly, in order to promote confidence in potential customers. Finally, the new set of quality standards will be exported in a simple document that outlines a quantitative standard for the quality of the system and how to properly test for the various primary metrics observed.

F. *Summarize the challenges, risks and assumptions that you can anticipate affecting your results.*

The anticipated problems range from ethical to technical in their nature. One important issue will be obtaining and fairly representing data collected from existing intercom systems. The team must be careful to protect intellectual and physical copyrights while collecting and interpreting data. This is absolutely essential in the development of broad standards, which is an aim of the work this semester. Another issue may be with forming a unified testing procedure. As seen in the previous semester, a balanced test may require the use of multiple disconnected software suites, increasing the complexity of the procedure and contributing to a higher probability of error in execution. There may also be issues with the use of the CPG, which has

not yet been tested in the complete system. The prototype's functionality may not transfer very well.

A substantial risk to the progress throughout the semester will be highly related to the effectiveness of the Tools and Media team. The previously noted problem of testing complexity may lead to difficulties in broadening the scope of the test, as well as collecting enough raw data.

G. *Discuss how the expected results will be incorporated in a proposed solution or contribute to a solution process.*

The data that will be collected throughout the semester will be used primarily in forming conclusions that indicate what system features are beneficial to a two-way drive-thru communication system. They will also indicate undesirable characteristics. Once data has been collected on the performance of existing intercom systems, there is the potential to demonstrate that these features do indeed result in noticeable improvements of quality. The completion of the SSM and the integration of the CPG will allow for more system configurations to be tested, which increases the robustness of the testing paradigm. Eventually, the improvement of speech intelligibility will need to be statistically correlated to improved order capture, and finally to customer satisfaction, in order to demonstrate a financial incentive for the usage of the intercom quality evaluation standard that is planned in this project.

3. Project Budget

Most of the $933 budget consists of electronics-related purchases. Because the focus of the effort this semester is on improving and clearly defining the testing procedure, most funds will go toward additions that contribute to this end, such as improving the usability/durability of the SSM, or making the kiosk easier to access. There is a large amount of money diverted toward board production, with the intent of allowing for prototype boards to be produced and tested in various system configurations. This will allow the test to include features such as noise cancellation, active filters, or advanced equalization. It will also allow for the SSM to be repackaged, with easier access to the internal boards for upgrades. In addition, the estimate for board production costs is credible because it is referenced to the cost for producing boards in the previous semester.

One goal of this semester is to use only free software in the testing process. This will make the test more distributable, and will greatly reduce the long-term cost by eliminating the need to upgrade versions for a regular price. However, a fund has been allotted for two to three software options in case a suitable program is found by Tools and Media or Research members.

The next page contains the itemized budget list.

Proposed Budget, IPRO 344 – Fall 2009

Item	Description	Cost Per Unit	Qty	Total	Supplier
Noise Cancel Boards	PCB Production Order	20	14	280	Advanced Circuits
Mixer Boards	PCB Production Order	102.93	1	102.93	Advanced Circuits
Preamp Boards	PCB Production Order	84.23	1	84.23	Advanced Circuits
Attwood 66385-3	Door Hinge, Steel	4.63	3	13.89	Home Depot
Hammond 1456WL1WHBU	Sloped Instrument Case	40.2	1	40.2	Mouser Electronics
LM837N-ND	IC OP AMP QUAD LOW NOISE 14-DIP	1.71	3	5.13	Digikey
CT2159-ND	POT 10K OHM 5W WIREWOUND W/HRDWA	3.61	4	14.44	Digikey
CT2257-ND	POT 100K OHM 1/8W CARB HORIZ	1.26	12	15.12	Digikey
ATMEGA168-20PU-ND	IC AVR MCU 16K 20MHZ 28DIP	4.11	4	16.44	Digikey
X116-ND	OSC 16.000 MHZ 5.0V FULL SIZE	1.88	4	7.52	Digikey
P3471-ND	.00047 UFD POLYPROPYLENE CAP	0.199	10	1.99	Digikey
P4725-ND	CAP .1UF 100V STACK METAL FILM	0.125	10	1.25	Digikey
P833-ND	100UF 16V MINI ALUM ELECT (KA)	0.102	10	1.02	Digikey
P807-ND	10UF 16V MINI ALUM ELECT (KA)	0.091	10	0.91	Digikey
P3102-ND	.001 UFD POLYPROPYLENE CAP	0.46	4	1.84	Digikey
P3271-ND	.00027 UFD POLYPROPYLENE CAP	0.199	10	1.99	Digikey
P4556-ND	CAP .0027UF 50V POLYESTER	0.072	10	0.72	Digikey
P3821-ND	.00082 UFD POLYPROPYLENE CAP	0.23	5	1.15	Digikey
P4719-ND	CAP.033UF 100V STACK METAL FILM	0.151	10	1.51	Digikey
P4713-ND	CAP .01UF 100V STACK METAL FILM	0.128	10	1.28	Digikey
P4518-ND	CAP .027UF 50V STACK METAL FILM	0.128	10	1.28	Digikey
P4731-ND	CAP .33UF 100V STACK METAL FILM	0.179	10	1.79	Digikey
P3822-ND	.0082 UFD POLYPROPYLENE CAP	0.49	3	1.47	Digikey
PF2105-ND	CAP 1.0UF 250V METAL POLYPRO	0.79	3	2.37	Digikey
1.0KH-ND	RES 1.0K OHM 1/2W 5% CARBON FILM	0.058	10	0.58	Digikey
CD4066BCN-ND	IC SWITCH BILATERAL QUAD 14-DIP	0.45	4	1.8	Digikey
A31120-ND	CONN RECEPT 2POS 22AWG MTA100	0.22	12	2.64	Digikey
A1911-ND	CONN HEADER VERT 2POS .100 TIN	0.21	12	2.52	Digikey
A31089-ND	CONN RECEPT 3POS 22AWG MTA100	0.22	10	2.2	Digikey
A31113-ND	CONN HEADER VERT 3POS .100 TIN	0.22	10	2.2	Digikey
P3C3103-ND	POT 10K OHM 9MM VERT NO BUSHING	0.99	3	2.97	Digikey
P3P5103-ND	POT 10K OHM 9MM HORZ NO BUSHING	0.849	10	8.49	Digikey
1N752A-ND	DIODE ZENER 5.6V 500MW 5% DO-35	0.059	10	0.59	Digikey
PT45-C	15,5,-15 45W power supply	40	2	80	Astrodyne
Belkin F8E066		29.23	1	29.23	
Test Software	Various suites for analyzing speech transmission	200	1	200	
Total				**933.69**	

4. Designation of Roles

Minute Takers: J Bian & A Bartolomei
Agenda Maker: Nathan Miller
Time Keeper: T Algie
iGroups Moderator: Jeff Chiles