AcousticShield DESIGNS

March 9, 2005

Mr. Lakshman One
School of Engineering
Science Simon Fraser University
Burnaby, BC
V5A 1S6

Re: ENSC 440 Design Specification for an Electronic Counter Sniper System

Dear Mr. One:

Attached you will find the *AcousticShield Designs'Design Specification* for an Electronic Counter Sniper System. This document lists the design specifications for our ENSC 440 project.

AcousticShield Designs is currently designing a system that would aid military and law enforcement personnel in quickly and accurately locating the origin of a gunshot.

Group members will be using this document as a reference for design. AcousticShield is an ENSC440 project group, consisting of one fourth year and three fifth year students: Marko Gasic, Sandeep Brar, Balraj Mattu, and Ehsan Dallalzadeh. If you have any concerns or questions regarding this proposal, please contact me by email or by telephone at 604 340-8603.

Sincerely,

Marko Gasic

Marko Gasic,
President and CEO
AcousticShield Designs

Enclosure: *Proposal for an Electronic Counter Sniper System*

Project Design Specification for a

Acoustic Counter Sniper System

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School of Engineering Science
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Issued Date: March 9, 2005

EXECUTIVE SUMMARY

Asymmetric warfare is an unfamiliar term to most of us. For members of our armed forces and civil services however, asymmetric warfare has become the embodiment of a new generation of threats faced in peacekeeping and domestic anti-terrorism operations. No longer is the field of battle dominated by large cohesive armies exhibiting a balance of force, instead, mobile groups or in many cases individuals threaten large, mechanized, and usually much less mobile military formations. The inherent mobility and capability for easy concealment is what allows these individuals to inflict great damage on the much larger force.

AcousticShield aims to develop an Electronic Counter Sniper (ECS) system that uses the acoustic response of a gunshot to identify the precise location of the shooter immediately after the shot is taken. By denying the shooter anonymity and enabling quick and accurate localization, our system will enable military and law enforcement personnel to quickly and effectively locate and respond to such attacks. By making a response much more likely and effective, we believe that our system will act as a significant deterrent in prevent these types of attacks in the first place.

With this document, AcousticShield proposes and outlines the functional specifications for the ECS system described above. Our group consists of 3 fifth year and one fourth year engineering science students with skills in systems integration and programming required to make this project a reality. We propose a development timeline in this document as well as a budget in the project proposal that will be required for the completion of the project by March 30 2005.

Table of Contents

1. Introduction

The purpose of this document is to record the Design Specifications for the Electronic Counter Sniper. Everything in this document is subject to change and/or refinement during the development process.

The purpose for the Electronic Counter Sniper device is to accurately detect the acoustic signature of a gunshot and to locate the origin of the shot within seconds of the event.

The task of developing such a device is divided into three stages: the signal retrieval stage, the signal processing stage, and finally the user output stage.

1.1 Glossary

***A/D*:** Analog to digital

ECS: Electronic Counter Sniper

CCD: Charged Coupled Device

DSP: Digital Signal Processing

PC: Personal Computer

GUI: Graphical User Interface

1.2 Intended Audience

This document is intended to be a design guideline for the designers and engineers within *AcousticShield*.. Its intention serves as ensuring that the product developed by *AcousticShield* meets the specified requirements for appropriate production.

2. System Overview

The Electronic Counter Sniper system, a product of AcousticShield Designs is an acoustic sniper localization system. **Error! Reference source not found.** below illustrates the conceptual design of the system.

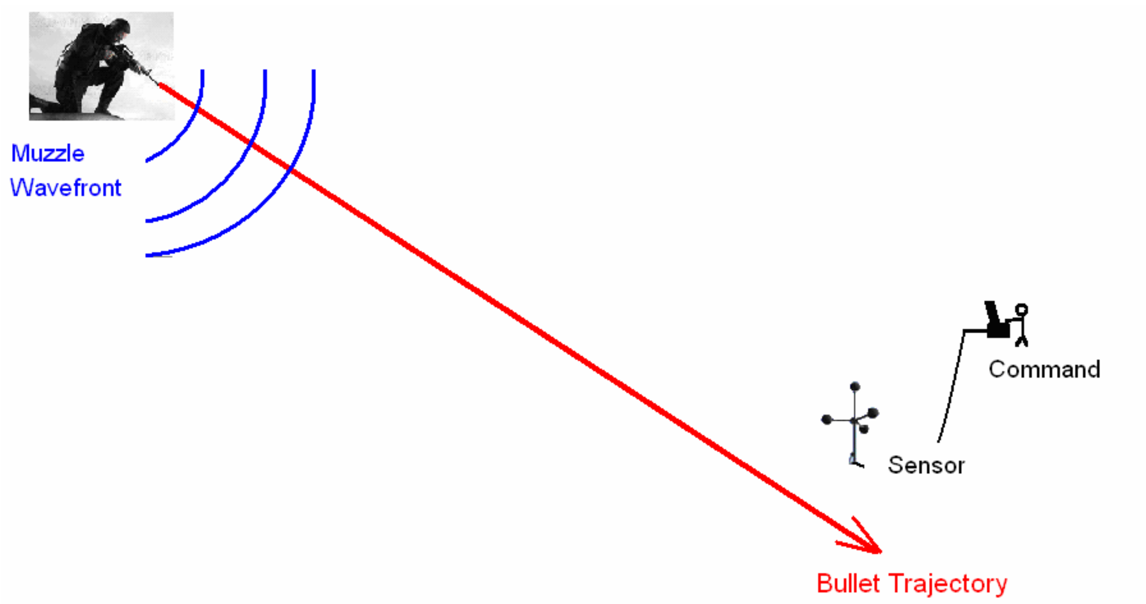

Figure 1: Sniper localization system concept

The system consists of three functional components as follows:

- Retrieval of the incident signal
- Processing of the incident signal
- User Output

Concerns for each of the stages are described below.

AcousticShield Designs ECS system intends to use a distributed network of omni-directional microphones to detect the sound of the bullet and calculate the location of its origin. Filtering of environmental noise may be necessary to ensure only useful signal information is processed. Again, the detector's sensitivity to external noise is essential to creating an accurate product.

In the signal processing stage, a device with high precision must be used to distinguish changes in the detected signal. Using the incoming signals from the detector, a DSP will be used to quickly calculate the origin of the sound. If a gunshot is detected, the information will be sent to the user output device.

Once the processor has calculated and output the co-ordinates of shot origin, a PC based application reproduces the output in a visual format so that the system operator can take appropriate action. In addition, these co-ordinates could be used to position a camera to capture an image of the location where the shot came from. Due to the limited time frame, this additional feature will not be implemented by AcousticShield at this time.

3. System Hardware

3.1 Microphone Array

At the instant a bullet leaves the barrel of a weapon, an acoustic wave front is generated and expands radially in 3 dimensions from the location of the shooter at the speed of sound. This is of course what we perceive as the sound of a gunshot. Using the same principles that humans use to locate the origin of a sound, AcousticShield Designs ECS system will use a system of four microphones, arranged in a tetrahedral pattern to determine the time delay between arrivals of the acoustic waves. The reason for a tetrahedral pattern lies in the fact that for geometric triangulation, n+1 points are required to determine a location in an n dimensional space, so for three dimensional space, four sensors are the minimum requirement. The tetrahedral pattern is a natural distribution that results in 4 equally spaced sensors in three dimensions. Filtering of environmental noise is necessary to ensure only useful signal information is processed. Again, the detector's sensitivity to external noise is essential to creating an accurate product.

The microphones will have a sampling rate of 11025Hz as determined by experimenting on the power spectrum of the gunshot characteristics. Microphone 1 and 2 will be linked to the 16-bit audio codec on the DSK (DSP Starter Kit) and the other 2 microphones will be linked to the 16-bit audio codec on the daughter board. This component is shown in the figure below.

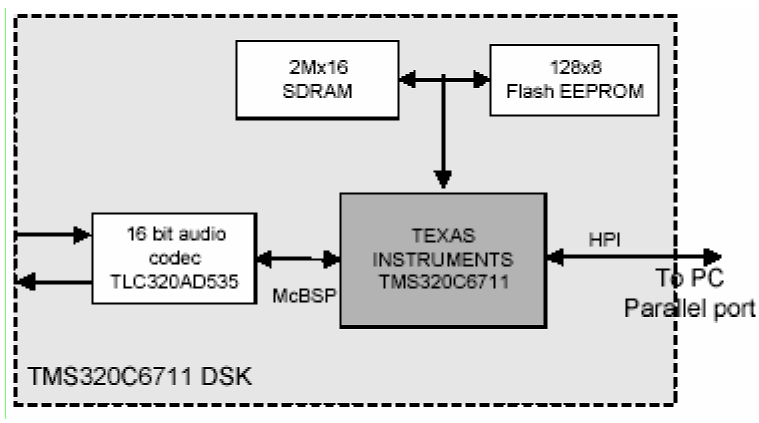

Figure 2: Audio Codec Interface

4. Signal Processing

The advantage of using a DSP based system is that it responds in real time, allowing for an almost zero lag output. In addition, the algorithms available on modern DSP processors allow for easy processing of input, easy echo cancellation and waveform identification. This means that once the basic system is implemented, it can easily be modified so that it tolerates operation in a complex environment where echo and other noise would pose a problem to similar systems. Since each type of weapon generates a distinct sound profile, the system could be trained not to respond to a particular sound profile, such as the sound generated by discharge of weapons used by friendly forces.

4.1 Input Signal

The DSP diagram is shown below

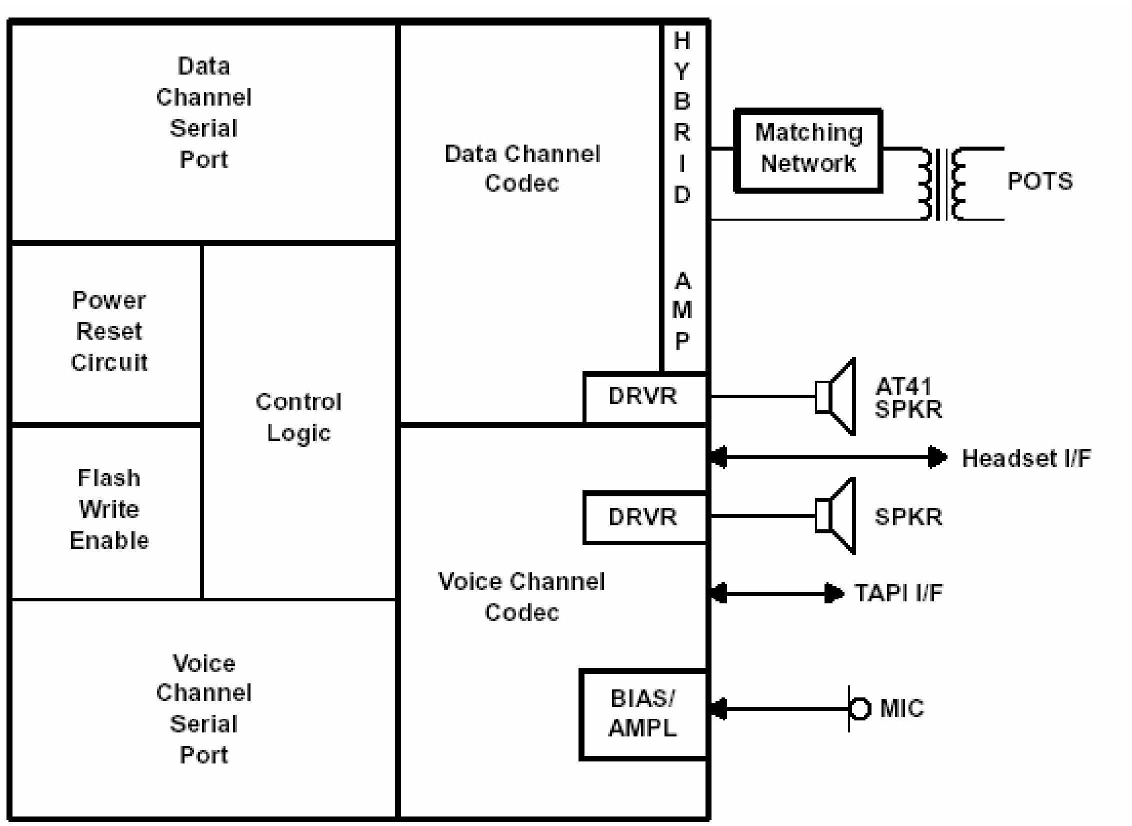

Figure 3: DSP Diagram

The input signals are amplified and filtered by on-chip DSP buffers before being applied to their respective A/D input. In the case of the voice channel, inputs from a microphone input and the handset input may be summed together before being amplified/attenuated by the A/D line. The A/D then converts the signal into discrete output digital words in 2s-complement format, corresponding to the analog signal value at the sampling time. These 16-bit digital words, representing sampled values of the analog input signal, are sent to the host through the serial port interface for their respective channels. If the A/D reaches its maximum value, a control register flag is set. This overflow bit resides at D0 in the data channel control register 2 or the voice channel control register 5. These bits can only be read from their respective serial ports, and the overflow flag is cleared only if it is read through the voice channel serial port, and similarly for the data channel. The A/D and D/A conversions are synchronous and phase-locked.

Four samples are sent by the audio codec to C6711 (in a serial manner) which stores the samples in the 2M SDRAM.

Sending of the data by the audio codec will done via Interrupts. When the data needs to be sent, an interrupt is generated (4 interrupts, 1 for each microphone). During the service of the interrupt, we will be saving the 16-bit value send by the codec to the SDRAM
The maximum number of samples stored for each Mic = 250msec * 11.025 kHz
This value is chosen since a gunshot sound only lasts approximately 232msec - found by experimental data and counting for speed of sound and our max range according to functional specifications and having some extra samples for just a safety precaution)

4.2 Recognition of Input

The following flow chart shows the algorithm that will be implemented in the DSP controller.

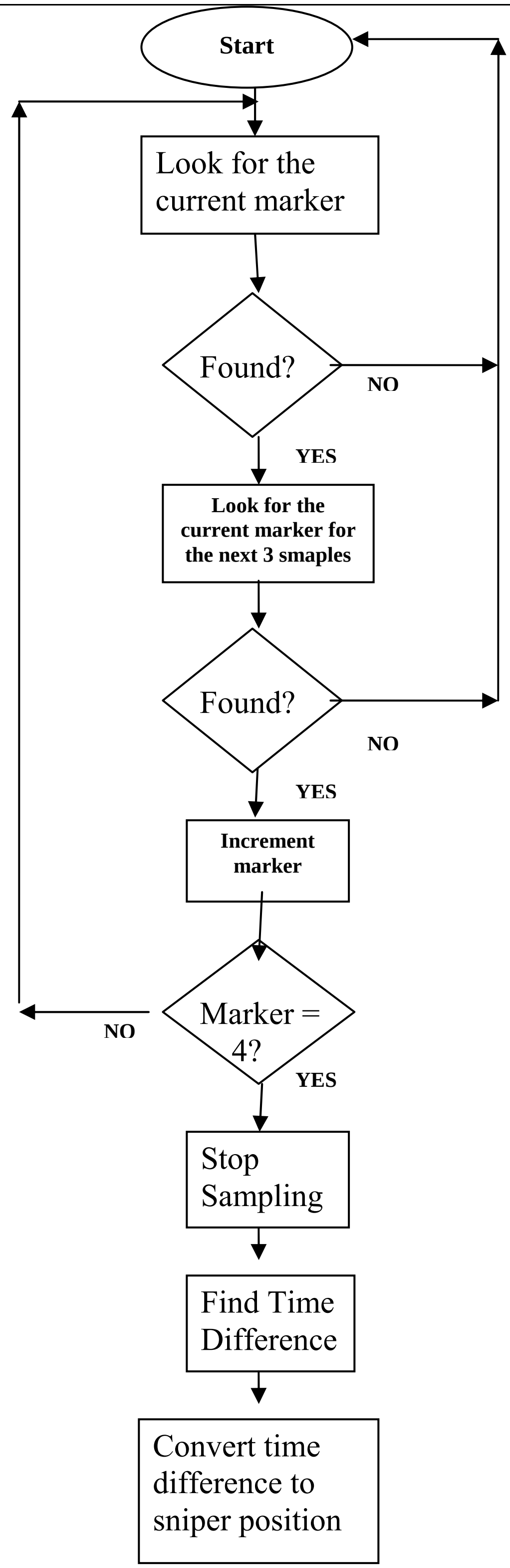

Figure 0 The DSP algorithm

Possible Errors may occur if the gunshot is detected by only some of the microphones. If this is the case the following action will be taken to ensure accurate readings are taken.

If the gunshot is detected only on 1 or 2 Microphones, a Display Warning - “Possible Gunshot Detected, Unable to locate origins of the Sound” will be sent to the GUI.

If the gunshot is detected only on 3 Microphones, a Display Warning - “Gunshot Detected but unable determine range” will be sent to the GUI.

4.3 Triangulation Algorithm

Once a sound has been identified as a gunshot by the DSP platform, the task of calculating where this sound originated remains. The approach we intend to use is similar in nature to the way our bodies use the time difference between when a sound reaches our ears to determine where it came from. To develop this algorithm we started with a simplified case; that of determining the origin of a sound in a 2D plane, and then expanded it to 3 dimensions.

2D Case

In figure 1, we depict the x-y plane. The origin of the plane is located in the centre of our microphone array, where microphones are indicated by the red dots. At the time a shot is taken, concentric acoustic shockwaves begin to expand radially at the speed of sound from the sniper location, the blue dot. The wave front will reach each of the 3 microphones at different times. We will use this time difference in sound reaching different microphones to construct a set of equations which we can solve to recover the x-y coordinates of the blue dot.

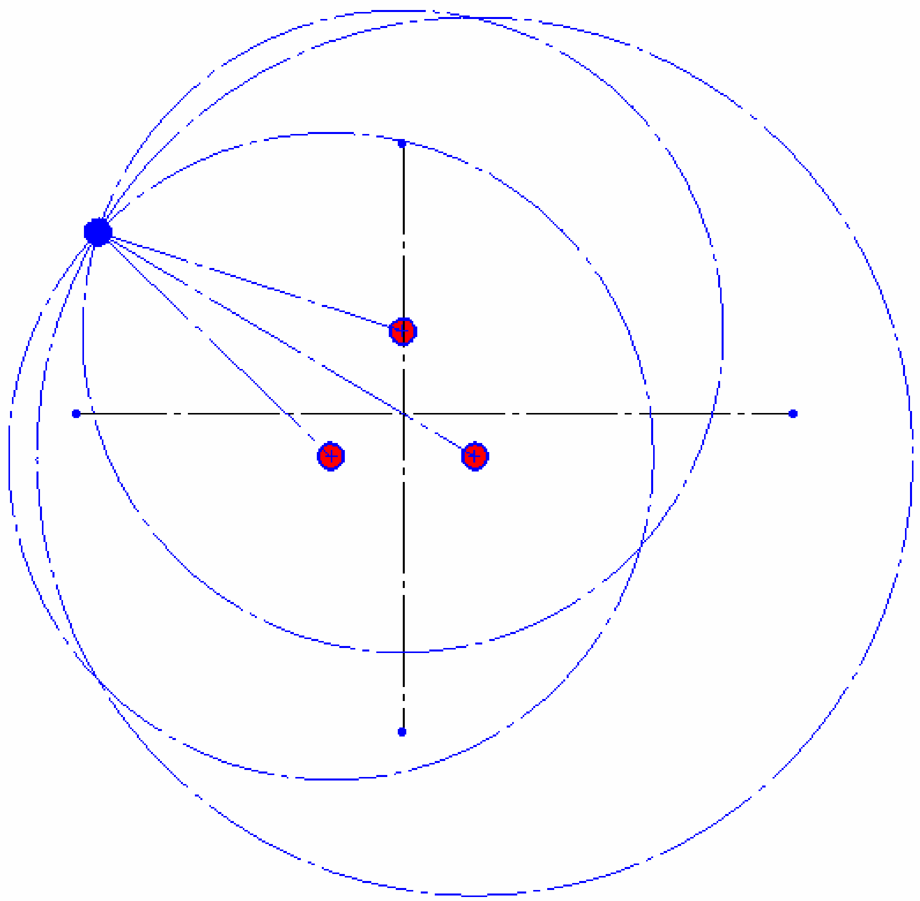

Figure 5 Triangulation

Let X and Y represent the unknown coordinates of the sniper. Let X_a and Y_a represent the coordinates of the first detector to receive the sound. Similarly let X_b and Y_b represent the coordinates of the second detector to receive the sound and X_c and Y_c be the coordinates of the third detector to receive the sound. Also, let C represent the speed of sound, a represent the distance from the sniper to the closest detector and Δt_{ab} represent the time delay between the sound reaching detector B from the time it reaches detector A. Using the formula for a circle, we construct the following set of equations.

$$(x - x_a)^2 + (y - y_a)^2 = a^2$$
$$(x - x_b)^2 + (y - y_b)^2 = (a + c\Delta t_{ab})^2$$
$$(x - x_c)^2 + (y - y_c)^2 = (a + c\Delta t_{ac})^2$$

We have 3 independent equations and 3 unknowns (x,y,a). These equations are solved to recover the coordinates of the target.

3D Case

For the 3D case, instead of expanding concentric circles, we have a case of concentric spherical shells. Using similar reasoning, we arrive at the following set of equations. Note that in three dimensional space we must use at least 4 sensors.

$$
\begin{aligned}
(x - x_a)^2 + (y - y_a)^2 + (z - z_a)^2 &= a^2 \\
(x - x_b)^2 + (y - y_b)^2 + (z - z_a)^2 &= (a + c\Delta t_{ab})^2 \\
(x - x_c)^2 + (y - y_c)^2 + (z - z_c)^2 &= (a + c\Delta t_{ac})^2 \\
(x - x_d)^2 + (y - y_d)^2 + (z - z_d)^2 &= (a + c\Delta t_{ad})^2
\end{aligned}
$$

Again, we solve this set of 4 nonlinear equations to recover the x, y and z coordinates of the target. Once the coordinates of the target are known, we can use a graphical user interface to display the target location to the user.

Since we are using Matlab to communicate to the DSP subsystem, as well as using Matlab for the GUI interface, we will make use of Matlab's powerful nonlinear equation solving algorithm to arrive at a solution to the above equations. The particular solution method will probably use the Gauss-Newton Method.

5. User Interface/Output

The user interface shall display all the useful information regarding the location of the origin of the gunshot and nothing else that may disturb the operator. After this information is processed and determined by the DSP, the result will be saved to an encoded text file. The user interface GUI will consist of an internet website based application using Microsoft .NET technology. This software is chosen for its ease of use and compatibilty with all computers that use the Windows Operating System. No additional software needs to be installed to run the application on a computer since the program is run through the internet browser. The results of the ECS System will be displayed by showing the results of the origin of the shot in spherical coordinates. A small diagram above the results will be programmed to show the location of the shot relative to the GUI user's current position.

Since the GUI is an internet based program, no training will be required for the user; although basic computer knowledge will be essential. To prevent system failure, a self diagnostic system will be implemented into the GUI. The GUI data will update every 1-2 seconds and a flag which is encoded into the input text file will inform the user if the system is operating properly or if there is a problem. In addition to the diagnostic system, a simple help file will be incorporated into the program to ensure proper operation and troubleshooting can be performed by the user if nesessary.

6. System Test Plan

To ensure that AcousticShield Designs ECS system produces very accurate and reproducible results, several phases of testing will need to be conducted. The prototype will be tested with a pre-recorded sound of a typical gunshot, played through a speaker to be positioned in various locations within the operational range of the device. The testing environment will be such that it simulates acoustics of field use

The tests will be considered a success if the device is able to identify the location of the shot and distinguish a gunshot from similar noises. The accuracy of the device will be as described by in the system functional requirements.

The Test plan lays out common scenarios that the system will undergo and shows the expected results given the described test conditions. This test plan is not a definitive guideline for testing the system and in not meant to limit ad hoc testing in anyway.

6.1 Test Cases

AcouticShield uses the bottom-up methodology to test the functionality of the system.

6.1.1 Receiver Test (RT01)

Overview: The following test shall be run to ensure the collection of audio data from the microphone array.

Objective: To check the functionality of the each microphone.

Pre-Condition(s): Apply each microphone to the audio input of a computer.

Post-Condition(s): A successful detection of audio from the computer audio channel.

Step	Test Conditions	Expected Results	Pass?
1	Connect a microphone to the desktop computer and run the Winamp software.	Expect Input	
2	Locate the microphone at the center of a circle with a radius of about 40 cm. Divide the circle's perimeter into 8 equal sections.	As shown in diagram	
3	Turn on the sound source while you are recording on the desktop.	Record and compare results	

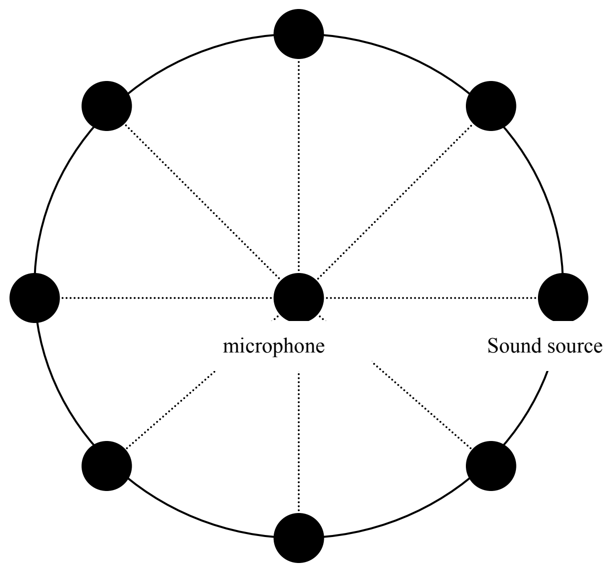

Figure 6 Configurations of the microphone and the sound source

At the end, you should be able to analyze the recorded signals. What the differences are and what is the effect of the relative angle that the source makes with microphone on the recorded signal.

6.1.2 Processor Test (PT01)

Overview: Much of the testing of the processor will be done with the DSP subsystem through MATLAB.

Objective: To check the functionality of the DSP

Pre-Condition(s): Apply sample program to DSP system where results are known.

Post-Condition(s): Predetermined results are verified.

Step	**Test Conditions**	**Expected Results**	**Pass?**
1	Record program into DSP memory	No errors in programming the code	
2	Apply input to program	Values equals predetermined value	

Variation(s): None

Note(s): None

6.1.3 GUI Test (GT01)

Overview: To ensure the GUI operates properly, the program will be run on several workstations to ensure robustness of the software.

Objective: To check the functionality of the GUI.

Pre-Condition(s): Run internet program on several PC computers.

Post-Condition(s): A successful error free operation of the program.

Step	Test Conditions	Expected Results	Pass?
1	Use all features of the GUI	No crashing or errors result	
2	Check results displayed are accurate	Results in text file match the GUI display	

12. Conclusion

This document outlines the design and requirements that must be completed for the Electronic Counter Sniper system to be a beneficial tool in law enforcement and threat deterrent products. Given these specifications, we are confident that we will satisfy at minimum our prototype requirements by the middle of April 2005.

13. References

[1] Unknown Author "TIME Magazine". Time Publishing: New York. [2002].

[2] Whitmore, Steve & Stevenson, Susan. "Engineering Science Communication Handbook". Simon Fraser University: British Columbia, Canada. [1999]

[3] Popatia, Shahir, "A case study of two engineering student design teams". [2000]

[4] Delisle, Julie. "Project Management and the Company". [1998]

[5] G.L. Duckworth, J.E. Barger, S.H. Carlson, D.C. Gilbert, M.L. Knack, J. Korn, R.J. Mullen. "Fixed and wearable acoustic counter-sniper systems for law enforcement". BBN Technologies: Cambridge, MA. [1998]

[6] Srour, Nino. "Army Acoustics Needs. DARPA Air-Coupled Acoustic" US Army Reserch Laboratory: Adelphi, MD. [1999]