

# **Ultrasonic Shark-tag Locator System for IVER2 AUV**

Author: Nathaniel Garcia  
Advisor: Dr. Christopher Lupo  
June, 2010

## Table of Contents

<b>1. Introduction</b> .....	4
<b>2. Description</b> .....	4
2.1 Background .....	4
2.2 Project Overview.....	4
2.3 Primary Constraints .....	5
<b>3. Hardware Equipment And Devices</b> .....	6
2.1 Sonotronics Ultrasonic Fish-tag .....	6
2.2 Desert Star Systems Hydrophone .....	6
2.3 Filter/Amplifier Circuit .....	7
2.4 Atmel STK500 microcontroller developer board .....	7
<b>4. System for Calculating Bearing</b> .....	8
3.1 General Theory .....	8
3.2 IVER2 Application.....	8
3.3 Non-Ideal Environment Limitations.....	9
3.4 Determining port vs. starboard heading .....	9
<b>5. Filter/Amplifier Circuit Design</b> .....	10
4.1 First Approach: Sonotronics Filter Circuit .....	10
4.2 Second Approach: Custom Design Circuit.....	10
<b>6. Microcontroller Implementation</b> .....	11
<b>7. Economic Evaluation</b> .....	12
7.1 Cost Report.....	12
7.2 Upkeep and Maintenance.....	12
7.3 Commercial Considerations .....	12
<b>8. Project Evaluation</b> .....	13
8.1 Development Report.....	13
8.2 Manufacturability .....	13
8.3 Sustainability .....	13
8.4 Social and Political Considerations.....	14
<b>9. Future Work</b> .....	14
9.1 Ocean Environment Field Testing.....	14
9.2 System Integration with IVER2 .....	14

9.3 Design Optimizations.....	14
9.4 Feature Additions .....	15
<b>10. Conclusion .....</b>	<b>15</b>
<b>11. Bibliography.....</b>	<b>16</b>
<b>Appendix A .....</b>	<b>17</b>
<b>Appendix B .....</b>	<b>18</b>

# 1. Introduction

Autonomous vehicles are at the forefront of technological advancement and research. The variety of applications spans wide from military defense with Unmanned Aerial Vehicles (UAV) and military promoted research with the DARPA Grand Challenge [1] to scientific research with Autonomous Underwater Vehicles (AUV) such as the OceanServer IVER2 [2]. Dr. Christopher Clark, a robotics professor at California Polytechnic State University San Luis Obispo, owns and uses AUVs such as IVER2 to assist archeologists and marine biologists around the globe [3]. As Dr. Clark continues to apply his AUVs to scientific research, the need for expanding the capabilities of his AUVs increases the variety of research projects he can apply his AUVs to.

The purpose of this project is to develop a system for tracking an ultrasonic underwater transmitter that can be integrated into an IVER2 AUV to allow it to follow and monitor tagged sharks in the ocean for scientific research. The project idea was proposed by Dr. Christopher Clark, who funded this project, and by Dr. Christopher Lupo, who advises many Cal Poly senior projects in embedded systems.

## Summary of Functional Requirements

- The system shall determine the directional bearing from the system to a single Sonotronics 73 kHz underwater transmitter.
- The system shall send this bearing information to a microcontroller on the IVER2.
- The system shall provide enough information about the location of the transmitter to allow the IVER2 to navigate with respect to it.

# 2. Description

## 2.1 Background

General knowledge or experience with analog signals and embedded systems architecture and programming are helpful in fully understanding this project. Additionally, some nautical terms should be understood. Bearing refers to a directional angle with forward typically being 0 degrees. Directions “bow”, “stern”, “port” and “starboard” refer to front, back, left, and right respectively.

## 2.2 Project Overview

The system consists of a four main components including a shark-tag, two hydrophones, a filter/amplifier & threshold detector circuit, and a microcontroller. The shark-tag transmits a 73 kHz acoustic signal which is received and converted into an electrical analog signal by the hydrophones. The analog signal is then amplified and run through a 73 kHz band-pass filter to remove excess noise in the signal. The clean 73 kHz signal is then compared with a threshold detector which converts the analog signal into a digital binary signal. This digital signal is then passed to a microcontroller which determines the bearing to the transmitter based on the time between the signal detection of one hydrophone with the signal detection of the other hydrophone. The bearing will then be passed to the main

microcontroller on the IVER2 AUV allowing it to employ logic in navigating about the shark. Figure 1 diagrams this system overview.

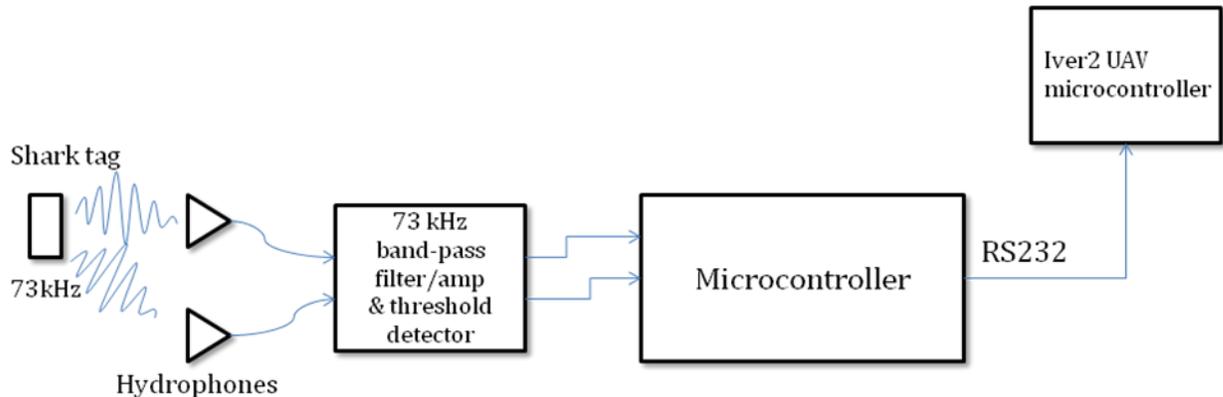


Figure 1: System Overview

### 2.3 Primary Constraints

There was several hardware constraints placed on the design of this system. The transmitter is a Sonotronics CTT transmitter (see section 2.1 for details) emits a 73 kHz acoustic signal in pulses 20 ms long and approximately 800 ms between each pulse at room temperature. This transmitter was provided by Dr. Clark and it was desired that the system locate a shark tagged with this transmitter.

In order to detect this signal, a hydrophone with a piezoelectric transducer was needed to convert the mechanical acoustic signal into an electrical analog signal. Dr. Christopher Clark provided a set of omnidirectional hydrophones manufactured by Desert Star Systems for this project (see section 2.2 for details). These hydrophones output a weak signal which required an amplifier circuit to boost the signal. In order to accurately differentiate the signal from noise in the ocean, a 73 kHz band-pass filter needed to be incorporated into the design. A Sonotronics USR96 filter/amplifier device was provided along with the transmitter. However, as this device main function was to process and convert an ultrasonic signal into an audible signal, only part of the circuit was needed. This delayed much design work initially as it took some time to acquire appropriate circuit schematics via email from Sonotronics technical support.

The main microcontroller on the IVER2 operated by Dr. Clark had one unoccupied input port which was an RS232 connector. In order to process the signal, calculate a bearing, and output information to the IVER2 via an RS232 connection, a microcontroller was needed. Dr. Bryan Mealy, who teaches an upper division embedded systems class at Cal Poly provided an Atmel STK500 microcontroller development board and an Atmega8 microcontroller (see section 2.4 for details). Design of this system considered the capabilities of this microcontroller board. Features taken into consideration included external interrupts from GPIO pins, a single up/down counter timer, an up/down counter with output compare, output via either USART or SPI protocol, AVR software library, and an RS232 port.

### 3. Hardware Equipment And Devices

#### 2.1 Sonotronics Ultrasonic Fish-tag

The “shark-tag” used for this project is a 73 kHz underwater acoustic transmitter designed and manufactured by Sonotronics. It is shown in Figure 2. The specific transmitter used is a Coded Temperature Transmitter model CTT-83-3-1 [4]. It is referred to as “fish-tag” or “shark-tag” in this report. This transmitter emits a 73 kHz acoustic ping approximately 20ms in duration. This transmitter is equipped with a smart temperature sensor that provides temperature measurements to a microcomputer that controls the ping interval (ms) according to the following formula where T is measured in °C [5]:

$$PI = 6(45 - T) + 550$$

With water temperatures between 3 C and 30 C, this yields ping intervals between 800ms and 640 ms respectively. These maximum and minimum ping intervals are taken into account in microcontroller code design.

#### 2.2 Desert Star Systems Hydrophone

The hydrophones used in this system are designed and manufactured by Desert Star Systems, LLC. As shown in Figure 3, they are omni-directional hydrophones meaning they are designed to receive signals from 360° on a plane perpendicular to the length of the speaker itself. The hydrophones contain a piezoelectric transducer which converts mechanical vibrations into a voltage [6]. Thus, this device converts the acoustic signal from the shark-tag into an analog electric signal.



Figure 2: Sonotronics 73 kHz transmitter (middle)



Figure 3: Desert Star Systems Omnidirectional Hydrophone

### 2.3 Filter/Amplifier Circuit

Before passing the signal to the microcontroller, an intermediate circuit is needed to perform several signal processing operations. Because the signal created by the hydrophones is too weak (measured at approximately 40  $\mu\text{V}$ ) for the microcontroller to accurately use, an amplifier was needed. Once the signal had been amplified, extra noise needed to be filtered out to accurately detect the 73 kHz signal. This required a band-pass filter.



Figure 4: Sonotronics USR-96

The Sonotronics shark-tag was packaged with an audio signal processing unit (USR-96) to amplify and filter the signal. The USR-96 is shown in Figure 4.

### 2.4 Atmel STK500 microcontroller developer board

In order to determine the time delay between the time of signal detection of one hydrophone and the detection time of the other and to calculate a bearing using that information, a microcontroller is needed.

The Atmel STK500 shown in Figure 5 is a microcontroller development board used for microcontroller prototyping. Some of its features include 8 push buttons, 8 LEDs, multiple general purpose I/O (GPIO) pins, two RS232 terminals and multiple sockets for microcontrollers, memory, and other integrated circuits (IC). Using Atmel's AVR Studio 4 software, a microcontroller on the board can be programmed in C using Atmel's AVR software library.

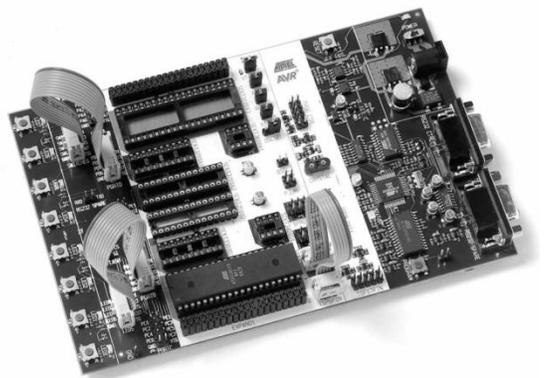


Figure 5: Atmel STK500 Developer Board

## 4. System for Calculating Bearing

### 3.1 General Theory

A directional bearing to the transmission source can be determined by measuring the time-delay between the signal detection of two passive hydrophones placed near opposite ends of the IVER2. This concept is illustrated in Figure 6. By knowing the speed of sound and the distance between the Hydrophones, the time  $\Delta T_{MAX}$  for sound to travel from one hydrophone to other can be calculated by dividing the distance  $\Delta d$  between the hydrophones by the speed of sound  $v_{sound}$ :

$$\Delta T_{MAX} = \frac{\Delta d}{v_{sound}}$$

Equation 1: Maximum time delay between hydrophones

This is the maximum time-delay of signal detection between the two hydrophones.

With a signal source at  $0^\circ$  off the bow of the IVER2, the time  $\Delta T$  measured between signal detections will be  $\Delta T_{MAX}$ . At  $90^\circ$ , the time  $\Delta T$  measured between signal detections will be 0s. By detecting which hydrophone detects a signal first, the source can be identified as either in front of or behind the IVER 2 using  $\Delta T = T_1 - T_2$ . Thus, at  $180^\circ$  off the bow of the IVER2 ( $0^\circ$  off the stern),  $\Delta T$  will be  $-\Delta T_{MAX}$ . A specific bearing (angle)  $\Theta$  from the midpoint between the two hydrophones can be calculated by dividing the time measured  $\Delta T$  by the maximum time difference  $\Delta T_{MAX}$  and taking the inverse cosine of the result:

$$\Theta = \text{acos} \left( \frac{\Delta T}{\Delta T_{MAX}} \right)$$

Equation 2: Angle to signal source

### 3.2 IVER2 Application

The IVER2 will utilize this passive sonar system to following sharks in the ocean. Desert Star Systems omnidirectional hydrophones provided by Dr. Christopher Clark are used to detect the audio signal. By placing the hydrophones 1 meter apart for simple calculations and using 1,560 m/s as an approximation for the speed of sound in salt water,  $\Delta T_{MAX}$  is calculated to be 641  $\mu s$  using equation 1:

$$\frac{1 \text{ m}}{1,560 \text{ m/s}} = 641 \mu s$$

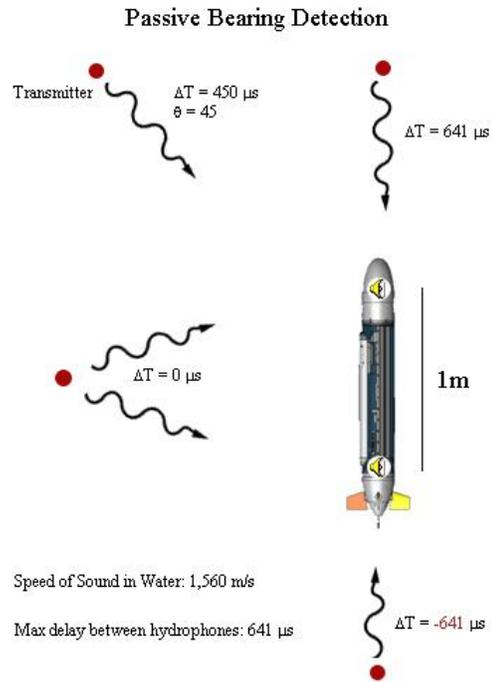


Figure 6: Bearing Detection Using Passive Sonar

Any angle off the bow of the IVER2 can then be calculated using equation 2. A transmitter that is positioned such that a time difference of  $450\ \mu\text{s}$  is measured, for example, would be  $45^\circ$  off the bow. This is illustrated in Figure 2.

$\Delta T$  is measured using an Atmel SDK500 microcontroller with an Atmega8 microprocessor. The Atmega8 uses a software timer to measure the time difference between signal detections of the two hydrophones. If rising edge signal detection occurs first on the stern hydrophone, then is a negative  $\Delta T$  value. The  $\Delta T$  value is then output to the IVER2 microcontroller via an RS232 port using a UART protocol.

### 3.3 Non-Ideal Environment Limitations

The 73 kHz audio signal travels through ideal salt water at approximately 1,560 m/s. Ideal salt water is taken to be salt water that is free of air bubbles or suspended sediment. While the IVER2 will almost certainly not be applied to ideal salt water environments, it is sufficient to assume ideal conditions as only a general bearing (within 30) is needed for methods to allow the IVER2 to locate and follow the transmitter.

### 3.4 Determining port vs. starboard heading

By using the time-delay between signal detection, bearing off of the bow and stern of the IVER2 can be determined. However, this alone cannot determine whether the bearing is off of either the starboard or the port side of the IVER2. A method for determining heading off the port or starboard side of the IVER2 involves turning while comparing the detected direction of bearing change with an expected direction of bearing change.

For example, if a positive time-delay with respect to the bow is determined, then by turning the IVER2 to the port side the time-delay would be expected to increase toward  $\Delta T_{\text{MAX}}$  if the transmitter is off the port side of the IVER2. If the time-delay decreases toward  $0\ \mu\text{s}$ , then it corresponds to the transmitter being off the starboard side of the IVER2. This method is illustrated in figure 4. For a negative time-delay with respect to the bow, expectations would be opposite: a time-delay approaching  $0\ \mu\text{s}$  while turning to port would mean the transmitter is off the port side while a time-delay approaching  $-\Delta T_{\text{MAX}}$  would mean the transmitter is off the starboard side.

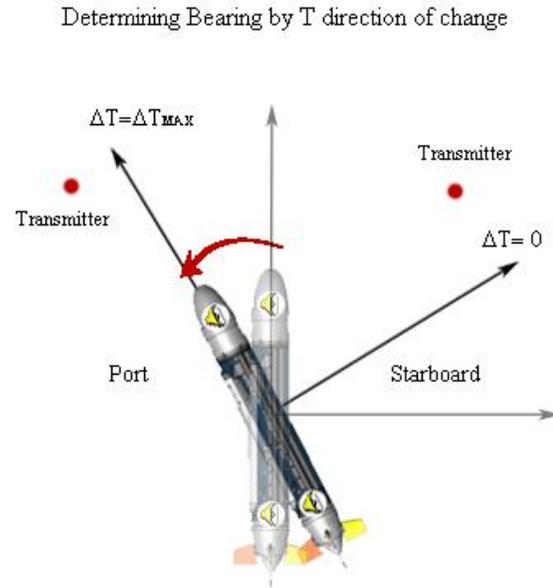


Figure 4: Determining bearing by time-delay change. Two possible transmitter locations will give the same initial bearing. After rotation, their bearings will be different from each other.

## 5. Filter/Amplifier Circuit Design

### 4.1 First Approach: Sonotronics Filter Circuit

The Sonotronics USR96 filter/amplifier circuit schematic was obtained through email from Sonotronics technical support (see Appendix A). The circuit contains three main components. The filter itself is a Rockwell Collins 455 kHz mechanical filter (526-8693-010) [7]. This mechanical filter is a high quality noise filter but requires a 455 kHz input signal. NE602A oscillator ICs are used to amplify and convert the 73 kHz signal into a 455 kHz and then deconstruct it into an audible 1 kHz signal after it is filtered by the Rockwell Collins filter. Aside from various capacitors and resistors, the final main components are a 380 kHz oscillator and a 456 kHz oscillator that input to the NE602A oscillators and are used to heterodyne the signal as explained by Sonotronics technical support:

“The “first” NE602 heterodynes the incoming signal with a variable frequency “LO” (local oscillator) to produce a 455kHz IF (when looking for a 75kHz input, LO is set to 380kHz to produce a ‘sideband’ of 455kHz). The resultant signal is passed through the 455kHz filter, and this output is heterodyned at the ‘second’ NE602 with a fixed 456kHz (aka beat frequency oscillator) to produce a 1kHz sideband... in this version of the receiver, the 1kHz signal is used to indicate the presence of the desired initial signal (75kHz) and to produce an audible note as well [8].”

Because oscillator schematics were not available, the oscillator circuits needed to be designed. Many different resistor/capacitor/op amp configurations were experimented with to construct a suitable oscillator but none could produce a clean signal higher than 240 kHz.

### 4.2 Second Approach: Custom Design Circuit

The Sonotronics filter was designed to produce an audible tone for the operator to listen for. However, the project did not require the signal to be converted to a certain frequency but rather to accurately detect the pulse received from each hydrophone. With this in mind, a new filter was designed in LabVIEW that used an adjustable 73 kHz band-pass filter rather than using the 455 kHz mechanical filter. A preamplifier circuit was chosen to boost the gain of the signal before filtering. After filtering, a full-wave rectifier circuit was designed to convert the signal into a DC voltage proportional to the amplitude of the signal so that it could then be passed to a threshold detector circuit to compare the DC voltage and produce a voltage of 0 or a fixed value passed to the microcontroller to indicate signal detection. This combined circuit was constructed and tested in a controlled environment. Each circuit component produced output as expected. Schematics for all four of these circuit components including a test circuit can be seen in Appendix B.

## 6. Microcontroller Implementation

The microcontroller performs three main tasks in this system. First, it determines which hydrophone detects the signal first so that it can calculate the bearing with respect to the correct direction (the bow of the IVER2 vs. the stern). The output of the threshold detector for each hydrophone is tied to PIND2 and PIND3 on the STK500 board corresponding to the external interrupts INT0 and INT0 on the Atmega8 microcontroller chip respectively.

When one of pins goes to a high voltage state, the interrupt service routine (ISR) in the microcontroller program checks a variable to see if it was the first or second signal detected. If it was the first, it sets the variable for the 2<sup>nd</sup> ISR, starts a timer, and disables the interrupt that the ISR handled. The 2<sup>nd</sup> ISR upon handling its interrupt stops the timer, stores the timer count in a variable representing the time delay, sets a 2<sup>nd</sup> variable to indicate that the signal has been received by both hydrophones, and disables the interrupt it handled.

The main program then divides the timer count variable to determine the number of microseconds in the delay. This is then used to calculate the bearing according to equation 2 in section 3.1. The bearing is then output using Universal Asynchronous Receiver/Transmitter (UART) protocol. A 50 ms timer is then set so that interrupts are not re-enabled until after the signal pulse has expired. Upon expiration of the 50ms timer, an interrupt is generated and an ISR that handles the interrupt re-enables both interrupts.

If button 0 on the microcontroller is pressed, then the program will set the max time delay value used in bearing calculation to the previous time delay recorded. In this way, the system can be calibrated to any water environment and is important because the speed of sound is not constant for all water environments. See microcontroller code in Appendix C.

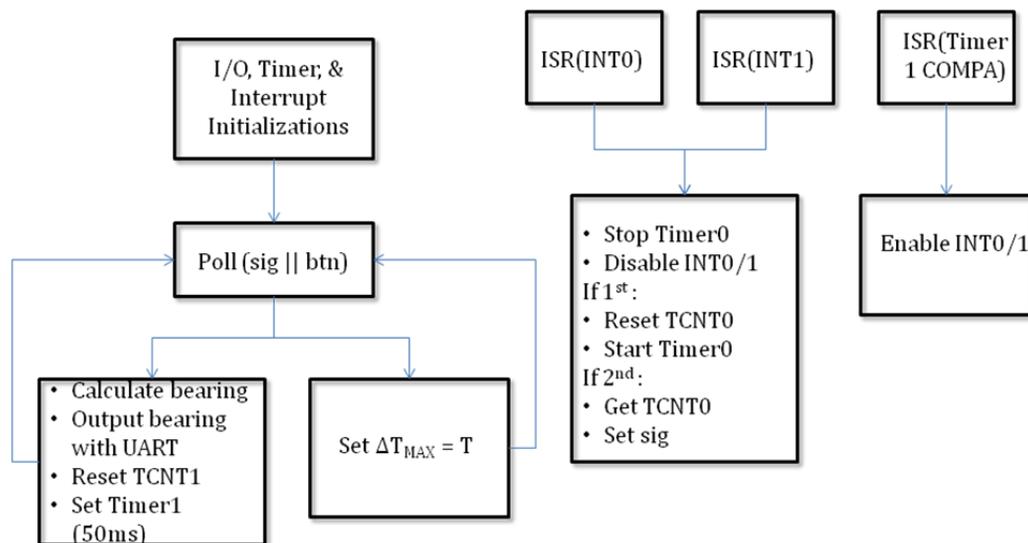


Figure 4: Block Diagram of Microcontroller Control Flow

## **7. Economic Evaluation**

### **7.1 Cost Report**

Most of the components for this project had already been purchased by Dr. Clark. This included the Sonotronics USR96 and transmitter as well as the Desert Star Systems omnidirectional hydrophones. The microcontroller was provided by Dr. Bryan Mealy. As all of these components are purchased by individual query only, the cost of each of these components is unknown however, it is estimated that the USR96 cost \$2,100 as per the Sonotronics suggested product price list though the USR96 itself is not needed for this system. Rather, it served as a model and guided development.

The initial approach required reproducing the signal filter/amplifier circuit in the Sonotronics USR96. The main components to be purchased were estimated at \$250 for two Rockwell Collins 455 kHz mechanical filters and eight NE602A oscillator ICs. Though only 4 NE602A oscillators were needed, extra were purchased as they were cheap compared to the mechanical filters and should any of them be damaged during circuit construction and testing, the project would be set back by waiting on shipping for replacement oscillators. Finally, several miscellaneous capacitors and resistors were needed at an estimated cost of \$15.

By the end of the project, the approach in designing and constructing a suitable filter/amplifier circuit had changed requiring additional capacitors, resistors, potentiometers, and op amps to be purchased adding another \$25 while the \$250 Rockwell Collins filters and oscillator ICs went unused. In total, the components purchased for the projected summed to \$290 while only approximately \$20 in components purchased were used in the final design. See bill of materials in appendix C for details.

### **7.2 Upkeep and Maintenance**

There is little monetary upkeep costs for this system. The only cost to the user in operating the device is providing and replacing a battery pack power source for the microcontroller and filter/amplifier circuit and replacing the Sonotronics shark-tag when the battery powering it drains. Upkeep for the shark-tag includes replacing it upon its battery draining. Replacement cost is estimated between \$180 and \$325 every 6 months to a year.

### **7.3 Commercial Considerations**

This system was intended for a single customer, Dr. Christopher Clark, for use in individual research projects and was not designed to be manufactured on a commercial basis. However, if commercial demand for this system existed, the target consumer base would likely be marine biologists. It is estimated that fewer than 10 ultrasonic shark-tag systems would be sold per year. As not all components for this system were purchased but rather were donated, the exact manufacturing cost per detector is unknown. A rough estimate of parts cost would be \$300 - \$500. This system was intended for nonprofit research and there are no marketing plans at this time.

## **8. Project Evaluation**

### **8.1 Development Report**

The project was initially estimated to require 5-8 weeks of development time which includes integration of the system into the IVER2 AUV. Work on the project began at the start of the Spring Quarter of 2010. However, many unforeseen setbacks were encountered most of which revolved around reproducing a suitable filter/amplifier circuit. The actual development time of the project was ultimately extended to 10 weeks. An estimated 2-3 weeks is further needed for system integration into the IVER2 AUV.

### **8.2 Manufacturability**

There are several manufacturing challenges associated with this system. The shark-tag, hydrophones, and microcontroller are manufactured by their respective designer companies: Sonotronics, Desert Star Systems, and Atmel. The only component of the system that was designed for this project and must be manufactured is the filter/amplifier circuit. The circuit consists of capacitors, resistors, and op amps which must be assembled on a printed circuit board (PCB) for placement inside the IVER2 where space is compact. As each of the component in the filter/amplifier circuit is common, it would not be difficult to have a 3<sup>rd</sup> party electronics prototype company assemble the circuit board as per the design schematics.

A different challenge in manufacturability comes in interfacing the Desert Star Systems omnidirectional hydrophones with the filter/amplifier circuit. The hydrophones were designed with a male XLR connector interface. In order to interface this to the circuit board, a female XLR connector needs to be cut with its terminal left intact and exposed wires from the severed cord soldered onto the input and ground of the filter/amplifier circuit. During testing of the filter/amplifier circuit, the circuit was assembled on a bread board and the connection between the hydrophone's XLR connector pins and input wires on the bread board was made using alligator clip wires.

### **8.3 Sustainability**

The system itself is very sustainable and requires no maintenance due to normal operation with exception to the Sonotronics 73 kHz shark-tag which may need to be replaced every 6 months to a year or more depending on frequency of usage as its battery will eventually drain. When the shark-tag is not in use, it can be deactivated by attaching a small magnet to the side of it with a piece of tape. This will pull open a switch in the transmitter effectively turning it off and thus extending its total lifetime. While this system doesn't directly impact the sustainable use of resources from a traditional energy standpoint, it does allow for an AUV to be used to closely monitor sharks in their environment without using human resources on a manned boat and diving crew that might otherwise follow and monitor a GPS tagged shark.

## **8.4 Social and Political Considerations**

While there are few ethical considerations to be aware of with this project, one possible issue could be considered with respect to the tagged sharks to be followed. As the system only determines bearing to the shark, it relies on the IVER2 to use appropriate control navigation logic to determine the relative distance to the shark by using the bearing rates of change with the speed of the IVER2. Thus, it's possible that an IVER2 employing this system without proper logic could navigate too close to the shark disrupting the accuracy of behavioral data gathered on the shark by scaring it or even colliding with it.

## **9. Future Work**

### **9.1 Ocean Environment Field Testing**

The next step for this project is to field test the system in the ocean. While it's not anticipated that there will be oceanic noise interference at a 73 kHz frequency, only a field test can confirm it. This requires attaching two Desert Star Hydrophones to a sturdy rig (a 2x4 piece of plywood would be sufficient), assembling and powering two filter/amplifier circuits along with the Atmel microcontroller and calibrating the system on site by placing the shark-tag directly in front of the forward-mounted hydrophone and pressing the calibration button on the STK500. Bearing can then be tested either by connecting the microcontroller to a laptop via an RS232 cable and reading the bearing output via UART or by monitoring the LEDs lit on the STK500 corresponding to the directional bearing within approximately 23 degrees of accuracy.

### **9.2 System Integration with IVER2**

After proven field tests, the system can be integrated into the IVER2. This requires space allotted inside the IVER2 for the microcontroller, and two filter/amplifier/threshold detector circuits. Additionally, they must be powered by the IVER2's battery pack or by a separate battery pack. The hydrophones must be secured onto the bottom of the IVER2 and the exterior where the hydrophone cords run inside to the IVER2 must be sealed and waterproof. Finally, control code must be written for the IVER2 to receive data from the shark-tag locator's microcontroller via UART protocol and for the IVER2 act appropriately according to it. This includes monitoring the bearing rate of change along with the IVER2's orientation rate of change to determine whether heading readings are with respect to the port or starboard side of the IVER2.

### **9.3 Design Optimizations**

When considering design optimizations, one improvement that can be made to the design of the project is microcontroller selection. The Atmel STK500 development board was used because it was available for this project without purchase as well as familiarity with the Atmel AVR software library. However, this board includes unnecessary features such as LEDs and interface ports for multiple microcontroller chips. These unneeded features add additional cost should a second system need to be constructed but the primary disadvantage is the amount of space the development board occupies. If a microcontroller and board are chosen that meet the minimum requirements and occupy the minimal

amount of space, then this system will be better accommodated to integration with the IVER2 AUV. There are many different microcontrollers available on the market each with their own libraries and architectures. A significant amount of time should be allotted for researching and selecting an appropriate microcontroller.

#### **9.4 Feature Additions**

When considering upgrades to system functionality, one feature that can improve the performance of the system is an auto-calibration function. One way to accomplish this is by using a 73 kHz speaker or transmitter mounted to the bow or stern of the IVER2 with signal output controlled by the system's microcontroller. By producing a controlled signal pulse in line with both Hydrophones, the maximum time delay between detections used for calculating bearing can be updated as frequently as desired (say once per minute) enabling the system to adapt to a dynamic environment and produce more accurate bearing measurements.

A further addition that could be made is the ability to determine relative distance to the transmitter. One way this could be accomplished is by tying the DC voltage output from the full-wave rectifier into an A/D converter on the microcontroller and comparing the voltage value against a set of tested voltages corresponding to distances. This would give the IVER2 greater ability to more precisely navigate about a tagged shark.

## **10. Conclusion**

During the course of this project, I learned several development tools and techniques. I learned Atmel Atmega8 microcontroller architecture as well as Atmel's AVR Studio 4 software used to program the microcontroller in C code utilizing the AVR software library. During the original approach of reproducing the Sonotronics USR96 filter/amplifier circuitry, I understood the heterodyning technique used to process the signal and produce an audible 20 kHz analog signal. When developing the system using only passive sonar, I intuitively derived the system for determining bearing based on time delay between hydrophone signal detections and time delay rates of change with respect to the changing orientation of the IVER2.

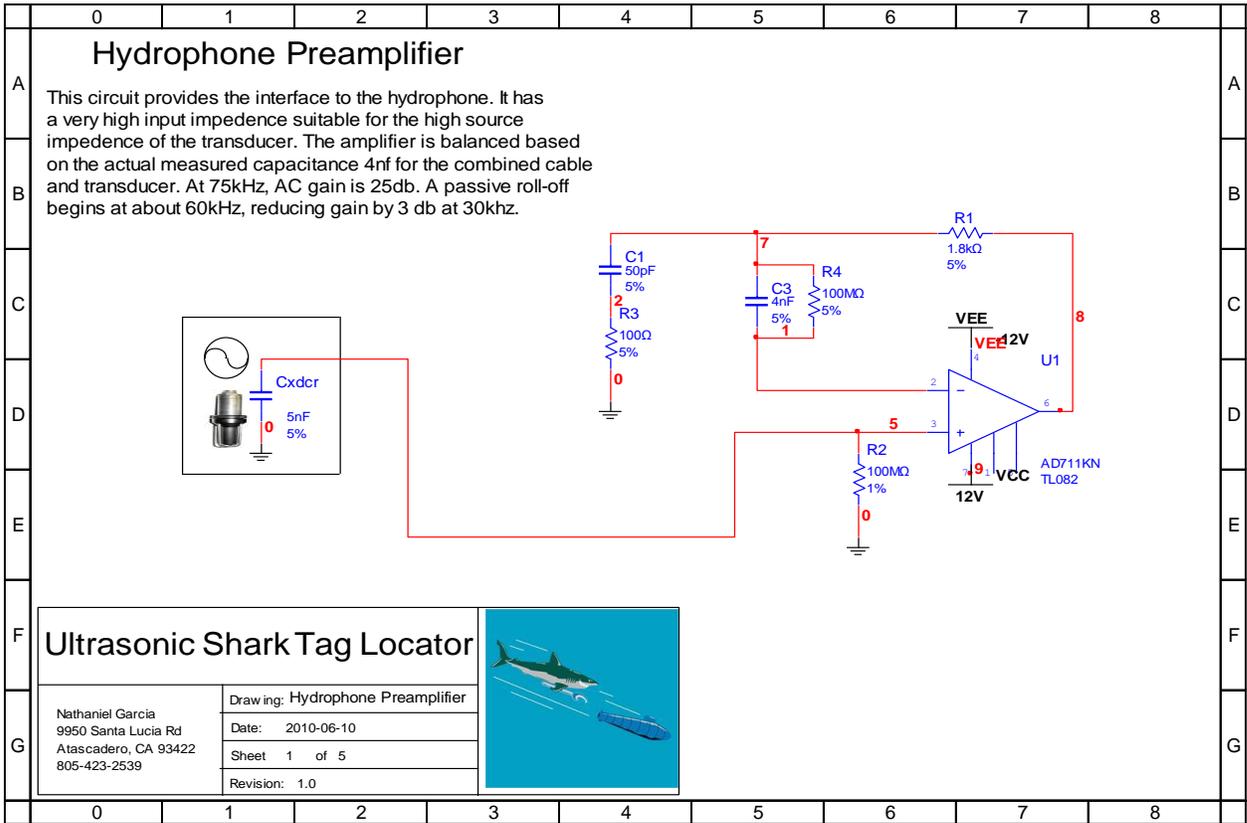
This project, while not completing field testing and integration with the IVER2, is a proof of concept of a system that utilizes passive sonar to determine a bearing from the system to a shark-tag transmitter. Additionally, it devised several further optimizations and feature additions for future IVER2 capability improvements. At this point, the system is ready for field testing and, pending desired results from the test, ready to be integrated into the IVER2 AUV.

## 11. Bibliography

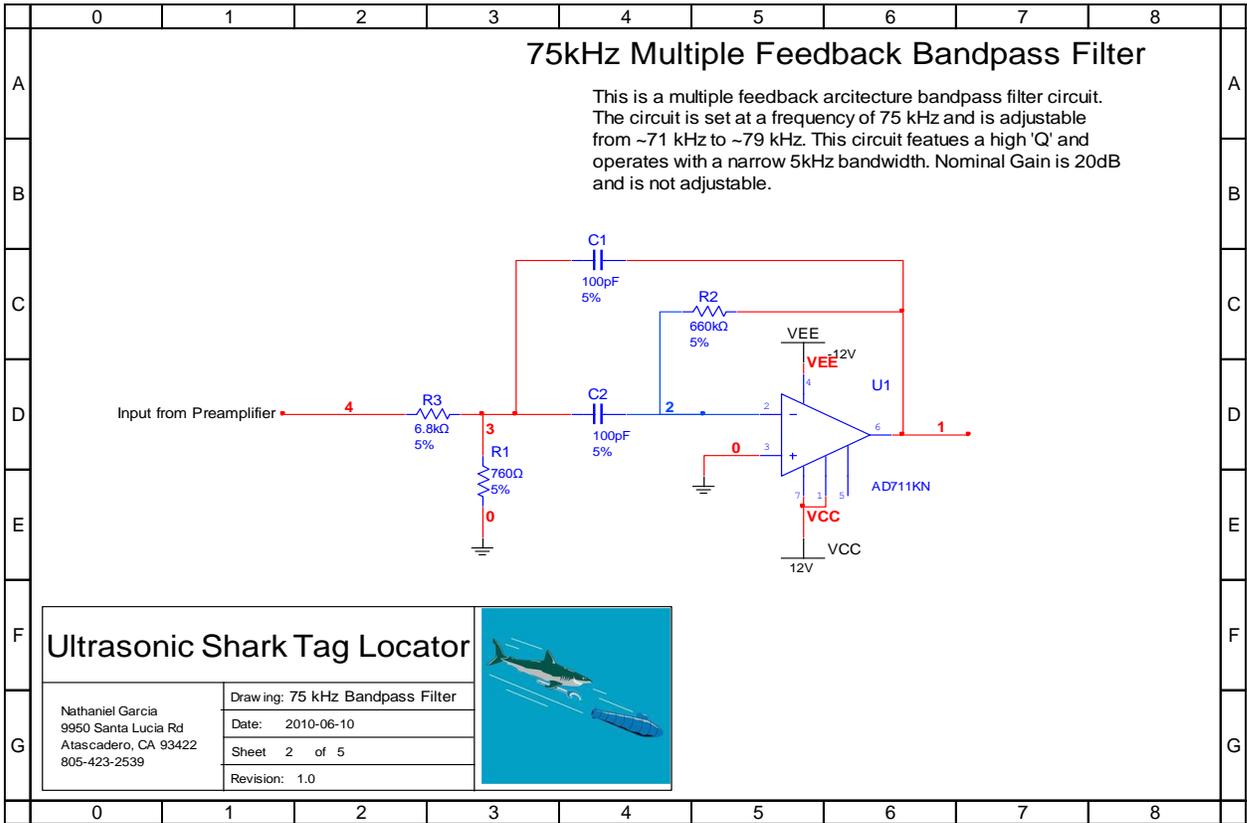
1. "DARPA Urban Challenge." DARPA | Home. DARPA. Web. 10 June 2010.  
<<http://www.darpa.mil/grandchallenge/index.asp>>.
2. "Iver2 AUV & Spares." OceanServer Online Store. OceanServer Technology, Inc. Web. 10 June 2010. <<http://www.oceanserver-store.com/iver2auv.html>>.
3. Clark, Christopher. Christopher Clark - Research. Christopher Clark - Research. California Polytechnic State University. Web. 10 June 2010.  
<<http://users.csc.calpoly.edu/~cmclark/research.html>>.
4. "Sonotronics - CTT Transmitters - Coded Temperature Telemetry." Sonotronics. Sonotronics. Web. 10 June 2010.  
<[http://www.sonotronics.com/products\\_html/ctt.html](http://www.sonotronics.com/products_html/ctt.html)>.
5. Sonotronics. CTT ACT Coded Temperature Transmitters. Tech. Sonotronics, 11 Dec. 2008. Web. 10 June 2010. <<http://www.sonotronics.com/docs/CTT%20Manual.pdf>>.
6. "Piezoelectric Sensor." Wikipedia, the Free Encyclopedia. Web. 10 June 2010.  
<[http://en.wikipedia.org/wiki/Piezoelectric\\_sensor](http://en.wikipedia.org/wiki/Piezoelectric_sensor)>.
7. "Low Cost Series." Rockwell Collins - Building Trust Every Day. Rockwell Collins. Web. 10 June 2010. <<http://www.rockwellcollins.com/about/additionalproducts/collinsfilters/lowcostseries/index.html>>.



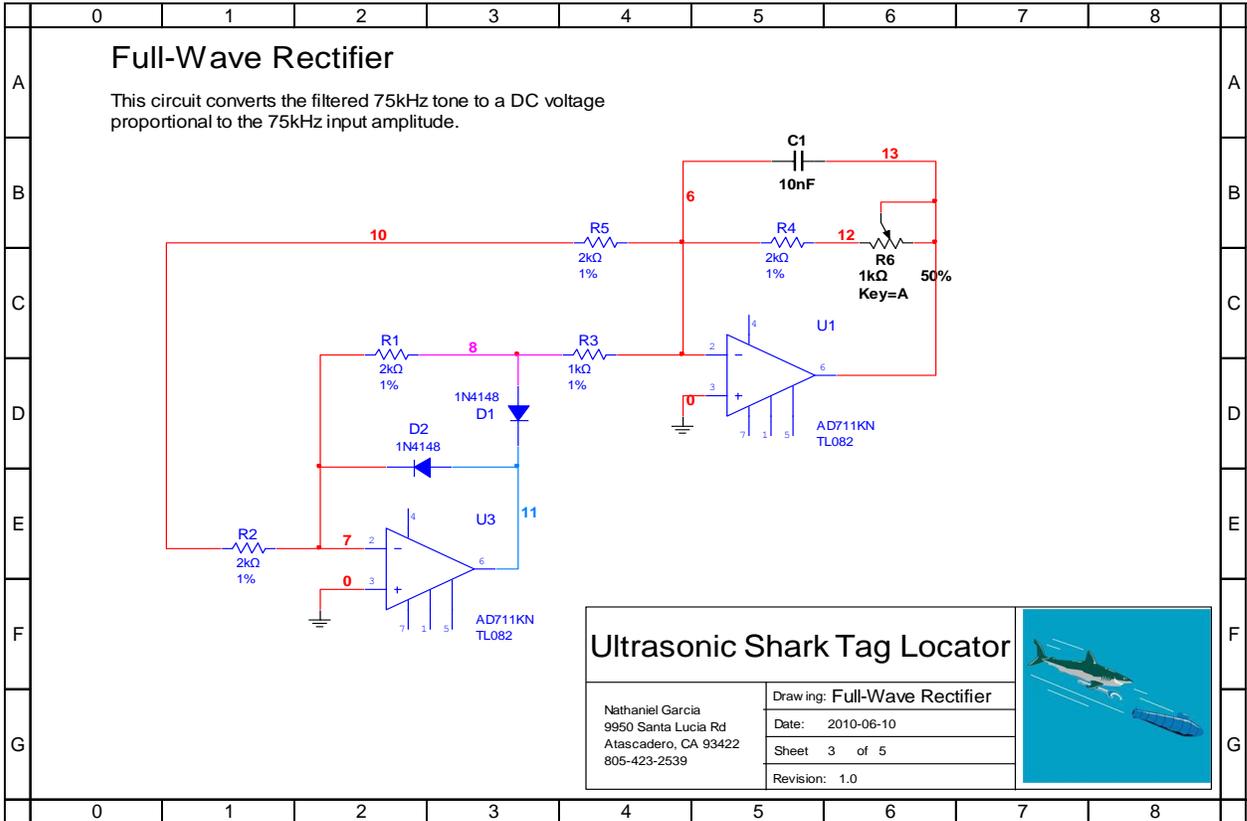
# Appendix B



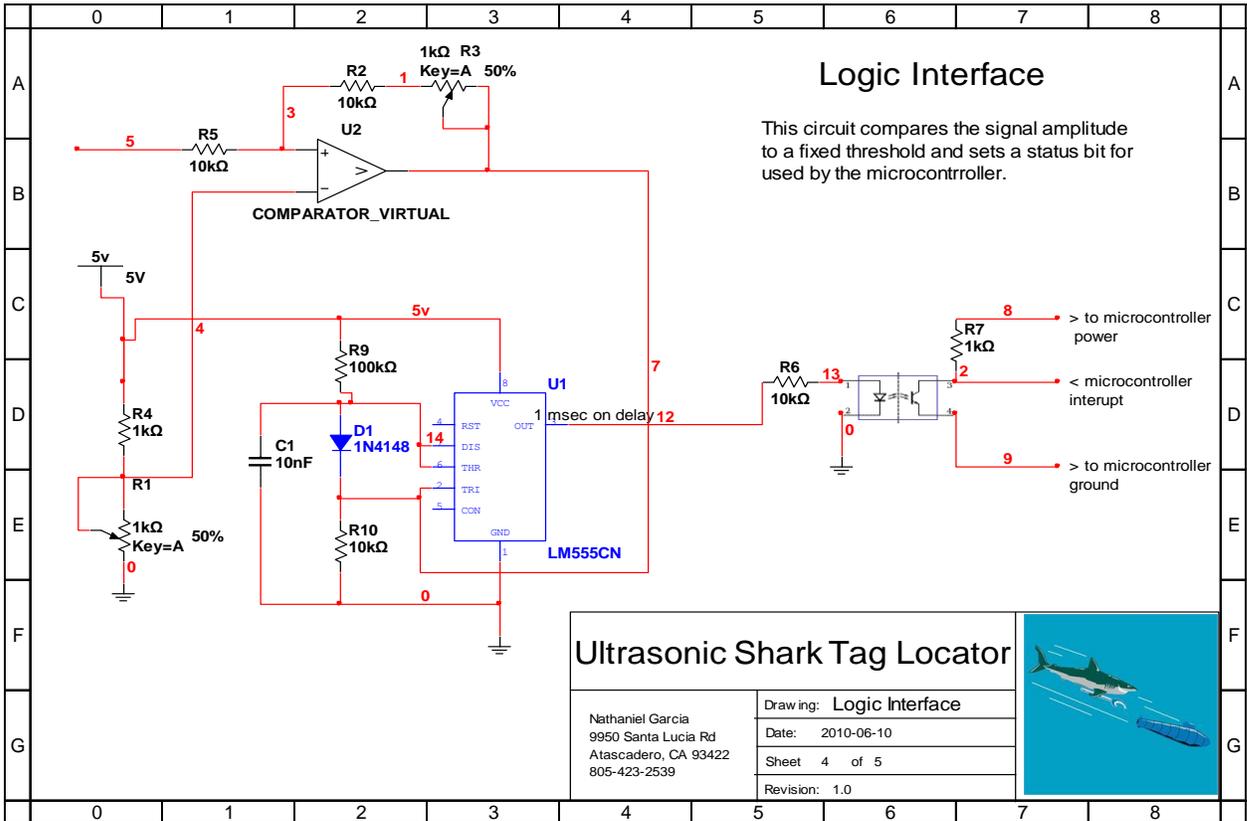
# Appendix B



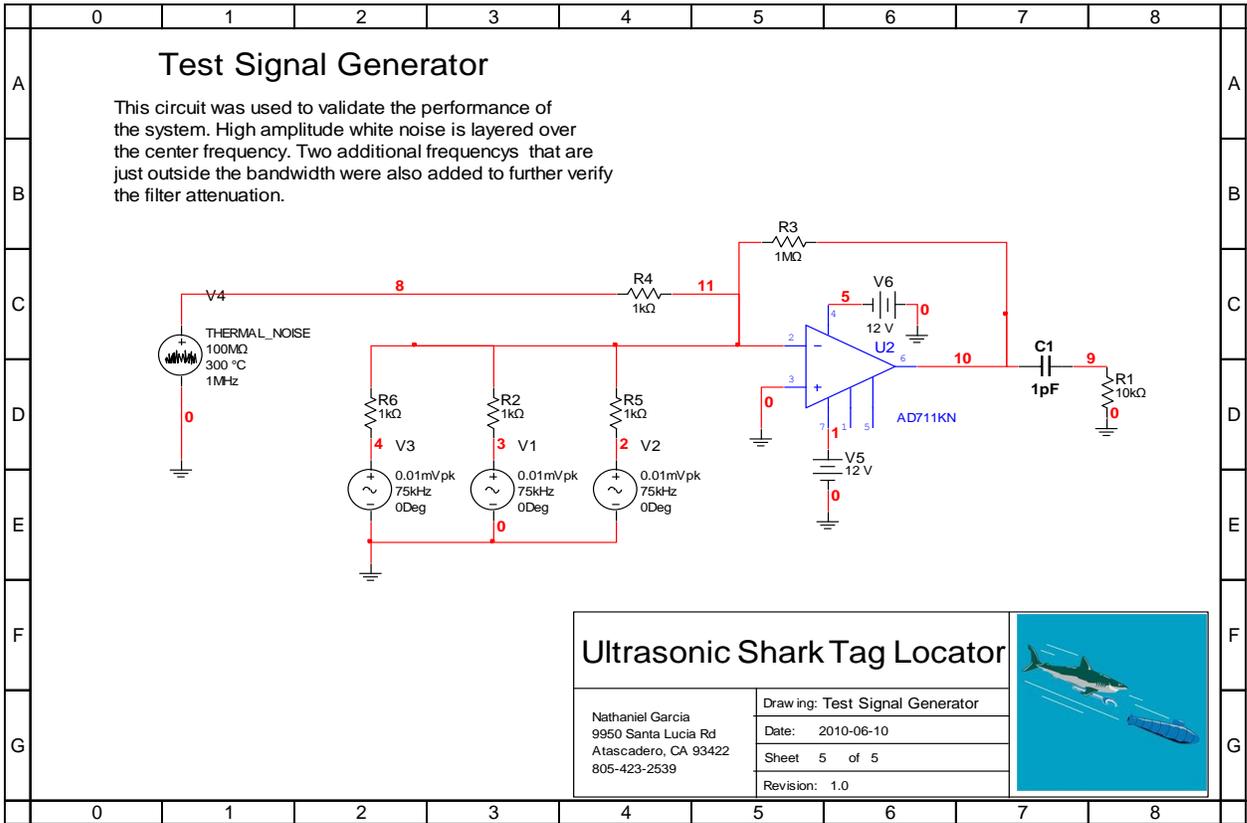
# Appendix B



# Appendix B



# Appendix B



## Appendix C

### Microcontroller C Code

```
//PORTB is connected to LEDs
//Switch 0 is connected to PD6
//External interrupts on pins PD2 and PD3

#include <stdio.h>
#include <inttypes.h>
#include <avr/io.h>
#include <avr/interrupt.h>
#include <math.h>

const uint16_t ctimemax = 641; //- Max us delay in ideal saltwater

//- timer prescaler / CLK frequency = 64 / 3,686,400 hz = 17.36 us
const uint16_t ctimeperiod = 17.36;

uint16_t signal, nosignal,time, timemax, isnegative;
int16_t bearing; //- can represent a positive or negative bearing

//- Interrupt service routine for external interrupt 0 (PD2)
//- Pin PD2 should be connected to the forward hydrophone. If this interrupt occurs first,
//- then the bearing is positive representing bearing with respect to the front Hydrophone
ISR(INT0_vect)
{
    //- Stop Timer0 if it's running
    TCCR0 &= ~(_BV(CS02) | _BV(CS01) | _BV(CS00));

    GICR &= ~_BV(INT0); //- Disable external interrupt0

    //- If 1st, start timer0. Else, store TCNT value, disable timer0, and set signal
    if(nosignal)
    {
        isnegative = 0; //- bearing calculated as positive
        nosignal = 0; //- set variable for 2nd interrupt

        TCNT0 = 0x0; //- reset Timer0 count
        TCCR0 = _BV(CS01) | _BV(CS00); //- Enable Timer0 with 64 prescaler
    }
    else
    {
        //- The time represented by the value in TCNT0 is equal to (TCNT0 / 57,600 Hz) seconds.
        //- 57,600 is derived from CLK frequency / prescaler = 3,686,400 / 64 = 57,600
        time = TCNT0; //- get timer count.

        nosignal = 1; //- reset variable for next 1st interrupt
    }
}

//- Interrupt service routine for UART data register empty interrupt.
```

```

//- Used to indicate
ISR(USART_UDRE_vect)
{
    //- Disable interrupt on data register empty status
    UCSRB ^= _BV(UDRIE);
}

//- Interrupt service routine for external interrupt 1 (PD3)
//- Pin PD3 should be connected to the back Hydrophone. If this interrupt occurs first,
//- then the bearing is negative representing bearing with respect to the back Hydrophone
ISR(INT1_vect)
{
    //- Stop Timer0 if it's running
    TCCR0 &= ~(_BV(CS02) | _BV(CS01) | _BV(CS00));

    GICR &= ~_BV(INT1); //- Disable external interrupt 1

    //- If 1st, start timer0. Else, store TCNT value, disable timer0, and set signal
    if(nosignal)
    {
        isnegative = 1; //- bearing calculated as negative
        nosignal = 0; //- set variable for 2nd interrupt

        TCNT0 = 0x0; //- reset Timer0 count
        TCCR0 = _BV(CS01) | _BV(CS00); //- Enable Timer0 with 64 prescaler
    }
    else
    {
        //- The time represented by the value in TCNT0 is equal to (TCNT0 / 57,600 Hz) seconds.
        //- 57,600 is derived from CLK frequency / prescaler = 3,686,400 / 64 = 57,600
        time = TCNT0; //- get timer count.

        nosignal = 1; //- reset variable for next 1st interrupt
    }
}

//- Interrupt handler for Timer1 Output Compare
ISR (TIMER1_COMPA_vect)
{
    TCCR1B &= ~(_BV(CS12) | _BV(CS11) | _BV(CS10)); //- disable Timer1

    GICR = _BV(INT1) | _BV(INT0); //- Enable external interrupts 0 & 1
}

```

```

//- Transmit 1 byte at a time from bearing with big endian network byte order
//- To read this data, the receiving microcontroller should use code similar to:
//- val_16 = (uint16_t)UDR << 8; //- get most significant byte
//- val_16 |= UDR; //- get least significant byte
void send_data()
{
    //- Write 1st byte of data
    UCSRB |= _BV(UDRIE); //- Enable interrupt on data register empty status
    while(!(UCSRA & _BV(UDRE))); //- Wait for empty UDR
    UDR = (bearing >> 8); //- Write 1 byte of data

    //- Write 2nd byte of data
    UCSRB |= _BV(UDRIE); //- Enable interrupt on data register empty status
    while(!(UCSRA & _BV(UDRE))); //- Wait for empty UDR
    UDR = (bearing & 0x0F); //- Write 1 byte of data
}

//- Represents the bearing using the LEDs on the STK500
//- 6 LEDs on STK500 / 180 degrees = 15 degrees of precision represented
//- by each LED. That is, 0 to 90 degrees is represented by LEDs 5 to 0
//- in segments of 15 degrees. Only the absolute value of degrees is
//- indicated by the LEDs.
void set_leds()
{
    static uint16_t degrees;
    degrees = fabs(bearing * 180.0 / M_PI); //- Get absolute value of degrees

    //- Show LED corresponding to bearing in 15 degree segments
    if(degrees <= 15.0) PORTB = ~(1<<5); //- Turn on LED5 only
    else if(degrees <= 30.0) PORTB = ~(1<<4); //- Turn on LED4 only
    else if(degrees <= 45.0) PORTB = ~(1<<3); //- Turn on LED3 only
    else if(degrees <= 60.0) PORTB = ~(1<<2); //- Turn on LED2 only
    else if(degrees <= 75.0) PORTB = ~(1<<1); //- Turn on LED1 only
    else PORTB = ~(1<<0); //- Turn on LED0 only
}

```

```

//- I/O, Timer, variable, and interrupt initializations
void ioinit (void)
{
    DDRB = 0xFF; //- set portB as output
    PORTB = 0xFF; //- Set LEDs off

    //- Set PD5 to output to enable OC1A on Timer1.
    //- Set all other pins as input.
    DDRD = _BV(PD5);
    PIND = 0x20; //- set pin for OC1A

    TIMSK = _BV(TOIE0); //- enable Timer0 overflow interrupt

    TCCR1B |= _BV(WGM12); //- set CTC mode

    //- Set output compare match for 1,199 (0x048F) to generate
    //- a 20hz (50ms delay) interrupt where the clock is 3,686,400 hz
    //- with a 1024 prescale using the frequency equation:
    //-  $f = 3,686,400 \text{ hz} / (1024 * (1 + 179)) = 20 \text{ hz}$ 
    OCR1AH = 0x00;
    OCR1AL = 0xB3;

    TIMSK |= _BV(OCIE1A); //- enable Output Compare A Match interrupt

    signal = nosignal = time = isnegative = 0; //- initialize globals
    timemax = ctimemax / ctimperiod; //- initialize Tmax for comparison with time

    //- Configure INT1 and INT0
    MCUCR = _BV(ISC10) | _BV(ISC00); //- Set interrupt on state change
    GICR = _BV(INT1) | _BV(INT0); //- Enable external interrupts 0 & 1
}

//- Initializes the UART
void init_uart(void)
{
    //- With baud rate 9600, fclk = 3686400 Hz:
    //-  $UBRR0 = fclk / (16 * BAUD) - 1 = 23$ 
    UBRR0 = (unsigned char)23;

    //- Enable transmitter
    UCSRB = _BV(TXEN) | _BV(RXEN);

    //- Set frame format: 8data, 1 stop bit
    UCSRC = _BV(URSEL) | _BV(UCSZ1) | _BV(UCSZ0);
    //- double transmission speed
    UCSRA |= _BV(U2X);
}

```

```

//- The main function
int main(void)
{
  ioinit(); //- I/O, interrupt, and timer initializations
  init_uart(); //- UART initializations
  sei(); //- global enable interrupts

  for(;;) { //- endless loop
    if(signal) //- wait until interrupts from both PD2 and PD3
    {
      //- Self calibration check to avoid acos( # > 1) = undefined
      if(time > timemax) timemax = time;

      bearing = acos(time/timemax); //- Calculate bearing (radians)
      if(isnegative) bearing = -bearing; //- Bearing is with respect to back hydrophone

      set_leds(); //- Represent the bearing using LEDs on the STK500

      send_data(); //- Send the data using UART

      TCNT1 = 0x00; //- Reset Timer1
      TCCR1B = _BV(CS12) | _BV(CS10); //- Enable Timer1 with 1024 prescaler
    }
    else if(!(PIND & 0x40)) //- Calibrate Tmax if switch 1 pressed
    {
      time = timemax;
    }
  }
  return 0;
}

```