Underwater Communications Device

Group 13

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“We pledge our honor that we have abided by the Stevens Honor System.”

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I. Abstract

Recreational, as well as professional diving has become extremely popular in the last 50 years. In this ever expanding market, new technology must be developed to handle diver's needs. Communication between divers, as well as topside with the crew is very limited. Most divers use hand signals or writing tablets as their only means of underwater communication. There is no way to check your fellow divers' information (air consumption, bottom time, etc.) except to manually read his or her gauges. If there was a way to network dive statistics between groups of divers, each diver could look up on his or her computer how their dive mates are doing and also communicate via text messaging. All this data could then be received by the dive master on the surface and he could track the progress of the dive from above. If there was an emergency, the dive master could look up the dive profile of that injured diver and give that important information to the hospital. For example, knowing how fast someone ascended could prove valuable to determine if there was lung damage or nitrogen sickness.

Our group has set out to develop all of the equipment necessary to implement a network of dive equipment and computers, similar to that of an ad-hoc network with access points and clients. We plan on having every diver equipped with handheld computers that will monitor all vital statistics. The boat will have an antenna that drops below the surface to receive all of this data and transmit it to a topside server. Each diver will have the ability to see the information of every diver, as well as receive messages from divers as well as the dive master. This can prove invaluable if conditions become too treacherous and fast communication is crucial. We have researched and come to conclusions as to what type of equipment should be used, how the network will work, and all of the details in-between. Two of the main theories we explored were using electromagnetic signals verses acoustic signals underwater, and which technology will be the better alternative.

II. Project Proposal Plan

1. Introduction

A. Transmitter/Receiver of Acoustic waves

Acoustic wave technology is nothing new. Ever since the implementation of sonar, sounds has been a very useful tool, especially used underwater. One of its key implantations today is underwater acoustic wave imaging. By sending sound waves to the ocean floor and surrounding areas, scientists are able to map with great detail, the size and shape of most rocks and formations. See Figure 1 in Appendix A-1 for an example of underwater acoustic wave imaging.

Not only is imaging used underwater, but also in testing for flaws in semiconductor production. Ray Thomas, of the SonoLab has been experimenting with using acoustic waves in combinations with x-rays to detect hairline fractures that will affect the quality of the materials made. The process uses and ultrasound to examine internal features. When the ultrasound penetrates solid materials, it is reflected back by two or more materials interfacing, and thus producing an image. The problem is having a computer detect which layers to process and which to ignore. To solve this, Ray Thomas wrote software is able to sort out the mess of images and provide a crisp, clear picture of the entire device [1]. See Figure 2 in Appendix A-1 for an example of ultrasound waves penetrating solid materials.

Smaller companies have been setup in order to study acoustics in the field of communication. One such company, called Applied Remote Technology Inc., has been created and they plan to develop autonomous undersea vehicle systems. These systems include undersea sensors, and all the communication links will be acoustic [2].

The military continue to be a source for innovation in acoustic communication. Just recently, the ICS Sensor Processing unit (ICS-1745) was released. It was a high-speed acoustic ADC board, designed for military sonar use. The main purpose of this board was to send out signals to detect mines both floating and on the floor, as well as provide vibration analysis using high frequencies [3]. See Figure 3 in Appendix A-1 for an image of the ICS-1745.

Wireless communication in itself, is a very low cost, high performance device. The difference in price between traditional radio frequencies is minimal, due to the fact that use of acoustic communications is smaller. The wireless connection must be extremely efficient in terms of energy, thus an optimal frequency must be chosen to lessen power consumption. Power out on the open seas is different from house hold power. Batteries much run almost every device, and this low amperage is preferred [4].

The frequency the military ICS-175 operates is at a standard 1.25 MHz, which has proven to be the best propagating frequency. The voltage, however, can be changed to amplify the power. This particular unit delivers 2.5 million samples per second, and supports voltage ranges from 20Vpp to .002Vpp differential. It is also compatible with windows and Linux [5]. See Figure 4 in Appendix A-2 for an image of the voltage amplifier mentioned above.

B. Connection between the receiver to the server onboard the boat

There are several components to consider when looking at the receiver in the water and the server located on the boat. The first is how the connection will be made. There are three possible considerations for the receiver communication being, coaxial, Ethernet, or wireless. Wireless is questionable, depending on the choice of receiver. For example, if our receiver is totally submerged than wireless will not be a viable option. However, if the receiver is mounted to the bottom of a buoy, the buoy will be sticking out of the water at the top and can have an antenna mounted that runs from the receiver. The signals can then be transmitted over standard wireless protocols to the main communication systems on the boat.

Regardless, there has to be a choice made whether to use coaxial or Ethernet cabling. Both mediums have had a wide array of applications in all sorts of locations for a high degree of projects. Coaxial has been mainly used to transmit cable TV signals, radio communication, as well as low speed data networks [6]. It is a rather outdated transmission medium compared to Ethernet. Ethernet cable has a wide range of uses in all aspects of networking. It is cheap to implement and can be used to wire a variety of equipment [7].

Looking at coaxial cable, it does not fare well in environments where humidity/water vapor, sunlight, or corrosive liquids (salt water) are present. Moisture migrating into the cables causes an increase in the level of attenuation in the cable. It increases the resistive loss arising from oxidation of the braid and it increases the loss arising in the dielectric. Water absorbed into the dielectric heats up when power is passed along the coax cable. This heat is as a result of power loss in the cable. Furthermore, sunlight and salt water in particular quickly degrade the integrity of the cabling reducing the serviceable life [8]. In the end, coaxial cables are not designed to withstand the harsh environmental conditions experienced outdoors; especially around salt water however it is possible to take the proper measures to water-proof as well as to use a high quality and durability cable.

On the other hand, there is a special connector for Ethernet cables that addresses the issues of water penetration and the corrosiveness of salt water [9]. The main issue with the Ethernet cable is at the connector so the Etherbus IP67 Water & Corrosion-Proof Connectors are the perfect solution in this application. They feature an easily installable connector that creates a water-proof seal resistant to fluids including water and oil. The connectors are rugged enough to withstand the above as well as shock, vibration and traction while maintaining standard Cat5E or Cat6 performance [10]. Additionally, a Kevlar-reinforced cable can be used to provide the extra durability and reliability necessary while exposed outdoors the elements. The cable is UV, hydrolysis, and microbial resistant and maintains the necessary toughness for an outdoor application [11]. This would be the perfect combination for any necessary connections between equipment.

Although it would be best to use this waterproof/ salt water resistant Ethernet cable and associated plugs where any data wires must be connected between devices in the network, we have decided to implement the use of a coaxial cable. The 600 series cable coaxial cable will be durable enough along with sealed connectors to be safely and effectively implemented in this design. Without any penetration from the elements, there will be no effect on the data passing through. Such a rugged cable is necessary especially when the data being transmitted already has a potentially high attenuation. It is important not to introduce any additional discrepancies especially in a comparatively trivial application.

C. Electromagnetic Wave Transmitters

Our first task towards choosing an electromagnetic wave transmitter/receiver system is to scope what frequencies our project is aiming to use. To help choose the frequency we would like to use, we can calculate the skin depth in seawater. In other words, the how deep an electromagnetic wave can penetrate the seawater medium. The skin depth (δ) can be modeled by the following equation:

$\delta = \frac{1}{\sqrt{\pi f u \sigma}}$ where f= frequency of the EM wave, μ = permeability of seawater, and σ = conductivity of the seawater [12]. For our purposes, we will be researching very low frequency (VLF) electromagnetic waves and low frequency (LF) electromagnetic waves.

Underwater antennas that have been used previously include loop antennas, long wires and dipoles. Research shows that the propagation (or skin depth) of electromagnetic waves are significantly influenced by the launching techniques used in EM transmitters. The launching and receiving of electromagnetic waves into water using conventional metal antennae occurs within the conduction band theory and could result in high signal loss [13].

One experiment in particular was similar to the setup of the system we are proposing. For their experimental trials, they constructed two identical antennae which were coated with an insulator and placed in salt water to transmit horizontal water transmissions. Different types of antennae were used, including loop, multi-loop, dipole, and folded dipole to test which types performed best in attenuation tests. Ultimately, the amplitude of the signal was greater over a longer distance for the loop control group, as seen in Figure 5 in Appendix A-2. Clearly, our implementation should prefer a loop configuration rather than a dipole [13].

D. Electromagnetic Wave Receivers

Although there have not been many experiments for the frequencies we are aiming to use in our implementation, there are several behaviors that others have seen which we should keep an eye out for. One of these experiments which dealt with receiving electromagnetic waves underwater used an identical antenna to the transmitter as described in the previous section. After the signal has been received, it is amplified. In this particular trial, they used a Mini-Circuits' MAN-1LN amplifier which cost about $22 each [14]. Unfortunately, there has not been much research for electromagnetic wave receivers at our desired frequencies. The best way to approach this problem is collect further information regarding this particular experiment and model electromagnetic wave transmitters and receivers based on their specifications.

E. Dive Algorithms/Computers

Dive computers use throughout the world of diving has been steadily increasing for years. Presently, almost everyone dives with some type of computer. Most computers nowadays display NDL (No-

Decompression Limit), depth, bottom time, and some do air gauge readings. The most advanced computers currently accept readings from various wireless sensors located on person and tank (such as air pressure from the first stage). [15]

Many dive computer companies have successfully used wireless communication (via RF) for intrapersonal (i.e. Bluetooth) type networks underwater. Not so many companies have taken the next step and tried to set up communications between divers and the surface wirelessly (RF). With respect to the dive algorithms aspect of the product, the type of algorithms used in the industry have been thoroughly tested and tweaked for over 20 years. There is nothing revolutionary concerning the NDL calculations. As discussed in the last paper, there are some different approaches we can take to calculate this highly important metric (along with all the associated calculations and measurements).

We will still be using RGBM (Reduced Bubble Gradient Model) to create our NDL algorithm. This document [16] builds upon the document referenced in the previous report. Whereas the previous document went over the theory and mathematical aspects of RGBM, this document goes over creating an algorithm (which is more useful to us). A shorter and more concise paper [17] shows just the math needed to create the algorithm. This math consists of partial derivatives and other high level mathematics. Programming partial derivatives and other calculus skills will be needed to create this algorithm in C code. C code has the power and ability to run an algorithm of this nature. Any embedded system board or SoC will need to be able to run and compile C code. These days, even light dimmers are programmed via C code so processing capability vs. portability and power consumption should not be an issue. Power saving features will need to be an integral part of this device and creating an algorithm that uses the least amount of processing cycles will help with power consumption.

II-2. Design Requirements

A. Overall Functions

To comprehend the overall function of the system, please reference Figure 6 in Appendix A-3. The overall function of our system consists of two separate devices; the dive computer and the receiver setup. The dive computer is what the diver will wear on his or her wrist, and consists of a microprocessor and a transmitter/transceiver. This device will have sensors that calculate the pressure, depth, nitrogen levels, times, and any other important information and display it on a screen. This information will also be transmitted wirelessly by either electromagnetic waves or by acoustic signals.

The second part of the setup consists of the receiver and transceiver, the signal converter box, and the onboard server/laptop. The incoming signals will be picked up by an antenna that is located underwater beneath the boat. For electromagnetic signals, this will be a loop antenna, and be wired directly into a signal converter box located topside. The signals will then be converted into data that the computer can read and input into the server. For acoustic signals, there will be a hydrophone that picks up signals and it will be connected directly to the computer by a coaxial cable. Just as before, the data will be logged and displayed.

B. Acoustic Functions

To comprehend the acoustic functions of the system, please reference Figure 7 in Appendix A-4. The acoustic functions are much different from that of electromagnetic signals. The hydrophone will pick up any and all frequencies. The first check is if the signal is in the range of frequencies it is looking for. If not, it is rejected and continues listening. If the signal is correct, it then begins to process. The first step is to check for reverberation. Since acoustic waves normally reverberate, especially after bouncing off objects, this needs to be corrected. The second step is to check for wave distortion. Since the sound waves stretch out as well as diffract off of the surface of the water, the device sometimes needs to wait for the entire signal before it can process.

Once the wave is clear of distortions, it is processed into data. From there, the data is sent to a server where it will be stored and time stamped. The data will also be displayed in real time on a display.

C. Electromagnetic Transceiver Functions

To comprehend the electromagnetic functions of the system, please reference Figure 8 in Appendix A-5. The system will be a 2-way communication network, which requires the use of two individual electromagnetic transceivers. One transceiver will be connected to the dive computer; the other transceiver will be connected to the on-board laptop/server via Ethernet cable. In other words, both components will be able to send AND receive data. The flowchart above contains all the components of one electromagnetic transceiver. The flowchart shows the process flow for both the receiving side (shown by the orange arrows) as well as the transmitting side (shown by the green arrows). The components of the flowchart which are separate system components than the transceiver are the Dive Computer, Ethernet cable, and Battery. These components were shown to show how the transceiver is connected to other portions of the system.

For the electromagnetic range we are planning on sending the waves (< 15 m), there have been few previous experiments documented which test different antennae underwater. One of the few we found included four experimental antennas. When the antennae were placed in direct contact with the seawater, no transmission was possible [18]. Horizontal propagation using electromagnetic waves was possible when identical loop antennas coated with insulation were placed underwater (see Figure 9 in Appendix A-5). Further research concluded that when electromagnetic waves propagate underwater, loop-type antennas had larger amplitudes over longer distances than dipole-type antennae. See Figure 10 in Appendix A-6.

To produce the electromagnetic signals, the group could use crystal oscillators. The function of crystal oscillators is to apply a voltage to a quartz resonator. This quartz resonator feeds the mechanical resonance of a vibrating crystal to an amplifier. The amplifier sends the amplified signal back to the resonator to create an electromagnetic wave at a correlated resonate frequency [19].

The receiver portion of the transceiver will send the raw data from the antenna through a direct Ethernet cable to the on-board laptop/server on one side. The opposite side's receiver will send the detected signals to the dive computer which will process the data.

These electrical components would have to be housed in a protective housing system. The protective housing's functions would be to protect the electrical components from water and salt.

Depending what side of the system the transceiver is located, the transceiver will connect to an Ethernet/standard cable OR through basic wiring to the dive computer. To visualize this better, please reference the overall functions block diagram near the beginning of the functional description section.

D. Server Functions

To comprehend the server's functions of the system, please reference Figure 11 in Appendix A-6. The computer on-board the boat will be the main base or server for communication. Data will be coming from either a RF/Acoustic converter if an Ethernet connection is used or through USB if coaxial cabling is used to connect to the transceiver. Please see Figure 12 in Appendix A-7 for a representation of the coaxial consideration. Regardless, all information regarding diving statistics such as nitrogen levels, depth, chat, etc. will be displayed on the computer and monitored by the person overseeing the diving expedition. The server will poll the dive computers that are linked to it at 5 second intervals to request a data update. This should be a good amount of time as to not flood the communication line with requests for updates. This value may have to be altered though through testing depending on bandwidth and loss. This polling communication will continue for as long as the divers are in the water. The incoming statistics and data will be logged and saved to the hard drive in a structured CSV file so it can be available for review or analysis if necessary post-dive. Each incoming message will be processed by the server to identify its type, appended with a time stamp, and recorded in its respective log file. This way, messages of one type are organized and stored together for easy review.

Additionally, the server will be able to relay a chat communication message to all divers or a specified diver. This communication will trump the polling process, effectively giving it priority on the communication medium. Regular polling will resume once the chat message has been transmitted.

E. Traditional Dive Computer Functions

Besides all the communication aspects of this system, it still needs to perform the most important function (computation of NDL times). What is needed is for the system to take in all the necessary inputs (depth, time, previous dives and their associated stats), air pressure, etc. and compute and dynamically change the NDL time. Then have that NDL time be displayed to the diver in the form of countdown, or graphically. The block diagram shown as Figure 13 in Appendix A-8 presents this.

The central piece to this part of the system is the part that computes the NDL times. To do this, it only needs one input (depth). The rest of the calculations and data inputs can be derived. The computer can monitor the depth gauge reading and start the dive timer if the computer goes below 5fsw or 1 meter. It does not need air pressure readings to calculate the NDL since we are only using compressed air and not any mixtures such as Heliox or Nitrox. [20] The air pressure gauge reading here is strictly to output it to the display so the diver can see how much air he has left. The computational part of the dive computer can also handle logging of previous dives, which play a role is calculation NDL for subsequent dives. It takes roughly 24 hours for a person to completely off-gas from a no-deco dive. So if you had a dive and then go dive again in an hour, you will still have dissolved nitrogen in your system. The dive computer can take that into account and base its NDL calculation on previous dive values and surface interval time. The dive computer can display the limit before deco at the depth you are currently at, a graphical representation of how close you are to deco, (via a bar graph or colors, etc.) the current bottom time, the air pressure in the tank, your current depth, and it can also calculation ascent speeds. (If you rise too fast, Boyle's law comes into play and you could blow out your lungs or risk dissolved nitrogen coming out of solution.) These are all functions a typical dive computer does these days.

The dive computer could also take inputs from the transceiver part of the system and have those messages show on the display. Messages such as communications or other diver's stats would be typical examples. This part of the system would also send out data to the transceiver part concerning this diver's status and statistics as well as any communications the diver would like to send out to the group or boat.

II-3. Design Approaches

A. Technical Description of Design and Components

a. Server Hardware Implementation

As described in the functional implementation, the computer on-board the boat will be the main base or server for communication. For this implementation it has been chosen to use a Panasonic Toughbook 52. See Figure 14 in Appendix A-9 for a block diagram of the server hardware implementation. The Toughbook is a rugged laptop designed to withstand environmental shock and exposure. It features a waterproof keyboard and water resistant port closures to prevent moisture from penetrating the internals [21]. The Toughbook is selected here as being the optimal hardware to use in a real-world regular use application. The pricing for this particular model is around the $1600 level [22]. Of course any laptop will do for preliminary testing as long as it is capable of running a rather simple application that monitors the dive computer network as described in the functional description. This hardware should not be considered as a cost of the project.

The next piece of necessary hardware to serve as a sort of gateway between the server and the transceiver is a type of data acquisition device that interfaces via coaxial from the transceiver end and USB to the laptop. This device is necessary as it would be rather difficult to incorporate a coaxial connection directly into a laptop. For this purpose the Behringer UCA202 USB Interface device will be used. It features two RCA inputs, two RCA outputs, and a USB interface [23]. A simple RCA to Coaxial adapter can be used to convert between the two cable types as it is a direct conversion and not a signal conversion. The UCA202 is fairly priced at $30.

A great amount has been mentioned about coaxial connectivity throughout amongst the wired components in this network. In particular, the connection coming from the surface water transceiver, located near the boat yet still underwater, to the server on the boat. The particular cable that will be used in this application is 600 series coaxial cable. It is designed for easy installation with maximum flexibility. The cable is constructed of a UV resistant polyethylene jacket providing maximum durability and protection from harsh elements and is designed for any application requiring high-quality [24]. The selected connector types to use with the cable are the Type N connector. The Type N uses an internal gasket to seal out the environment, and is hand tightened [25]. This feature aids in sealing out water from penetrating the dielectric material within. Obviously, the entire connector will be further waterproofed with a coaxial sealant to limit direct exposure to water. A 50 foot length of this cable with connectors and sealant costs roughly $100. It is on the expensive end of the spectrum but in this case necessary in dealing with water or salt water environment. As an alternative, the 900 series coaxial cable offers higher water resistivity; however, it is at a premium. The cable is thicker, making it more difficult to maneuver as well as being nearly 3 times the price of the 600 series [26]. Hence, the 600 series cable with the Type N connectors will be the necessary means for wiring together the non-wireless devices in the network.

b. Acoustic Transceiver

The acoustic transceiver consists of three main components. Please reference figure 15 in Appendix A-9. The first is the hydrophone. In the industry, hydrophones are used in numerous applications, from whale watching to fishing. You can buy hydrophones that detect certain frequencies depending on what you are broadcasting. One popular Hydrophone is the SQ26-08. This particular piece of equipment has a linear frequency range of .016 to 122 dB, 122 to 250+ with a usable frequency from .006 to 250+dB. In other words, it is good at detecting infrasonic, audible, and ultrasonic sounds. It is completely waterproof and good up to 460 meters [25]. Since this is a standard piece of equipment, it does not need special software. This hardware is relatively affordable, only costing about $100.

The second component is the Transmitter. However, in researching an acoustic transmitter, the group soon realized that hydrophones are readily available; transmitters are never sold by themselves. Instead they are coupled with their own, inferior hydrophone. For this project, our group would use a separate, superior hydrophone which was mentioned above. The receive we chose was the Aquacom SSB-1001B. This particular device can transmit audio signals, as well as data with a single connection. IT is a US Navy approved transmitter device that can travel 1,500 meters in calm see (150 meters in extremely rough sea). It has a 120dB range, and has multiple preset channels [27]. This device retails for about $2,000 since it is also coupled with a hydrophone. In order to use this piece of equipment, all that is needed is a STX-101M adapter to USB to hook into a computer. The software we are using is going to be self-written for the product.

The last component is the connection to the computer. The cabling used is a standard twist pair with ruggedized polyurethane martial on the outside. This not only makes the cable waterproof, but also protects it from the elements. This particular cabling was designed for underwater use as well as use in Sea Water, so corrosion has already been factored into the design [28].

c. Electromagnetic Transceivers - Receiver portion

There will be two electromagnetic transceivers; one will be located on the dive computer end, the other on the server end. See Figure 16 in Appendix A-10 for a block diagram of the electromagnetic receiver's hardware implementation. Regardless of which end the receiver portion is located on, it will first receive an electromagnetic signal underwater. This signal will oscillate the electrons in the loop antenna receiver so they will detect a signal. As mentioned previously, there have been experiments conducted in the past which show that the best type of antenna to transmit/receive electromagnetic waves underwater is a "loop-type" antenna which is covered by insulation. For the group's hardware implementation, copper wire antennas will be constructed for both transceivers. As the transmitted electromagnetic signal arrives at the loop antenna receiver, the copper will resonate at the corresponding frequency of the signal.

Since the signals are modulated, these signals will be sent to a demodulator. Demodulation is the act of extracting the original information-bearing signal from the modulated carrier wave. The actual circuit recovers the information from the carrier wave [29]. There are two different types of demodulators for AM signals- envelope detectors and product detectors. Although envelope detector circuits are simpler (they generally consist of a crystal diode to detect tiny fluctuating currents [30]), the group decided to use the product detector type of demodulation. The product detector multiplies the incoming analog signal by the signal of a local oscillator with the same frequency. After filtering, the original audio signal will result [29]. Despite the more complex setup, the product detector will be necessary because of the great attenuation of electromagnetic waves underwater. The filtering of these incoming EM signals will ensure that the information received is accurate.

After the electromagnetic waves have been sent through the product detector, the signals are amplified by a RF amplifier. This portion of the process is necessary to aid the direct-conversion receiver with filtering out additional noise during the demodulation process.

The amplified signals are now sent to the direct-conversion receiver portion of the demodulator. This is where the amplified signal is mixed with the local oscillator signal synchronized in frequency to the carrier of the unwanted signal. By passing through a low-pass filter, the signal containing information can be obtained [31].

Finally, the resulting demodulated signal can be passed onto the dive computer or the boat's server. On the server end, the direct conversion receiver will be connected to the server using coaxial cable. The other end will connect to the direct conversion receiver to the dive computer by electrical wires.

d. Electromagnetic Transceivers - Transmitter Portion

The source of the transmission will be from the dive computer or the server. For signals coming from the on-board server, there will be a coaxial computer which connects the server to the underwater transmitter. There will be electrical wiring to connect the dive computer transmissions to the modulator. See Figure 17 in Appendix A-11 for a block diagram of the electromagnetic transmitter's hardware implementation

The source signals will be sent to a modulator which is built into the transceiver. The modulator modulates the strength of the radio wave [30] by converting the signals into specific pulses which will then be forwarded to the crystal oscillator.

A crystal oscillator is a circuit which sends a voltage through a crystal. The crystal will resonate at a predetermined resonating frequency of the material. This resonating frequency will generate electromagnetic waves. These waves will be fed through an amplifier to ensure the wave will have ample attenuation through the water medium.

The amplified signals will be sent from the oscillator to the transmitting loop antenna. The antenna will be identical to the receiving loop antenna, again coated with insulation to protect the antenna from the elements and difference in conduction between the copper antenna and the seawater.

e. Transceiver to Dive Computer

The microcontroller will also connect to the network stack. (In this case either the acoustic or EM transceiver) The hardware needed (besides the antenna) can be located on the same PCB. The transceiver will change either the RF or acoustic wave signals into electrical signals that can be interpreted by the microcontroller. These signals can then be modified in the program and interpreted correctly. For example, a communication from the boat would be displayed on the LCD.

f. Acoustic vs. Electromagnetic

Throughout the project, the group has been debating on using either electromagnetic waves or acoustic waves. Through our research, we found the electromagnetic waves do travel underwater, however much less efficient than in air. Since sound waves propagate approximately 5 times faster underwater then they do in are, it has been shown that acoustics is the more efficient way to go without the limitations of distance and power. Electromagnetic waves would allow us to carry a massive amount of data, whereas acoustic only can carry about 10 kHz for a normal setup. However, this should be plenty of bandwidth to support our needs [32].

g. Dive computer hardware/software (including output to LCD)

The dive computer's brains will be a SoC like chip that offers a C-code complier so we can do the advanced programming necessary to compute NDL times. A microprocessor such as the 8/16-bit AVR XMEGA from Atmel would allow us the compute power necessary to calculate the NDL times as well as drive the LCD and handle IO from the transceiver stack. [33] We could have a company print us up a PCB with this microcontroller that could also include all the of the network stack components located on the same board. This will allow for decreased power consumption and a smaller unit. This microcontroller also has ADC and DAC capabilities so we can easily hook up our pressure gauge and depth gauge directly to the controller. It also includes a DMA controller that would help increase performance for the LCD display and the flash memory used to store dive data. The AVR UC3 Software Framework allows for complete software framework in C code, which is exactly what we need. C code is used all throughout industry and is a proven language that has been used for decades. The ability to have all the dive computer functions programmed in C is huge. Most programmers know C very well and components nowadays have the ability to take C code and run it that would have needed assembly code 20 years ago. The NDL algorithm will be programmed in C.

We would add either an analog or digital depth gauge and also the air pressure sensor. These would serve as inputs into the microcontroller. The microcontroller would then output to the LCD whatever data that needs to be displayed. The microcontroller will handle all NDL calculations and output those numbers both to the LCD and to the network stack. The LCD that we could use would be monochrome (since colors are subdued at depth) and monochrome LCDs are also more energy efficient. [34]

B. Mathematical or Other Principles Embedded in the Project

a. Acoustic Underwater Communication Research

The oceans make up approximately 2/3 of the Earth's surface. We as humans mainly stay on the 1/3 dry land sections, but due to increasing technology, we have been heading more and more towards the seas. The need for communication underwater has been an issue plaguing designers for years. The military demands state of the art communication technology between underwater vessels and is constantly looking for innovations. On a smaller scale, divers both recreational and professional have this same need to share information with other divers and with a host. There have been attempts to create Underwater Ad-hoc Networks (UANET) in order to communicate with mobile robots, but have so far been only mildly successful [35].

In researching many ways to communicate, one of the most prominent methods might be acoustic communication. Electromagnetic waves cannot propagate over long distances in underwater situations. Optical signals become strongly scattered and absorbed underwater, and they need ideal conditions to work properly (clear water with no sunlight or objects in-between). However, sound waves propagate approximately 5 times faster underwater then they do in air [36]. Data has been shown to be sent by acoustics using the orthogonal frequency-division multiplexing, or OFDM. OFDM is a multi-tone modulation to carry data. This data is separated in parallel streams, allowing multicast of single-carrier modulation setups. This type of technology is superior for it can compensate for defects or high frequencies in long copper wire without a filter. In our case, it can propagate through water with very little distortion [37].

This new type of network is not in existence today. As it stands, traditional underwater communication is point-to point communication. In other words, there is one sender and one receiver, usually a rover or robot. The network we are proposing consists of multi senders to a single receiver as well as the other senders, creating a network. Acoustic communication is very different from basic ground base radio communications. The bandwidth is extremely limited, approximately 10 kHz for a mid-range setup. This drop in bandwidth is due to the speed, as well as the absorption from objects as well as the ocean floor. This will work perfectly for our needs, for there is not much data being sent besides raw data, mostly raw binary data with field indicators, which will be interrupted by the host [38].

As the acoustic wave transmits in water, there is a propagation delay which is five times lower than the standard radio wave. This has to be accounted for in our receiver. As well as distortion cause by objects, we must worry about the reflection off of the water surface, particularly in shallow areas. The Doppler shift is relatively high and must be accounted for. All these problems we will address [38].

b. Underwater Signal Communication Overview

Looking through many articles it is evident that there has been a great amount of research taking place in the field underwater communication. Since electrical frequencies do not bode so well underwater, a majority of the research has been related to underwater acoustic communication. In many of the papers the goal has been to collect data "wirelessly" from an underwater sensor array or network measuring various environmental characteristics [39]. The information in this article dealt more so with the out of water receiver design looking a vector sensor versus pressure only array receiver. However this is still one aspect that will be important to our project as well.

Furthermore, there is a lot of information on signal to noise ratio (SNR) and bit error rate analysis using a variety of protocols and signal processing techniques. For example, there is analysis of various frequencies and their attenuation over distances as well as the resulting SNR. See Figures 19-21 in Appendix A-13 and A-14 for SNR data.

As a result, the bandwidth varies greatly with the range [40]. The greater the range, the lower the bandwidth as is shown in the table (Figure 22 in Appendix A-14). Others have looked at applying terrestrial networking protocols for use with the acoustic underwater communication. A study was done to analyze the performance of three such varieties [41]:

- ALOHA based half duplex protocol
- ALOHA based half duplex protocol with acknowledgements and retires
- MACA based half duplex protocol using RTS/CTS handshaking

Additionally, some useful equations for dealing with acoustics in water are [42]:

$$\mathrm{C} = 1449.2 + 4.6\mathrm{T} - .55\mathrm{T}^2 + .00029\mathrm{T}^3 + (1.34 - .01\mathrm{T})(\mathrm{S} - 35) + .016\mathrm{D}\frac{\mathrm{m}}{\mathrm{s}}$$

Where

C = velocity of sound
T = Temperature in degrees C
S = salinity in parts per thousand
D = depth in meters of the water layer in consideration

$$\alpha = 3.3x10^{-3} + \frac{.11fr^2}{1 + fr^2} + \frac{44fr^2}{4100 + fr^2} + (3.3x10^{-4}fr^2)dB/km$$

Where

α = attenuation in dB/km
fr = acoustic frequency in kHz

c. Electromagnetic Communication Underwater

In addition to underwater *acoustic* networks, another possibility is to use electromagnetic communication. Since we will be working with relatively shallow water, the phenomenon of multi-path propagation would be amplified. The speed of acoustic waves are relatively slow, approximately 1,500 m/s. Due to these slow speeds, the waves will arrive at the receiver at substantially different times causing an elongated data stream [43]. Taking multi-path propagation into account would require a hefty amount of signal processing; therefore we are researching the use of electromagnetic waves as well. See Figure 23 in Appendix A-15 for an example of multi path propagation [44]. The multi-path propagation delay present in acoustic signals would be very small for electromagnetic signals whose frequencies were kept in between 10-30 kHz.

On the other hand, there will be exponentially higher attenuation loss at 10-30 kHz frequencies. See Figure 24 in Appendix A-15 for a graphical representation of how the attenuation loss increases with an increase of propagation distance as well as frequency [45]. Our case will be an optimization problem of minimizing the attenuation loss while decreasing the propagation delay. As the graph suggests, when transmitting EM signals less than 10m there is attenuation loss less than 100dB (which can be considered a fair loss).

As far as mathematical representation of the attenuation between an electromagnetic wave transmitter and receiver underwater, use Maxwell's Equation:

$E = E_0 e^{-\alpha x}$ where x is the distance between the transmitter and receiver and α represents the attenuation coefficient [43]. There have been studies conducted which conclude that signal propagation strength decreases dramatically for transmitter-receiver distances over 15 meters in underwater communication [43]. Our receiver will not obtain a strong enough electromagnetic signal for distances greater than 10 meters. See Figure 25 in Appendix A-16 and note how the signal strength initially decreases rapidly as the distance between the receiver and transmitter increases. In the Liverpool study mentioned above, 5 watts of power was used to transmit the initial signal (which is not an exceedingly large power draw). Another interesting note about this study reveals that a 5MHz signal could theoretically enable a data rate of 500 kbits/sec.

Another factor our group must explore is the antenna equipment used for underwater communication. In practice, when conventional metal antennae are used, the true attenuation greatly differs from the theoretical calculation. In further research efforts, the investigation of what types of antennas may be used for our implementation of transmitting and receiving signals should be explored.

d. Diving Algorithms

The device, besides its wireless and networking functions, will need to perform all the regular functions that a normal, no-thrills dive computer would do. This includes the calculation of nitrogen on gassing and off gassing. The only two inputs needed for the calculation of nitrogen uptake are bottom time and depth. In a traditional dive table problem, these two variables are used to calculate "nitrogen time," whose values are based upon research and trial and error experiments done by the US navy. Nowadays, most people dive with devices that calculate their "nitrogen time" and tell the diver how long they have at that depth before they go into decompression. For the purposes of recreational sport diving (limited to 130 feet and no decompression) there are many algorithms available that can be used and adapted for specific needs. These algorithms were based upon the work of researchers and scientists over the years. Some examples of these algorithms include the ZHL (Buhlmann), Haldane, and RGBM (Reduced Bubble Gradient Model). For the limits of sport diving (where we plan to place this device) we are not using inert gases mixtures (Heliox) or Nitrox (enriched oxygen). We will be using plain old compressed air.

At pressures greater than 1 atmosphere, gases that are not exhaled or inhaled (carbon dioxide and oxygen) are absorbed into bodily tissues. The main gas in plain old air besides oxygen is nitrogen. At depth, our bodies absorb nitrogen and our tissues can become saturated. When this happens, nitrogen bubbles form and can cause the bends or decompression sickness, sometimes resulting in death. Also, when a diver ascends from depth, the pressure lowers, thus decreasing the saturation level of the tissue. Rising too fast from depth can also cause the bends, hence the need for decompression stops at varying depths. It is also standard practice in the sport diving world to do a 3 minute safety stop at 15 feet/ 5 meters for three minutes even when in a no-decompression profile.

Of the various algorithms, the RGBM is the newest and considered the most advanced. But for the purposes of sport diving, all these models can be used with adding our own safety buffer. Each company that makes dive computers, they consider their variation of whatever algorithm they use a trade secret. Each company adds on features to it, or more variables or more tissue regions. They also all build in a safety buffer. It is known in the diving community that certain brands are more conservative or more liberal than others. For the purposes of our devices, we will error on the side of caution and use the more physically correct model of RGBM.

Figure 26 in Appendix A-16 shows the risk estimate for each of the widely accepted dive tables and the oceanic dive algorithm, which is based solely on the dive tables and does not take into account things such as micro bubble behavior in the bloodstream (as RBGM does). Figure 27 in Appendix A-17 shows the risk estimate for various dive profiles according to two algorithms, the RGBM and ZHL. Their risk factor compares favorably to the tables [32].

One issue that could affect our ability to completely use the full RGBM model is the trade secret aspect of dive algorithms. If we are unable to procure a full RGBM model with equations, then we might have to switch to an older algorithm that is more publicly available. I have referenced a website that shows a basic coding scheme for the ZHL model. [46] This might be needed if RGBM does not pan out.

II-4. Financial Budget

See Appendix B for a numerical breakdown of the project's financial budget [49].

The dive computer industry is well saturated with many players, all employing various features and touting various algorithms, each claiming to be better than the competition. At the low end you have your no-frills basic dive computer, whereas at the top you have custom logging via windows programs and SCUBA mask HUB integration. Being able to differentiate our product via a new feature (electronic communication while at depth) will allow us to slot our product against the other dive computers while having a potential "killer" feature that could be a must have in ten years.

We could easily build a prototype in the price range of a few hundred dollars based on receiving evaluation materials and donations. We could then show potential financiers our prototype. The biggest risk to this project is the means of communication. If the means of communication can be proved, tested, and shown working to potential financiers, it will become a low risk/ medium risk project. In this case, a bank can finance the project. If the communication via RF is still untested, venture capitalists will be the only ones who would finance the project. In order to secure money for the funding of the project, we will need to prove to financiers that either acoustic or RF communication can work at depth and at a cost effective price. We could also try to win over some wealthy divers (who could be venture capitalists) since these type of people will realize the potential upside of electronic communication underwater more so than non-divers.

The military could also be interested in a new form of underwater communication. We could search for grant money based around this subject and apply for grant money in order to finance our project as well.

II-5. Project Schedule

Presented in the Gantt Chart and Work Breakdown Structure above is the timeline for this semester's work on the project and the division of labor of various components of the project (please reference Appendix C). The charts outline the major milestones and divisions that are needed to be completed during the course of the semester. The team attempts to stick to this outline but dates can be shifted accordingly as long as the deliverables are completed on time.

As the group lead and project idea developer, Brett has played a key role in developing the Design Requirements. He has the big picture in mind and is able to make sure the team keeps on track, heading the right direction. He also plays a key role in researching communication methods, protocols, standards, etc. for transmission that will need to take place within the system the team is developing.

Bryan and Ryan have similar responsibilities in that they have both researched necessary hardware and its operation that would be necessary in the system regarding underwater communication in their respective areas as outline above. Furthermore, Bryan is responsible getting the major deliverables together and organized from each team member as well as keeping track of budgetary expenditures. On the other hand, Ryan has taken on the task of getting the team's website up and is constantly working on updates.

Finally, Miroslaw's responsibilities lie in the scheduling for the team to make sure deadlines are met and the team is on track time wise in completing tasks and objectives. Furthermore, he is responsible for the interconnection of all the systems components. This is especially important since the team will be work on isolated components of the whole and everything will need to mesh together in the end.

In essence there is a lead person for each subject area of research and then each person has other responsibilities for things that simply need to get done. At each meeting, the team comes up with topics that need to be covered for the particular week and the more specific bullet points to address for each topic. The team members then select the area of most interest and focuses on that for the week. The team attempts to divide the topics as evenly as possible amongst the team so that each team member has a relatively equal responsibility. At the following week's meeting the research is integrated into the overall report under a specific category. The team feels this is an effective method of getting work accomplished efficiently and fairly and has worked effectively thus far. Through this method each team member does not have to be stuck doing research in a particular area and can expand and build up the knowledge necessary to complete the project.

III. Conclusion

The general purpose of this report is to research, analyze, and draw conclusions surrounding our project. This includes studying the technology, mathematics, and research topics in the field of underwater acoustics and networking. Our group was able to understand the difficulties of communicating underwater and by dividing up the research among all four group members, we each have become experts in the specialized field that has been assigned.

Having a firm grasp of the necessary technologies and concepts, the next step is to begin to design the actual device. By researching deep into what technology is available for purchase as well as what needs to be designed, we have set forth a plan to purchase items and begin the first phase of construction relatively soon. If successful, the group plans to have a completely working prototype and demonstration ready by next year. This prototype will consist of a dive computer attached to a submerged hydrophone that we have constructed. On the opposite end of the tank, there will be a wrist mounted dive computer (all of which is designed, built and programed by our group), and we will demonstrate communication between both of these devices by using acoustic waves.

Overall, we expect our group to be very successful. We have committed an extensive amount of time researching and studying the problem at hand, and we are extremely confident in our approach. By carefully weighing the pros and cons of every decision along the way, we can be sure our project will be a success.

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V. Appendices

Appendix A – Charts, Diagrams and Graphs

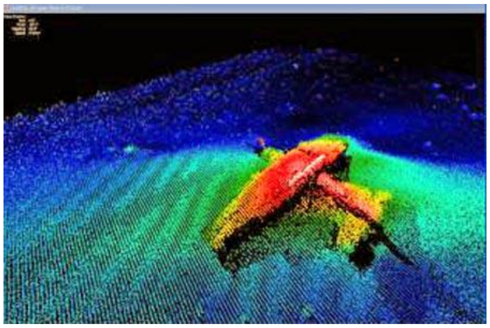


Figure 1. Here is an example of underwater acoustic wave imaging used to find an airplane which has sunk onto the ocean floor.

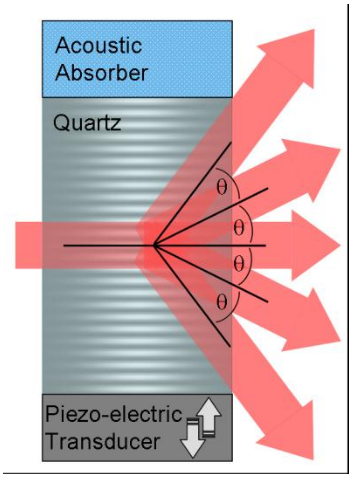


Figure 2. This figure shows an example of the effect of ultrasound waves penetrating quartz. The ultrasound is being reflected back by materials interfacing, and thus produces an image.

Figure 3. This is an image of the ICS Sensor Processing unit (ICS-1745).

Figure 4. This is an image of the voltage amplifier mentioned in the "Transmitter/Receiver of Acoustic waves" section.

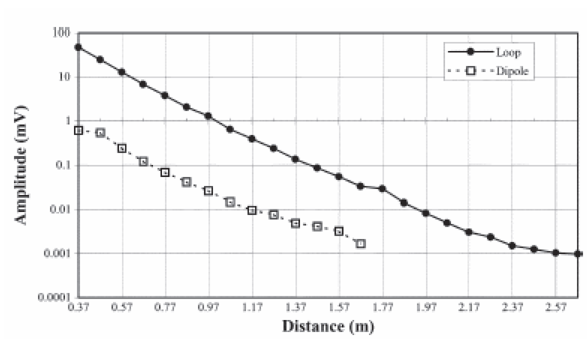


Fig. 12. Results of dock trials at 1 MHz frequency in vertical water.

Figure 5. For electromagnetic wave transmitters, it was found that the amplitude of the transmitted signal was greater over a longer distance for the "loop" type of transmitter.

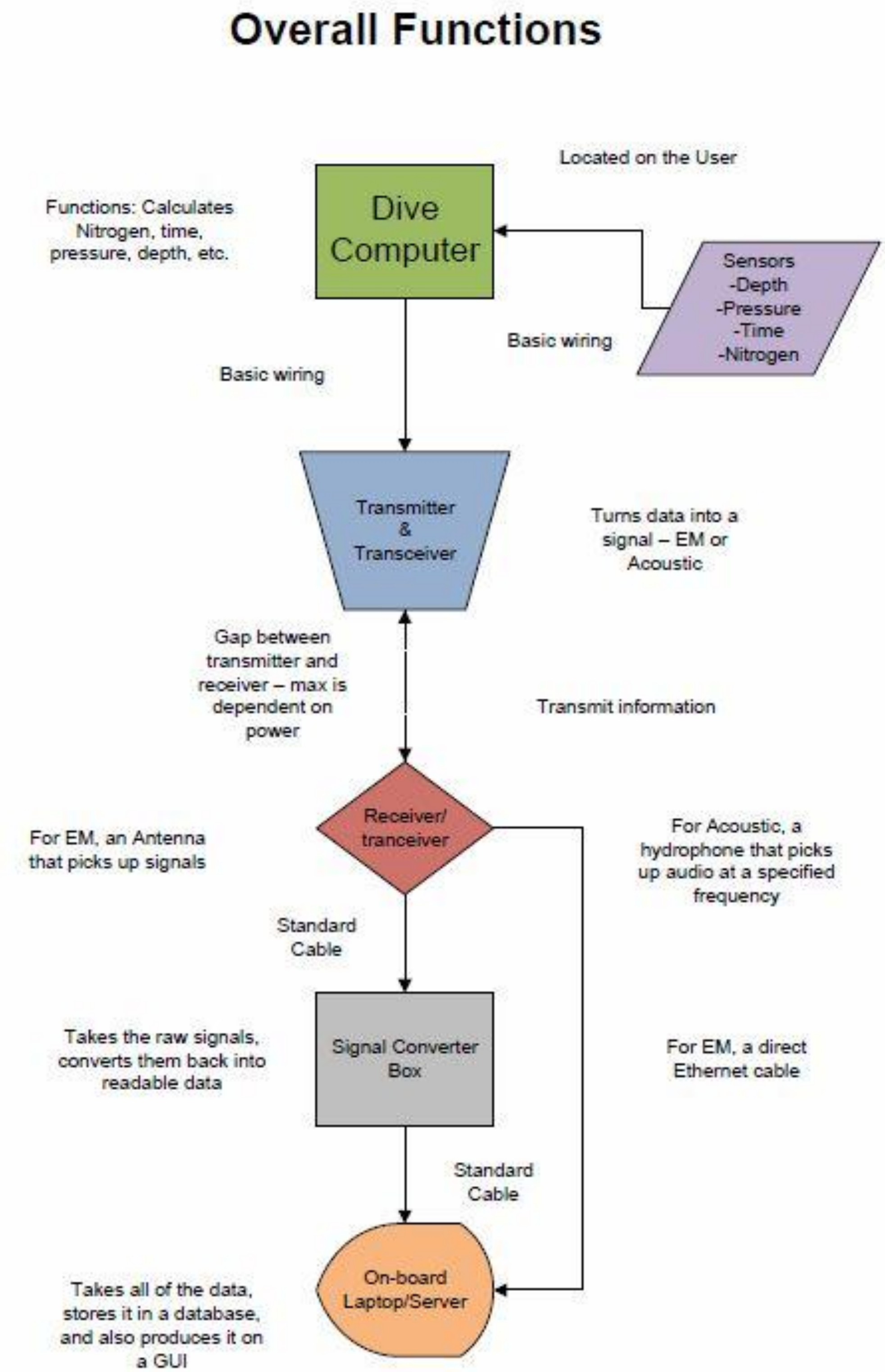


Figure 6. This figure represents all of the high-level functions of each individual component of the system.

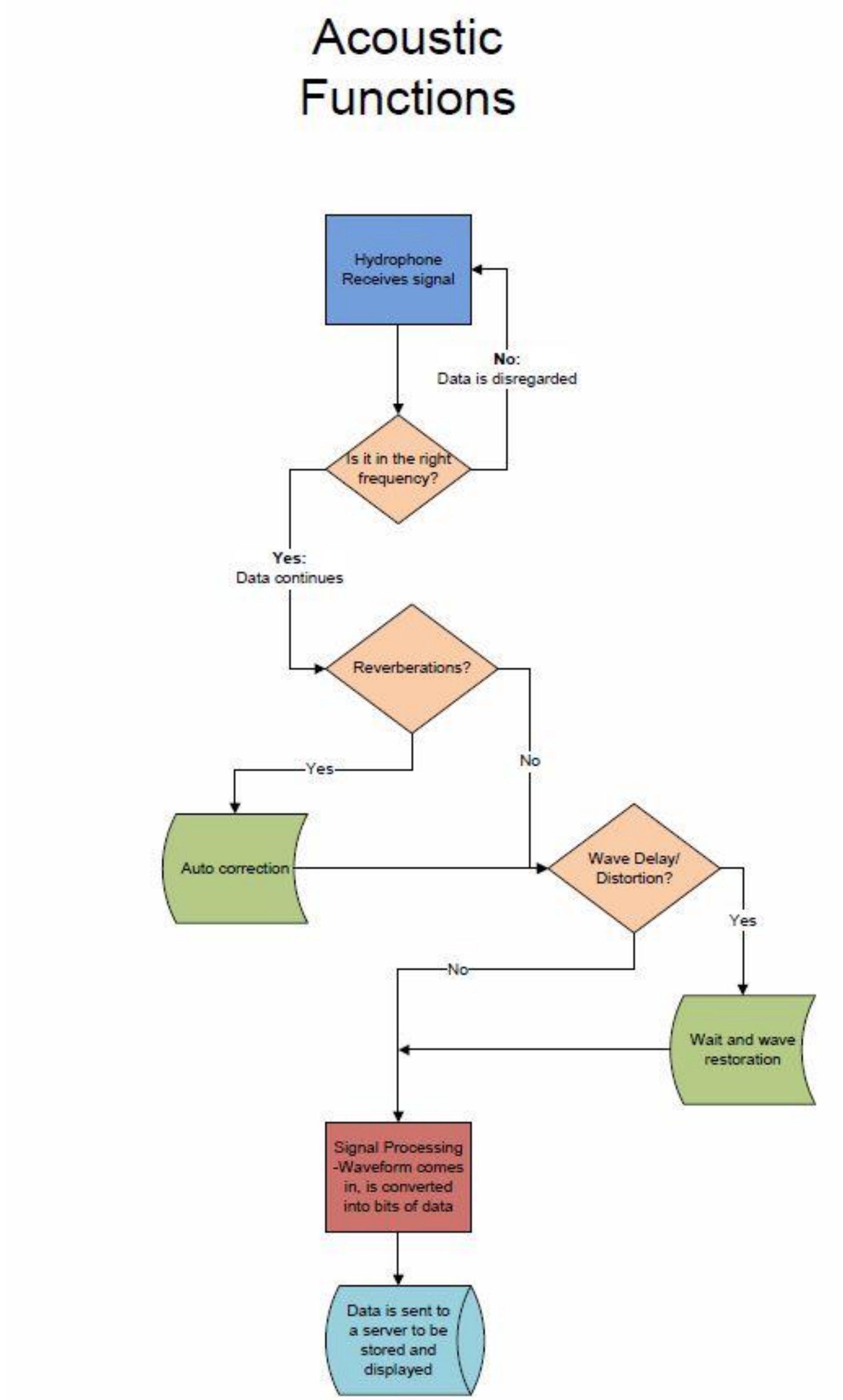


Figure 7. This figure represents all of the functions of the acoustic components of the system.

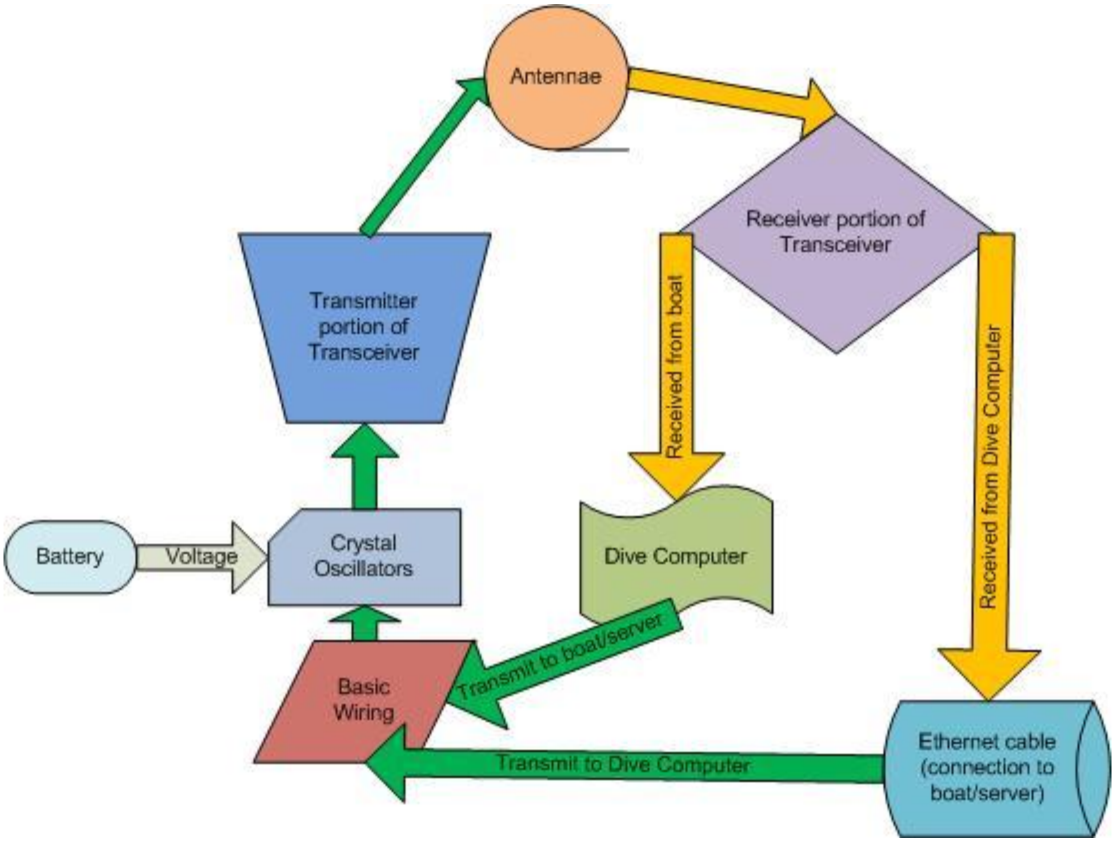


Figure 8. This figure represents all of the functions of the electromagnetic transceiver components of the system.

Figure 9. Identical loop antennas coated with insulation were placed underwater and successfully used electromagnetic waves for horizontal propagation.

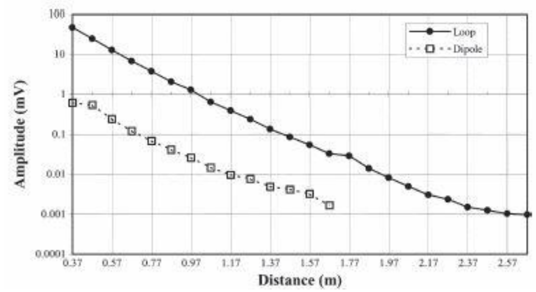


Figure 10. Further research concluded that when electromagnetic waves propagate underwater, loop-type antennas had larger amplitudes over longer distances than dipole-type antennae.

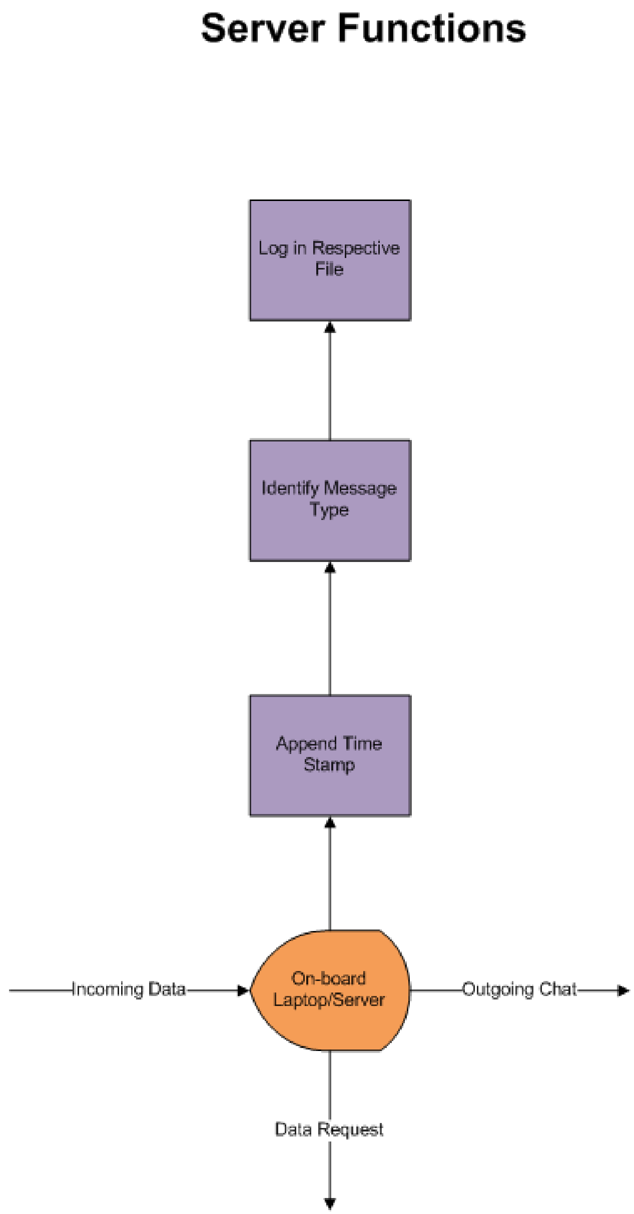


Figure 11. This figure represents all of the functions of the server onboard the vessel.

Coaxial Consideration

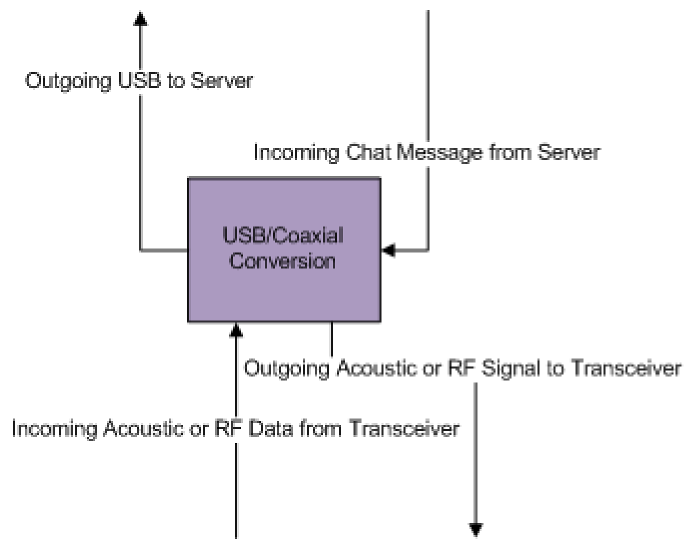


Figure 12. This figure represents all of the functions of the coaxial wire between the underwater transceiver and the server onboard the vessel.

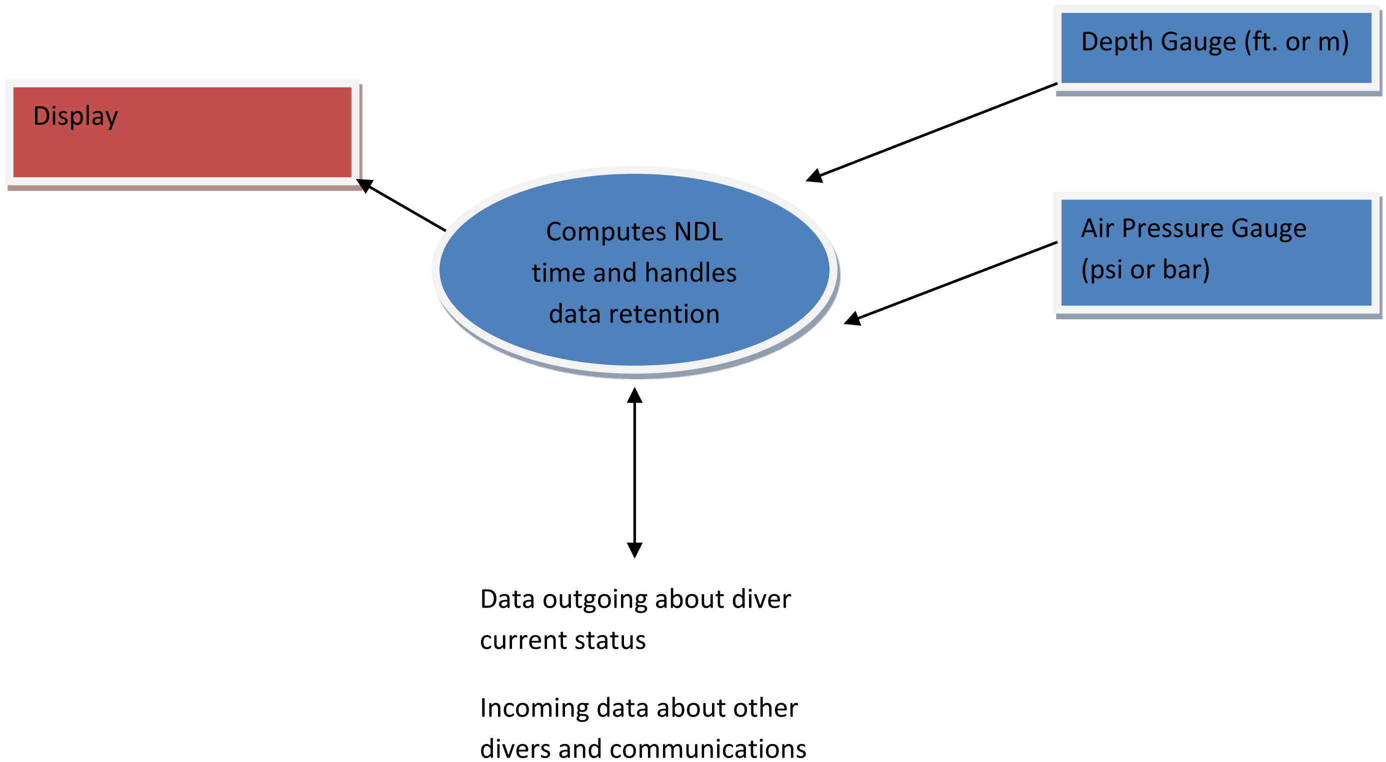


Figure 13. This block diagram represents a traditional dive computer's functions. The system takes all of the necessary inputs and dynamically changes the NDL time, as denoted in the figure.

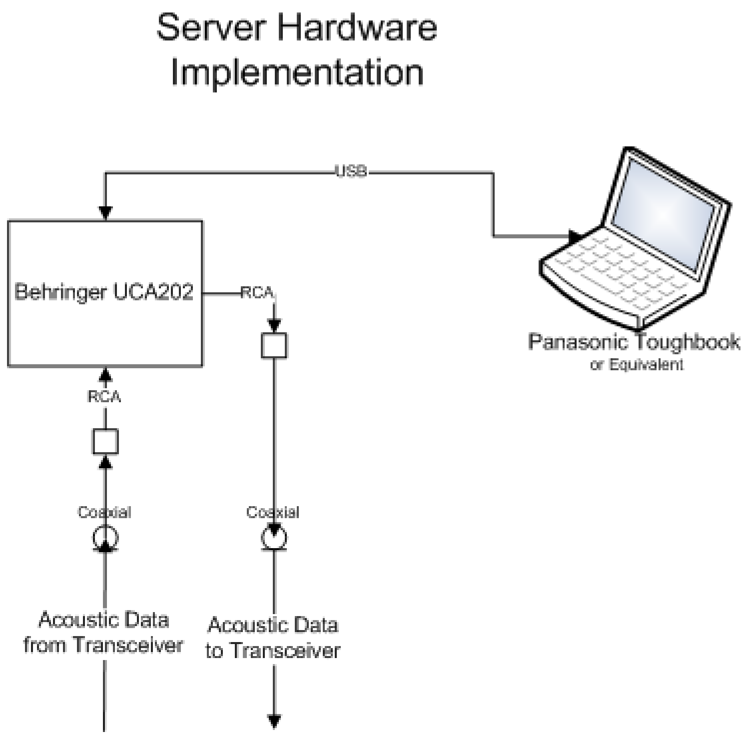


Figure 14. This figure represents a block diagram of the server hardware implementation.

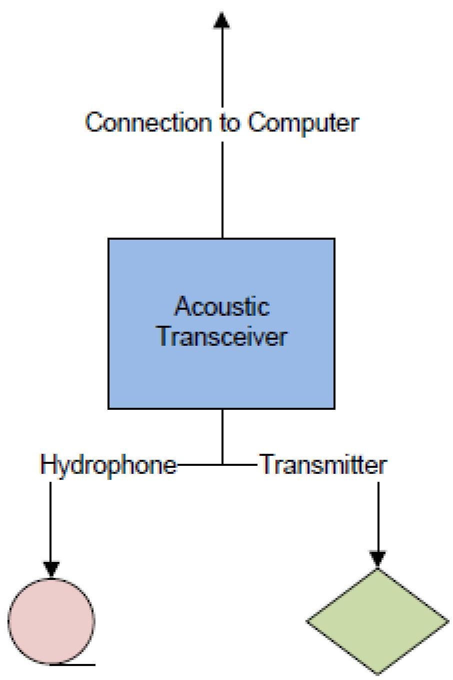


Figure 15. This figure represents a block diagram of the acoustic transceiver's hardware implementation.

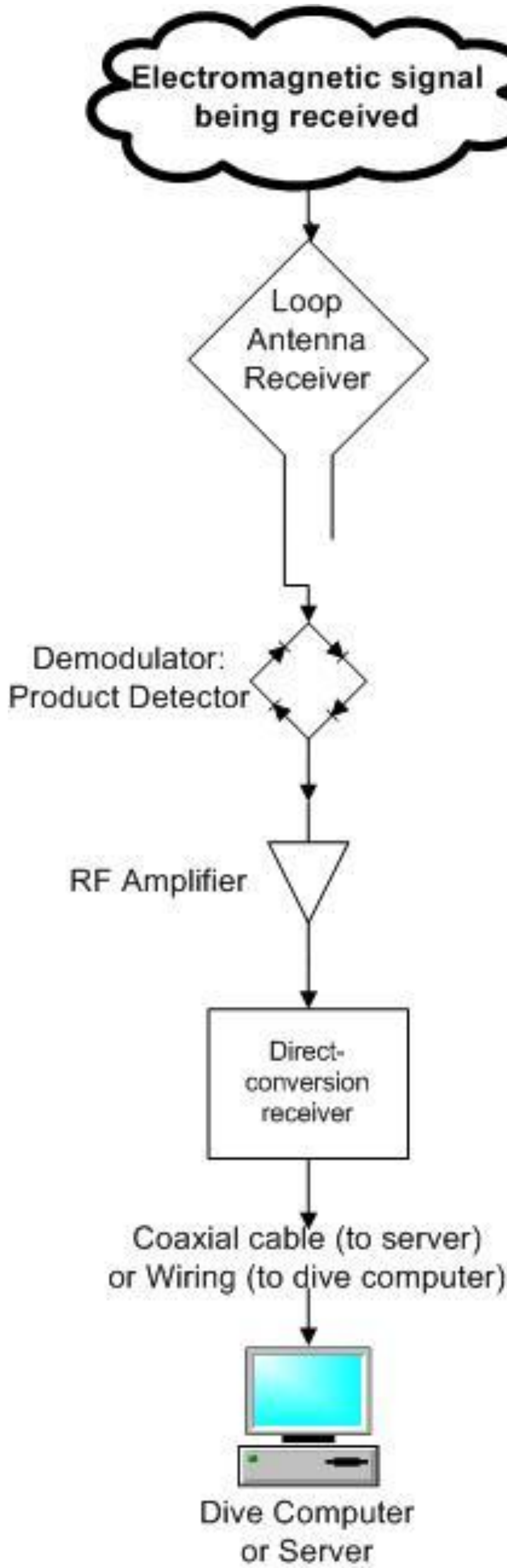


Figure 16. This figure is a block diagram of the electromagnetic receiver's hardware implementation.

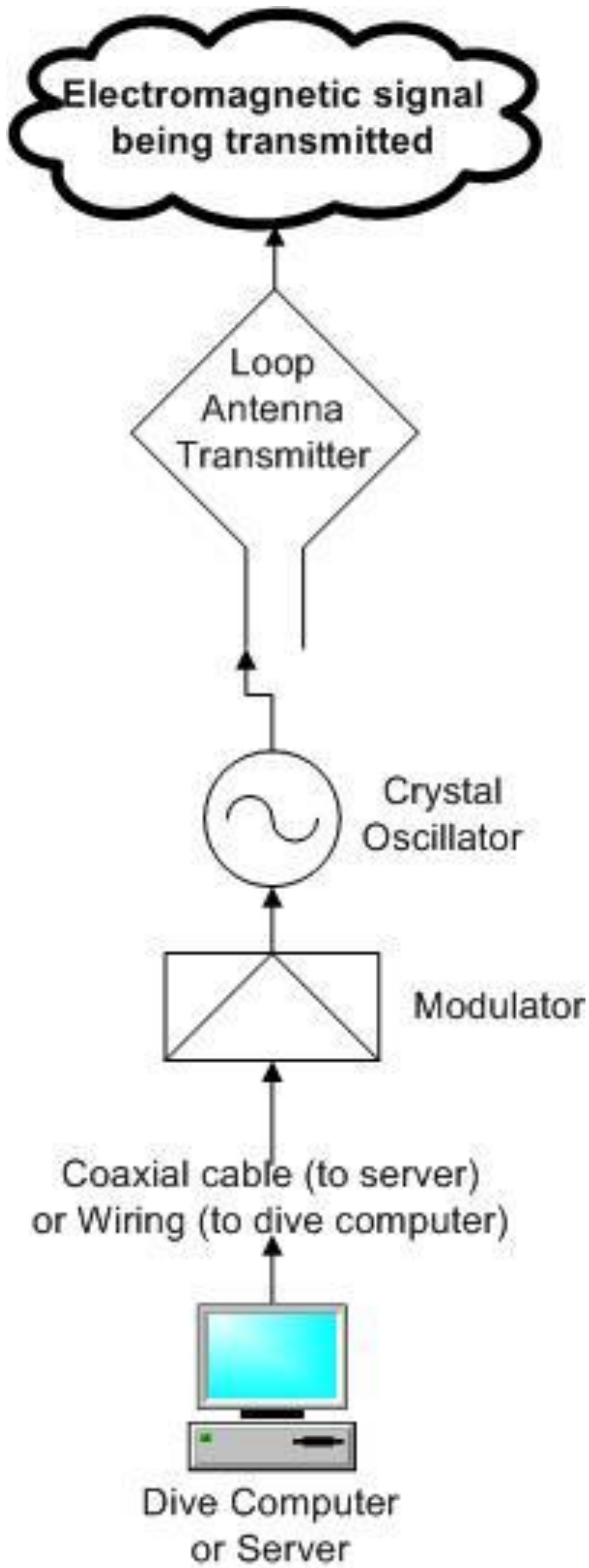


Figure 17. This figure is a block diagram of the electromagnetic transmitter's hardware implementation.

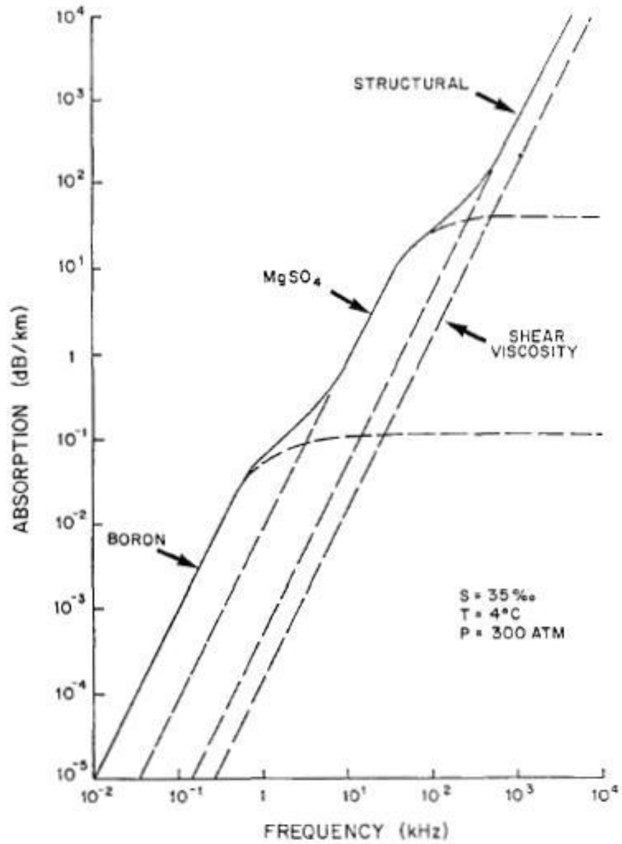


Figure 18. This figure shows how the frequency (in kHz) of a wave affects the absorption (dB/km) underwater for different materials. Boron clearly has the least absorption.

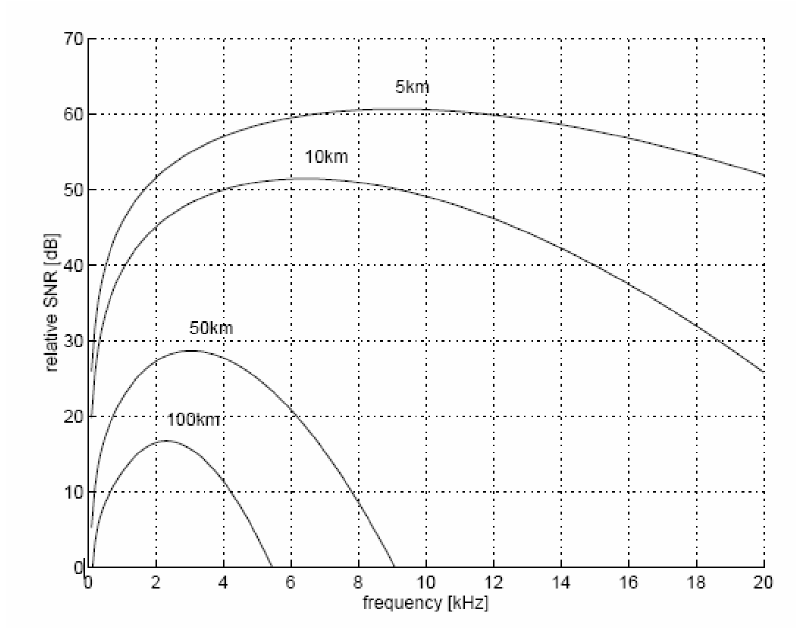


Figure 19. This graph shows the relationship between the frequency of the transmitted wave and the relative SNR as a function of the distance the signal travels.

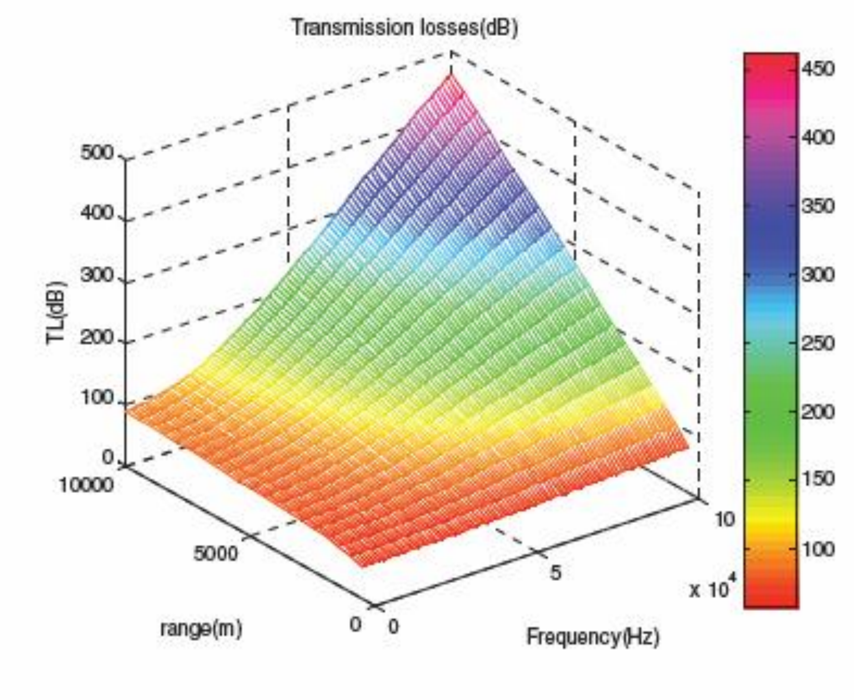


Fig.1. Attenuation vs distance

Figure 20. This graph shows that for larger frequencies and ranges, there will be much larger transmission losses.

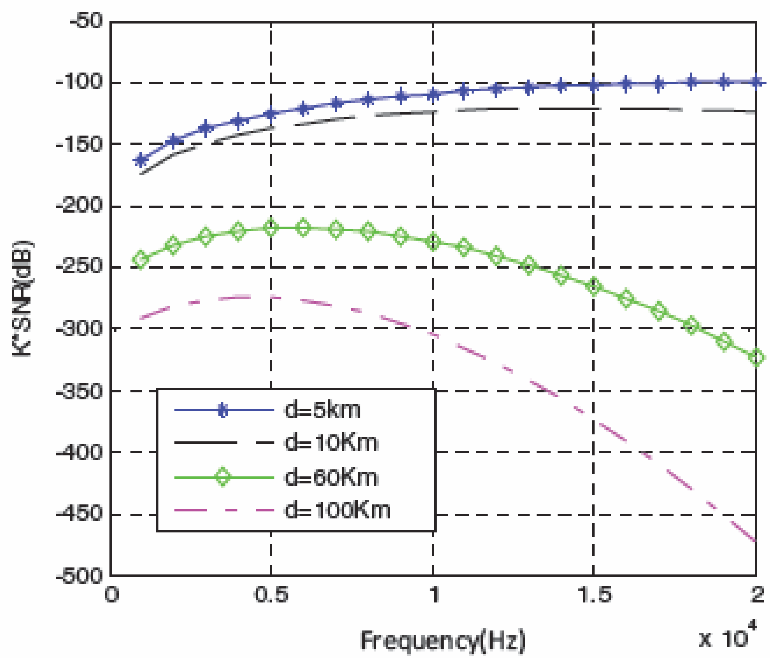


Fig.2. Frequency-dependent part of SNR,1/TL (d, f).N(f)

Figure 21. This graph shows how the signal to noise ratio varies based on the frequency.

TABLE II. AVAILABLE BANDWIDTH FOR DIFFERENT RANGES IN UWA CHANNELS

	Range[Km]	Bandwidth[KHz]
Very long	20≥	≤10
Long	5-20	5-10
Medium	1-5	≈20
short	0.1-1	20-50
Very Short	≤0.1	≥100

Figure 22. This table shows how the bandwidth varies greatly with the range. The larger the range is, the lower the bandwidth has to be.

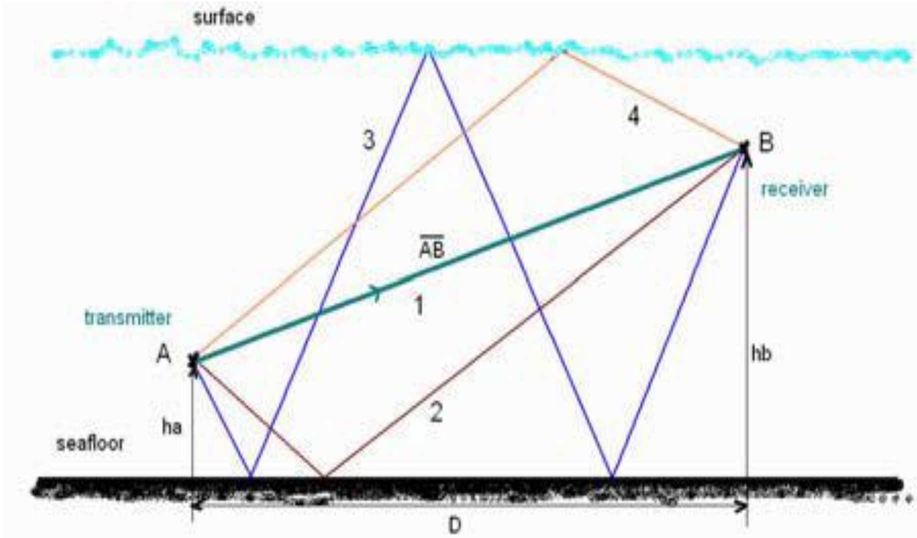


Figure 23. This figure shows an example of multi-path propagation underwater.

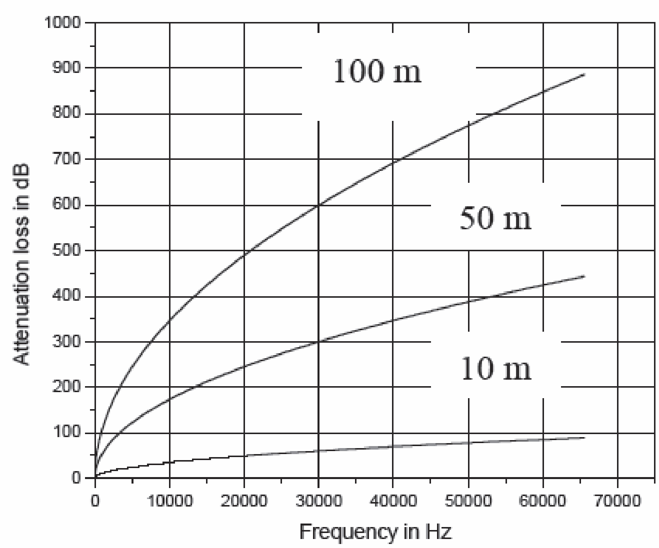


Fig 5: Variation of attenuation loss with frequency for different values of propagation distance.

Figure 24. This figure shows a graphical representation of how the attenuation loss increases with an increase of propagation distance as well as frequency.

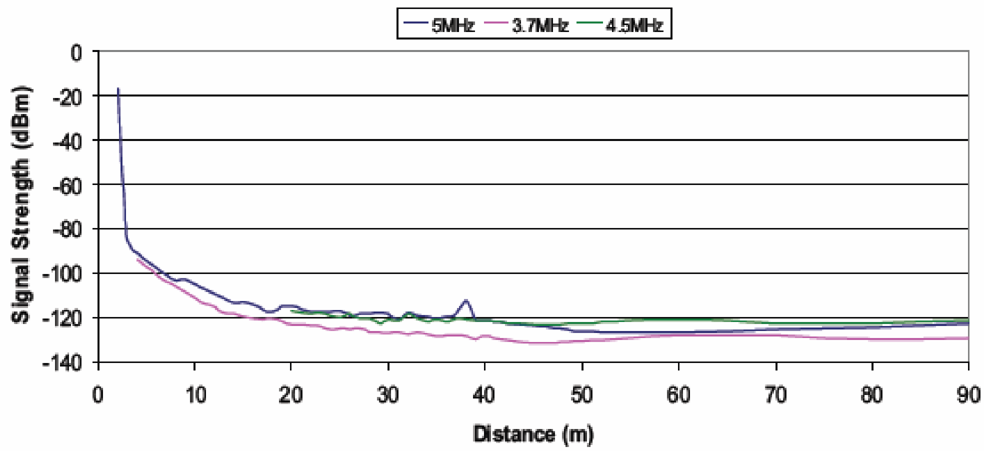


Fig. 7. Signal propagation with an RF power of 5W at the Liverpool marina long range test site.

Figure 25. Signal strength decreases rapidly as the distance between the receiver and transmitter increases.

Table 3. Risk Estimates For Various NDLs.

$d\ (fsw)$	USN $t_n\ (min)$	PADI $t_n\ (min)$	NAUI $t_n\ (min)$	Oceanic $t_n\ (min)$
35	310 (4.3%)	205 (2.0%)		181 (1.3%)
40	200 (3.1%)	140 (1.5%)	130 (1.4%)	137 (1.5%)
50	100 (2.1%)	80 (1.1%)	80 (1.1%)	80 (1.1%)
60	60 (1.7%)	55 (1.4%)	55 (1.4%)	57 (1.5%)
70	50 (2.0%)	40 (1.2%)	45 (1.3%)	40 (1.2%)
80	40 (2.1%)	30 (1.3%)	35 (1.5%)	30 (1.3%)
90	30 (2.1%)	25 (1.5%)	25 (1.5%)	24 (1.4%)
100	25 (2.1%)	20 (1.3%)	22 (1.4%)	19 (1.2%)
110	20 (2.2%)	13 (1.1%)	15 (1.2%)	16 (1.3%)
120	15 (2.0%)	13 (1.3%)	12 (1.2%)	13 (1.3%)
130	10 (1.7%)	10 (1.7%)	8 (1.3%)	10 (1.7%)

Figure 26. Shows the risk estimate for each of the widely accepted dive tables and the oceanic dive algorithm, which is based solely on the dive tables and does not take into account things such as micro bubble behavior in the bloodstream (as RBGM does).

Table 4. Dissolved And Separated Phase Risk Estimates For Nominal Profiles.

profile (*depth*/*min*)	descent rate (*msw*/*min*)	ascent rate (*msw*/*min*)	safety stop (*depth*/*min*)	*r* RGBM	*r* ZHL
14 *msw*/38 *min*	18	9	5 *msw*/3 *min*	.0034	.0062
19 *msw*/38 *min*	18	9	5 *msw*/3 *min*	.0095	.0110
37 *msw*/17 *min*	18	9	5 *msw*/3 *min*	.0165	.0151
18 *msw*/31 *min*	18	9	5 *msw*/3 *min*	.0063	.0072
	18	9		.0088	.0084
	18	18		.0101	.0135
	18	18	5 *msw*/3 *min*	.0069	.0084
17 *msw*/32 *min*	18	9	5 *msw*/3 *min*		
SI 176 *min*					
13 *msw*/37 *min*	18	9	5 *msw*/3 *min*		
SI 174 *min*					
23 *msw*/17 *min*	18	18	5 *msw*/3 *min*	.0127	.0232

Figure 27. Shows the risk estimate for various dive profiles according to two algorithms: the RGBM and ZHL.

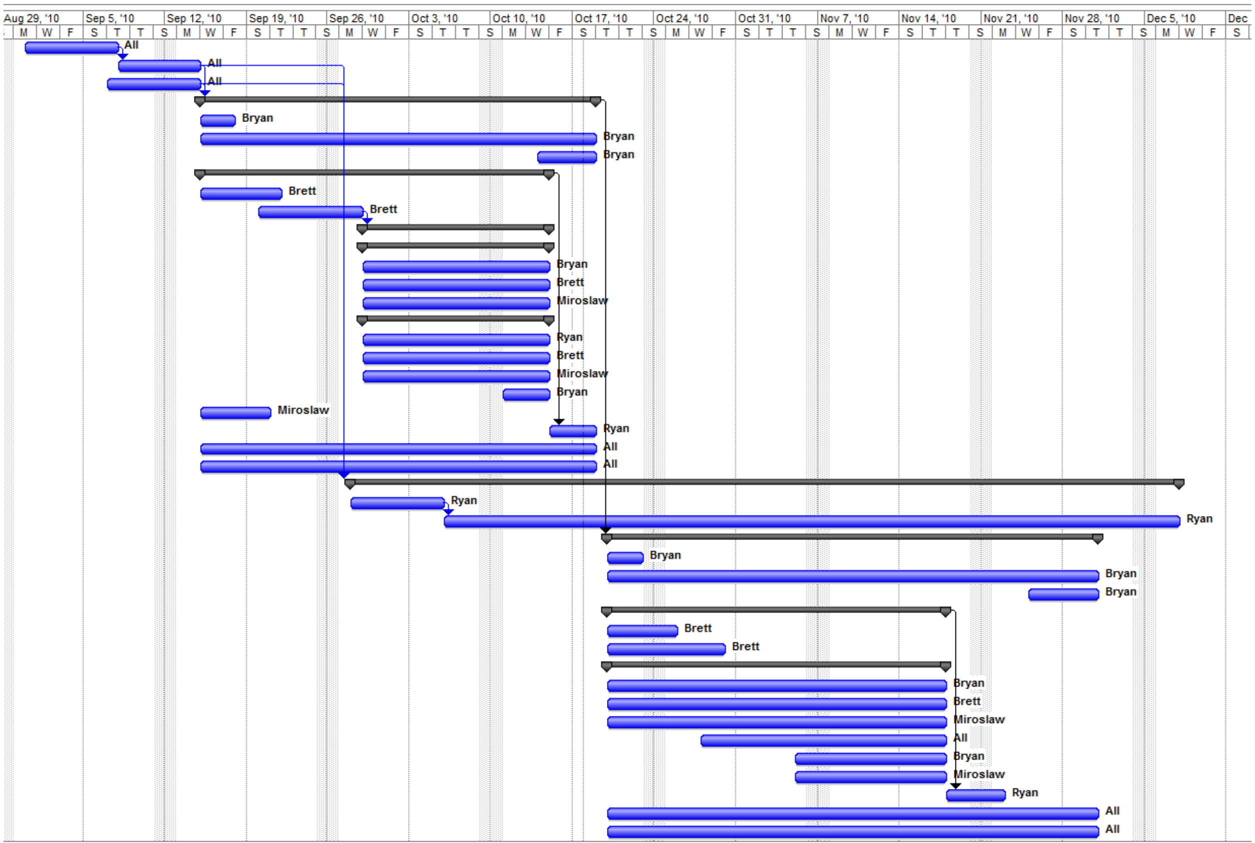
Appendix B – Financial Analysis

Acoustic Approach		
Item/Cost Center	**Quantity**	**Price**
Coaxial Cable (100 ft.)	1	$ 8.00
USB Cable	1	$ 2.00
Aquarian Audio Products H2a hydrophone	1	$ 159.99
Aquarian Audio Products H1a hydrophone	1	$ 129.99
C5000 Ultra Low Power DSP	1	$ 10.00
Purdy Electronics AND791GST (Display)	1	$ 87.00
Casing/Housing	1	$ 25.00
Travel Cost to Dutch Springs PA	1	$ 20.00
Entrance Fee for divers	2	$ 45.00
Entrance Fee for non-divers	2	$ 15.00
Total		**$ 501.98**

RF Approach		
Item/Cost Center	**Quantity**	**Price**
Coaxial Cable (100 ft.)	1	$ 8.00
USB Cable	1	$ 2.00
C5000 Ultra Low Power DSP	2	$ 10.00
Purdy Electronics AND791GST (Display)	1	$ 87.00
Casing/Housing	1	$ 25.00
Travel Cost to Dutch Springs PA	1	$ 20.00
Entrance Fee for divers	2	$ 45.00
Entrance Fee for non-divers	2	$ 15.00
Parts to build crystal oscillators	2	$ 35.00
Antenna	2	$ 10.00
Total		$ 257.00

Appendix C – Scheduling

ID	WBS	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	1	Form Group	6 days?	Tue 8/31/10	Tue 9/7/10		All
2	2	Identify Project	5 days?	Wed 9/8/10	Tue 9/14/10	1	All
3	3	Select Advisor	6 days?	Tue 9/7/10	Tue 9/14/10		All
4	**4**	**Project Proposal**	**24 days?**	**Wed 9/15/10**	**Mon 10/18/10**	**2,3**	
5	4.1	Title Page	3 days?	Wed 9/15/10	Fri 9/17/10		Bryan
6	4.2	Table of Contents	24 days?	Wed 9/15/10	Mon 10/18/10		Bryan
7	4.3	Abstract	3 days?	Thu 10/14/10	Mon 10/18/10		Bryan
8	**4.4**	**Proposal**	**22 days?**	**Wed 9/15/10**	**Thu 10/14/10**		
9	4.4.1	Introduction	5 days?	Wed 9/15/10	Tue 9/21/10		Brett
10	4.4.2	Design Requirements	7 days?	Mon 9/20/10	Tue 9/28/10		Brett
11	**4.4.3**	**Design Approaches**	**12 days?**	**Wed 9/29/10**	**Thu 10/14/10**	**10**	**All**
12	**4.4.3.1**	**Acoustic**	**12 days?**	**Wed 9/29/10**	**Thu 10/14/10**		
13	4.4.3.1.1	Hardware	12 days?	Wed 9/29/10	Thu 10/14/10		Bryan
14	4.4.3.1.2	Communications	12 days?	Wed 9/29/10	Thu 10/14/10		Brett
15	4.4.3.1.3	System Interconnectior	12 days?	Wed 9/29/10	Thu 10/14/10		Miroslaw
16	**4.4.3.2**	**Electromagnetic**	**12 days?**	**Wed 9/29/10**	**Thu 10/14/10**		
17	4.4.3.2.1	Hardware	12 days?	Wed 9/29/10	Thu 10/14/10		Ryan
18	4.4.3.2.2	Communications	12 days?	Wed 9/29/10	Thu 10/14/10		Brett
19	4.4.3.2.3	System Interconnectior	12 days?	Wed 9/29/10	Thu 10/14/10		Miroslaw
20	4.4.4	Financial Budget	4 days?	Mon 10/11/10	Thu 10/14/10		Bryan
21	4.4.5	Schedule	4 days?	Wed 9/15/10	Mon 9/20/10		Miroslaw
22	4.5	Conclusion	2 days?	Fri 10/15/10	Mon 10/18/10	8	Ryan
23	4.6	References	24 days?	Wed 9/15/10	Mon 10/18/10		All
24	4.7	Appendices	24 days?	Wed 9/15/10	Mon 10/18/10		All
25	**5**	**Project Website**	**51 days?**	**Tue 9/28/10**	**Tue 12/7/10**	**2,3**	
26	5.1	Establish a Website	6 days?	Tue 9/28/10	Tue 10/5/10		Ryan
27	5.2	Post Updates	45 days?	Wed 10/6/10	Tue 12/7/10	26	Ryan
28	**6**	**Final Design Report**	**30 days?**	**Wed 10/20/10**	**Tue 11/30/10**	**4**	
29	6.1	Title Page	3 days?	Wed 10/20/10	Fri 10/22/10		Bryan
30	6.2	Table of Contents	30 days?	Wed 10/20/10	Tue 11/30/10		Bryan
31	6.3	Abstract	4 days?	Thu 11/25/10	Tue 11/30/10		Bryan
32	**6.4**	**Final Design Plan**	**21 days?**	**Wed 10/20/10**	**Wed 11/17/10**		
33	6.4.1	Introduction	4 days?	Wed 10/20/10	Mon 10/25/10		Brett
34	6.4.2	Design Requirements	8 days?	Wed 10/20/10	Fri 10/29/10		Brett
35	**6.4.3**	**System Design**	**21 days?**	**Wed 10/20/10**	**Wed 11/17/10**		**All**
36	6.4.3.1	Hardware	21 days?	Wed 10/20/10	Wed 11/17/10		Bryan
37	6.4.3.2	Communications	21 days?	Wed 10/20/10	Wed 11/17/10		Brett
38	6.4.3.3	System Interconnection	21 days?	Wed 10/20/10	Wed 11/17/10		Miroslaw
39	6.4.4	Parts List	15 days?	Thu 10/28/10	Wed 11/17/10		All
40	6.4.5	Financial Budget	9 days?	Fri 11/5/10	Wed 11/17/10		Bryan
41	6.4.6	Schedule	9 days?	Fri 11/5/10	Wed 11/17/10		Miroslaw
42	6.5	Summary	3 days?	Thu 11/18/10	Mon 11/22/10	32	Ryan
43	6.6	References	30 days?	Wed 10/20/10	Tue 11/30/10		All
44	6.7	Appendices	30 days?	Wed 10/20/10	Tue 11/30/10		All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Sep 12, '10
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Oct 3, '10
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Oct 24, '10
Oct 31, '10
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Nov 14, '10
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