UNDER WATER DATA COMMUNICATION

(UwDCOM)

By

Rehan Ali Khan

Ubaid Nasir

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ABSTRACT

Mariners all over the world use various types of platforms for transportation of men and material. The safe operation of ships at sea depends on the efficiency and performance of sensors fitted on these platforms. The sensors mainly include radar, sonar and communication equipment. Underwater data communication system will find applications in oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, diving, assisted navigation and tactical surveillance applications. Moreover, in near future unmanned or autonomous underwater vehicles (UUVs, AUVs), equipped with sensors, will help the researchers to exploit the rich natural resources buried under the depth of oceans.

The Data communication system contains software GUI developed in C# that will be used for messaging, locally built modem circuitry to generate voltage signals and finally a transducer to transmit the signal underwater. On reception end a similar transducer to receive sound waves signal for converting it back into an equivalent electrical signal. The modem will convert this into a digital signal to be displayed on the GUI at the receiver end. The hardware in this system involves both the design and development of the acoustic modem circuitry. The eventual aim is production of a cheap, low power acoustic modem for real-time data collection and transmission in marine environment.

DECLARATION

No portion of the work presented in this dissertation has been submitted in support of any other award or qualification either at this institution or elsewhere.

DEDICATION

In the name of Allah, the Most Merciful, the Most Beneficent

To our parents, and families without whose unflinching support and unstinting cooperation, a work of this magnitude would not have been possible

ACKNOWLEDGMENTS

We are grateful to Almighty Allah for bestowing us with the strength and resolve to undertake and complete the project.

We gratefully recognize the continuous supervision and motivation provided to us by our Project Supervisor, Major Ather Mohsin Zaidi. We are extremely grateful to all the people who have helped us in getting the project funded by the NUST. We deeply treasure the unparallel support and tolerance that we received from our friends for their useful suggestions that helped us in completion of this project. We are also deeply obliged to our families for their never ending patience and support for our mental peace and to our parents for the strength that they gave us through their prayers.

And above all, a word of thanks to MILITARY COLLEGE OF SIGNALS (MCS) as it had been our foundation and has made us capable to undertake the project.

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Definitions, Acronyms and Abbreviations

UwDCOM : underwater data communication

UUVs, AUVs : unmanned or autonomous underwater vehicles

SONAR : Sound navigation and ranging

C# : C sharp

MCS : MILITARY COLLEGE OF SIGNALS

EM : Electro magnetic

PN : Pakistan Navy

R & D : Research and development

US : United States

MSDN : Microsoft Development Network

H/W : Hard ware

S/W : Soft ware

RF : Radio frequencies

kHz : Kilo hertz

dBs : Decibels

TL : Transmission loss

SNR : Signal to noise ratio

SVP : Sound Velocity Profile

BN : Background Noise

DI	: Directivity Index
TS	: Target Strength
PL	: Propagation Loss
SL	: Source Level
DT	: Detection Threshold
BW	: Bandwidth Correction Factor
TN	: Target noises
ASK	: Amplitude Shift Keying
FSK	**:** Frequency Shift Keying
PSK	: Phase Shift Keying
BPSK	: Binary Phase Shift Keying
QPSK	: Quadrature Phase Shift Keying
ISI	: Inter Symbol Interference
Modem	: Modulator Demodulator
ISP	: Internet service provider
GUI	: Graphical user interface
Kbps	: Kilo bytes per second
Tx	: Transmitter
Rx	: Receiver

Chapter 1

Introduction

1.1 Introduction

The marine environment has always been challenging and causes some kind of a dilemma for any kind of engineering activity. This difficulty is further augmented when the task is of an electronic nature. It is perhaps one of the reasons why the underwater communications applications are an arena which has vastly been overlooked over recent times. Another reason for this situation would be the obvious limitations of this market, which is restricted to commercial and recreational purposes only. Due to this limitation, applications developed for this purpose have been extremely costly and targeted primarily at data communication, professional fishing, boating, diving and the military purposes.

The underwater wireless modems have a very wide scale application which includes data communications, navigation, diving, surveillance, and monitoring. The inefficiency of EM waves has left researchers with an obvious choice of selecting acoustics (sound waves) for carrying out transmission in this medium. The Sonar is a device which is being used primarily on board PN ships to detect and track enemy targets. However, sonar has got certain limitations which are usually governed by the propagation pattern of underwater sound wave and the temperature variations in the water with respect to its depth. These thermal changes results in the formation of a layer in which the sound energy travels and detects the targets. The changes in the sound waves pattern also depend upon temperature and velocity gradients.

1.2 Background

With the advancements in the field of oceanography and the use of technology by various organizations worldwide especially the naval services of the advanced countries the idea was perceived to carry out research on the subject of underwater communication. Pakistan Navy is striving at its best to equip her seagoing platforms with the latest state of art technology. The R & D work is in progress for the indigenous development of equipment for diverse nature of platforms. Even though there is a wide range of underwater communication equipment available in the western markets but the cost to utility price is much more than normal. We have strived to carry out research and worked out a solution for development of a cost effective and workable evolutionary prototype which can be further enhanced and be used for more research on the subject of underwater data transmission, and eventually lead predecessors of the project at some stage to develop a working acoustic modem for use on board seagoing platforms. Motivation to do this work were the failure of Wolf pack strategy of Germans in II-world war causing defeat of Germans against Allies and recently US Navy submarine Dolphins' successful transmission of e-mails on the shore while submerged.

1.3 Problem Statement

The underwater wireless modems have a very wide scale application which includes data communication, navigation, diving, surveillance, and monitoring. Due to inherent problems of Radio, Infrared and Laser underwater propagation, researchers are left with an obvious choice of selecting Sound waves for carrying out transmission in this medium. In this work detail study has been carried out about the fundamental concepts of sound waves transmission and work which is done in this field globally. To carry out effective underwater data communication, we have designed a relatively simple but practicable and cost effective acoustic modem that can successfully transmit digital data underwater and allow users to communicate with underwater devices without interference. For acoustic communication, special acoustic modems are required which can convert special underwater sound signals into digital data (and vice versa) that can ultimately be transmitted between two points. The acoustic modems are relatively slow compared to telephone or cable modems on land. Nonetheless, this technology is very important because it provides an accurate and efficient means to send and receive data underwater.

1.4 Aim

To develop a cost effective easy to use evolutionary prototype model comprising of hardware and software module to transmit and receive data underwater.

1.5 Objectives

Pakistan Navy uses various types of platforms namely aircraft, surface ships and submarines. The safe operation of these units out in the sea depends on the efficiency and performance of sensors fitted on these platforms. The sensors mainly include radar, sonar and communication equipment. Some special type of platforms like submarines and midgets heavily depend on the performance of sonar. Sound Navigation and Ranging (sonar) not only serves as an eye for the submarines but also facilitates data communication, target acquisition, tracking, self noise monitoring and bathy (temperature, salinity with respect to depth) conditions.

The objective of this project is to develop a relatively simple but inexpensive form of underwater data communications system that will allow users to communicate between submerged platforms like submarines and with the surface platforms like ships in an amicable manner. Development of underwater data communication system would facilitate Pakistan Navy in particular and commercial users in general.

1.6 Outline Of The Report

The report covers all the relevant details regarding the project under the following chapters. Chapter 2 covers Fundamental Concepts Of Sound Waves Transmission, chapter 3 describes Digital Data Modulation Techniques, chapter 4 is about the Telephonic Modem And Acoustic Modems, Hardware Design And Interfacing Issues are discussed in chapter 5 with Software and its step by step guide in chapter 6 and Results And Analysis in chapter 7 and in the end Conclusion And Future Work is covered in chapter 8

Chapter 2

Fundamental Concepts Of Sound Waves Transmission

2.1 Introduction

Since this project essentially commenced without any prior work done in Pakistan as a basis, it therefore required a substantial amount of research to understand the full scope of the problem and what the project entail.

2.2 Transmission of sound underwater

The vast majority of wireless communications applications in use today utilize Radio frequencies (RF). This technology forms the basis for the use of mobile phones and Telephones. Unfortunately, the transmission of radio waves underwater is extremely limited. The reason for this being that water appears to have the effect of "shorting out" radio wave signals. Unlike in air, RF transmissions are severely impeded when traveling through water creating an effect similar to placing a radio antenna down flat on the hood of a car instead of vertical, and trying to transmit a radio signal. The metal car hood shorts out the radio signal. This unfortunate limitation thereby restricts the simple adaptation of surface communication technology for underwater usage. Another possibility examined was the use of infrared. Unfortunately the characteristics of infrared transmission are highly unsuitable for water applications for a wide number of reasons. The primary reason for this being that it is highly dependant on traveling through a clear medium, any silt or debris clouding the water would severely affect the effectiveness of the transmission.

Table 2.1 Acoustic Frequency Bands

LF	100 Hz - 1 kHz
MF	1 kHz - 10 kHz
HF	10 kHz – 100 kHz
VHF	100 kHz - 1 MHz

2.3 Sonar Propagation

By knowing the fact that the speed with which acoustic waves travel depends on the properties of the medium (i.e. sea water), the propagation of sonar will be complicated. It is so complicated in fact, that it will be impossible to accurately predict it without the use of a computer model. However, sonar systems rely heavily on operator input and control to maximize their performance. Many of the decisions made regarding the maneuvering of the ship carrying the sonar system will also affect the sonar's performance. Therefore a detailed knowledge of the salient features of sonar propagation is essential to its successful employment. The speed of sound waves depends on the compressibility and inertia of the medium through which they are traveling. Therefore, the speed of sound is much higher in solids/liquids then in gases and air. When the sound wave propagates through water it will be subjected to various losses. These can be split into categories described below

2.3.1 Absorption of Sound Waves

Unlike the spreading effect on sound intensity, absorption involves a process of conversion of acoustic energy into heat, and thus represents a true loss of energy to the medium. Absorption of sound in seawater is about 30 times greater than that in pure water in the frequency range 5-50 kHz. The increase is attributed to a chemical reaction involving one of the minor dissolved salts in the sea (MgSO4 - effect dominant below 100 kHz). The fact that higher frequencies are severely attenuated is of great significance in the design and use of military sonars.

2.3.2 Propagation Loss

When propagation measurements are made at sea, it is found that spherical spreading plus absorption provides a reasonable fit to measured data under a wide variety of conditions. Thus, it is possible to provide a handy 'working rule' for estimation of propagation loss (in dBs) for a given range, R:

$$\mathbf{PL = 20 \log_{10} R + \lambda R} \qquad \mathbf{(2.1)}$$

2.3.3 Spreading Of Sound Waves

A sound wave radiating in an infinite body of water will suffer spreading losses of intensity proportional to the inverse square of range:

$$\mathbf{Intensity \propto 1/R^2 \qquad (NB\ for\ an\ echo,\ Intensity \propto 1/R^4)} \qquad \mathbf{(2.2)}$$

This is known as 'free-field', or spherical spreading, and is generally the case for mid-

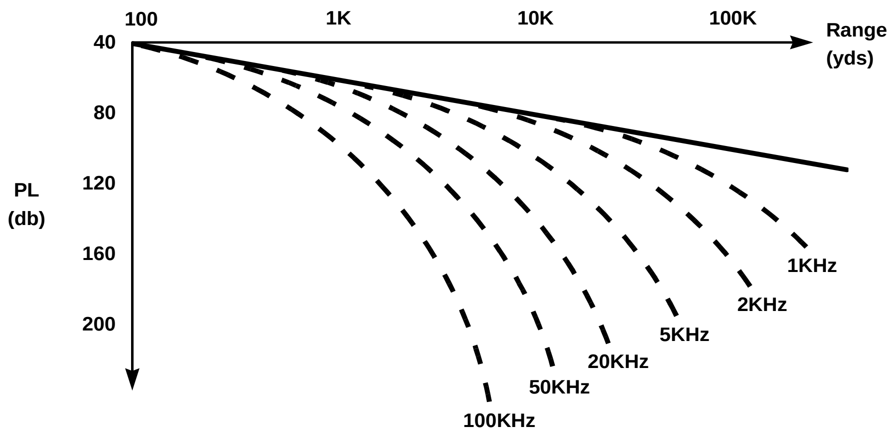


Figure 2.1 Propagation Range vs. Range (w.r.t. frequency)

ocean, deep water transmissions. If the body of water has containing boundaries (e.g. shallow water or a surface duct) the sound intensity will suffer spreading losses known as cylindrical spreading proportional to the inverse of range:

$$\textbf{Intensity} \propto \mathbf{1/R} \qquad \textbf{(2.3)}$$

Spreading may follow various laws, but the above types are most typical. A special kind of spreading occurs when the signal from a pulsed source is spread out in time. The pulse becomes elongated by multi-path propagation effects and is 'smeared' in time as range increases.

2.4 Transmission Loss

Transmission loss (TL) can be predicted, to a very rough degree, solely on the basis of a few factors. These factors are range, and frequency.

2.5 Range Effect

The simplest case, which is the identical case used in electro-optics and radar, is to assume all of the acoustic energy is uniformly distributed in all directions. In sonar this is termed *spherical spreading loss*, since the intensity will fall off proportional to the surface area of a sphere.

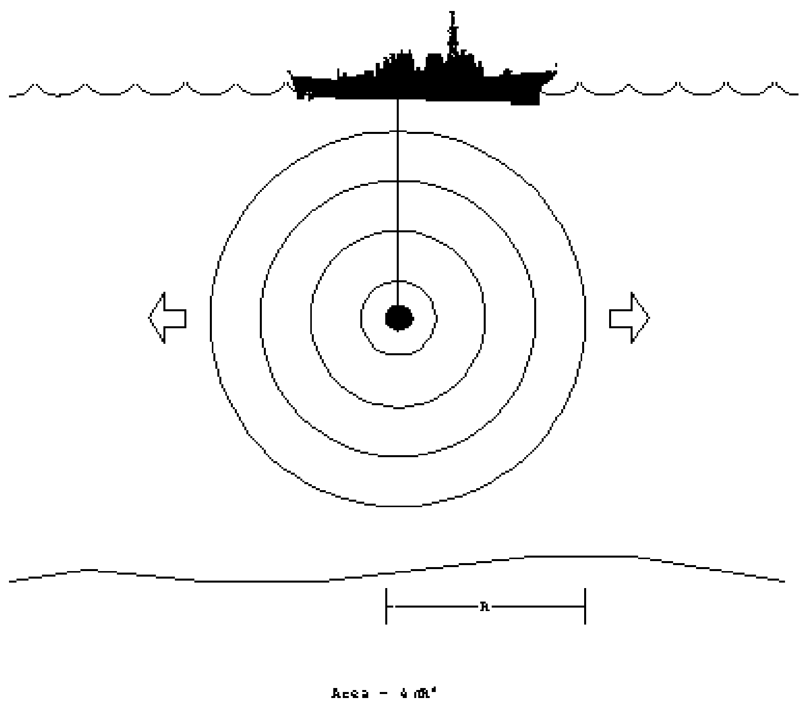


Figure 2.2 Spherical spreading.

Since the area over which the energy is distributed at range, R, is 4*pi*R^2, the ratio of any two intensity levels at different ranges can be computed. If we take the decibel equivalent, and take the first range as one meter, which happens to be where the source level is defined, we obtain the spherical spreading loss f part of TL:

$TL_{spherical}$=-10Log{I(R)/I(1m)}=-10Log{1/R^2} **(2.4)**

$TL_{spherical}$=20Log(R). **(2.5)**

The negative sign was included since TL is defined to be positive quantity, and is subtracted in the SNR equations. When the acoustic energy reaches either the surface or the bottom of the ocean, it is generally reflected back. A long range, all of the acoustic energy will tend to confined between two planes, one at the surface and the other at the bottom. Therefore, the energy can no longer spread out like the spherical spreading case, but now becomes *cylindrical spreading*.

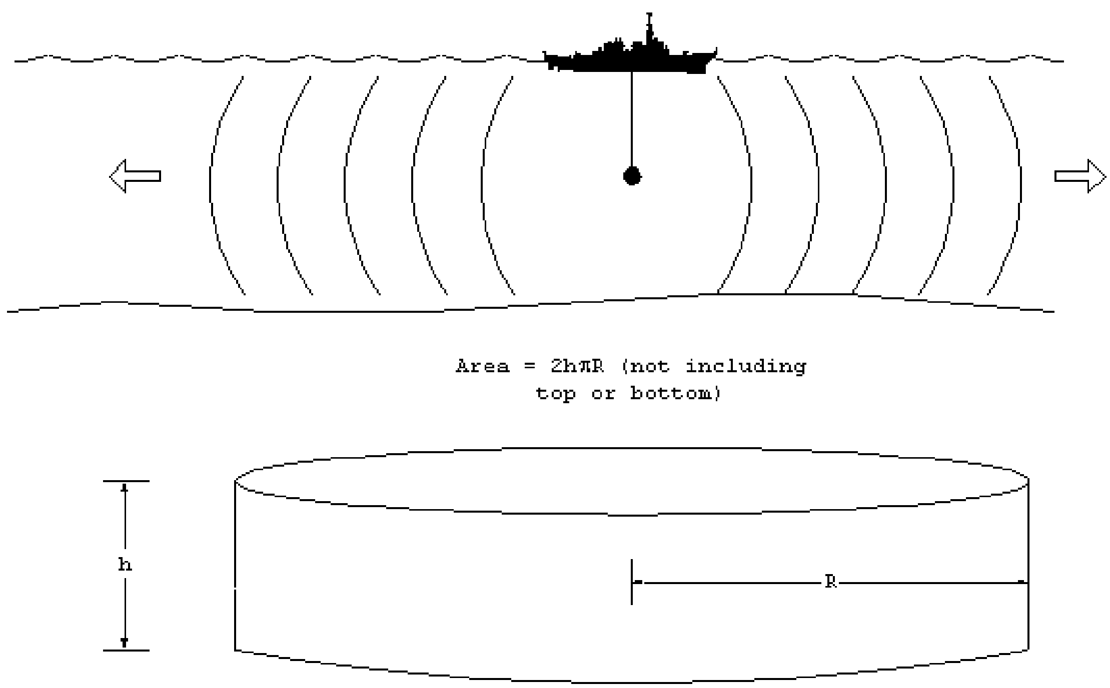


Figure 2.3 Cylindrical spreading

The area over which the energy is distributed now varies directly with range, R. The common factors will cancel, and the transmission loss between two ranges will be 10 Log(R). Explicitly this means

$$\mathbf{SPL(R_2)=SPL(R_1)-10Log(R_2/R_1).} \qquad \mathbf{(2.6)}$$

It would be better if we could choose R_1 to be one meter in which case SPL (R_1) = SL, but this would be incorrect. That would be akin to claiming that the spreading losses were cylindrical starting from one meter. Clearly, in regions where the water depth is larger than the range, the spreading must be spherical. The question now becomes: at what range does the spreading loss transition between the spherical and cylindrical case. If the source where located exactly in the middle (halfway between the surface and bottom), then it seems plausible to make the transition when the range is one-half the water depth since this is when the surface of the sphere will just touch the bottom and top. The transition range will depend on the location of the source and the depth of water. For purposes we assume the transition range to be 1000 m, since the average ocean depth is about 2000m.

At 1000 m, the transmission loss due solely to spherical spreading will be 60 dB. Taking this as the starting point for cylindrical spreading, we can patch the two equations together by adding 30 dB to the 10 Log(R) spreading. This is proven below:

$$\mathbf{TL_{spherical}(at1000\ m) = 20\ Log\ (1000) = 60\ dB} \qquad \mathbf{(2.7)}$$

$$\mathbf{TL_{cylindrical}(at\ 1000m) = 10\ Log(1000) = 30\ dB} \qquad \mathbf{(2.8)}$$

If we wish to apply the $TL_{cylindrical}$ formula starting at 1 m, then we must add the differenceat1000m, therefore

$$\mathbf{TL_{cylindrical}\ (R) = 10\ Log(R) + 30\ dB.\ (valid\ when\ R > 1000\ m)} \qquad \mathbf{(2.9)}$$

At ranges of less than 1000 m, you must use the spreading spreading loss formula,

$$\mathbf{TL_{spherical} = 20\ Log(R)} \qquad \mathbf{(2.10)}$$

All of these factors just discussed can be lumped into a single term, A, called the *transmission loss anomaly*. This is surely artificial and is only used in order to be able to write a complete equation for TL. All deviations from the predicted result can be explained away in the term A. The equation so written is

$$\mathbf{TL = 10\ Log(R) + 30 + pi*R + A} \qquad \mathbf{(2.11)}$$

If we ignore, the last two terms, the range dependence is very straight forward, and can be used to generate some rules of thumb:

TL 60 dB at 1 km. **(2.11 a)**

TL 70 dB at 10 km. **(2.11b)**

TL 80 dB at 100 km. **(2.11 c)**

This is based on nothing but the spherical and cylindrical spreading losses, assuming the source is exactly in the middle of 2000 m deep water. What one finds in practice, are variations about these baseline numbers. This can also be shown in graphical form, TL vs. range.

2.6 Propagation Paths

To gain further insight into how the environment can affect propagation, first thing to be studied is how the propagation speed varies in the ocean. The Sound Velocity Profile (SVP)

The largest variation is the speed of sound in water occurs with changes in depth. Obviously the pressure increases with depth causing a uniform increase of +1.7 m/s for every 100 m. Furthermore, the ambient temperature changes with depth. A plot of

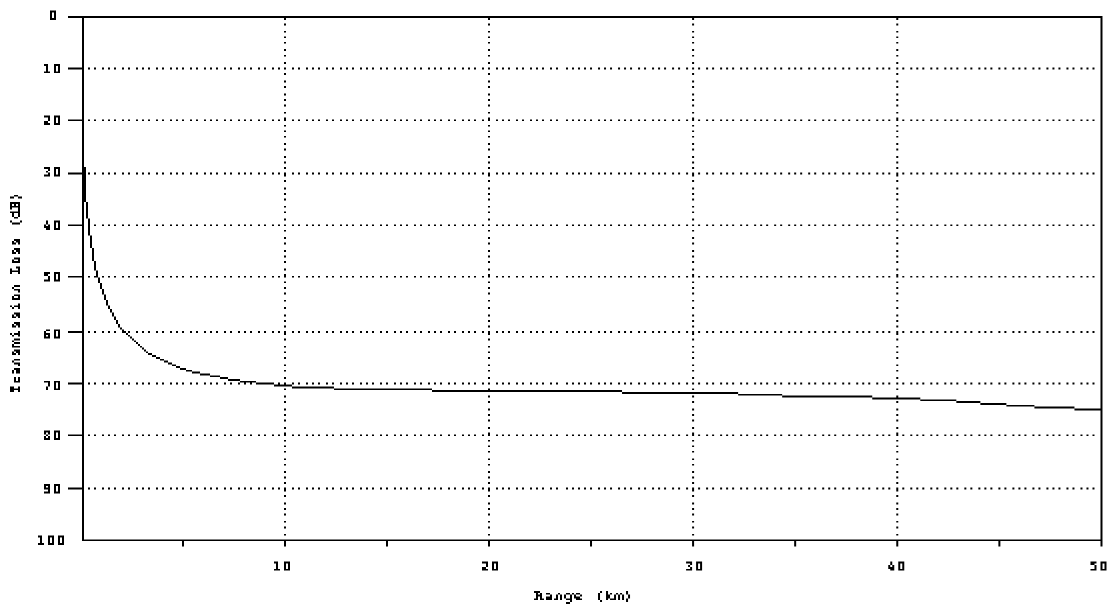


Figure 2.4 Geometrical Transmission Loss Curve.

propagation speed (velocity) as a function of depth is called the *sound velocity profile* (SVP), and it is the fundamental tool for predicting how sound will travel. Neglecting salinity, the SVP can be obtained from sampling the ambient temperature at various depths (the pressure contribution never varies). The resulting SVP looks like this Fig 2.7.

The SVP reveals some common structure to the ocean. The water can be divided into three vertical regions. The surface (seasonal) layer is at the top and is the most variable part. As the name suggests, the profile will changes depending on the time of day (diurnal variation) and the season (seasonal variation). During the day, the heat from the sun (insulation) causes the water at the very top to be warmer than the water below. Since the condition of warm over cold is stable, the condition is quite common. Late in the afternoon, particularly on a bright day, the surface temperature will be the greatest and so one would expect the greatest gradient (change with depth)

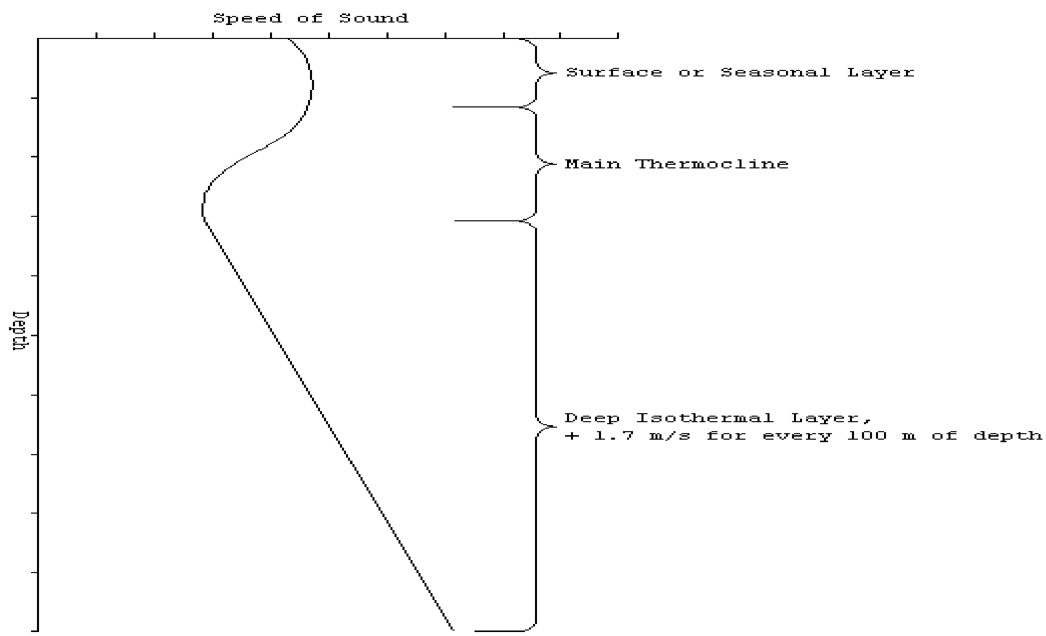


Figure 2.5 Ocean Layers.

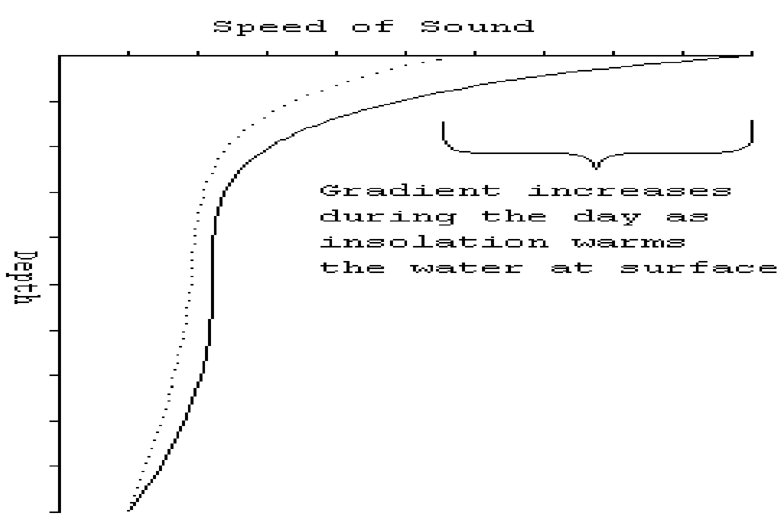


Figure 2.6 Diurnal Variations in SVP.

The main thermo cline connects the seasonal layer with the uniformly cold water found deep in the ocean. Below about 500 m, all of the world's oceans are at about 34° F. The positive gradient in the deep isothermal region is solely due to the pressure effect. In the summer, the seasonal layer tends to have a strongly negative gradient, for the same reason as given to explain the diurnal variation. So the summer profile looks like:

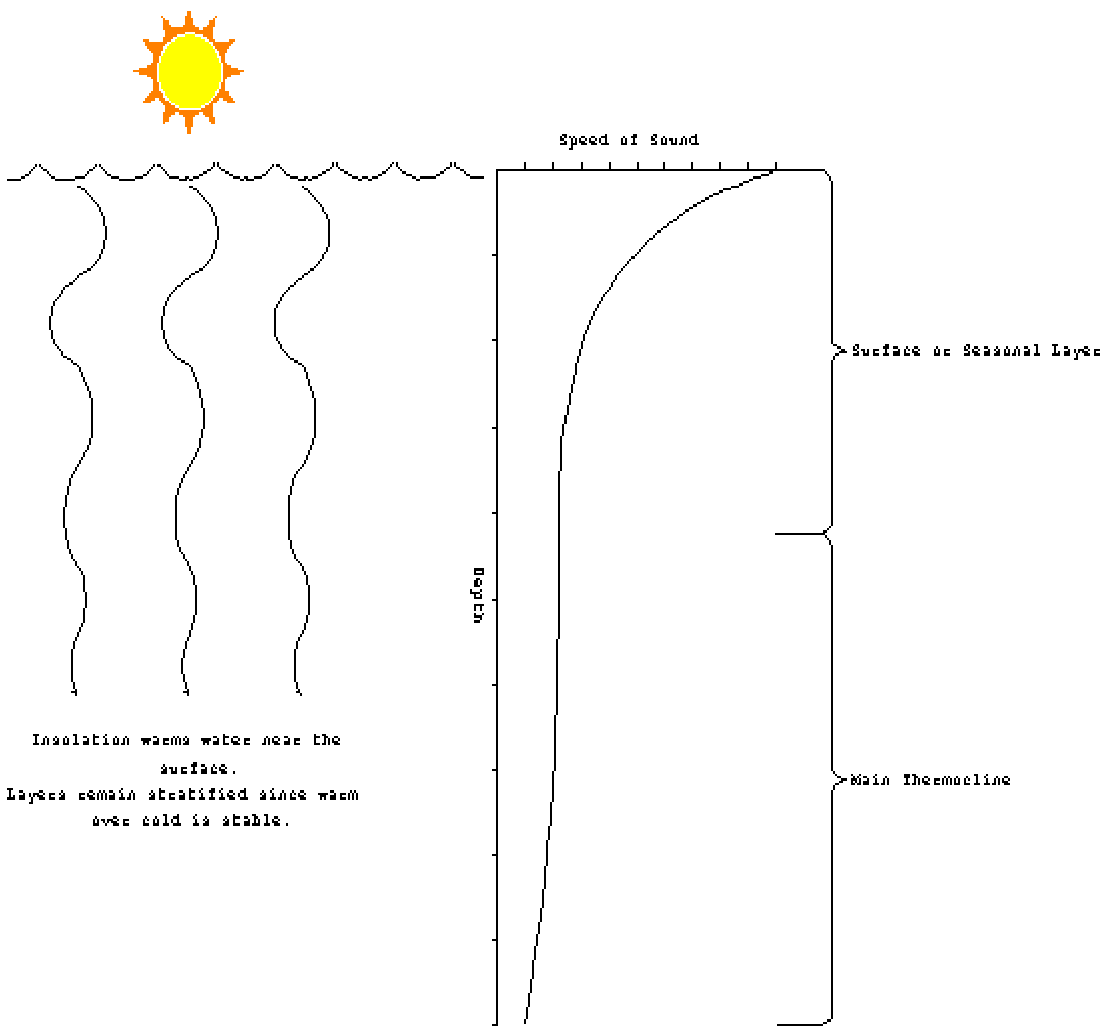


Figure 2.7 Summers SVP.

In winter, the water is generally warmer than the air. A lot of heat is lost through advection and radiation. However, one would not expect to see cold water setting on top of warm water for very long. Convection brings the warm water to the surface destroying the effect. The surface layer tends to be closer to isothermal than anything else. Additionally, strong winter storms and their large waves frequently mix the surface layer to a depth of up to 100 m. For the nearly isothermal surface layer, one could expect a weakly positive gradient above the main thermo cline and reduced transmission loss.

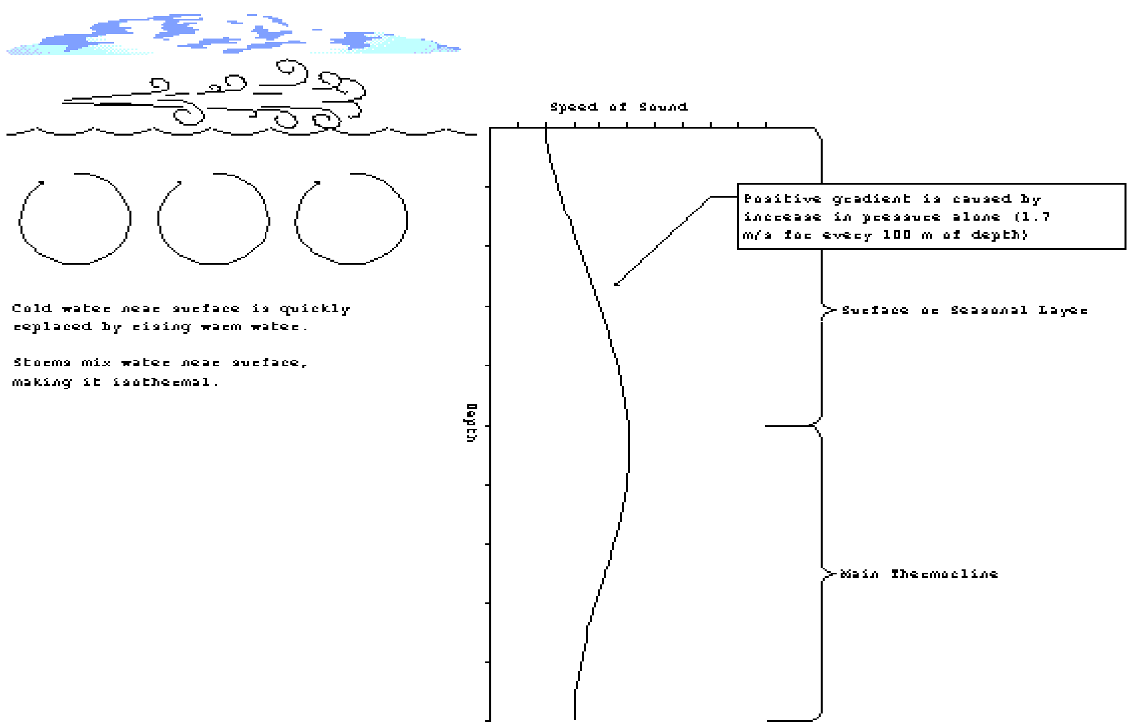


Figure 2.8 Winters SVP.

This is called *bottom bounce* propagation. Rays from bottom bounce can be identified from the others because of the larger angle of incidence. Typical bottom bound comes into the sonar at angles of more than 30^{o} from horizontal.

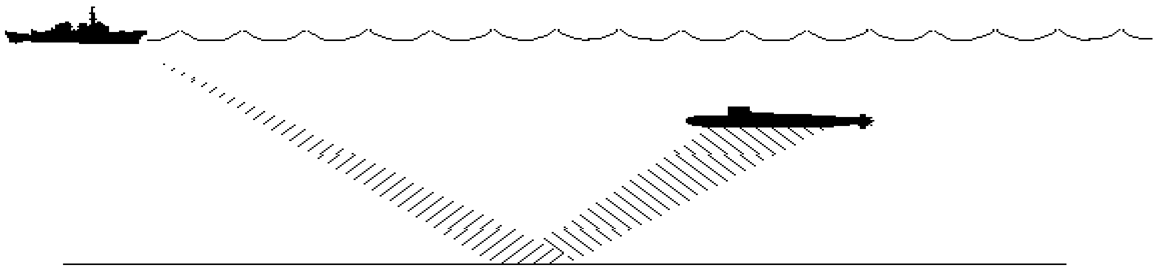


Figure 2.9 Bottom Bounce.

Only certain ocean floor conditions are conducive to bottom bounce propagation. Flat and hard ocean floors tend to be the best. Soft mud, on the other hand is the worst.

2.7 Sound Path Prediction

Sound paths in the ocean can be very complex and difficult to predict. The environment affects the passage of sound in two major ways, both of which are significant. Firstly, the sound rays bend or refract as they pass through the medium, and secondly the energy is dissipated (and attenuated) thus weakening the strength of the signal. However, at times sound can become trapped in ducts allowing long range detections to occur. It is possible to mathematically describe the propagation of sound in an elastic medium such as sea water by the use of Ray Theory. This enables representation of propagation by the use of ray diagrams obtained from Snell's Law which states that in a medium consisting of layers of constant velocity, a ray will be refracted between layers by an amount proportional to the layer velocities.

$$\cos\theta_1 / C_1 = \cos\theta_2 / C_2 = \cos\theta_3 / C_3 = \text{constant for any one ray.} \qquad (2.12)$$

Sound is refracted toward a region of lower velocity.

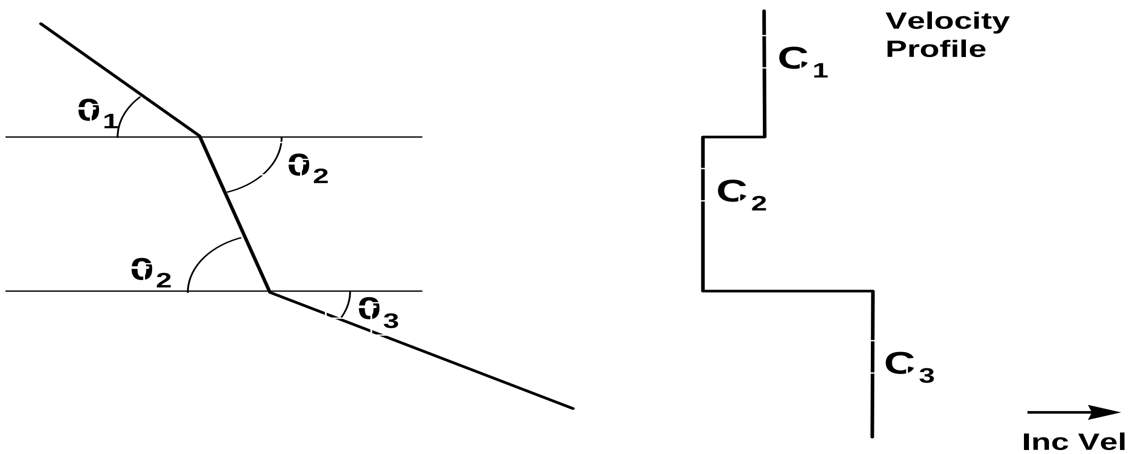


Figure 2.10 Snell's Law

2.8 Sonar Equation

There are numerous factors that control the behavior of underwater sound propagation; which when considered altogether is known as sonar parameters. These parameters are inter-related to each other and the expression which gives the relation of these parameters is known as sonar equation. The sonar equation mainly deals with the nature and effects of medium, target and the equipment itself. The main purpose of underwater acoustics is to detect the wanted signal i.e. target from that of the background noises caused due to unwanted energy reflection, ambient noise and the self noise of the platform. The target detection can only take place when the signal to noise ration is greater then the threshold level. The ability of the sonar to detect the target depends on the characteristics of the sea water, type of target and the noise generated by the sonar itself. In order to monitor the performance of sonar, these parameter are noted and related with the help of a sonar equation. Depending on the nature of the sonar equipment the equations can be of two types i.e. Active and Passive sonar equations.

2.9 Development of Active Sonar Equation

The performance and efficiency of active sonar depends on various factors. Few of these factors are common and will be used in the development of passive sonar equation as well. The development of active sonar equation requires a brief introduction of few important factors that plays an important role for both active and passive sonars. These factors are:

Background Noise (BN) Ambient noise together with self noise degrades the ability of the sonar to extract the target information from the received signal.

Directivity Index (DI) Noises and signals arrive at the receiver from all the directions. In case of directional sonars the beam former cancels out the signal which arrives from out side the beam of interest. This amount of signal cancellation is the measure of the directional property of the transducer and is known as the Directivity Index.

Target Strength (TS) The target strength may be defined as the difference in reflecting ability between the actual target and the reference target (Reference target is the target having target strength of 0 dB from a perfect reflecting sphere of 1m radius). Therefore, the target strength is the echo level of the signal that is reflected back towards the source and it depends on the target size, shape, aspect and construction of the target.

Propagation Loss (PL) The attenuation in the level of a sound signal once measured at a distance of 1m from the sensor. It depends on the expansion of the wave front, scattering and absorption of acoustic energy in the medium.

Source Level (SL) It is the intensity of the sound measured at 1m from the face of the transmitter.

Detection Threshold (DT) It is the value of SNR that can give the detection probability of 50%.

Bandwidth Correction Factor (BW) In case of active sonars the band width of the receiver is always set greater to that of the bandwidth of its transmitter. Therefore, the bandwidth correction factor must be applied.

The active sonar equation can now be developed by considering the above mentioned factors and can be given as:

The energy returned to the receiver after traveling the distance twice will be

$$\textbf{Signal} = \textbf{SL} - \textbf{2PL} + \textbf{TS} \qquad \textbf{(2.13)}$$

The noise of the receiver will be

$$\textbf{Noise} = \textbf{BN} - \textbf{DI} - \textbf{BW} \qquad \textbf{(2.14)}$$

So SNR at the transducer will be given as

$$\textbf{SNR} = (\textbf{SL} - \textbf{2PL} + \textbf{TS}) - (\textbf{BN} - \textbf{DI} + \textbf{BW}) \qquad \textbf{(2.15)}$$

2.10 Passive Sonar Equation

In case of passive sonar, most of the factors are same as that of active sonar. The factor which is additional is the target noises (TN) which may be define as the measure of the level of acoustic noise at a distance of 1m from the acoustic centre of the target.

The signal that reaches to the to the receiver is given as

$$\textbf{Signal} = \textbf{TN} - \textbf{PL} \qquad \textbf{(2.16)}$$

Noise seen at the receiver will be

$$\textbf{Noise} = \textbf{BN} - \textbf{DI} \qquad \textbf{(2.17)}$$

$$\textbf{SNR} = (\textbf{TN} - \textbf{PL}) - (\textbf{BN} - \textbf{DI}) \qquad \textbf{(2.18)}$$

2.11 Conclusion

In this chapter theoretical understanding of the sonars has been dealt with, which is important to understand the basics of sonar for carrying out effective underwater data communication. In absence of this basic knowledge it was difficult to overcome the difficulties which were encountered in the development of the system as discussed in forthcoming chapters.

Chapter 3

Digital Data Modulation

3.1 Introduction

The bit rate defines the rate at which information is passed. The baud (or signaling) rate defines the number of symbols per second. Each symbol represents n bits, and has M signal states, where M=2n.

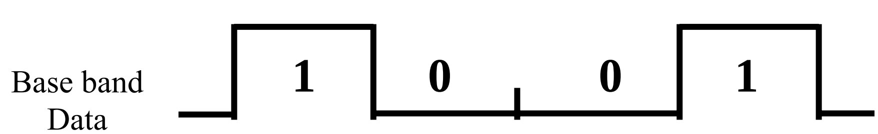
This is called M-ary signaling. The maximum rate of information transfer through a base band channel is given by:

Capacity fb = 2 W log2M bits per second

Where W = bandwidth of modulating base band signal

3.2 Amplitude Shift Keying (ASK)

Pulse shaping can be employed to remove spectral spreading. ASK demonstrates poor performance, as it is heavily affected by Noise and interference.



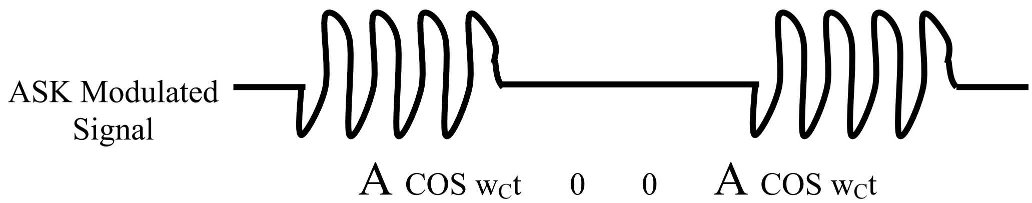
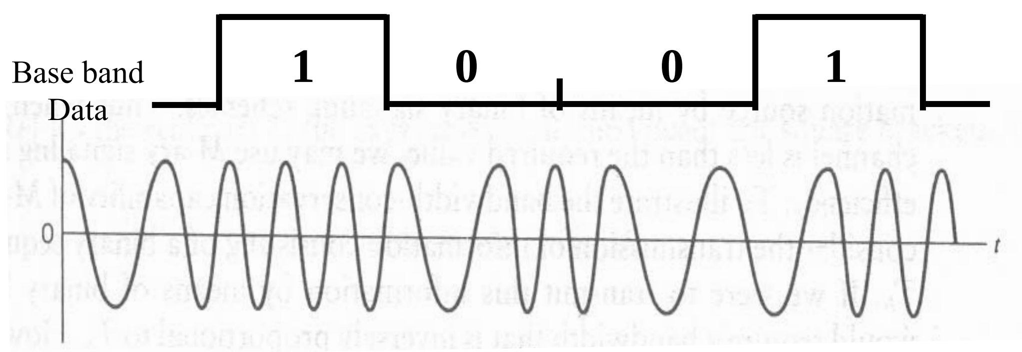


Figure 3.1 Amplitude modulated signal

3.3 Frequency Shift Keying (FSK)

Bandwidth occupancy of FSK is dependant on the spacing of the two symbols. A frequency spacing of 0.5 times the symbol period is typically used. FSK can be expanded to an M-ary scheme, employing multiple frequencies as Different states.



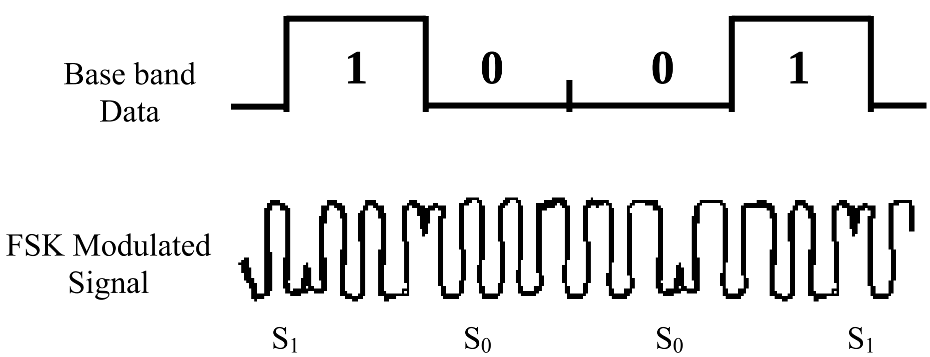
Where $f_0 = A \cos(w_c - \Delta w)t$ and $f_1 = A \cos(w_c + \Delta w)t$

Figure 3.2 FSK Modulated Signal

In FSK modulation schemes developed for underwater communications, the multi-path effects are suppressed by inserting time guards between successive pulses to ensure that the reverberation, caused by the rough ocean surface and bottom, vanishes before each subsequent pulse is received. Dynamic frequency guards can also be used between frequency tones to adapt the communication to the Doppler spreading of the channel. Although non-coherent modulation schemes are characterized by high power efficiency, their low bandwidth efficiency makes them unsuitable for high data rate multi-user networks. Hence, coherent modulation techniques have been developed for long-range, high-throughput systems.

3.4 Phase Shift Keying (PSK)

Binary Phase Shift Keying (BPSK) demonstrates better performance than ASK and FSK. PSK can be expanded to a M-ary scheme, employing multiple phases and Amplitudes as different states. Filtering can be employed to avoid spectral spreading.



Where $S_0 = - A \text{ COS } w_c t$ and $S_1 = A \text{ COS } w_c t$

Figure 3.3 Binary PSK Modulated Signal

3.5 Modulation QPSK

Quadrature Phase Shift Keying is effectively two independent BPSK system (I & Q), and therefore exhibits the same performance but twice the bandwidth efficiency. Quadrature phase shift keying can be filtered using raised cosine filters to achieve excellent out of band suppression. Large envelope variations occur during phase transitions, thus requiring linear amplification.

W_c = Carrier Frequency, I= In phase channel, Q=Quadrature channel

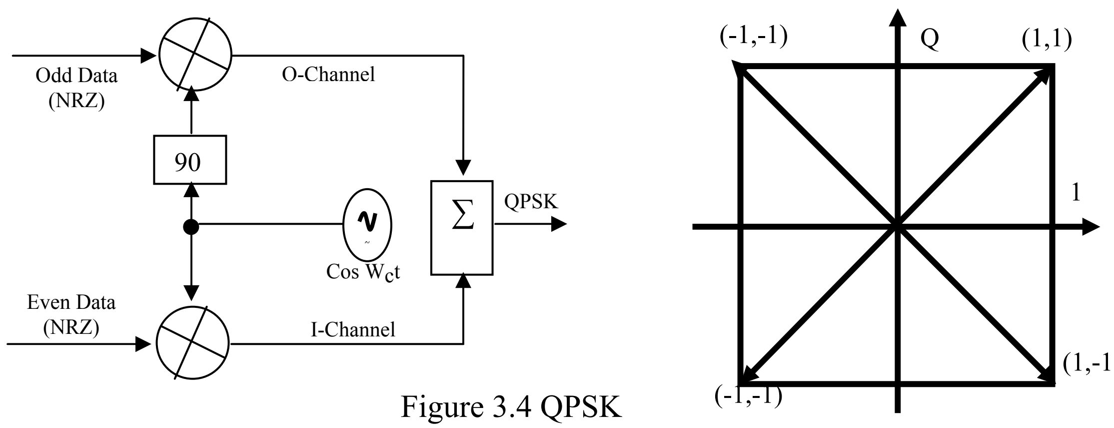


Figure 3.4 QPSK

3.6 Inter Symbol Interference (ISI)

ISI arises when energy from one symbol slot is spread out over neighboring symbol slots. The channel introduces ISI when the RMS delay spread becomes an appreciable fraction of the bit period (say greater than 10%).

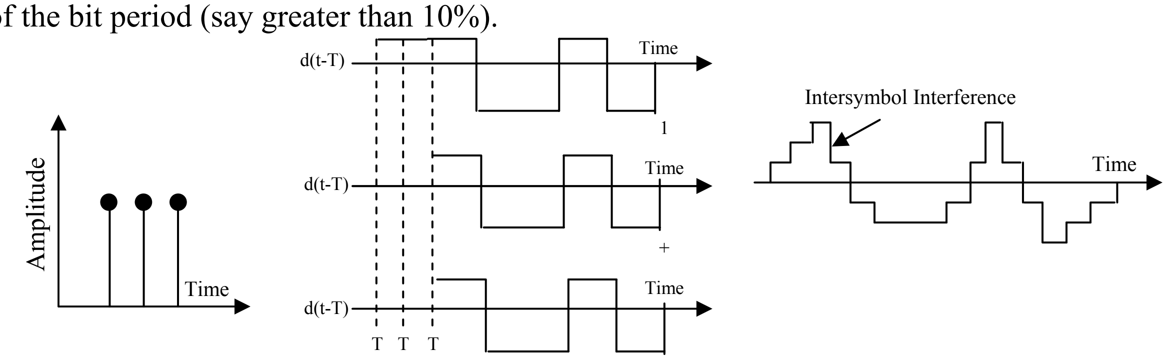


Figure 3.5 Inter symbol Interference

3.7 Summary of Error Mechanisms

Noise arises from a variety of sources, including internal noise and thermal noise in the receiver. Man-made radio transmissions cause adjacent channel interference and co-channel interference in the presence of noise and interference, it is necessary to increase signal power to reduce the possibility of errors.

Chapter 4

Telephone Modem and an Acoustic Modem

4.1 Introduction

While the computer is capable of doing thousands of jobs, from functional to recreational, there is a peripheral one can buy that will open up a whole new world of computer a modem. With a modem, you can communicate over ordinary telephone lines with other computers also equipped with modems.

While the basic job of modems is to serve as signal converters and translators, they are becoming more and more sophisticated. The new breed of modems can automatically dial phone numbers, answer phone calls, sign on to commercial information services, retrieve data, and perform other tasks under program control with no human intervention.

Besides making modems more sophisticated, modem designers and programmers are also trying to make the devices easier to use. They're trying to overcome the intimidation some people feel when they sit down to a desk filled with new technology—especially computers and modems. But that fear should fade as more people become involved with personal computers, manufacturers feel.

4.2 Modem (Modulator Demodulator)

Basically, a modem performs two jobs. At one end, the modem transforms the digital information from the computer into analog sounds that can be transmitted over the phone line. This is called *modulation*. At the receiving end, the second modem translates the analog tones back into the original digital information *(demodulation)*. Hence the term *modem stands for (mo*dulator-*dem*odulator). Coupled with terminal software that tells the computer how to communicate with another computer, a modem puts the user in business to tele-communicate.

4.3 The Beginning of Telephonic Modem

Modems since the time they were attached and used by the computer users are either *acoustic-coupled* or *direct-connect*. Acoustic modems (modem developed in the early days, not the modem for underwater communication) were developed first and used to be cheaper and more popular, but lately direct-connect models have drastically dropped in price and are pushing many acoustic modems off the market rather those old type of modems are almost out of the market.

The old time acoustic modems had a pair of soft rubber cups into which the telephone handset fitted snugly. One cup contained a speaker, which generated the tones to be transmitted over the phone line, and the other cup contained a microphone, which in turn received the tones sent by the other modem. If you listen closely that modem, you can hear the high-pitched whistling of the tones being transmitted.

The old telephone acoustic modems had two main drawbacks: Many newer phones have nonstandard handsets which won't fit into the rubber cups; and since acoustic modems depend on a tight seal between the handset and the cups, a poor fit means the telecommunications link can be garbled by outside room noises.

Direct-connect modems bypass the handset and the cups. They connect directly into any modular phone jack and work in total silence. Some direct-connect modems look like cartridges and plug into an expansion port on the computer, while others are stand-alone units that hook up between the computer and your phone. There are also internal modems which fit into the expansion slots inside some computers, and modems built into telephones, such as Code-A-Phone's Tel-A-Modem 212A.

4.4 Acoustic modems

Acoustic underwater communication is a mature field and there are several commercially available underwater acoustic modems. The exorbitant cost of commercial underwater modems has been an impediment to the wide deployment of dense underwater networks, until the recent development of research versions of hardware acoustic modems. A lot of efforts have been made by researchers aimed at making underwater acoustic modems more affordable and accessible to the research community by developing specialized affordable hardware. In this project it is intended to bring the size and cost even lower and making acoustic underwater communications even more accessible through the indigenous development of acoustic modems so that they can operate effectively and be utilized by many anticipated organizations. The work done in parallel to achieve cost effectiveness has been mainly by making use of generic microphones and speakers along with a specialized integrated circuit that generates an ASK or FSK modulated sound signal in order to demonstrate the acoustic communication capability underwater. This makes it a little too cumbersome to have two microphones and speakers at both the nodes. In UwDCOM relatively simple circuitry has been made with the help of low cost transducers to enable communication in simplex mode.

Chapter 5

Hardware Design and Interfacing Issues

5.1 Introduction

Wireless networks (network has two or more devices) are becoming enormously common in use these days due to the rapid advancements in the field of computer networks however, not all environments can support the typical wireless sensor model, which utilizes RF as a communication medium. Communication environments, especially underwater require the use of other methods. The underwater domain in particular has necessitated the use of acoustics to enable communication in underwater. There is a lot of work being done in this field where researchers have strived to develop all sorts of effective methods using different hardware to enable two or more devices to communicate with each other in a wireless network. Mostly work in this area consists of units built with bulky, costly acoustic modems. In this project it is preferred to use lightweight, low cost and interactive hardware and software to enable two devices namely two computers to communicate with each other. The model comprises of low cost light weight transducers, a microcontroller-based architecture and interface circuitry and a graphical user interface (GUI) based S/W. To illustrate the operation of this evolutionary prototype the performance it was tested in varying environmental conditions.

In an underwater environment, a typical RF-based communication subsystem would not be appropriate due to the fact that antennas (of a fairly large length) would be needed to communicate efficiently at Kilohertz frequencies. Furthermore, these antennas would be power-intensive. Previous research done in this area has shown that, while there are significant challenges, acoustic communication is fairly suitable for this task. Reliable communications through audio signals are already established for certain applications. Telephone modems have for decades used acoustic signals over copper cables to modulate information, reaching a max data rate of 56 Kbps. Acoustic signals have always been the top choice for underwater wireless communications, with applications that include oil prospecting, marine biology research, and environmental monitoring. Most existing wired and wireless audio communication techniques rely on specialized hardware. In particular, acoustic communication typically requires hardware that performs signal modulation and transmission at the sender side, in addition to hardware capable of receiving and decoding the audio signal at the receiver side. In the case of wired acoustic communications, telephone modems typically integrate all the hardware required to modulate, transmit, receive and demodulate audio signals. Wireless underwater acoustic communications often rely on specialized and expensive acoustic modems, as well as acoustic transducers and hydrophones to send and receive the signals underwater. Requiring the use of specialized hardware limits the pervasive use of acoustic communications, since it typically reduces system portability, increases the system cost, and requires more time and effort for installing and interfacing hardware components.

5.2 Acoustic Modem Design Requirements

The marine environment puts many restrictions on the researchers. The only way to transmit any info underwater is the use of acoustic signal as perceived by the researchers long time ago by the method called echolocation (method by which dolphins and whales communicate with each other) .

To enable two computers to send and receive data wirelessly underwater use of acoustic signals has been made. The hardware that made this communication possible is called an acoustic modem because modulation is taking place at the transmitter end and demodulation of the signal is done at the receiver end respectively. In the following the design requirements are discussed in detail:

5.2.1 Packaging

Due to the extreme nature of environment all oceanographic instruments need waterproofing and bio-fouling resistance so will this equipment be, now with the limitation that it will not be possible to test the model in a real oceanic environment so only the transducers being waterproof is good enough for the testing and demonstration purpose.

5.2.2 Power

Majority of oceanographic instruments depend upon battery power therefore using 12 volts battery supply is being used for energizing of the circuit. Since with the acoustic modem the data download requirement is eliminated so otherwise power required is reduced considerably. The commercial acoustic modems are not only cost heavy they are also power hungry so this issue is handled appropriately.

5.2.3 Low Cost

At present almost all commercial modems cost more than a 1000+ US$ it has tried to reduce the cost by a large factor using the most cheaply, reliable and efficient hardware.

5.2.4 Data Transmission Range

Though it being an extremely important issue the modem is expected to be able transmit to a longer range but due to non availability of real time oceanic environment it might not be possible to test the modem's optimum range.

5.2.5 Data Transmission Rate

Seeing the advancements in the technology of acoustics this modem is quite slow in terms of data rate because the maximum achievable data rate is pretty slow as per the design the modem should operate at least 12 baud (bytes per sec) or 96 bits per sec.

5.2.6 Acoustic Modem (a single component)

As required the modems are essentially having two components: a transmitter and a receiver; for simplex they would be able to communicate uni-directionally one node should be able to transmit the other to receive.

5.3 The Project Hardware

The following specifications provide details of the full project design goals and objectives. They outline the design requirements of the fully functional device to be eventually produced. The proposed design is of an acoustic data communication system which allows for the basic transmission of messages between a transmitter and receiver unit. The system should be able to function reliably underwater. The functionality of the device should be simple and user-friendly while also being reliable enough to be depended upon as a data communication device. The physical design should be light-weight and portable, while remaining compact and hydrodynamic.

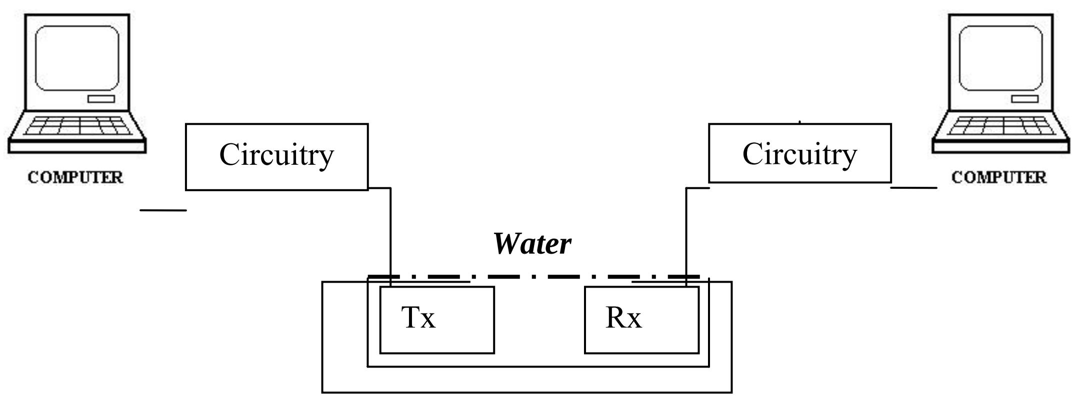


Figure 5.1 Block Diagram of the Transmitter/Receiver Communications unit.

5.4 The Transmitter Unit

The data communication transmitter unit is the component which transmits a signal to the receiver unit once the user presses the input. The unit consists of several major components, the user interface, the microcontroller, the power supply, the timer and interfacing circuitry, the ultrasonic underwater transceiver and the waterproof housing. The Data communication unit should be a small device easily integrated into submarines. The unit also must be neutrally buoyant to prevent it from floating away from the hull of the submarine, which is very less likely in this case.

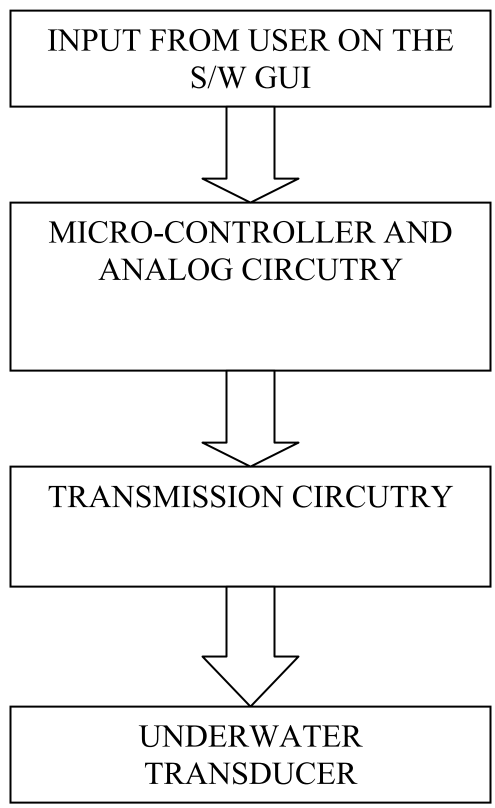


Figure 5.2 Block diagram Transmitter unit

The transmitter mechanism comprises of an interface circuit consisting a microcontroller, amplification circuit a constant voltage oscillator and an acoustic transducer. This interface circuit is constructed on a PCB and is tested to transmit effectively within the H/W limitations mentioned by the manufacturer. In the transmitter the digital signal as received from the serial port is stored in the random access memory of the microcontroller and then moves through the DAC to amplifier where the signal is amplified and then in the form of appropriate mark (digital 1) and space (digital 0) is sent to the frequency multiplier where input from the oscillator also comes in and multiplier mounts the marks and space signal onto the carrier from the oscillator to be sent to the transducer from where he signal is transmitted through water to the receiver.

5.5 The Receiver Unit

The receiver unit is used to receive and process signals sent to it from the transmitter unit.

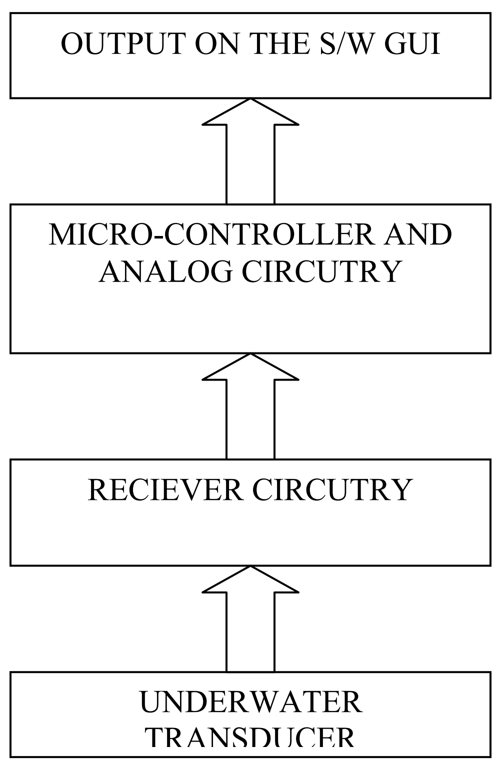


Figure 5.3 Block Diagram Receiver unit

It should consist of all of the same major components as the transmitter unit and should be of the same relative size. Once fully operational, the receiver is to be integrated into a hull of submarine and thus should be suitably rugged to withstand normal open water conditions. It should be completely watertight to maintain buoyancy but yet be easily opened for servicing. The receiver converts the analog waveform it receives back into the digital signal that was transmitted. In other words, the receiver detects the mark and space frequencies in the received signal and converts them back to digital '1's and '0's respectively.

5.6 Observations and Limitations

Following are some features and limitations of the design

5.6.1 Hardware Interfacing

Not much has been achieved on the Modem to make it 'plug and play' with the computer. As it has already been mentioned above that all the sensors for the underwater communication use the RS-232 data protocol therefore this Modem also adopts the RS-232 data protocol.

5.6.2 Packaging

Well as it can be seen that the complete circuitry is not water proof except for only one component i.e. the transducer. It would be better if the complete equipment is made water proof may be by the time it is matured it is achieved.

5.6.3 Power

This has been an extremely important issue, since on the ground power from the adopter or the main power supply can be used but in the underwater environment special rechargeable batteries will be required which might add a bit to the overall cost but that can be handled. The Modem in the case of underwater nodes will not be used for a specific measured distance as the floating platforms cannot be kept completely static, as far as smaller distances are concerned we can operate at low power.

5.6.4 Cost

As it was one of the most important issues to deal with. A major cost of existing underwater acoustic modems is the custom made and highly proprietary transducers used with the modems that cost $1000+. Replacing these $1000+ transducers with $150 Transducers (commercial-off-the-shelf transducers already mass produced for anglers and industry fishers) greatly reduces the overall cost of the modem. All the components of the prototype modem implementation are inexpensive except for the microcontrollers and the transducers. The anticipated cost of both units is **US$ 600.** In designing an indigenous acoustic modem a tradeoff between data rate and aesthetics must be accepted.

Chapter 6

Results and Analysis

6.1 Introduction

The testing of system was carried out on different designs evolved during the development of the system. This was done mainly due to the very different nature of hardware involved in the development of the system. All these designs underwent some form of basic testing procedures to ascertain the functionality of the system. The original design was tested underwater as the device was capable of transmission in this medium. The following results demonstrate the effectiveness of the device under these conditions.

6.2 Lab Testing

The underwater testing of the system was carried out to determine the performance of the hardware. Both of these devices tested inside the lab while connected to the digital oscilloscope. The initial test was conducted while the devices were powered by the laboratory power supply and also when connected to the battery supply positioned on the lab bench. The ultrasonic devices were dipped into the water during the course of the testing as it was quite cumbersome to access a large body of water within The Lab, A Fish aquarium of reasonably good size i.e. (length 4 ft, width 1.5 feet and height 3.5feet) was arranged for testing purposes. In the confined volume of water within this basin the two ultrasonic transceivers were placed at 06``, 12``, 24``, 36``and 48 inches respectively. Within this volume of water, not much of the signal attenuation was observed. As the volume was bounded in the confined area, therefore much of the attenuation that might have occurred would most likely have been veiled by the enormous amount of echo reflection that would have been generated from the walls and bottom of the basin. Though it was clear that this test for the device was very limited, yet it did serve to provide considerable data for analysis.

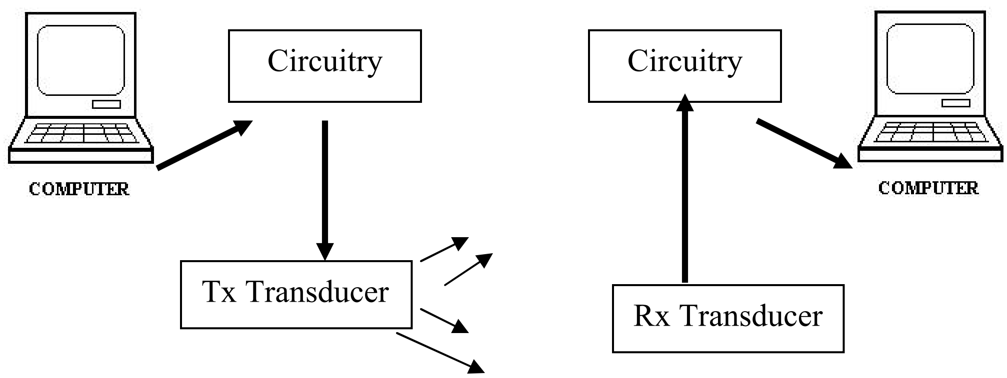


Figure 6.1 Signal Reception Testing

6.3 Proposed Additional Testing Procedures

Unfortunately the degree to which thorough testing was performed for this project was very limited. An effort was also made to carryout trial of the device in open water but the test was limited to the extent of carrying out transmission between two devices only. This was also due to the non-availability of the expensive testing equipment at the outdoor location in a larger body of water. The following experiments are designed to fully determine the operational capabilities of the device in different environmental conditions.

6.3.1 Straight Range Testing

Straight/ Horizontal range testing was performed in order to determine the effective range of the device. This is purely an expansion of the test done in the fish aquarium. The obvious limitations that prevented the performance evaluation of this system were that the equipment (transducers) required for carrying out actual testing came very late therefore not much could be achieved in this regard. Furthermore within the scope of this project is was not viable to transport the necessary testing equipment i.e. the DC Power supply and the oscilloscope, to a location where such a test could be performed, i.e. an Olympic-sized swimming pool. The swimming pools are also not available these days to carryout successful testing.

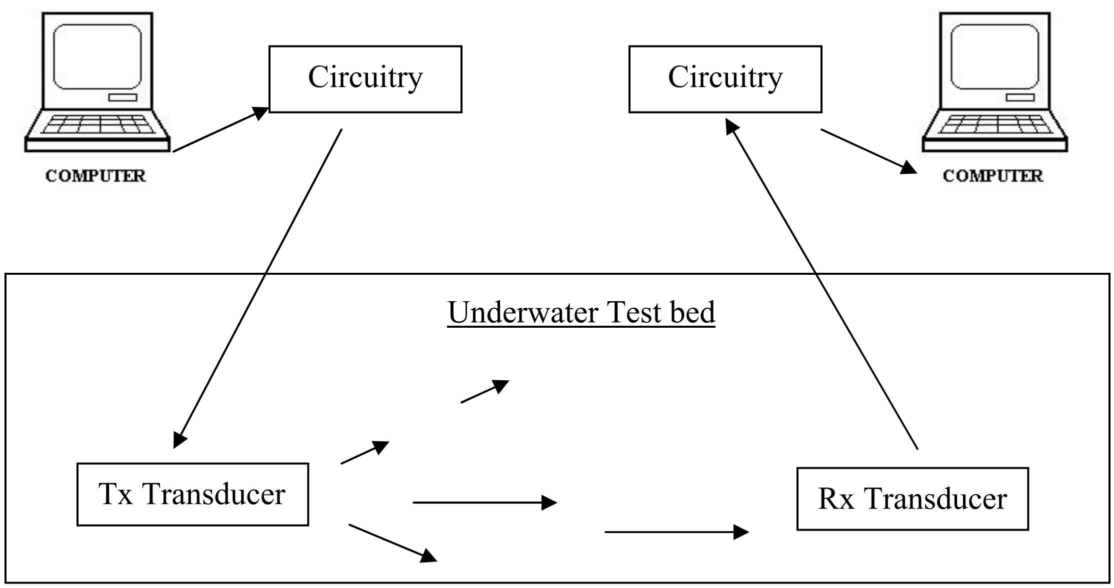


Figure 6.2 Horizontal Effective Range Testing (underwater)

Fundamentally, this test involves slow increase in the range between the two transducers heads and recording the deterioration in signal strength on the oscilloscope. Such experiments would require the two sensors to be submerged rather than the entire device or system.

6.3.2 Perpendicular Depth Testing

This test procedure would be possible with access to a deep volume of water such as a lake or at some public swimming pools. It was however still possible to test this device by only submerging the transducers. The tests carried out under these conditions will give an indication that how these devices will perform when they will be displaced vertically to each other. This can be taken as a safe assumption as to how this system will perform under actual conditions.

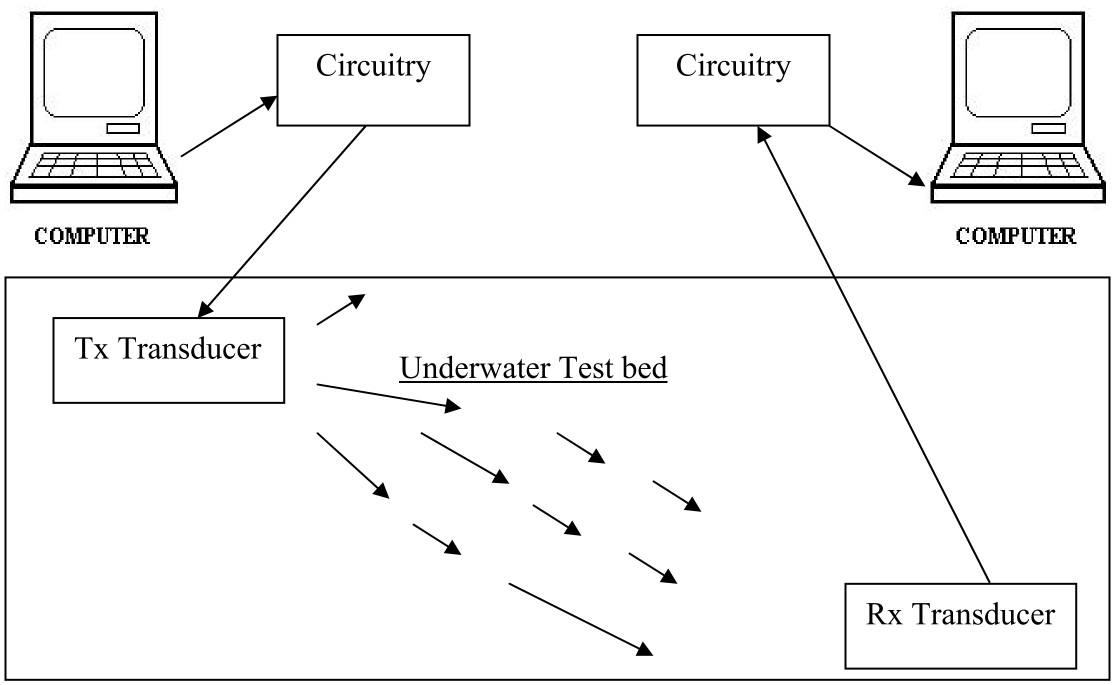


Figure 6.3 Vertical Effective Range Testing (underwater)

Chapter 7

The Software

7.1 Introduction

In this endeavor of building an acoustic modem many options were worked upon to enable interfacing the hardware with the software in that research the conclusion was to use one of the most recent software environments of .Net framework and in that C# has been used as the basic tool to develop the software. The biggest advantage of motivation of using C# was that it has great facilitation of usage of serial port which was a limitation since serial port was to be used for data transmission.

7.2 Basic Structure

The software comprises of basic window forms of C# where the forms are having features like buttons text boxes and labels for various operations, the details of which are explained in the following paras. By using a self explanatory graphical user interface it has been tried to make it easy for any layman to understand the software.

7.3 Step By Step User Guide

When launched the first page opens up (image pasted below).

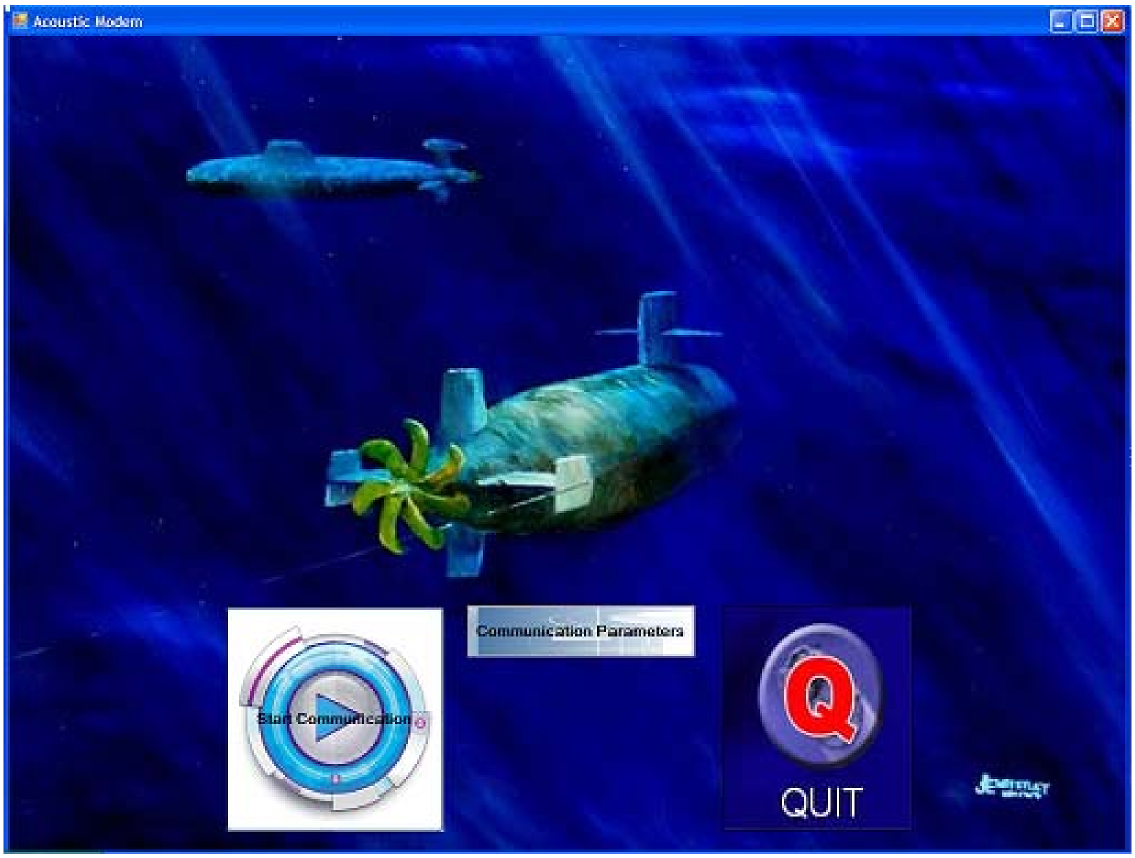


Figure 7.1 Main GUI

There are three buttons naming Start Communication, Communication Parameters and Quit button. If the user wants to see the communication parameters he just has to press the button and the following group box will drop down.

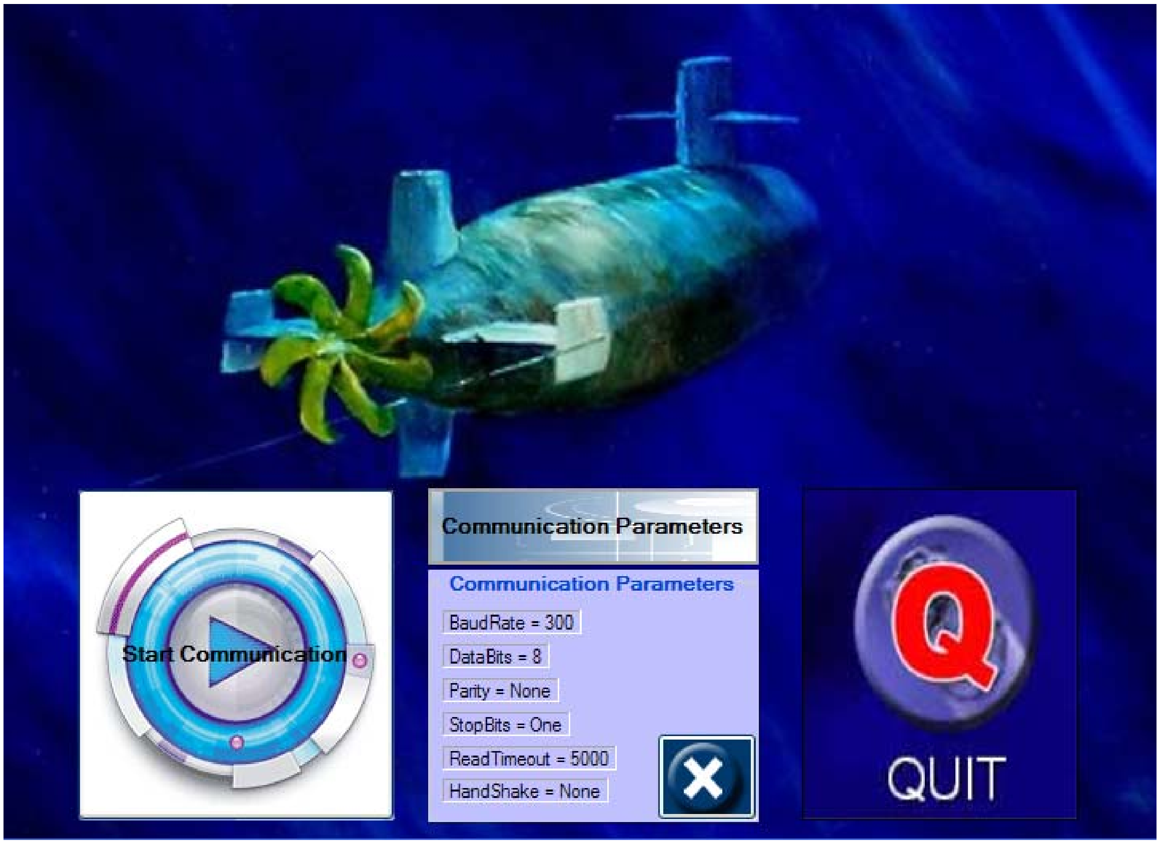


Figure 7.2 Communication Parameters

The communication parameters include

Baud rate, Data bits, Parity, Stop bits, Read time out, Hand shake.

When the user intends to start communication he has to press start communication button and the next menu opens up. It is clear from the GUI that what the user has to do just type in the text and press the button. A point to be highlighted here is that initially the intention was to have a half duplex communication but that could not be achieved so this modem enables only simplex communication. This means that although the S/W is the same at both the nodes but ability is different i.e. one node is the transmitter and the other is the receiver.

Figure 7.3 Communication Window

7.4 Mat lab simulation Model

In order to investigate the model efficiency a simulation is prepared using Mat lab in which various theoretical issues were highlighted so as to mould the implementation according to those real time variables. This interface has following options displayed as window buttons Sonar Equations, Simulation, Bit Error rate .

Figure 7.4 Mat Lab Main GUI

7.4.1 Sonar Equations

The Sonar equation button opens up another window which contains all the functionality of Active and Passive sonar equations. Different characteristics of sonar equations along with their graphs are evaluated in this GUI.

7.4.2 Simulation

The simulation button takes the user to the Simulation model prepared to demonstrate the working of the entire UwDCOM system.

7.4.3 Bit Error rate

An error is a discrepancy between corresponding points in the two sets of data. The bit error rate option compares data and computes the number of bit errors and the bit error rate. This button facilitates in the calculation of the errors in the message which will be transmitted and received in the system.

7.5 Sonar Equations

The Sonar equations window contains following option buttons:

Power, Distance, Depth, Frequency, Transmission Loss Vs Range, Source Level Vs Power, Propagation Loss Vs Range, Comparison of Equations.

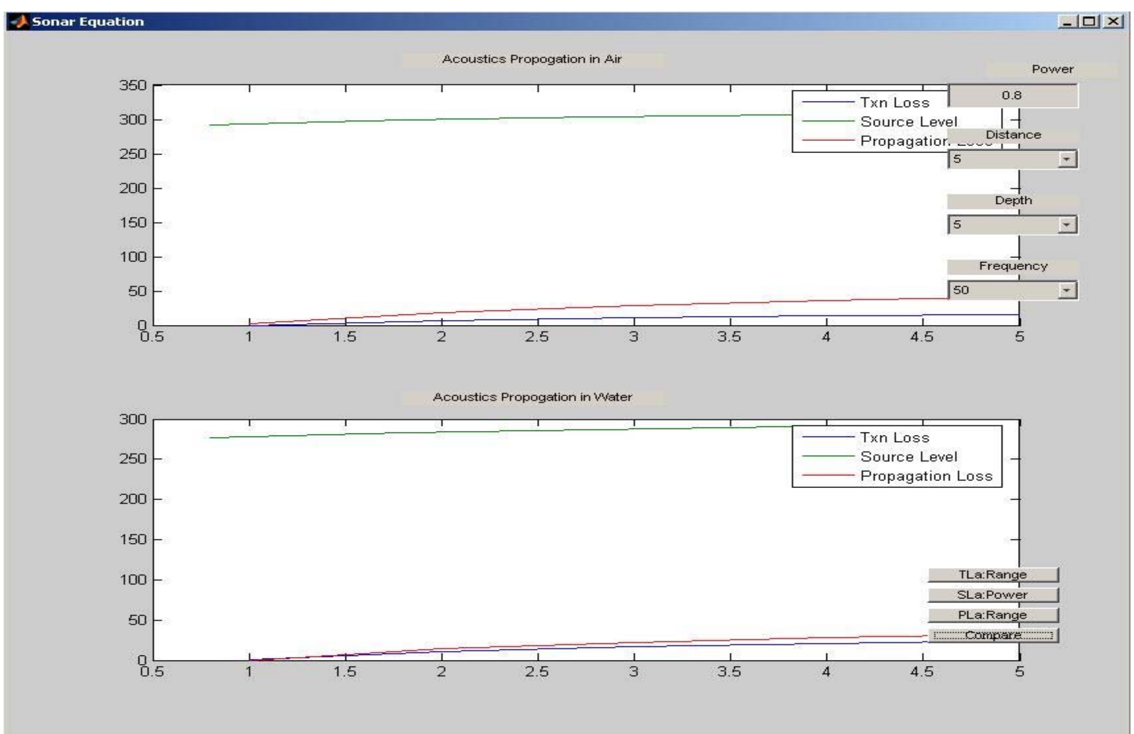


Figure 7.5 Sonar Equations menu

7.6 UwDCOM

This GUI contains following option buttons

Sample Time, Initial Seed, Simulate, Close, Help.

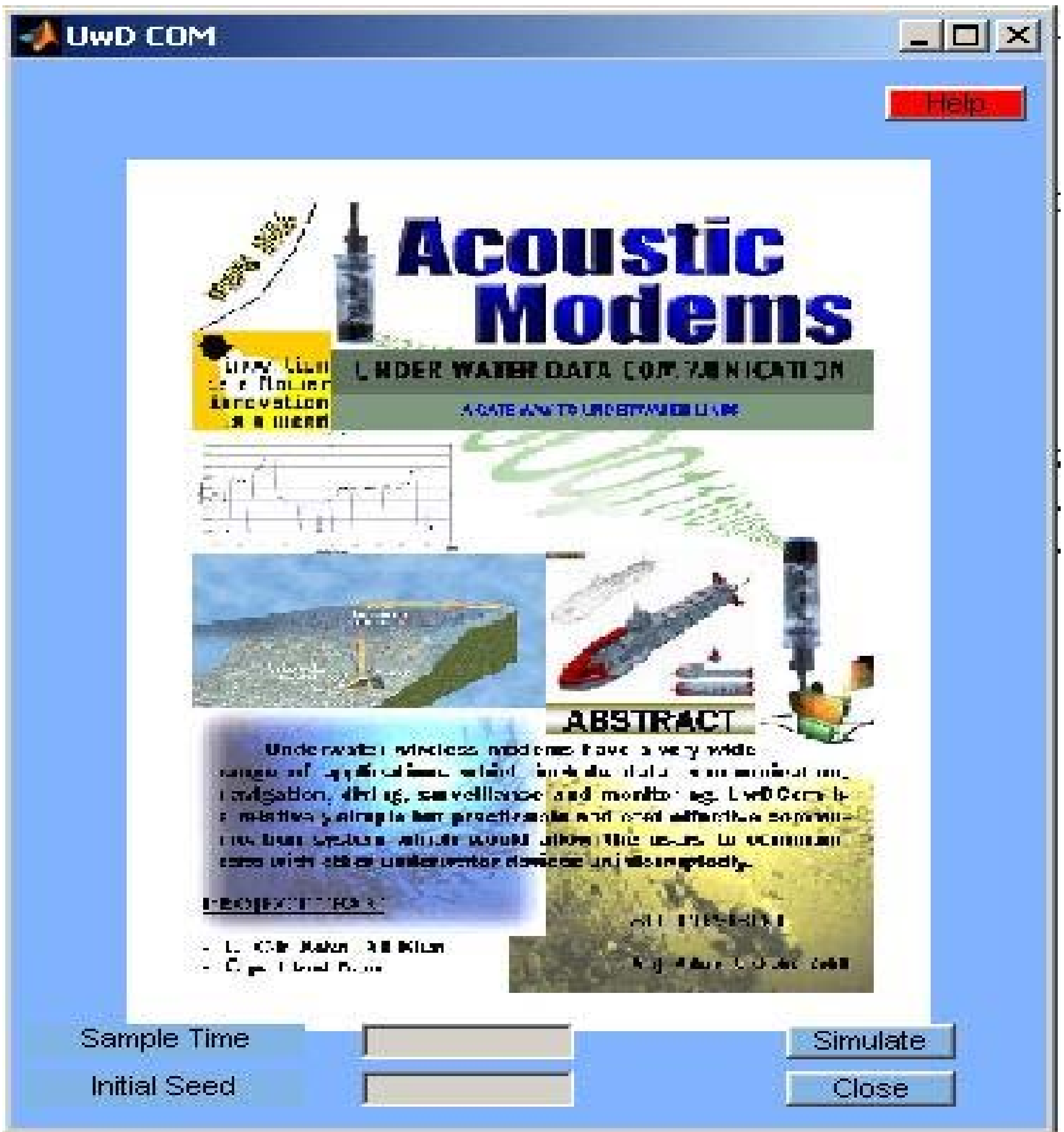


Figure 7.6 UwDCOM menu

Sample Time: This sets the period of each sample-based vector. Initial seed: The initial seed value for the random number generator. Simulate: This button will open the model along with the displays and scopes i.e. the error detection block and the message which has been transmitted and received along with the degree of agreement and disagreement. Help: The help button will open the file which contains the details of the system as to how the actual system works. It also contains the functionality of different blocks which were used in the system. Close: The close button will exit the entire MATLAB application.

7.7 Error Rate Correction User Interface

Length of Message, Evaluate and store results, Error Rate detection in Decode Message, Error Rate correction in Received Message

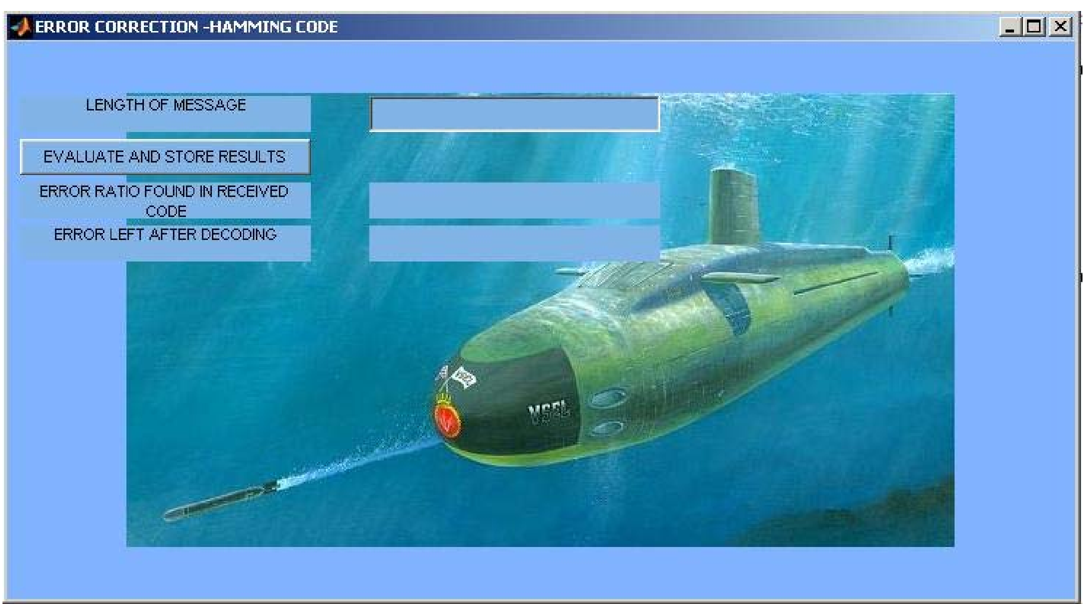


Figure 7.7 Error Correction menu

7.7.1 Length of Message

The length of message is an integer value greater than or equal to 3.

7.7.2 Evaluate and store results

This button will start evaluation after taking the input i.e. Length of message, it will then evaluate the results which will be displayed in the Error Ratio found in decoded message block and Error Rate left after decoding in the received message.

Chapter 8

Conclusion and Future Work

8.1 Conclusion

The prototype was designed to demonstrate that construction of a miniature acoustic communication system for underwater applications is possible even with limited resources and indigenous material. This system has its limitations but also its successes. It was shown to transmit underwater and to take data to be transmitted from a microcontroller. Conversion of the signal to relevant data at the receiving point was attempted by two low-power receiver interface circuits, but more work is required to increase communication accuracy and efficiency. Various characteristics of the environment such as harmonic loss, acoustic reflections, and medium noise limited the performance of the interface circuitry and pose a fundamental challenge. These are issues that need to be solved before this modem can be practically deployed. However, considering that existing underwater acoustic modems are large and expensive, and one of the priorities is to develop miniature and inexpensive systems, this model is still very promising.

While reviewing the progress made in this project, it can be claimed that the effort made in this direction can be considered as an initial step towards the development of the complete working system. The objectives set out at the onset of the project has been achieved successfully, however this project beyond any doubt can be graded as an ongoing project, the work done in this section can be seen as a solid foundation on which further development of the overall project can be built upon. The prototype developed based on the projects design specifications has had positive results from the limited testing that has been performed and with further development and testing a more functional prototype can be redesigned and constructed. In terms of software, the project has had made sufficient development in terms of a functional program for integration with the hardware and simulation was also developed for better understanding of the system. Architecture of the system has been developed and all future work for the software model has been planned.

8.2 Future work

At this stage, the system is capable of transmitting ultrasonic signal between the transmitter and receiver unit. This fulfils the initial objectives of project that was to develop a viable ultrasonic communications platform on which further applications can be based. Further enhancement of the system would allow it to be much more user-friendly and increase functionality. The proposed future developments contain various additions and extended applications to different aspects of the project, each with varying levels of intricacies. In some cases these proposals are simply an extension of current work and perfecting current existing systems whereas others require much more research and development before a working prototype could even be implemented.

8.3 Testing

The actual experimental facet of this project was limited. Several unforeseeable constraints prevented a full and thorough open water test of the device, although this could be deemed as one of the most important aspects of this project. Further testing of the device under more open conditions should be at the head of any future work to be undertaken. The testing of this device should be carried out under full environmental conditions in order to thoroughly assess its operational capabilities.

8.4 Software

The software development for the device at this stage is good enough to handle the basic communications, however it is hoped that at a later stage the current software can be stretched out to include error detection and error correction mechanisms. The simulations can also be made more interactive by collecting real time data from the PN ships and submarines. Once this is completed, it would then be possible to consider adding more complex functionality to the device.

8.5 Transmitter/Receiver Integration

The first enhancements that would be necessary is integration of both transmitter and receiver modules so that a single device can transmit and receive signals. In order to do this, it would be necessary to carryout some modifications in the initial design. To accommodate more functionality it may be necessary to switch over from the current microcontroller to a more advanced one or DSP chip. This change would not limit itself to the hardware but certainly changes would be required in the design of software of the system as well. Interfacing this underwater data communications system with ship/submarine computers would allow the command in establishing a useful command and control system. The UwDCOM system can also be modified so that it can capture useful environmental information such as temperature, depth and direction, current depth, maximum depth which can also be used as an alternative to the equipment held on board ships and submarines for such purposes.

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