Chapter 1

1. INTRODUCTION

While wireless communication technology today has become part of our daily life, the idea of wireless undersea communications may still seem far-fetched. However, research has been active for over a decade on designing the methods for wireless information transmission underwater. Human knowledge and understanding of the world's oceans, which constitute the major part of our planet, rests on our ability to collect information from remote undersea locations.

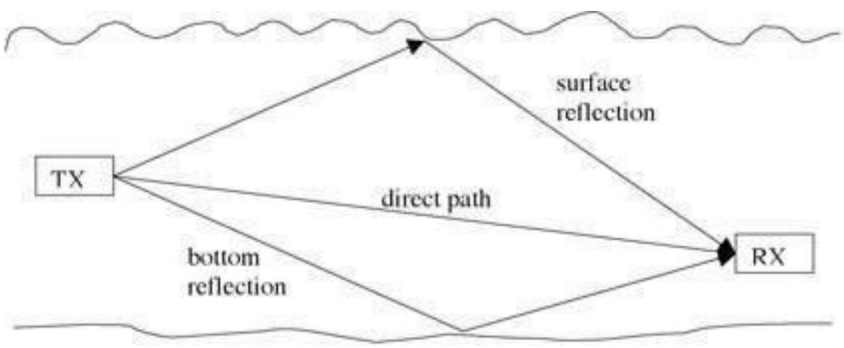

Fig.1.1.Basic underwater communication system

It is extremely difficult to achieve a high data rate communication link underwater due to various constraints such as poor propagation of electromagnetic signals underwater, high attenuation of acoustic signals, lack of accurate mathematical models of the underwater acoustic channel etc. Also, some of the wired underwater communication links would be prone to attacks by aquatic animals. Also, these wired links have problems related to dispersion and low data rate due to extreme pressure underwater.

Hence the motivation and interest in wireless underwater communications. Together with sensor technology and vehicular technology, wireless communications will enable new applications ranging from environmental monitoring to gathering of oceanographic data, marine archaeology, and search and rescue missions, emergency Communications from a ship - Wired Media, mobile communication from a submarine, AUV with other stations that include ships, land based stations and other submarines – wireless acoustic media and many more.

The primary research goal of this project is to investigate various algorithms for underwater communication systems and hence enhance the performance. Since, low data rate is the major bottleneck in successfully implementing an underwater communication system. The project aims to address the data rate issue by investigating numerous novel algorithms customized for underwater systems. This would be done by studying and optimizing the modulation schemes and the communication parameters for an underwater channel. The underwater channel model would be adopted from published literature and used for simulations. Then for this channel various studies would be performed to explore for better performance.

1.1 Literature Survey

Effective under-water communication systems require detailed study of acoustic wave propagation in ocean. The preamplifier parameter tuning techniques for the underwater communication systems have been greatly affected by the recent information available on the respective area. Many investigators have studied the absorption of acoustic waves in ocean water and formulated empirical equations, however no one has made an attempt to offer the simulation model for the under-water acoustic propagation. The comparative study of acoustic wave absorption carried out by means of modeling in MATLAB.[5]

The depths of the oceans have a high potential for future industrial development and applications. Robotic autonomous systems will greatly depend on a reliable communications channel with operators and equipment either performing joint operations or on the surface. However, communications must face harsh conditions that hinder the performance. Neither electromagnetic nor optical technologies are suitable for communication because of their short range in this medium. Due to this, acoustic equipment is envisaged as the most appropriate technology, even though it suffers several negative effects such as strong attenuation at high (ultrasonic) frequencies, Doppler shifts and a time-varying multipath. In this paper, we describe the characteristics of the acoustic underwater channel and how it impacts the mechanisms at the link and network layers.[4]

Light propagation in an underwater environment encounters scattering effect creating dispersion which introduces inter-symbol-interference to the data communication. The attenuation effect further reduces the signal to noise ratio. Both scattering and absorption have adverse effects on underwater data communication.[6]

High-speed communication in the underwater acoustic channel has been challenging because of limited bandwidth, extended multipath, refractive properties of the medium, severe fading, rapid time variation and large Doppler shifts. In the initial years, rapid progress was made in deep water communication, but the shallow water channel was considered difficult. In the past decade, significant advances have been made in shallow water communication.[8]

The new generation of underwater communication systems, employing phase-coherent modulation techniques, has a potential of achieving at least an order of magnitude increase in data throughput. The emerging communication scenario in which the modern underwater acoustic systems will operate is that of an underwater network consisting of stationary and mobile nodes. Current research focuses on the development of efficient signal processing algorithms, multiuser communications in the presence of interference, and design of efficient modulation and coding schemes.[9]

Acoustic propagation is characterized by three major factors: attenuation that depends on the signal frequency multipath propagation and low speed of sound. The channel has a spars impulse response, where each physical path acts as a time varying low pass filter, and motion introduces additional Doppler spreading and shifting. Because propagation is best supported at low frequencies, acoustic communication systems are inherently wide band. The way in which these facts influence the design of signal processing methods is considered for single-carrier and multi-carrier systems. Moreover the facts that the available bandwidth and transmission power depend heavily on the distance, and that channel latency is high, bear important implications on the design of the network architectures and related protocols.[3]

1.2 Limitation of the current work

As for terrestrial application, the underwater wireless communication is not a straight forward process. When considering the underwater communication process, the primary concern that researchers always consider are the channel model(underwater), attenuation, transmission distance, power consumption, SNR ratio, bit error, Inter symbol interference, error coding, modulation strategies, instrumentation and underwater interferences. Dealing with interferences for underwater research is a complex task due to dynamic nature of water. Interferences are mainly caused by three major factors:

1.2.1 Characteristics of signal carrier

In underwater world, there are 3 types of carrier wave that are most commonly used in wireless communication.

i. Electromagnetic wave: Using electromagnetic wave, the communication can be established at higher frequency and bandwidth. The limitation is due to high absorption/attenuation that has significant effect on the transmitted signal. Big antenna also needed for this type of communication, thus affects the design complexity and cost.

ii. Optical wave: Optical wave also offers high data rate transmission. Nevertheless, the signal is rapidly absorbed in water and suffers from scattering effect. This will affect the data transmission accuracy.

iii. Acoustic wave: Acoustic is the most preferred signal used as carrier by many application, owing to its low absorption characteristic for underwater communication. Even though the data transmission is slower compared to other carrier signal, the low absorption characteristic enables the carrier to travel at longer range as less absorption faced by the carrier.

1.2.2 Environment/Propagation Medium

Here, the challenges are quite different. Water itself has become the main source for the signal interference. The type of water (freshwater/sea water), depth pressure, dissolved impurities, water composition and temperature affect the sound propagation. Common terrestrial phenomena like scattering, reflection, refraction also occurs underwater communication.

1.2.3 Instrumentation System Devices

For effective communication, the communication system design plays a vital role. Factors such as transducer parameters (sensitivity, power consumption, noise immunity, transduction mechanism, directivity, resolution and properly matched impedance) must be taken into account during the design process. One of the important areas that worth focusing on is the receiver (sensor) design. Nowadays, with the advancement in electronic technology, the transducer design (especially receiver) can adopt MEMS technology to overcome several sensor issues that proves to have several advantages compared to the conventional approach. It is found to have many advantages compared to the conventional design.

1.3 Problem Definition

Design of Modulation and Demodulation of broadband signal of 16 tones (32-bits) using PSK (Phase Shift Keying) technique for underwater communication.

1.3.1 Applications

- Communication with and between manned and unmanned vehicles.
- Pollution monitoring
- Data harvesting for environmental monitoring
- Seismic monitoring
- Ocean currents monitoring
- Acoustic navigation for multiple AUVs

1.4 Objectives

To Obtain Accurate Communication

i. Using Acoustic wave

Acoustic is the most preferred signal used as carrier by many application, following to its low absorption characteristic for underwater communication. Even though the data transmission is slower compared to other carrier signal, the low absorption characteristic enables the carrier to travel at longer range as less absorption faced by the carrier.

ii. Optimize SNR

Optimize SNR value until we get accurate transmission of the signal without any loss in the signal amplitude.

iii. By reducing noises and losses as more as possible, this helps us to obtain an accurate communication.

1.5 Methodology

Characterization of underwater channel with a well-known mathematical model, to be borrowed from published literature. To survey the various novel communication schemes in Digital Communication such as wireless, to study MSE and BER performance: MIMO, OFDM, hybrid solutions would be explored and various modulation techniques like BPSK, QPSK are studied from various journals dedicated to digital communication, the motive behind this is that the underwater acoustic communication channel would be fundamentally a digital communication system, novel ideas in a conventional digital system might be helpful for performance enhancement of underwater communication. Mathematical models for the same would be built using academic software. Also, the results published in the literature and simulated results would be compared. The primary difference between a conventional wireless channel and a underwater channel is the impulse response of the channel is quite different in both the cases.

Attempt to implement the same schemes and variations of it for an underwater communication channel in the theoretical domain. First, the mathematical model for underwater channel would be adopted from published literature, assuming realistic parameters. Later, the novel schemes simulated and tested (ideas from typical wireless systems) would be tested for a underwater channel. Optimize the schemes for better performance. Once, the various schemes for an underwater channel is performed. Tweaking of the scheme or optimization process would be performed to extract suitable results. In other words, the communication system's scheme would be customized for a underwater scenario. Compare and contrast the new model with previously established schemes.

We use PSK modulation technique

1.5.1 Phase Shift Keying (PSK):

Phase-shift keying (PSK) is a digital modulation scheme that conveys data by changing (modulating) the phase of a reference signal (the carrier wave). The modulation occurs by varying the sine and cosine inputs at a precise time. It is widely used for wireless LANs, RFID and Bluetooth communication.

Any digital modulation scheme uses a finite number of distinct signals to represent digital data. PSK uses a finite number of phases, each assigned a unique pattern of binary digits. Usually, each phase encodes an equal number of bits. Each pattern of bits forms the symbol that is represented by the particular phase. The demodulator, which is designed specifically for the symbol-set used by the modulator, determines the phase of the received signal and maps it back to the symbol it represents, thus recovering the original data. This requires the receiver to be able to compare the phase of the received signal to a reference signal — such a system is termed coherent (and referred to as CPSK). Alternatively, instead of operating with respect to a constant reference wave, the broadcast can operate with respect to itself. Changes in phase of a single broadcast waveform can be considered the significant items. In this system, the demodulator determines the changes in the phase of the received signal rather than the phase (relative to a reference wave) itself. Since this scheme depends on the difference between successive phases, it is termed differential phase-shift keying (DPSK). DPSK can be significantly simpler to implement than ordinary PSK, since there is no need for the demodulator to have a copy of the reference signal to determine the exact phase of the received signal (it is a non-coherent scheme). In exchange, it produces more erroneous demodulation.

1.6 Software Tools

1.6.1 Matlab: MATLAB (matrix laboratory) is a multi-paradigm environment and fourth-generation programming language. A proprietary programming language developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, C#, Java, Fortran and Python.

Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the MuPAD symbolic engine, allowing access to symbolic computing abilities. An additional package, Simulink, adds graphical multi-domain simulation and model-based design for dynamic and embedded systems.

Chapter 2

2. BASIC THEORY

An acoustic communication network is a method of positioning equipment using sound waves. It is primarily used in water, and can be as small or as large as required by the users specifications. The principle behind all acoustic communication networks is the same. Distance = speed x travel time. If the travel time and speed of the sound signal are known, we can calculate the distance between source and receiver. In most networks, the speed of the acoustic signal is assumed at a specific value. This value is either derived from measuring a signal between two known points, or by using specific equipment to calculate it from environmental conditions.

2.1 Underwater acoustic communication

Underwater acoustics is the study of the propagation of sound in water and the interaction of the mechanical waves that constitute sound with the water and its boundaries. The water may be in the ocean, a lake or a tank. Typical frequencies associated with underwater acoustics are between 10 Hz and 1 MHz. The propagation of sound in the ocean at frequencies lower than 10 Hz is usually not possible without penetrating deep into the seabed, whereas frequencies above 1 MHz are rarely used because they are absorbed very quickly. Underwater acoustics is sometimes known as hydro acoustics.

The field of underwater acoustics is closely related to a number of other fields of acoustic study, including sonar, transduction, acoustic signal processing, acoustic oceanography, bioacoustics, physical acoustics.

Underwater acoustic communication is a technique of sending and receiving messages below water. There are several ways of employing such communication but the most common is by using hydrophones. Underwater communication is difficult due to factors such as multi-path propagation, time variations of the channel, small available bandwidth and strong Signal attenuation, especially over long ranges. Compared to terrestrial communication, underwater communication has low data rates because it uses acoustic waves instead of Electromagnetic waves.

At the beginning of the 20th century, some ships communicated by underwater bells, the system being competitive with the primitive Maritime radio navigation service of the time. The later Fessenden oscillator allowed communication with submarines.

Underwater acoustic channels are generally recognized as one of the most difficult communication media in use today. Acoustic propagation is best supported at low frequencies, and the bandwidth available for communication is extremely limited. For example, an acoustic system may operate in a frequency range between 10 and 15 kHz. Although the total communication bandwidth is very low (5 kHz), the system is in fact ultra-wideband, in the sense that bandwidth is not negligible with respect to the center frequency. Sound propagates underwater at a very low speed of 1500 m/s, and propagation occurs over multiple paths. Delay spreading over tens or even hundreds of milliseconds results in a frequency selective signal distortion, while motion creates an extreme Doppler effect. The worst properties of radio channels–poor physical link quality of a mobile terrestrial radio channel and high latency of a satellite channel–are combined in an underwater acoustic channel.

Broadly defined, modeling is a method for organizing knowledge accumulated through observation or deduced from underlying principles while simulation refers to a method for implementing a model over time. The field of underwater acoustic modeling and simulation translates our physical understanding of sound in the sea into mathematical models that can simulate the performance of complex acoustic systems operating in the undersea environment.

2.2 Sound waves in water

A sound wave propagating underwater consists of alternating compressions and rarefactions of the water. These compressions and rarefactions are detected by a receiver, such as the human ear or a hydrophone, as changes in pressure. These waves may be man-made or naturally generated.

Underwater acoustics entails the development and employment of acoustical methods to image underwater features, to communicate information via the oceanic waveguide or to measure oceanic properties. In its most fundamental sense, modelling is a method for organizing knowledge accumulated through observation or deduced from underlying principles. Simulation refers to a method for implementing a model over time.

SONAR is the acronym for Sound Navigation And Ranging. Sonar technology is similar to other technologies such as: RADAR = Radio Detection And Ranging, ultrasound, which typically is used with higher frequencies in medical applications, seismics, which typically use slower frequencies in the sediments. The knowledge and understanding of underwater sound is not new. Leonardo Da Vinci discovered in 1490that acoustics propagate well in the ocean Sound is pressure perturbations that travels as a wave. Sound is also referred to as compressional waves, longitudinal waves, and mechanical waves The acoustic vibrations can be characterized by the following Sonar technologists initiated the development of underwater acoustic modeling to improve sonar system design and evaluation efforts principally in support of naval operations. These models were used to train sonar operators, assess fleet requirements, predict sonar performance and develop new tactics. Despite the restrictiveness of military security, an extensive body of relevant research accumulated in the open literature, and much of this literature addressed the development and refinement of numerical codes that modeled the ocean as an acoustic medium. This situation stimulated the formation of a new sub-discipline known as computational ocean acoustics

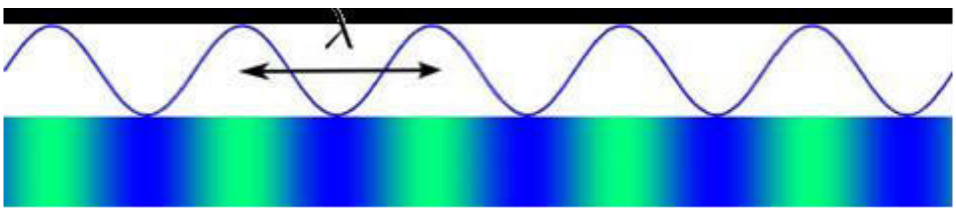

Fig. 2.1 Basic acoustic wave

Wave period T= [s]

Frequency f = 1\T [Hz]

Sound speed c = [m/s]

Wavelength l = c\f [m]

Underwater acoustic models are now routinely used to forecast acoustic conditions for planning at-sea experiments, designing optimized sonar.

This module consists of three broad types of underwater acoustics models

Environmental models: The first category – environmental models – includes empirical algorithms that are used to quantify the boundary conditions (surface and bottom) and volumetric effects of the ocean environment. Such models include sound speed, absorption coefficients, surface and bottom reflection losses and surface, bottom and volume backscattering strengths.

Basic acoustic models: This is second category – basic acoustic models – comprises propagation (transmission loss), noise and reverberation models.

Sonar performance models: The third category – sonar performance models – is composed of environmental models, basic acoustic models and appropriate signal processing models. Sonar performance models are organized to solve specific sonar applications problems such as submarine detection, mine hunting, torpedo homing and bathymetric sounding.

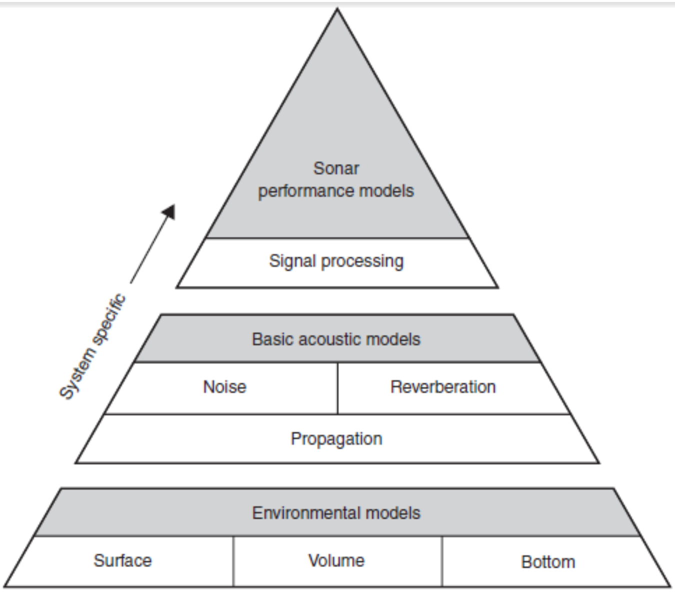

Fig. 2.2 Generalized relationships among environmental models,

basic acoustic models and sonar performance models.

Modeling a channel is the important task in the UWA communications .Simulation of that developed model is a complex issue .Simulation refers to the method for implementing a model over time .The term “modeling and simulation” (M&S) will refer collectively to those techniques that can predict or diagnose the performance of complex systems operating in the undersea environment. The functions of M&S can be categorized as either prognostic or diagnostic. Prognostic functions include prediction and forecasting, where future oceanic conditions or acoustic sensor performance must be anticipated. Diagnostic functions include systems design and analyses.

ENVIRONMENTAL MODELS

The very first category in the models of UWA communication channels are environmental models .the environmental models are classified into three different categories as shown below.

- Propagation models.
- Surface loss models.
- Bottom loss models.
- Noise models.

Applications of these models are generally fall into two categories

- Research –oriented applications
- Operation-oriented applications

Research-oriented applications are conducted in laboratory environments where accuracy is important and computer time is not a critical factor. Examples of research applications include sonar system design and field experiment planning Operationally oriented applications are conducted as field activities, including fleet operations at sea and sonar system training ashore. Operational applications generally require rapid execution, often under demanding conditions.

2.2.1 Propagation of sound

Underwater acoustic propagation depends on many factors. The direction of sound propagation is determined by the sound speed gradients in the water. This is an important thing that happens in water, because the speed of sound travel in water with velocity regular. In the sea the vertical gradients are generally much larger than the horizontal ones. Combining this with a tendency towards increasing sound speed at increasing depth, due to the increasing pressure in the deep sea, causes a reversal of the sound speed gradient in the thermo line, creating an efficient waveguide at the depth, corresponding to the minimum sound speed. The sound speed profile may cause regions of low sound intensity called "Shadow Zones", and regions of high intensity called "Caustics". These may be found by ray tracing methods.

At equator and temperate latitudes in the ocean, the surface temperature is high enough to reverse the pressure effect, such that a sound speed minimum occurs at depth of a few hundred meters. The presence of this minimum creates a special channel known as Deep Sound Channel, previously known as the SOFAR (sound fixing and ranging) channel, permitting guided propagation of underwater sound for thousands of kilometers without interaction with the sea surface or the seabed. Another phenomenon in the deep sea is the formation of sound focusing areas, known as Convergence Zones. In this case sound is refracted downward from a near-surface source and then back up again. The horizontal distance from the source at which this occurs depends on the positive and negative sound speed gradients. A surface duct can also occur in both deep and moderately shallow water when there is upward refraction, for example due to cold surface temperatures. Propagation is by repeated sound bounces off the surface.

In general, as sound propagates underwater there is a reduction in the sound intensity over increasing ranges, though in some circumstances a gain can be obtained due to focusing. Propagation loss (sometimes referred to as transmission loss) is a quantitative measure of the reduction in sound intensity between two points, normally the sound source and a distant receiver. If cis the far field intensity of the source referred to a point

1 m from its acoustic centre and I_r is the intensity at the receiver, then the propagation loss is given by PL= $10\log(I_s/I_r)$. In this equation I_r is not the true acoustic intensity at the receiver, which is a vector quantity, but a scalar equal to the equivalent plane wave intensity (EPWI) of the sound field. The EPWI is defined as the magnitude of the intensity of a plane wave of the same RMS pressure as the true acoustic field. At short range the propagation loss is dominated by spreading while at long range it is dominated by absorption and/or scattering losses. An alternative definition is possible in terms of pressure instead of intensity, giving PL= $20\log(P_s/P_r)$, where P_s is the RMS acoustic pressure in the far-field of the projector, scaled to a standard distance of 1 m, and P_r is the RMS pressure at the receiver position. These two definitions are not exactly equivalent because the characteristic impedance at the receiver may be different from that at the source. Because of this, the use of the intensity definition leads to a different sonar

equation to the definition based on a pressure ratio. If the source and receiver are both in water, the difference is small.

2.2.2 Underwater Noises

(i) Attenuation: This is the loss in sound signal as it propagates. Practically, whatever we transmit, it will undergo some or other kind of attenuation in nature. It may attenuate because of its own limitations because nothing has 100% efficiency or limitations provided by nature. It is given by,

A(l,f) = dk * a(f)d **(1)**

(ii) Shipping: It can exhibit spatial and temporal variabilities, because of the speed of ship and also the if the ship movement is in more dense areas when compared to ship movements in arctic regions where the traffic is less. Shipping noise is extremely less due to less surface traffic. But in extremely busy areas like the English Channel, shipping noise starts to dominate. There is no theoretical formula, because it depends on various factors like traffic on a particular route, it is time variant, with how much thrust a ship moves and causes ripples in water due to which sound signals may vary. But it is given by,

Ns = 10(40+20(s-0.5))+(26log10(f)(60log10(f+0.03))/10)Nsoff **(2)**

(iii) Wave: It is because of the movements of waves, it also depends on various factors. On a given day, if the waves are calm, the effect caused by them on sound signal is significantly less. But on a full moon day, the waves are at their full threshold, so this may start to induce noise in the sound signal. Only from few Hz to 50kHz, wave generated noise starts to dominate. It is given by,

Nw = 10(50+(7.5(w)1/2))+20log10(f)-40log10(f+0.4))Nwoff **(3)**

(iv) Thermal: In underwater acoustics, thermal noise provides a lower limit on the detection of underwater acoustic signals. It means that weaker noise sources cannot be measured, so thermal noise is of no use. But for frequencies above 50kHz, the molecular bombardment of the medium with the receiver generates thermal noise. It is given by,

Nth = 10((-15+20log10(f))/10)Nthoff **(4)**

(v) Ambient: It is the prevailing, unwanted background of sound at particular location in the ocean at the given time for the year. For ex, if some signal is transmitted from source to destination, then some part of the sound signal may be prevailing in the ocean and it may interfere when communication is taking place at a particular location at a given time. It doesn't include noises of nearby ships(shipping) or marine organisms(bio acoustics). It is given by,

N(angle) = $I_o$sec(angle) **(5)**

(vi) Wind & Rain: There is some interference caused to underwater acoustics, because of wind and rain. Wind effect starts to dampen sound signals due to factors like velocity of wind, direction of wind to which the sound signal is being transmitted. Similarly, rain causes disturbances due to impact of droplets falling on the sea surface, oscillations of the droplets upon falling, oscillation of the entrained air carried below the surface. It is independent of frequency but it depends only on the amount of rainfall.

(vii) Seismo Acoustic: These are the low frequency signals origination in Earth's Interior and the oceans. In simple terms, seismo acoustics is the turbulence caused in earth's crust due to the plates. This results in slight tremors, which cause seismo acoustic waves which interfere with the sound signal. The formula is given by,

P = ρcu = 2(pi)ρcfa **(6)**

where ρ = density, c= speed of sound in water, f = frequency,

a = amplitude of the displacement

In the frequency range below 3Hz, there are specific frequency bands:

Microseism band(80mHz - 3Hz) - results from non linear wave-wave interactions. Noise-notch Band(20-80mHz) - results due to currents and turbulence in the layer near sea floor. Ultralow-frequency(ULF) band (<20mHz) - resulting from surface gravity waves.

(viii) Arctic Ambient: The noise environment in the polar region. Here, the Arctic ice is different from than any other ocean area. The ice is not contaminated when compared to other ocean regions. So it has more of pure water with less ions in it. Here, shipping noise is extremely low due to lack of surface traffic. But, the ice cover affects the noise. It produces ambient noise conditions, that are much quieter than other sea state zero in the open ocean. The ice may produces noises such as wind, waves and thermal effects on it.

Also, the ice cover is different in different zones. Some are shore-fast ice, moving-pack ice and marginal ice zone. In shore fast ice, here the ice is hard as it is found in the freezing In moving pack ice, the ice starts to melt and keeps moving in the arctic region. In marginal ice zone, here the ice is less because most of the ice is turned into water due to varying temperatures.

(ix) Bio Acoustic: These are the acoustic noises due to marine animals. Marine animals transmit signals to communicate with each other. These signals interfere with the transmitted acoustic wave from the transmitter. Here in bio acoustics, the factors affecting are the frequency of the sound by marine animals, how often theytransmitsignals, how many different bio acoustic signals co-relate with the each other and with the sound signal(Transmitter). Whales are the most notable contributors because they transmit signal at a very high frequency which causes deviation in our own signal.

(x) Beam: It is used to model the low frequency ambient-noise field in the ocean. Here, we use passive sonar systems, narrow beams because if the beam is narrow, there are less chances of it being attenuated. Because when we use a narrow beam, it is more of a point-point transmission. The probability measures of beam noise depend on array configuration, orientation, location and season. Here the orientation is nothing but how a beam is oriented, what angle it is moving at, is it a narrow or a wide beam. Location and season are slight tricky to notify. They vary from ocean to ocean. Even if we consider an specific ocean, it may have various seasons and each season causes specific impact on the sound signal. It is given by,

Y = summation(i = 1 to i=m)summation(j = 1 to j=n)

summation(k = 1 to k=A_{ij}) S_{ijk} Z_{ijk} B_{ijk} **(7)**

where,

m is the number of routes in the ocean, *n* the number different ships,

A_{ij}, the number of ships of type *j* on route *i*(a random variable),

S_{ijk}, the source intensity of the k^{th} ship of type *j* on route *i*(a random variable that is statistically independent of the source intensity of any other ship),

Z_{ijk} the intensity transmission ratio from ship *ijk*to the receiving point and $B_{ijk}$the gain for a plane wave arriving at the array from ship *ijk*.

(xi) Volume Reverberation: The main source of volume reverberation in the sea has been biological. Different marine animals affect different bands of the active sonar spectrum. At frequencies more than that 30 kHz, the scatterers are zooplankton. At frequencies between 2 and 10 kHz, the main scatterers are the various types of fish that possess a swim bladder. The bladder amounts to an internal air bubble that becomes resonant at a frequency depending on the size and depth of the fish. It is given by,

$$\mathbf{S_L = 10log_{10}\ summation(i=1\ to\ i=n)\{sigma_i(f) * 10^{-4}\}} \quad \textbf{(8)}$$

(xii) Sea Surface Reverberation: In this reverberation, the roughness of sea surface and the presence of trapped air bubbles make the sea surface an effective scatterer of sound. It can take occur due to out-of-plane as well as Vertical plane. Here, the scattering of the sea surface varies with grazing angle, frequency and roughness of the surface. If the roughness is more, then the scattering effect is high and vice versa. Sea surface roughness is because of the wind speed or the height of the wave. Here, there is a large variation for low frequencies and low grazing angles, and less variation for high frequency and high grazing angles. It is given by,

$$\mathbf{S_s = 3.3(\beta)log_{10}[(angle)/30] - 42.2log_{10}(\beta) + 2.6} \quad \textbf{(9)}$$

where $\boldsymbol{\beta = 158[vf^{1/3}]^{-0.58}}$

(xiii) Under Ice Reverberation: In this reverberation, large chunks of ice causes reverberation takes place due to rough under ice surface. In arctic region, the ice is the main cause of reverberation. Because of the difference in under-ice surface, scattering strength is different at different grazing angles. Because different under ice properties scatter at different angles. We can use directional sources/receivers for optimum ray paths can minimize reverberation under the ice. There is increase of scattering strength with increasing frequency and grazing angle. It is given by,

$$\mathbf{R_{ls} = L_p - 40log(r)+10log(S_sC(tow)/2r(angle))} \quad \textbf{(10)}$$

(xiv) Sea floor Reverberation: The sea surface is an effective reflector and scatterer of sound. It can take place due to out of plane or vertical plane. Similarly, if the sea floor is rough, the scattering is more and if the sea floor is smooth, then less scattering takes place. Also, the sea floor has sediment composition(sand, clay, silt) which result in scattering at different angles. For ex, as mud is smooth, therefore it has low impedance when compared to water. Similarly, silt tends to be rough, with high impedance. It follows lambertz law which is given by,

$$S_B = 10\log10\mu + 10\log10\sin^2(\text{angle}) \tag{11}$$

(xv) Turbulence: It is caused by various factors. As ships propagate faster, they cause turbulence in water. This may lead to ripples which in turn affect the propagation of sound. Turbulence is also caused by instability. It is caused by tidal energy, when waves gush in and out causing more force on water which in turn affects our sound wave. It is given by,

$$Nth = 10(50+(7.5(w)1/2))+20\log10(f)40\log10(f+0.4))Nwoff \tag{12}$$

(xvi) Self-Noise: This noise is generated due to the transmitters/receivers that emit and receive acoustic waves. This noise is the radiated noise from the transceivers, noise from their structural components, flow of water around the transceivers. When the transmitters transmit acoustic waves, they cause turbulence in the water. Similarly, on the receiver side, the receivers while receiving the acoustic waves, there is some turbulence in the water around it. There are 2 kinds of self noise - Flow noise& Strumming noise.

(xvii) Flow noise: The movement of ocean water also causes some form of hindrance to underwater communication. Here, the water is not stagnant, the water keeps moving because of the waves formation, this causes the flow noise and is given by,

$$R_e = p\ V_s\ L/(\mu) \tag{13}$$

where V_s = mean fluid velocity

(xviii) Strumming Noise: This noise is low frequency humming/vibration sound that is prevailing in water. This is the low frequency sound that is difficult to measure as it is vibration takes place when sound signal travels. It is given by,

$$F_{strum} = S(v/d) \tag{14}$$

where v = flow velocity, d = diameter

(xix) Blade Rate: It is triggered by the flow irregularities because of the changes in the moving action of the blades. It causes a series of frequencies radiated by the blade rate noise as follows,

$$F_{Blade} = mnf_r \quad (15)$$

(xx)Propeller Noise: Propeller noise is generated and radiated from the propellers which is in direct contact with the water. Propellers create turbulence when they propagate. It can also be sub classified, based on their source, Blade rate, resonance & cavitation noises. It is given by,

$$F_{propeller} = 60\log(V_t/25) \quad (16)$$

(xxi)Resonance Noise: This is caused due to the mechanical vibrations of the structural components, matching with the natural frequency. Due to this, it results in high amplitude vibrations. The components consists of plates, struts, propeller blades and the complete structure, when vibrated at natural frequencies generate resonance noise. These resonant signals have much greater bandwidths than compared to normal working machinery. For example, the noise generated by the Hull resonance frequencies are of significantly lower amplitude than compared to the resonance frequencies of propeller blade, because of the shear larger size. It is given by,

$$F_{resonance} = 10\log(V_t/25) \quad (17)$$

(xxii)Machinery Noise: All moving components/parts of the ship, contribute to this noise. These noises increases with both the speed of vessel and frequency of acoustic waves. At some point within the well defined speeds, the noise components of the moving parts of the ship might complement the fundamental frequencies corresponding to the structural vibrations to cause a significant increase in the overall radiated noise. The overall radiated noise is given by taking into considerations such as propeller noise, resonance noise and machinery noise.

$$N_r = 154 + 60\log(V_t/25) + 10\log(n/4) - 20\log(f) \quad (18)$$

where N_r = Total Radiated noise

(xxiii)Facet Scattering: In this scattering, as the sound wave propagates, from the normal to the average surface, the number of facets with correct orientation decreases monotonically and therefore the strength of back-scattering rapidly decreases. Here we are assuming that the slope will follow a normal distribution, then the following equation can be given,

$$Prob(\tan(\Phi f) = 1/2(pi)e^{-\tan(\Phi f)/2(sigma)sq} \quad (19)$$

(xxiv)Scattering due to air bubbles(near surface): Air bubbles are caused by waves, which trap the air in the vicinity of the ocean surface. For frequencies greater than 10 KHz, scattering due to these air bubbles become dominant. These air bubbles become dominant and cause obstruction to the flow of acoustic waves. The obstruction caused by them is different for different depths. Near the surface, the tendency of obstruction is more, when compared to deeper depths. It is given by,

(β)v = 10-5.2577+0.4701U(f/25)0.85 for U < 11m/s

= $(\beta)_v(11)$ for U = 11m/s

= $(\beta)_v(11)(U/11)^{3.5}$for U > 11m/s **(20)**

2.2.3 Underwater Losses

(i) Transmission Loss: The transmission loss is the loss at the point we are calculating with respect to the reference point(origin of signal). The spreading and absorption effects all come under transmission loss only.

General transmission loss formula is

NT =-10log(I(r,d)/I_0) **(21)**

Here I(r,d) is the signal strength at the point of interest, Whereas I_0 is the strength at the original point.

(ii) Spreading Loss: The path loss which occurs due to the area covered by the signal energy and the wave front moves outward from the source. It is given by the formula

PL(spreading) = K x 10log(r) **(22)**

Where K is the spreading factor and r is the range in meters. When the area is unbounded the factor K =2. From original transmission formula

NT = -10log(I(r,d)/I_0)

The area is spherical so it will be

$A = 4\pi r^2$

I(r,d) $4\pi r^2$**=I0**$4\pi ro^2$

So (I(r,d)/I0) = $4\pi ro^2/4\pi r^2$

NT = -10log(I(r,d)/I0) = -10log($4\pi ro^2/4\pi r^2$)

= -20log(r0/r)

And assuming $r_0 = 1$ we have K= 2

From the general formula. And when is bounded it differs for, cylindrical Boundary it is k=1.This factor has only short range applications. The spreading loss has a logarithmic relationship with r we can see from the formula.

(iii) Absorption Loss: The absorption loss is the energy lost in the form of heat due to viscous friction and ionic relaxation.

It is given by the formula

AL(spreading)= 10log(α) x r **(23)**

(α) is absorption coefficient and depends on frequency

As there is a change in frequency there will be a change in α. Based on frequencies the loss is divided into 3 effects – Viscosity, ionic relaxation due to boric acid and magnesium and relaxation time.

Viscosity effect is for high frequencies above 100Khz. Ionic relaxation effect due to magnesium is for the range of frequencies between 10 and 100khz whereas boric acid effect the lower frequencies. Basically the coefficient should increase as the frequency increases and decrease as the depth decreases.

(iv) Path Loss: The combination of both spreading and absorption losses gives this loss.

PL(path) = Kx10log(r) + α **(24)**

(v) Multipath Loss: These losses are due to two forms

1) Sound reflection over the surface, bottom and by any objects underwater

2) Sound refraction

The speed of sound is usually constant at the surface of the water but as the depth increases and the factors like temperature, salinity and pressure the sound wave ray slightly changes the path.

The sound ray bends towards the region with lower propagation speed. When there are multiple sound waves coming out from the source, the waves get reflected or refracted and intersect each other which fades the signal. This phenomenon is called multipath fading or multipath loss.

(vi) Surface Loss: This loss is due to the reflection of sound waves at the air-water interface nothing but the surface of the water.

(vii) Schulkin marsh model: This model was developed so that the surface loss will be independent of the grazing angle. Assumption made was the limiting ray cycle distance and distance between reflections are equal.

$$SL_{SM} = \begin{cases} 10\log\left[1+\left(\frac{fh}{4.14}\right)^4\right] & \text{for } fh < 4.2691 \\ 1.59\sqrt{fh} & \text{for } fh > 4.2691 \end{cases} \quad \textbf{(25)}$$

Where f is the frequency and h is the average wave height.

(viii) Bottom Loss: This loss is due to the interaction of sound waves with sea floor. There are losses due to both reflection and absorption underwater.

(ix) The Doppler Shift Loss: When there is a movement of both transmitter and receiver then the frequency shifts and spreads according to the motion. This creates a loss effect which is known as DOPPLER LOSS EFFECT. The magnitude of the Doppler effect is proportional to the ratio a = v/c of the relative transmitter-receiver velocity to the speed of sound. Because the speed of sound is very low compared to the speed of electro-magnetic waves, motion-induced Doppler distortion of an acoustic signal can be extreme. Doppler shift appears equal for all subcarriers, in an acoustic system each subcarrier may experience a different Doppler shift, creating non-uniform Doppler distortion across the signal bandwidth.

(x) Sound absorption Sim model: The fig.2.2.3.1 shows the sim model of sound absorption in sea water. The model consists of eleven edit boxes named as Depth, Temp, Pressure, Salinity and Sound speed. The data is read in this sim model. These buttons invoke the programs which calculate the sound absorption coefficient (alpha).When the acoustic wave propagates in sea water, absorption loss occurs, which is caused by a part of the energy changing into the heat owing to the viscous friction of the water molecule, aside from the spreading loss. The absorption loss is represented as αr, where α is the coefficient in dB/Km and r is the transmission distance.

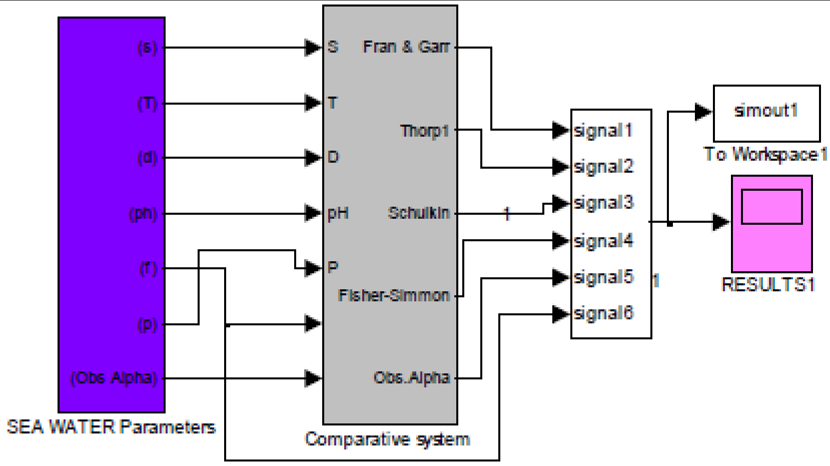

Fig. 2.3 Main sim model of coefficient of absorption.

The main simulation model in fig 2.2.3.1 has been designed using simulink toolbox of MATLAB [1] to determine the coefficient of absorption in the sea water .The input data like depth, salinity, temperature, frequency, pressure and observed coefficient of absorption have been read from workspace through the sim block in the simulink library. The empirical formulae proposed by different investigators have been used to calculate the coefficient of absorption. Each subsystem has been designated by the name of the investigator e.g. a)Francois-Garrison b) Fisher c) Schulkin-marsh and d) Thorp. The exhaustive model showing the different methods used is shown in fig.2.2.3.2

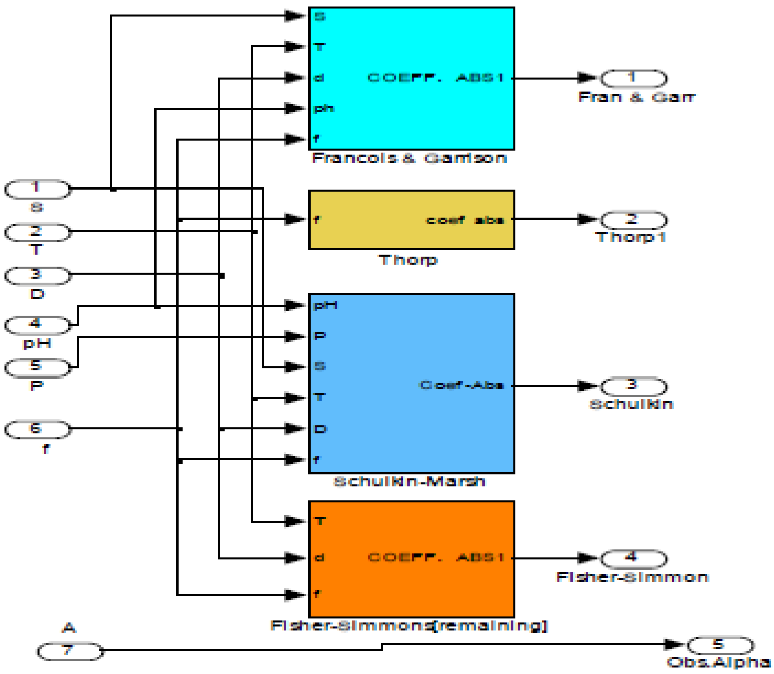

Fig. 2.4 Detailed sim model of coefficient of absorption.

Expressions of absorption coefficient α have been proposed by various researchers on the basis of the laboratory and sea –based experiments. Some of these expressions have been given below. The empirical expression of Fisher-simmons as a function of salinity, frequency, depth, pH and temperature is expressed as follows.

α = {((A1 * P1 * f1 * f2) / (f12 + f2)) +((A2 * P2 * f2 * f2) / (f22 + f2)) + (A3 * P3 * f2)} *8686 **(26)**

The first term gives the sound absorption due to the Boric Acid and second term gives the sound absorption due to the magnesium sulfate. The contribution of sound absorption due to these chemical ingredients has been found to be small. The third term represents the sound absorption due to pure water. The pressure dependency of above equation is shown by P1 ,P2 and P3 constants .Frequency dependency is given by f1,and f2 which are the relaxation frequencies of Boric Acid and Magnesium sulfate. f is the frequency of sound. The constants A1, A2 and A3 shown are not purely constants but it has been experimentally proved that their values vary with the water properties, like temperature, salinity and pH of water. The total coefficient of absorption of sea water is calculated by considering separately the absorption due to boric acid, magnesium sulphate and pure water. Separate contribution by the ingredients has been given below. On entering the depth (d), temperature (t), pressure(p),salinity(s),pH and frequency in edit boxes and pressing the push button plot(Alpha v/s d)' displays the graph of coefficient of absorption v/s depth and pressing the push button plot(Alpha v/s f)' displays the graph of coefficient of absorption v/s frequency .

The empirical expression of Thorp is shown as a function of the frequency

$$\alpha = f^2 \{ 3.01 * 10^{-4} + (43.7/(4100 + f^2)) + (0.109/(1 + f^2))\} \quad (27)$$

The empirical expression of Ainslie and mccolm is shown as a function of the frequency

α=(0.106*((f1*f.*f)./(f1*f1+f.*f))*exp((ph8)/0.56)+.52*(1+temp/43)*(s/35)*((f2*f.*f)./(f2*f2+f.*f))*exp(-d/6)+4.9*10^(-4)*f.*f*exp(-(temp/27+d/17))) **(28)**

Chapter 3

3. TOOL DESCRIPTION

A programming tool or software development tool is a computer program that software developers use to create, debug, maintain, or otherwise support other programs and applications. The term usually refers to relatively simple programs, that can be combined together to accomplish a task, much as one might use multiple hand tools to fix a physical object. The ability to use a variety of tools productively is one hallmark of a skilled software engineer.

The most basic tools are a source code editor and a compiler or interpreter, which are used ubiquitously and continuously. Other tools are used more or less depending on the language, development methodology, and individual engineer, and are often used for a discrete task, like a debugger or profiler. Tools may be discrete programs, executed separately – often from the command line – or may be parts of a single large program, called an integrated development environment (IDE). In many cases, particularly for simpler use, simple ad hoc techniques are used instead of a tool, such as print debugging instead of using a debugger, manual timing (of overall program or section of code) instead of a profiler, or tracking bugs in a text file or spreadsheet instead of a bug tracking system.

Uses of programming tools:

(i) Translating human-written source code into computer language.

Modern computers are very complex and in order to productively program them, various abstractions are needed. For example rather than writing down a program's binary representation a programmer will write a program in a programming language like C, Java or Python. Programming tools like assemblers, compilers and linkers translate a program from a human writable and readable source language into the bits and bytes that can be executed by a computer. Interpreter’s interpret the program on the fly to produce the desired behavior. These programs perform many well defined and repetitive tasks that would nonetheless be time consuming and error-prone when performed by a human, like laying out parts of a program in memory and fixing up the references between parts of a program as a linker does. Optimizing compilers on the other hand can perform complex transformations on the source code in order to improve the execution speed or other characteristics of a program. This allows a programmer to focus more on higher level, conceptual aspects of a program without worrying about the details of the machine it is running on.

(ii) Extracting information about programs and make it understandable for humans.

Because of the high complexity of software, it is not possible to understand most programs at a single glance even for the most experienced software developer. The abstractions provided by high-level programming languages also make it harder to understand the connection between the source code written by a programmer and the actual program's behaviour. In order to find bugs in programs and to prevent creating new bugs when extending a program, a software developer uses some programming tools to visualize all kinds of information about programs.

For example a debugger allows a programmer to extract information about a running program in terms of the source language used to program it. The debugger can compute the value of a variable in the source program from the state of the concrete machine by using information stored by the compiler. Memory debuggers can directly point out questionable or outright wrong memory accesses of running programs which may otherwise remain undetected and are a common source of program failures.

3.1 Matlab

MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment and fourt-generation programming language. A proprietary programming language developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data implementation of algorithms, creation of user interfaces and interfacing with program written in other language, including C, C++, C#, Java, Fortran and Python. As of 2017, MATLAB has over 2 million users across industry and academia. MATLAB users come from various backgrounds of engineering, science, and economics.

3.1.1 Syntax

The MATLAB application is built around the MATLAB scripting language. Common usage of the MATLAB application involves using the Command Window as an interactive mathematical shell or executing text files containing MATLAB code.

variables: Variables are defined using the assignment operator, =. MATLAB is a weakly typed programming language because types are implicitly converted. It is an inferred typed language because variables can be assigned without declaring their type, except if they are to be treated as symbolic objects, and that their type can change. Values can come from constants, from computation involving values of other variables, or from the output of a function. For example:

```
>> x = 17
x =
17

>> x = 'hat'
x =
hat
```

vectors and matrices: A simple array is defined using the colon syntax: init:increment:terminator. For instance: defines a variable named array (or assigns a new value to an existing variable with the name array) which is an array consisting of the values 1, 3, 5, 7, and 9. That is, the array starts at 1 (the init value), increments with each step from the previous value by 2 (the increment value), and stops once it reaches (or to avoid exceeding) 9 (the terminator value).The increment value can actually be left out of this syntax (along with one of the colons), to use a default value of 1.

```
>> array = 1:3:9
array =
147
>> ari = 1:5
ari =12345
```

assigns to the variable named ari an array with the values 1, 2, 3, 4, and 5, since the default value of 1 is used as the incrementer. Indexing is one-based, which is the usual convention for matrices in mathematics, although not for some programming languages such as C, C++, and Java. Matrices can be defined by separating the elements of a row with blank space or comma and using a semicolon to terminate each row. The list of elements should be surrounded by square brackets: []. Parentheses: () are used to access elements and sub-arrays (they are also used to denote a function argument list).

```
>> A = [163213; 510118; 96712; 415141]
A =
163213
510118
96712
415141

>> A(2,3)
ans =
11
```

A square identity matrix of size *n* can be generated using the function eye, and matrices of any size with zeros or ones can be generated with the functions zeros and ones, respectively.

```
>>eye(3,3)
ans =
100
010
001

>>zeros(2,3)
ans =
000
000

>>ones(2,3)
ans =
111
111
```

Most MATLAB functions can accept matrices and will apply themselves to each element. For example, mod(2*J,n) will multiply every element in "J" by 2, and then reduce each element modulo "n". MATLAB does include standard "for" and "while" loops, but (as in other similar applications such as R), using the vectorized notation often produces code that is faster to execute. This code, excerpted from the function *magic.m*, creates a magic square *M* for odd values of *n* (MATLAB function mesh grid is used here to generate square matrices I and J containing 1:n).

```
[J,I] = meshgrid(1:n);
A = mod(I + J - (n +3) /2, n);
B = mod(I +2* J -2, n);
M = n * A + B +1;
```

Functions: When creating a MATLAB function, the name of the file should match the name of the first function in the file. Valid function names begin with an alphabetic character, and can contain letters, numbers, or underscores. Functions are also often case sensitive. Function handles - MATLAB supports elements of lambda calculus by introducing function handles, or function references, which are implemented either in .m files or anonymous/nested functions.

Classes and object-oriented programming: MATLAB supports object-oriented programming including classes, inheritance, virtual dispatch, packages, pass-by-value semantics, and pass-by-reference semantics.[21] However, the syntax and calling conventions are significantly different from other languages. MATLAB has value classes and reference classes, depending on whether the class has *handle* as a super-class (for reference classes) or not (for value classes). Method call behaviour is different between value and reference classes. For example, a call to a method can alter any member of object only if *object* is an instance of a reference class.

```
object.method();
```

An example of a simple class is provided below.

```
classdef hello
methods
        functiongreet(this)
disp('Hello!')
end
end
```

```
end
```

3.1.2 Graphics and Graphical user interface programming

MATLAB supports developing applications with graphical user interface (GUI) features. MATLAB includes GUIDE(GUI development environment) for graphically designing GUIs. It also has tightly integrated graph-plotting features. For example, the function *plot* can be used to produce a graph from two vectors *x* and *y*. The code:

```
x = 0:pi/100:2*pi;
y = sin(x);
plot(x,y)
```

produces the following figure of the sine function:

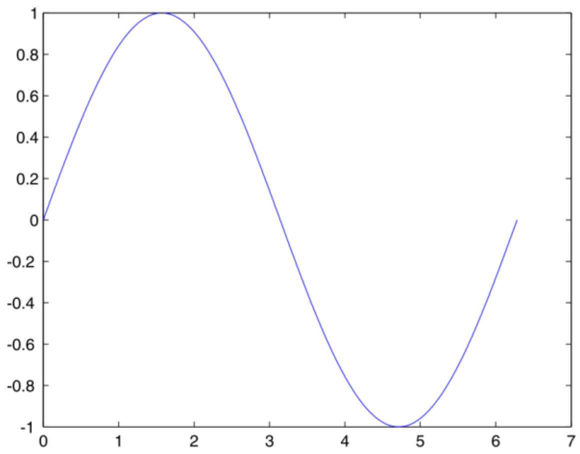

Fig. 3.1 Basic sine function plot output

A MATLAB program can produce three-dimensional graphics using the functions surf, plot3 or mesh.

```
[X,Y] = meshgrid(-10:0.25:10,-10:0.25:10);
f = sinc(sqrt((X/pi).^2+(Y/pi).^2));
mesh(X,Y,f);
axis([-1010-1010-0.31])
xlabel('{\bfx}')
ylabel('{\bfy}')
zlabel('{\bfsinc} ({\bfR})')
hidden off
```

This code produces a wireframe 3D plot of the two-dimensional un normalized sine function:

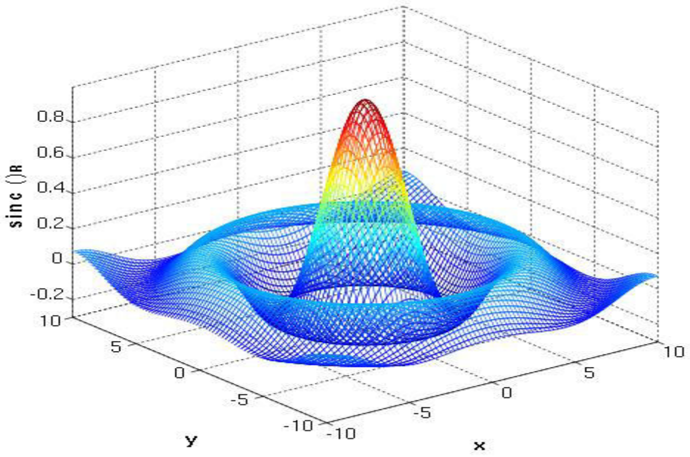

Fig. 3.2 Sine wireframe 3D

3.1.3 Interfacing with other languages

MATLAB can call functions and subroutines written in the programming languages C or Fortran. A wrapper function is created allowing MATLAB data types to be passed and returned. The dynamically loadable object files created by compiling such functions are termed "MEX-files" (for MATLAB executable). Since 2014 increasing two-way interfacing with Python is being added.

Libraries written in Perl, Java, ActiveX or .NET can be directly called from MATLAB, and many MATLAB libraries (for example XML or SQL support) are implemented as wrappers around Java or ActiveX libraries. Calling MATLAB from Java is more complicated, but can be done with a MATLAB toolbox which is sold separately by MathWorks, or using an undocumented mechanism called JMI (Java-to-MATLAB Interface), (which should not be confused with the unrelated Java Metadata Interface that is also called JMI). Official MATLAB API for Java was added in 2016. As alternatives to the MuPAD based Symbolic Math Toolbox available from MathWorks, MATLAB can be connected to Maple or Mathematica. Libraries also exist to import and export MathML.

3.1.4 File extensions

.m

MATLAB code (function, script, or class)

.mat

MATLAB data (binary file for storing variables)

.p

MATLAB content-obscured .m file (P-code)

.mlx

MATLAB live script

.mdl

Simulink Model

.mdlp

Simulink Protected Model

.slx

Simulink Model (SLX format)

.slxp

Simulink Protected Model (SLX format)

Chapter 4

4. IMPLEMENTATION

To get desired output we are going to implement the code in three different models. Ainslie-Mccolm model, fisher-simmons and thorp model. In each model we are taking results by varying parameters like range, shipping factor, wind factor. Firstly we take the results by varying wind factor and keeping shipping factor constant for three ranges 1Km, 5Km and 10Km for all three models Ainslie-Mccolm model, fisher-simmons and thorp individually. Later we take results varying shipping factor keeping wind factor constant for three ranges 1Km, 5Km and 10Km for all three models Ainslie-Mccolm model, fisher-simmons and thorp individually. After this we tabulate the results to compare each and every result based on transmitted signal strength, received signal strength and SNR profile. Based on the comparison we comment whether Ainslie-Mccolm model or fisher-simmons or thorp gives better results for what maximum range.

4.1 Software Algorithm

Step 1: Give the inputs like power, range, margin.

Step 2: Define transmitter properties which include transmitter symbol rate(depends on frequency), receiver symbol rate, number of tones, frame duration.

Step 3: Assign frequency values to each tone.

Step 4: Generate QPSK bit pattern by randomly generated 16 tones (32-bits).

Step 5: Convert the bits into frequency domain using IFFT definition.

Step 6: Display the transmitted signal.

Step 7: Estimate noise and calculate attenuation.

Step 8: Calculate the effect of channel on signal at the receiver end.

Step 9: Plot the received signal.

Step 10: Calculate the SNR, C/B ratio.

Step 11: Floor the C/B ratio value using round off algorithm.

Step 12: Plot SNR and C/B ratio values before and after round off algorithm.

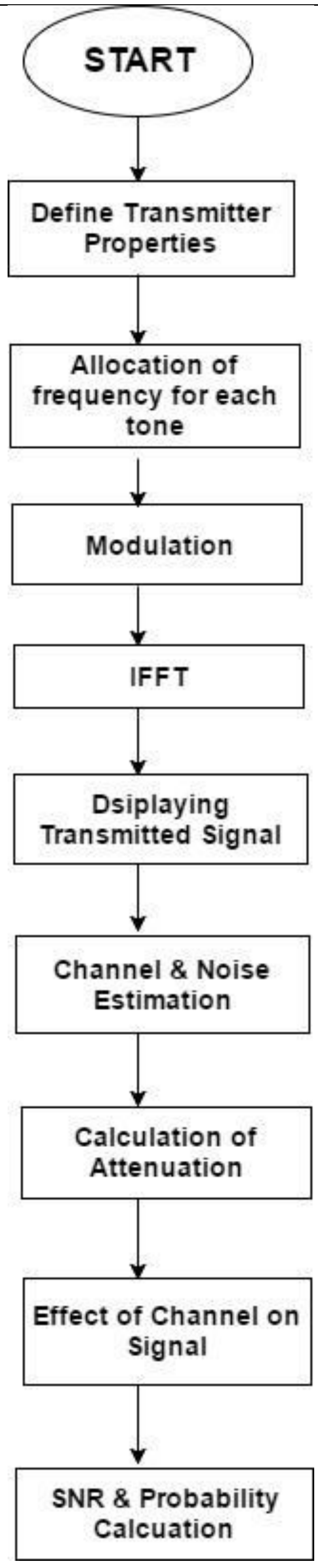

Fig. 4.1 Flow of code

Chapter 5

5. Results And Declaration

5.1 Experimental Results

5.1.1 Wind Factor-15, Shipping Factor-2

The following results shows transmitted signal, received signal, SNR profile, probability profile, probability profile after round off for a wind factor of 15 and a shipping factor of 2 for different ranges and for different models.

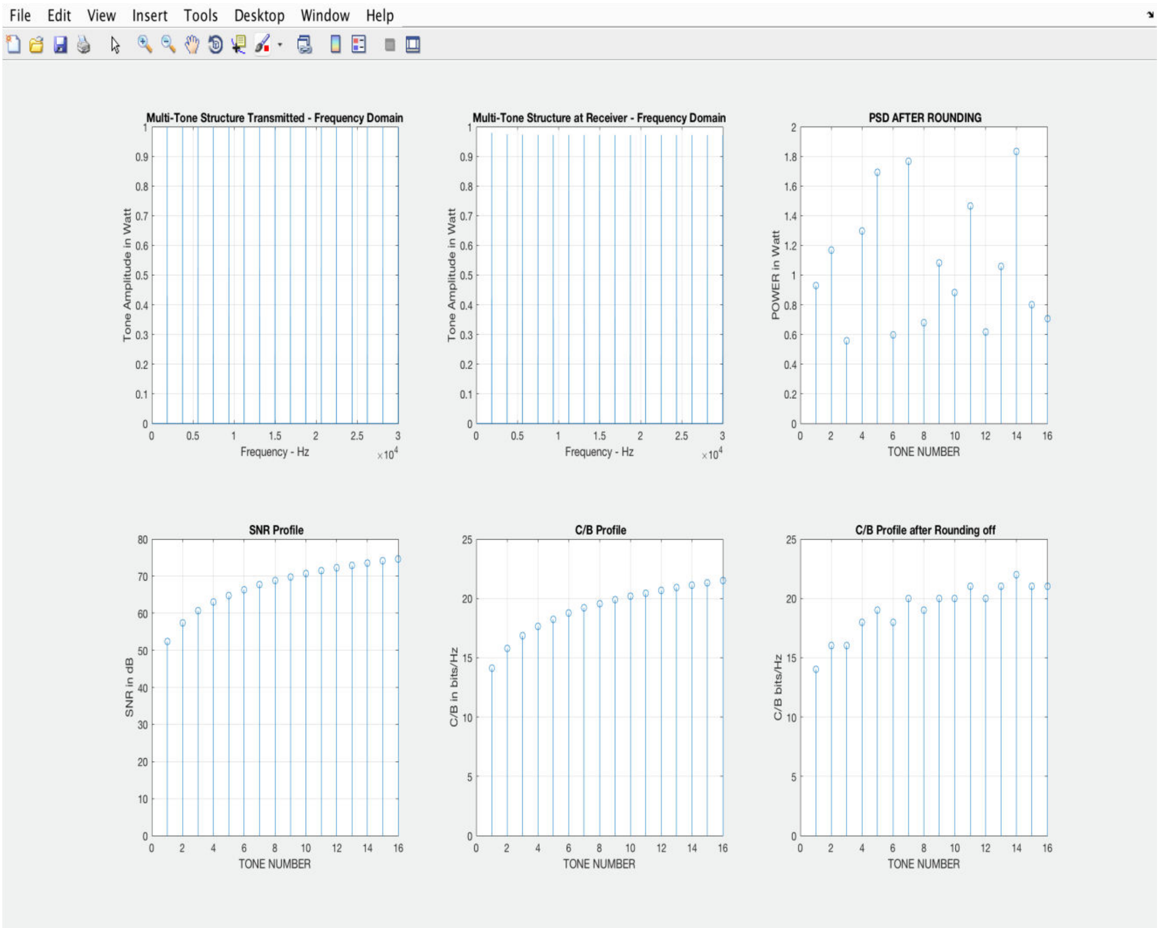

Fig. 5.1 Ainslie Model for Range-1Km

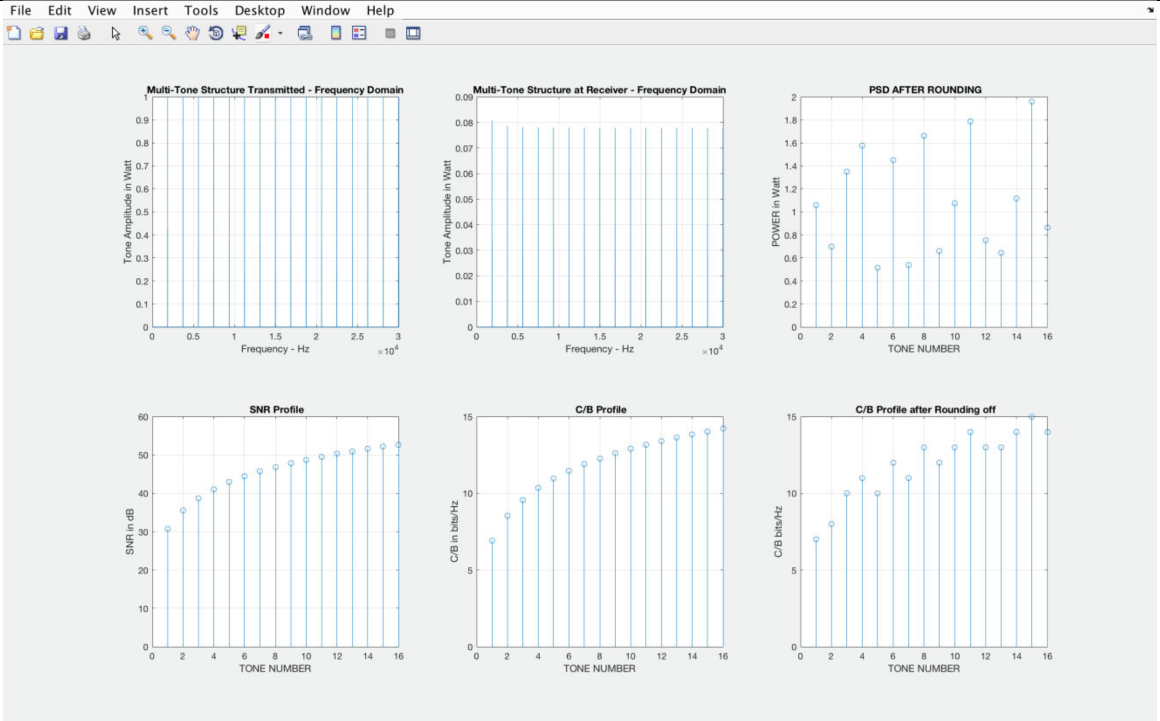

Fig. 5.2 Ainslie Model for Range-5Km

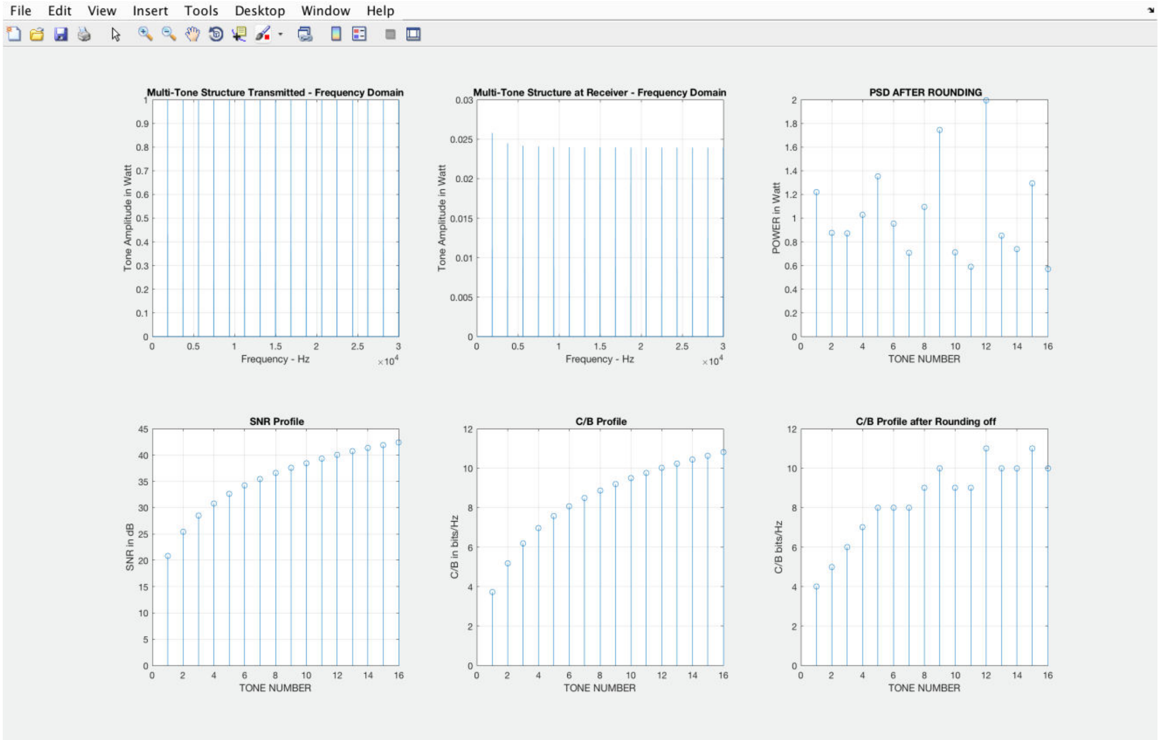

Fig. 5.3 Ainslie Model for Range-10Km

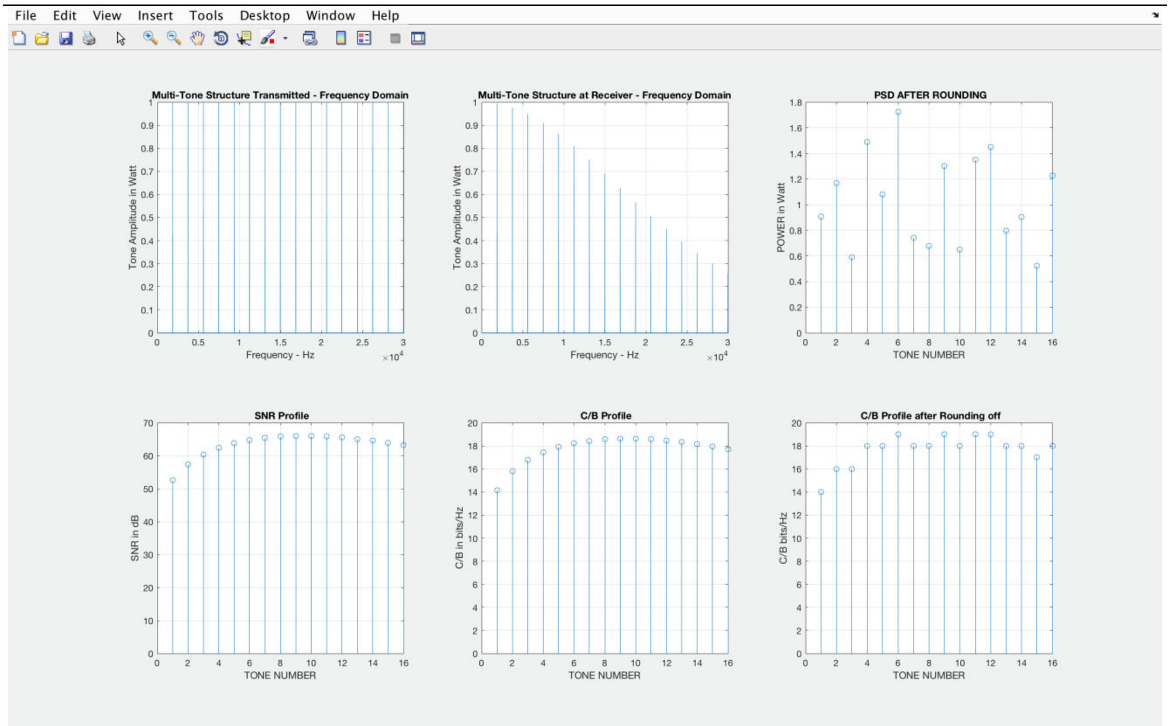

Fig. 5.4 Fisher Simmons Model for Range-1Km

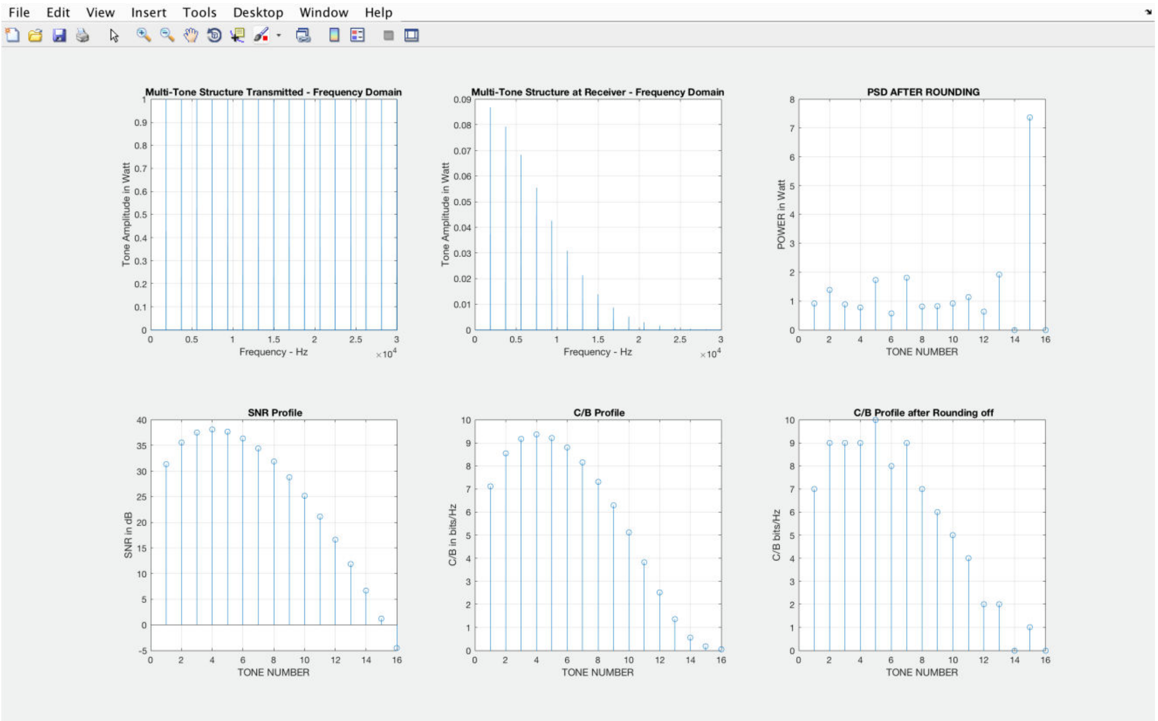

Fig. 5.5 Fisher Simmons Model for Range-5Km

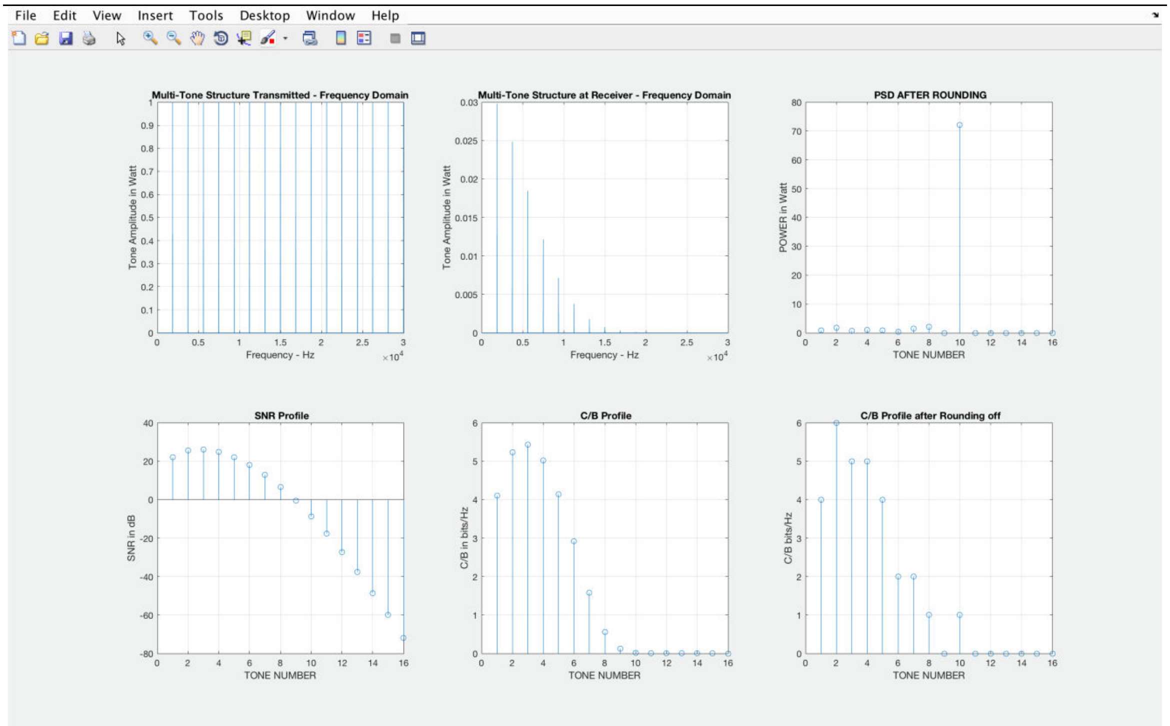

Fig. 5.6 Fisher Simmons Model for Range-10Km

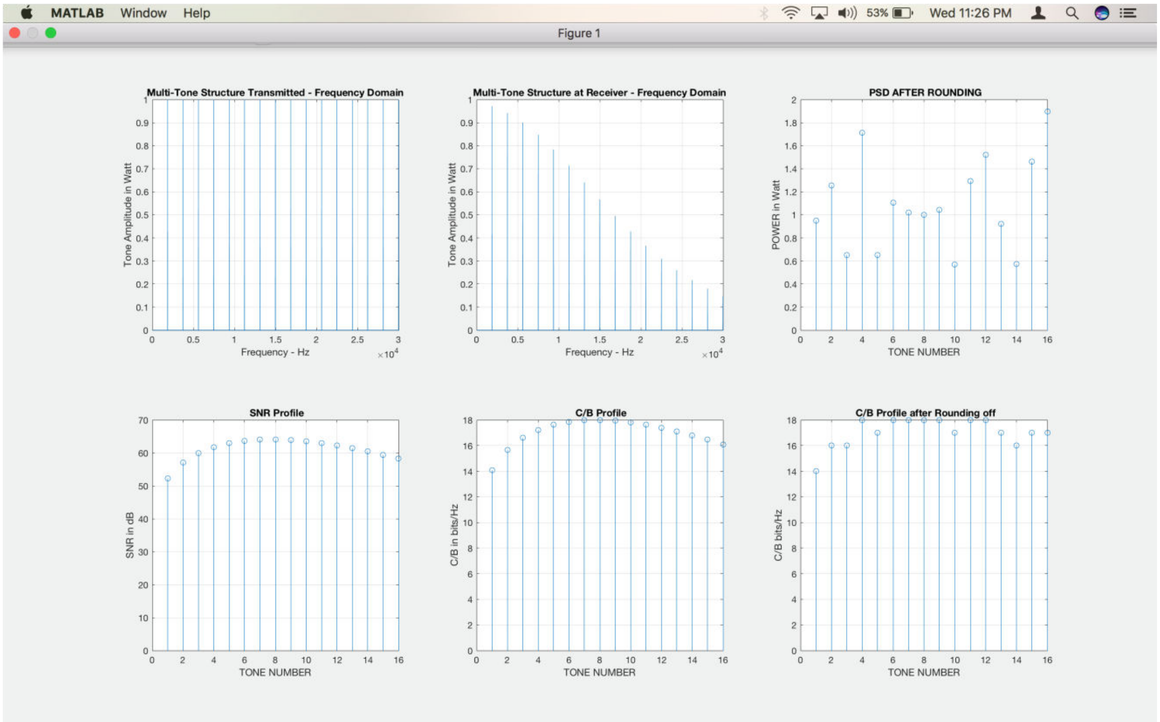

Fig. 5.7 Thorp Model for Range-1Km

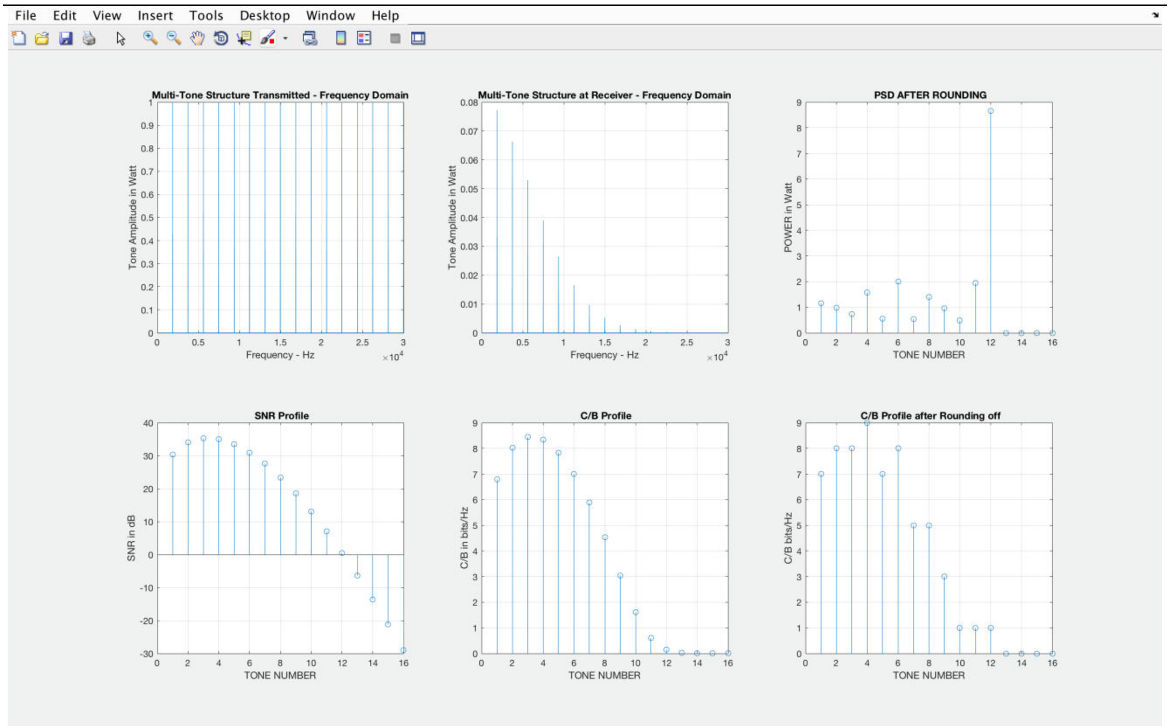

Fig. 5.8 Thorp Model for Range-5Km

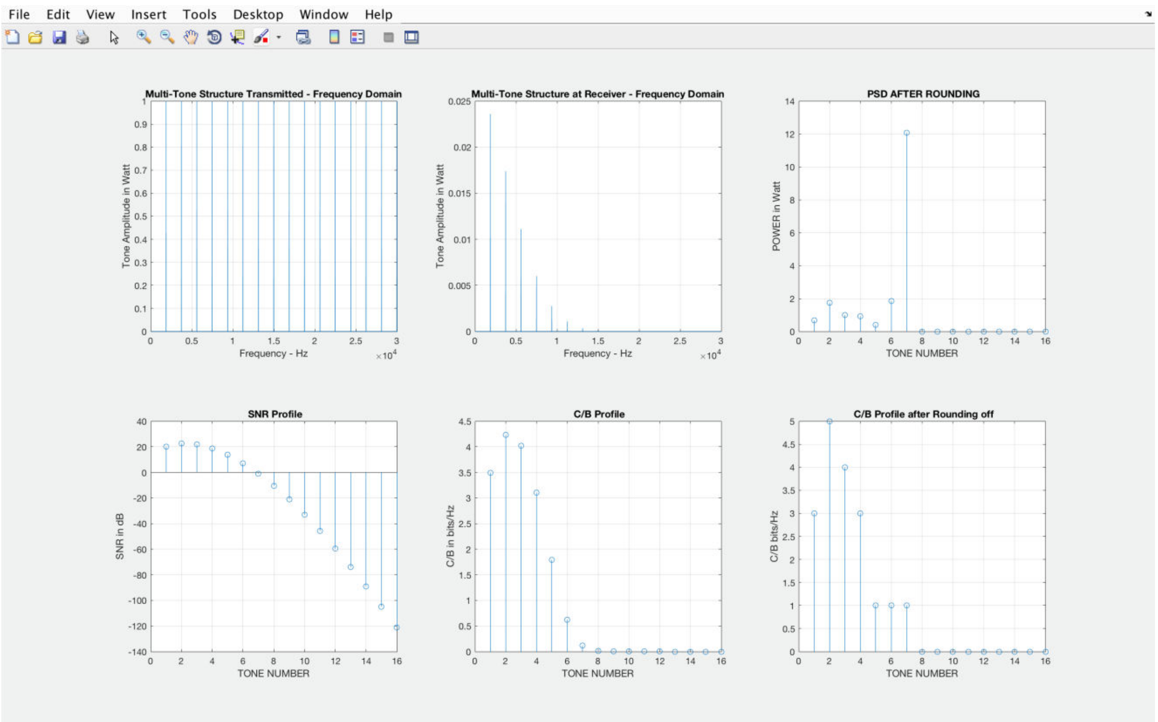

Fig. 5.9 Thorp Model for Range-10Km

5.1.2 WIND FACTOR-25, SHIPPING FACTOR -2

The following results shows transmitted signal, received signal, SNR profile, probability profile, probability profile after round off for a wind factor of 25 and a shipping factor of 2 for different ranges and for different models.

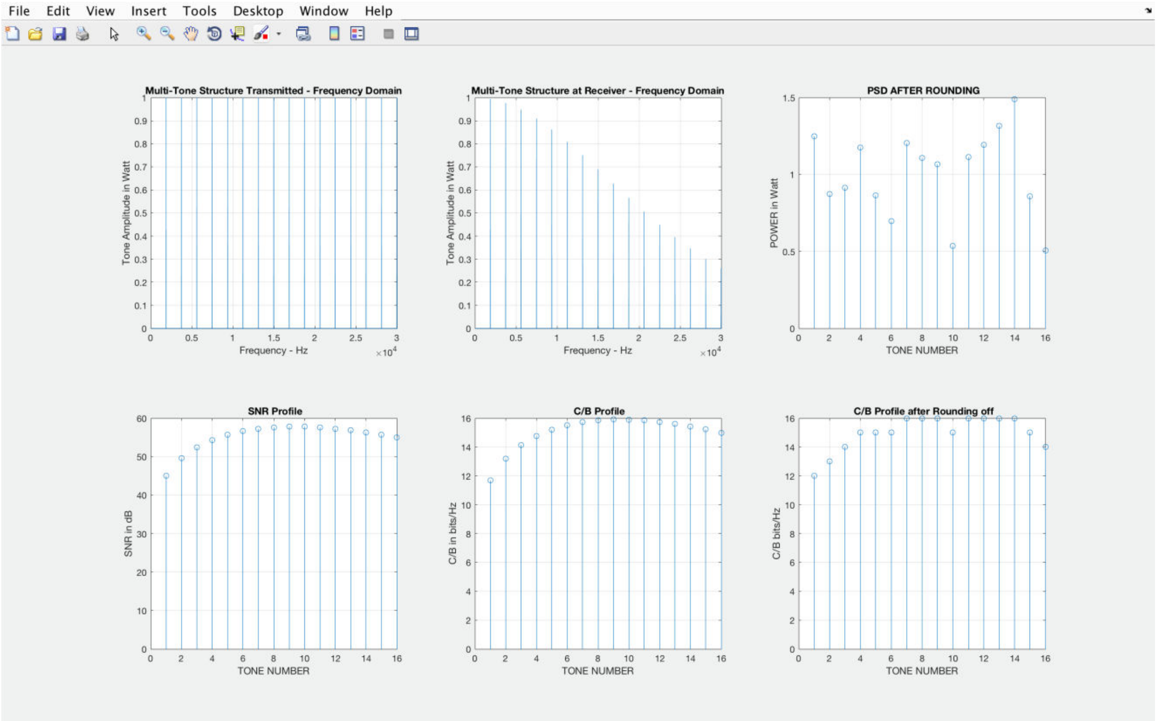

Fig. 5.10 Fisher Simmons Model for Range-1Km

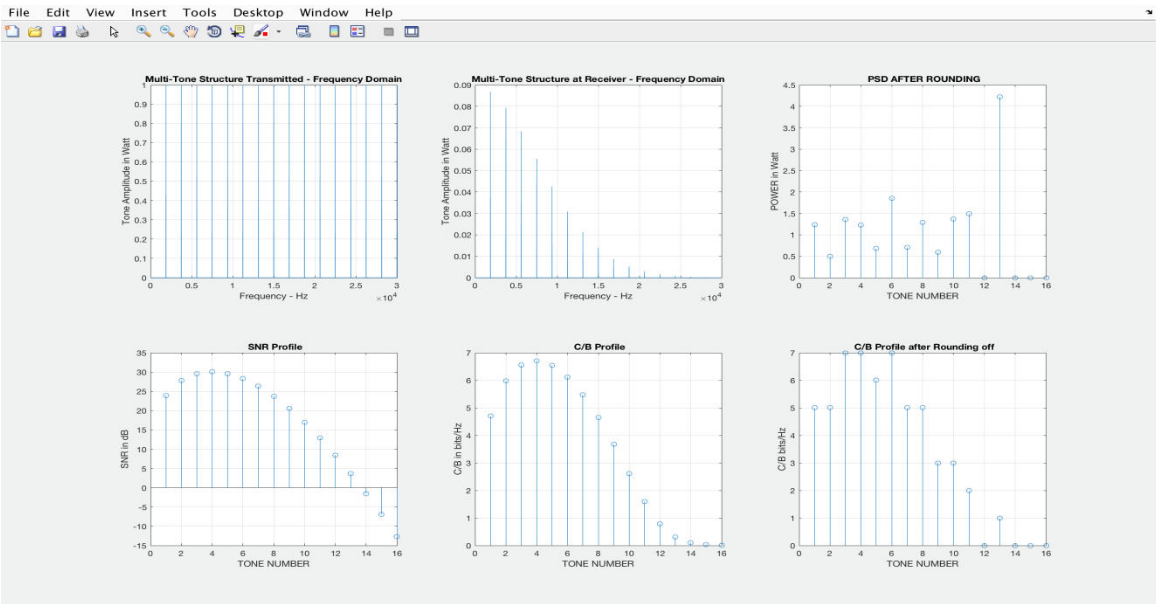

Fig. 5.11 Fisher Simmons Model for Range-5Km

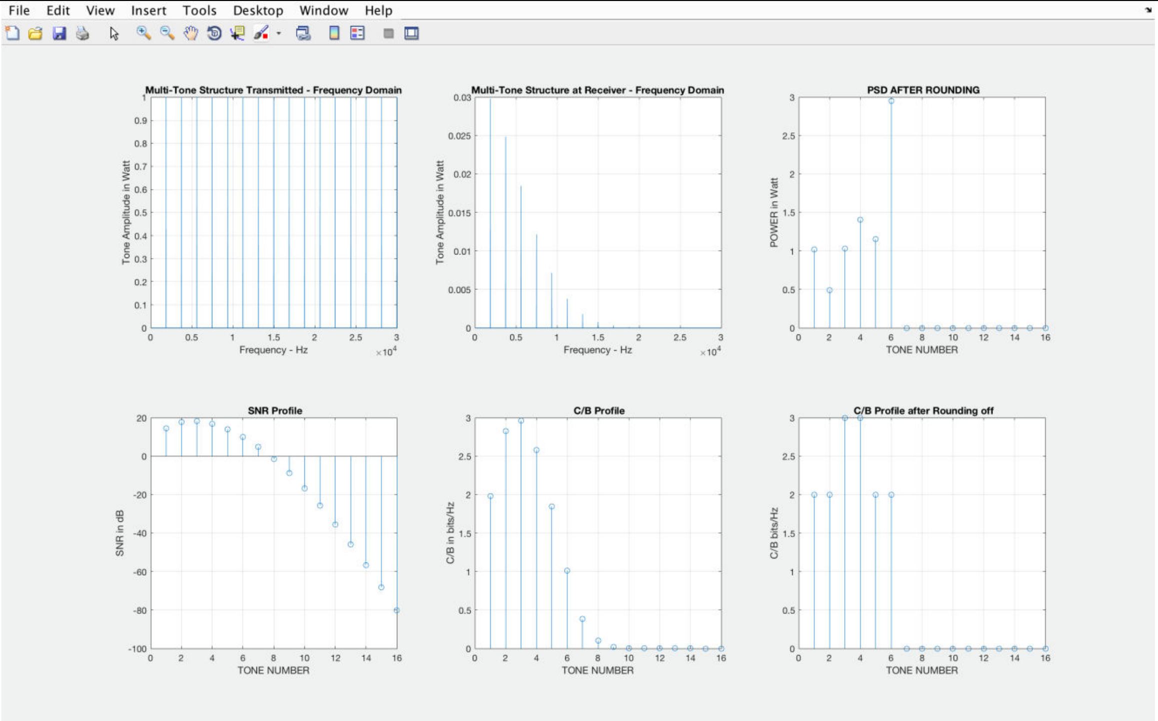

Fig. 5.12 Fisher Simmons Model for Range-10Km

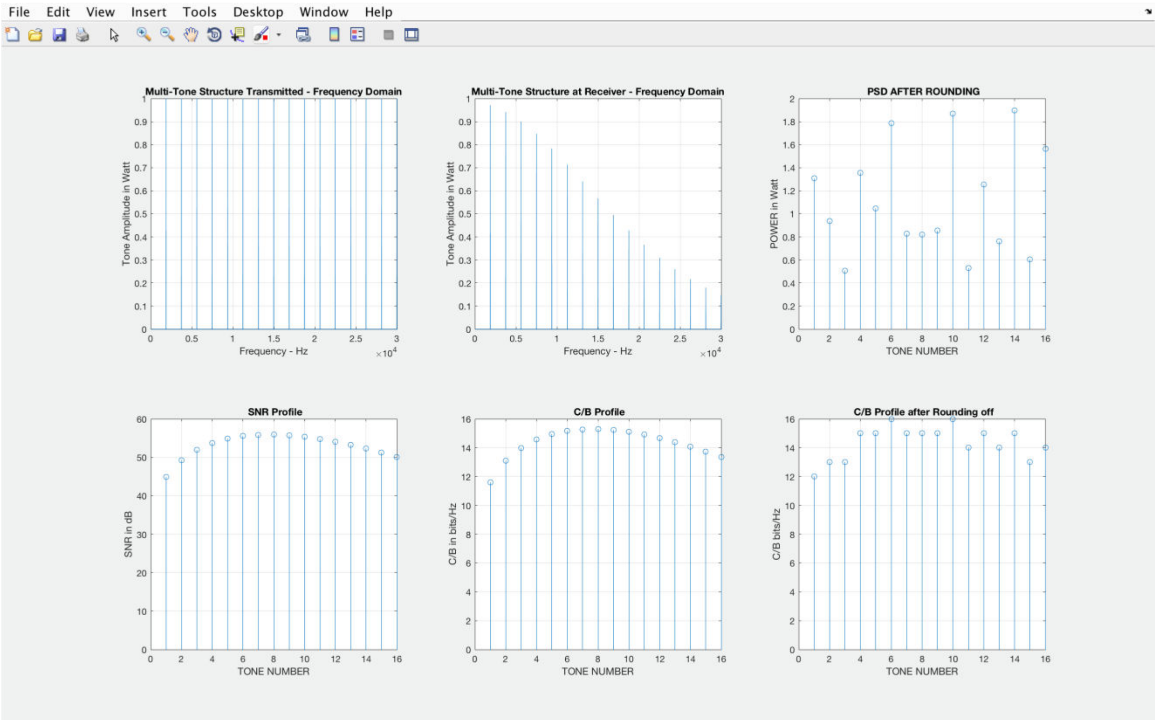

Fig. 5.13 Thorp Model for Range-1Km

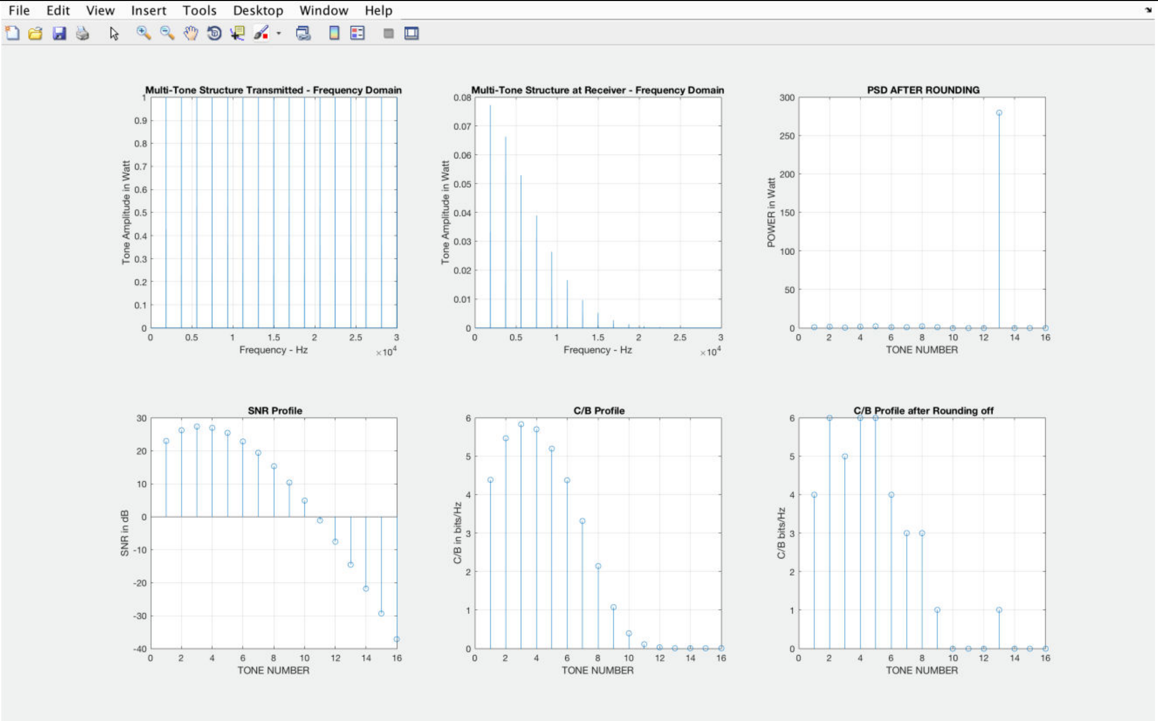

Fig. 5.14 Thorp Model for Range-5Km

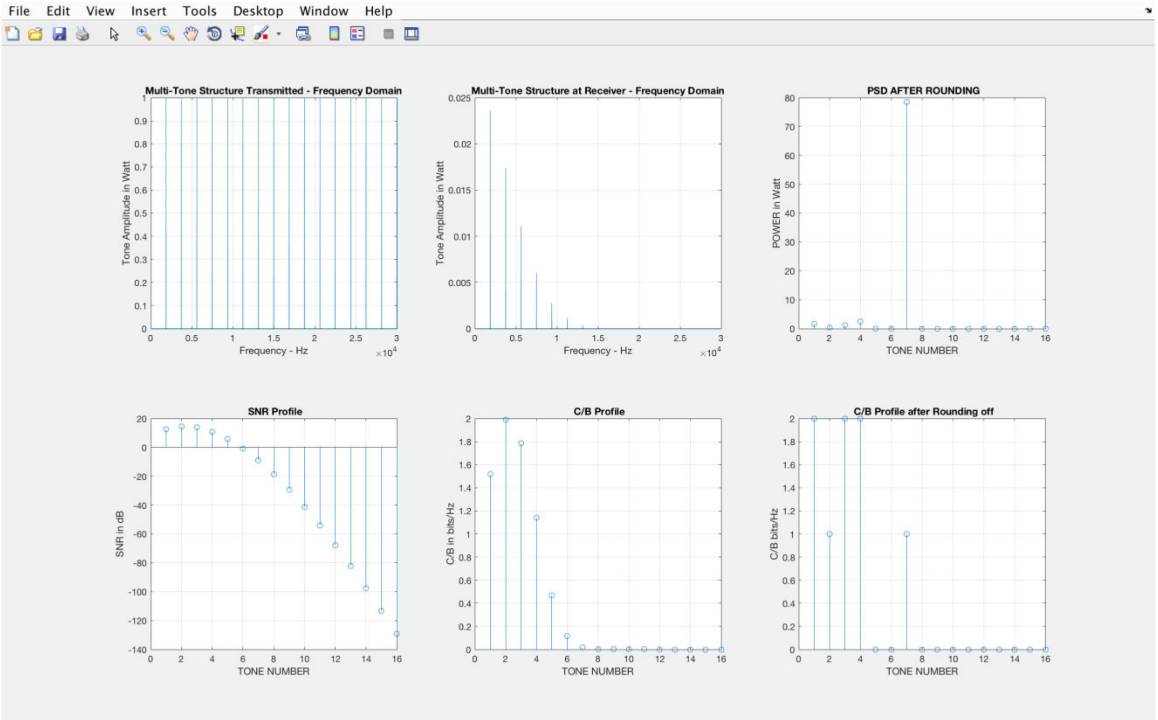

Fig. 5.15 Thorp Model for Range-10Km

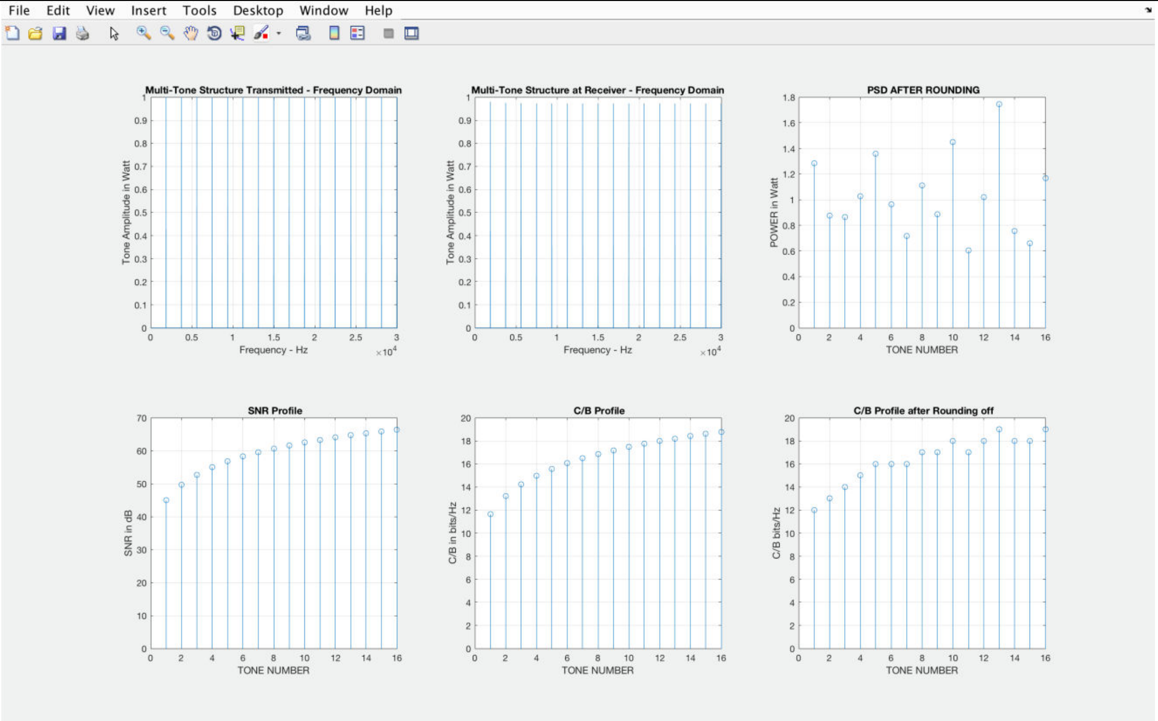

Fig. 5.16 Ainslie Model for Range-1Km

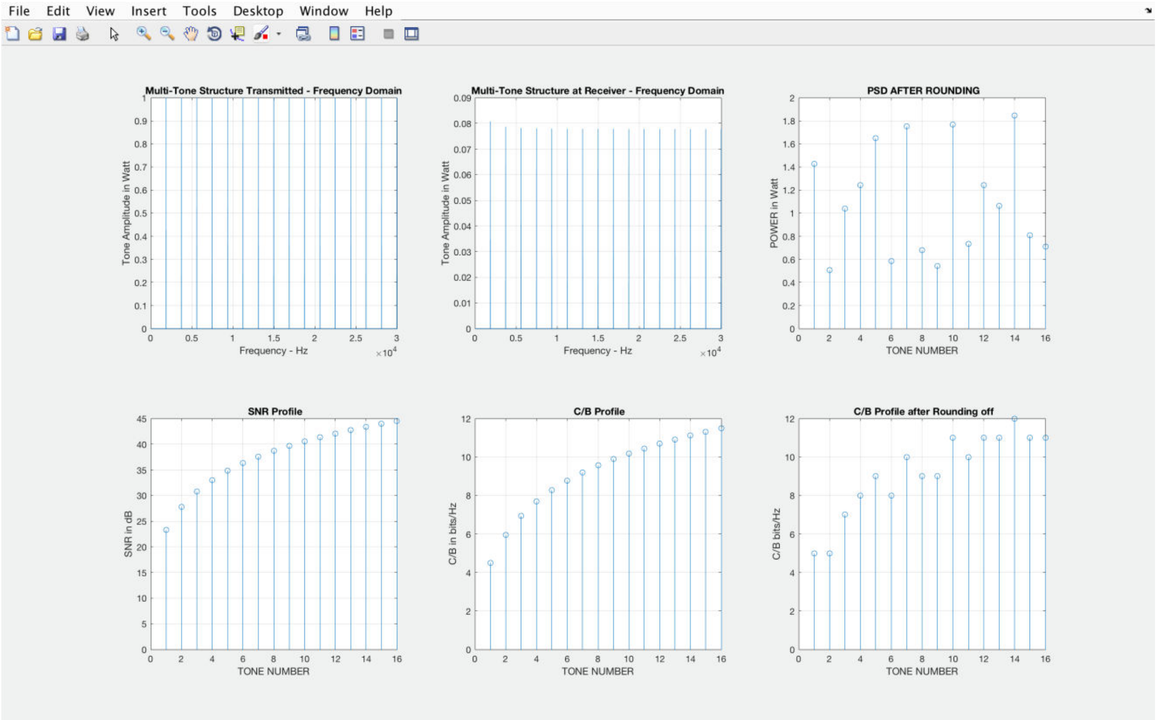

Fig. 5.17 Ainslie Model for Range-5Km

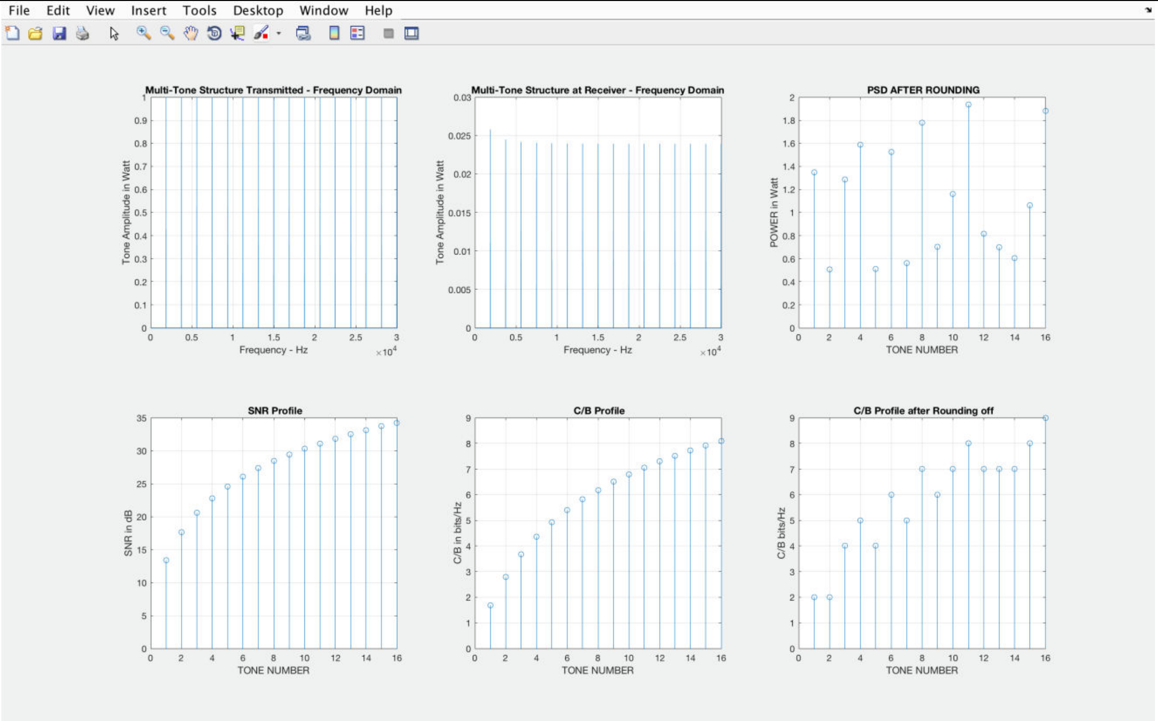

Fig. 5.18 Ainslie Model for Range-10Km

5.1.3 SHIPPING FACTOR -1, WIND FACTOR-25

The following results shows transmitted signal, received signal, SNR profile, probability profile, probability profile after round off for a wind factor of 25 and a shipping factor of 1 for different ranges and for different models.

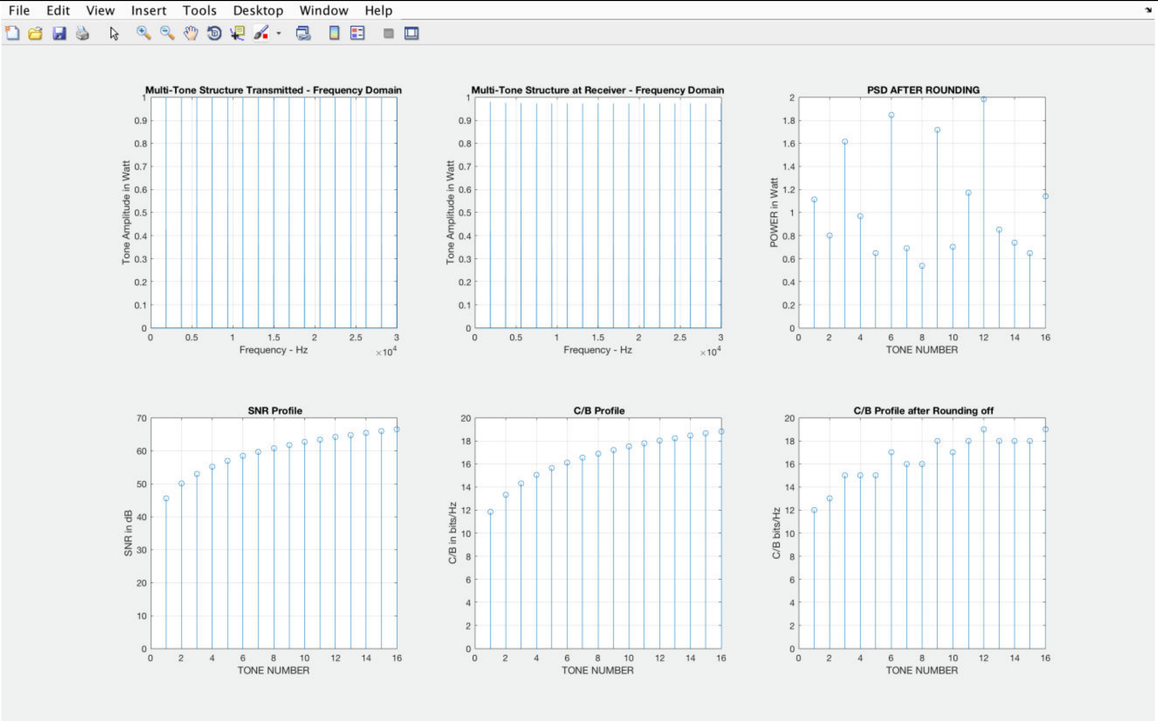

Fig. 5.19 Ainslie Model for Range-1Km

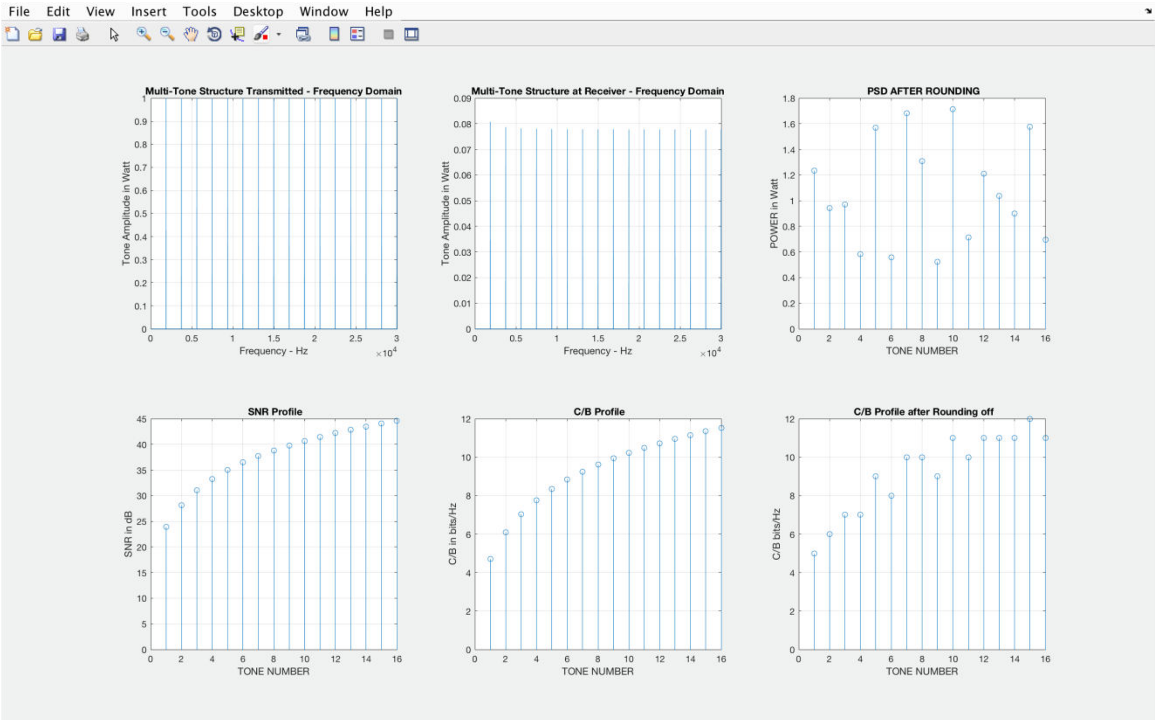

Fig. 5.20 Ainslie Model for Range-5Km

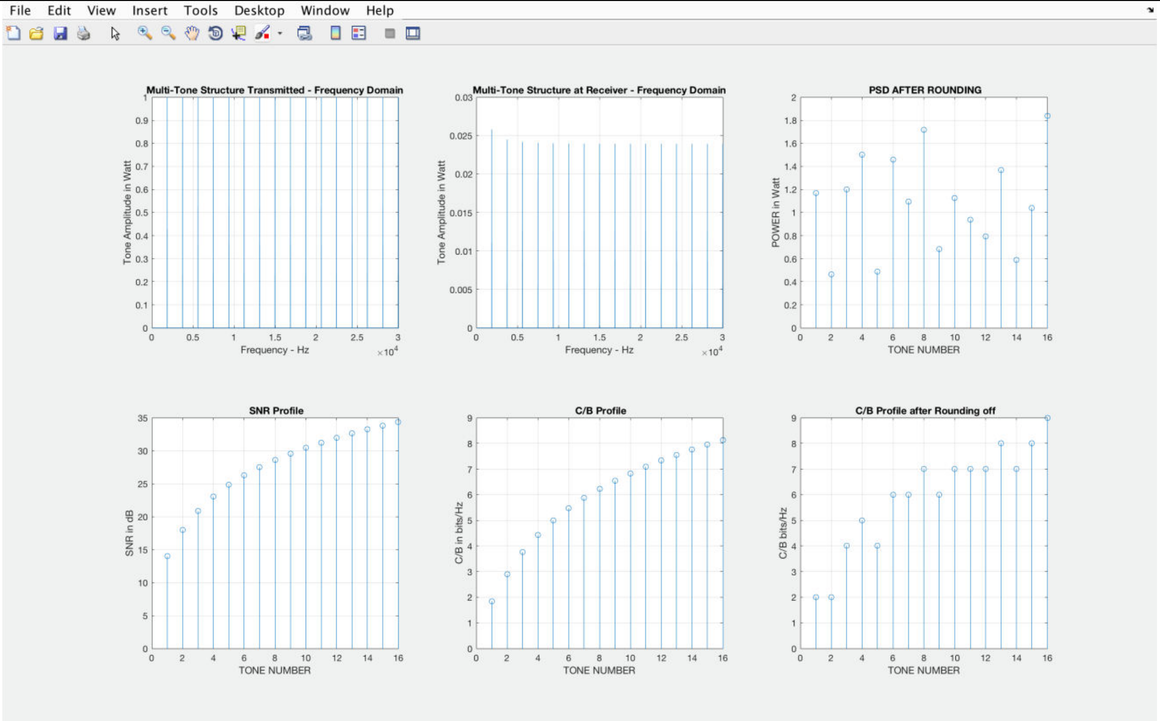

Fig. 5.21 Ainslie Model for Range-10Km

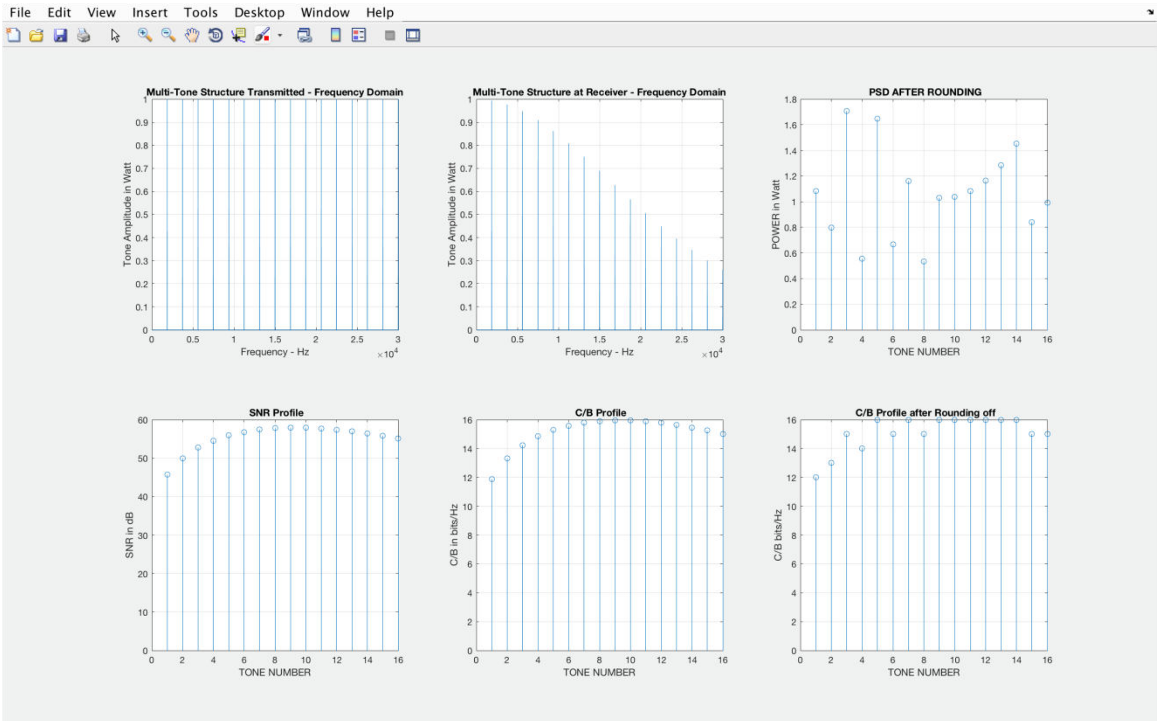

Fig. 5.22 Fisher Simmons Model for Range-1Km

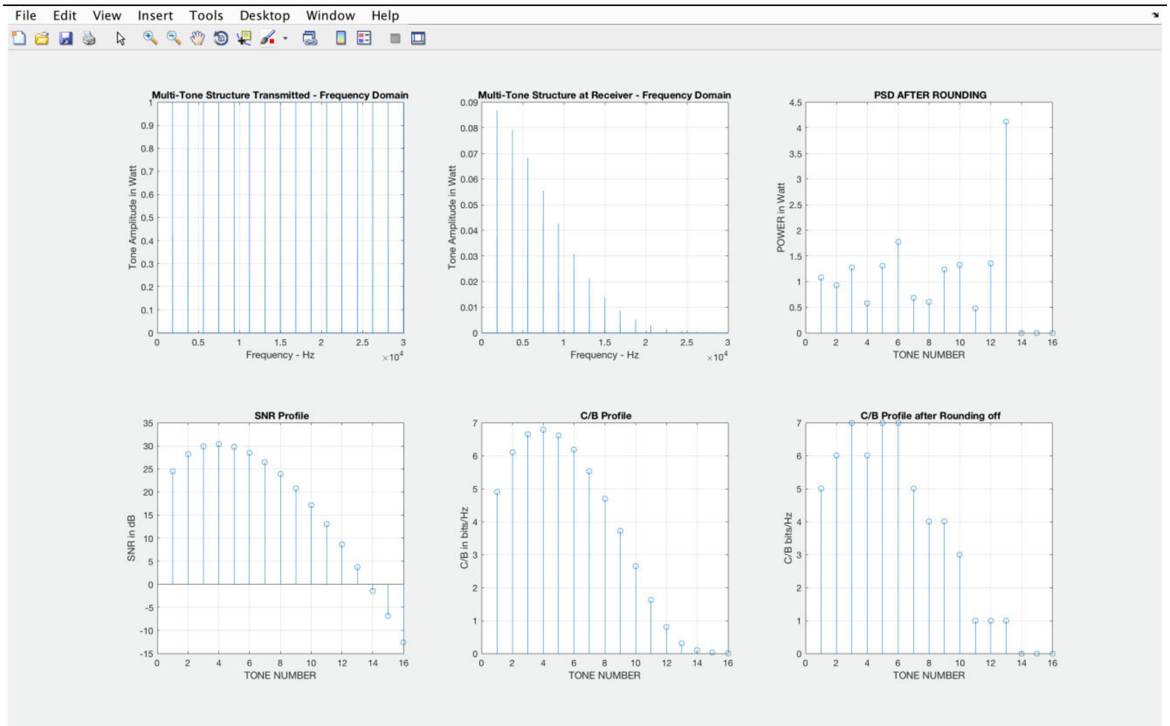

Fig. 5.23 Fisher Simmons Model for Range-5Km

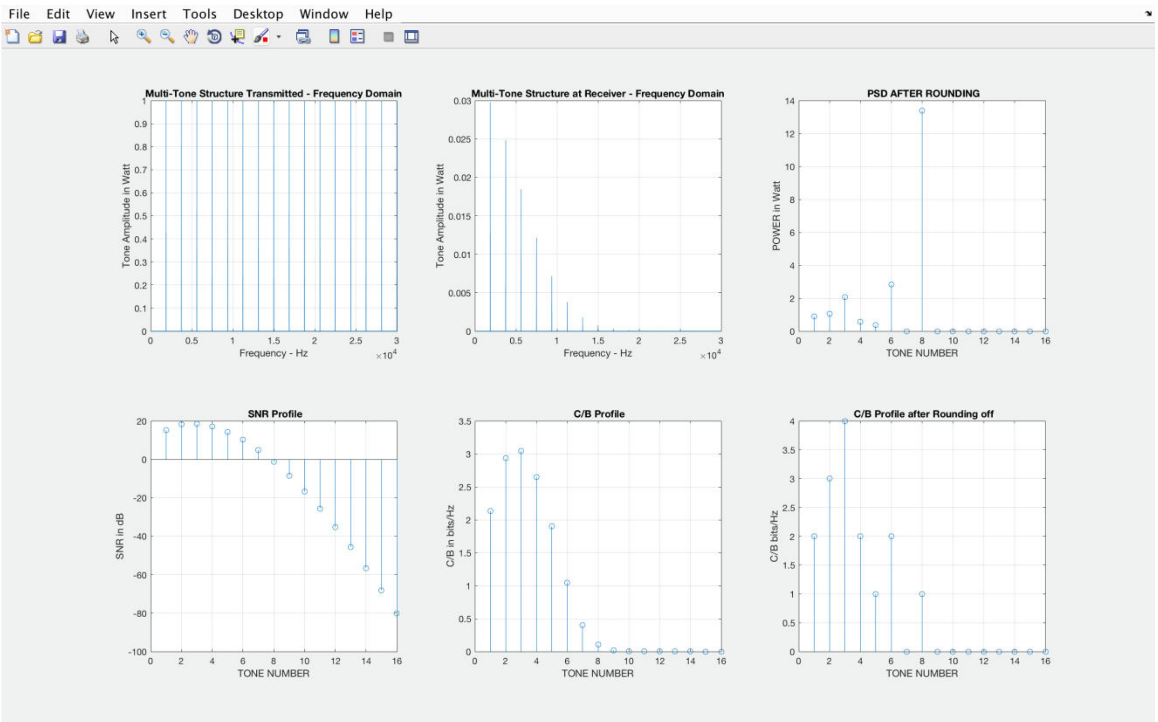

Fig. 5.24 Fisher Simmons Model for Range-10Km

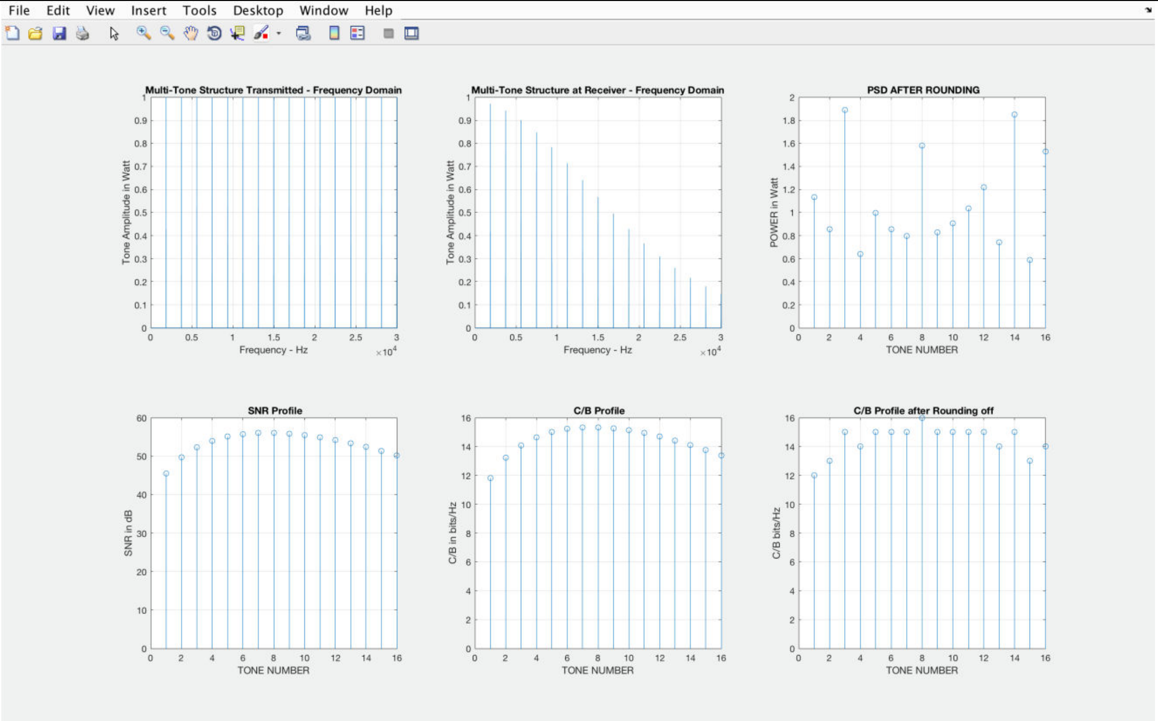

Fig. 5.25 Thorp Model for Range-1Km

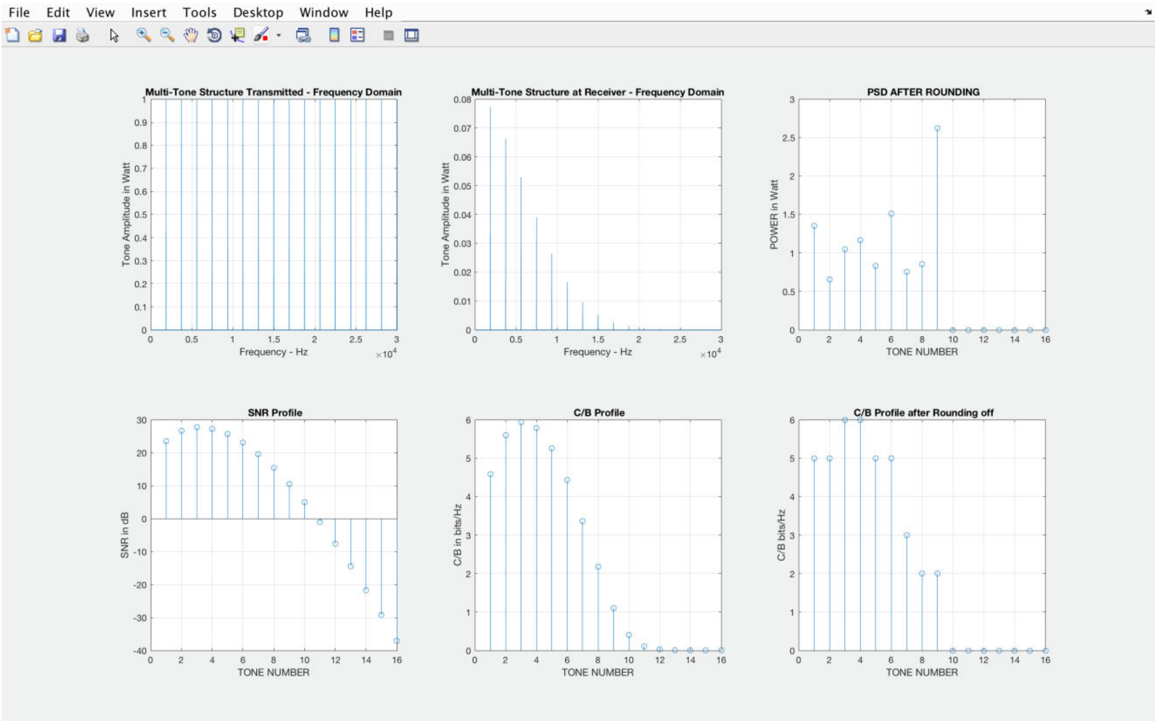

Fig. 5.26 Thorp Model for Range-5Km

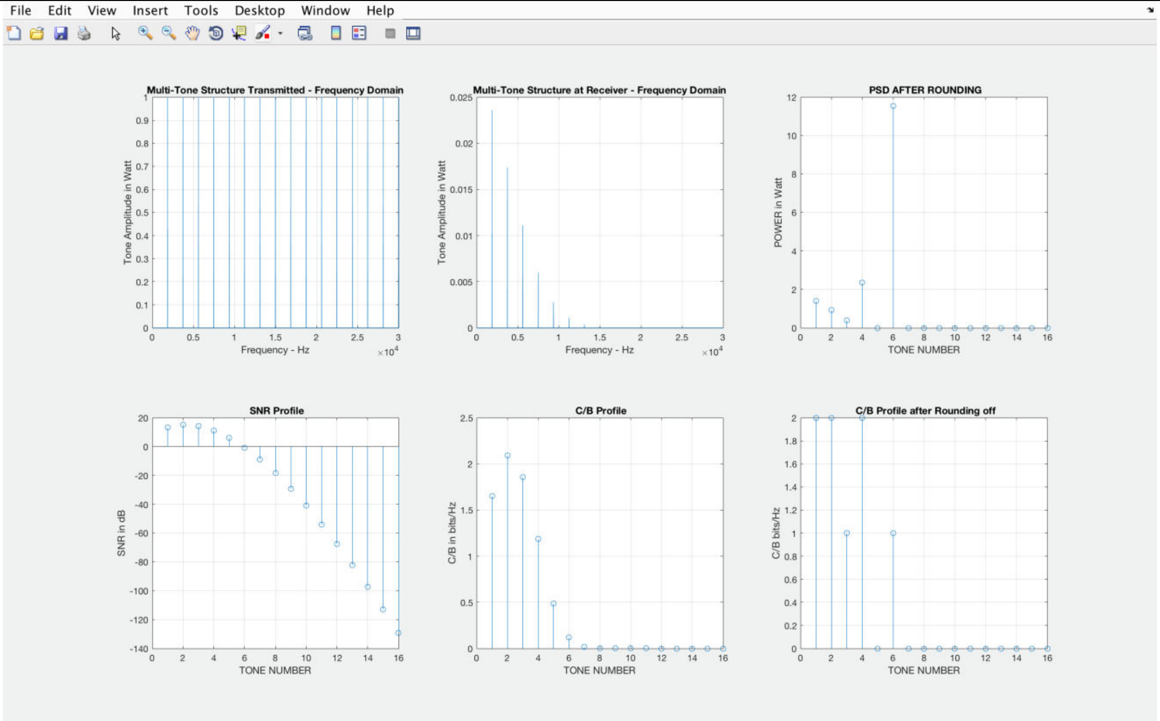

Fig. 5.27 Thorp Model for Range-10Km

5.2 Comparison Table Of All Models

Model Type	Range, Wind factor, shipping factor	Transmitted Signal Strength	Received Signal Strength	SNR
AINSLIE	1km , SF-1, WF-25	Good	Good	Good
FISHER-SIMMONS	1km, SF-1, WF-25	Good	Average	Good
THORP	1km, SF-1, wf-25	Good	Average	Good
AINSLIE	5km, SF-1, wf-25	Good	Good	Good
FISHER-SIMMONS	5km, SF-1, wf-25	Good	Bad	Average
THORP	5km, SF-1, wf-25	Good	Bad	Bad
AINSLIE	10km, SF-1, wf-25	Good	Good	Good
FISHER-SIMMONS	10km, SF-1, wf-25	Good	Bad	Bad
THORP	10km,SF-1,wf-25	Good	Bad	Bad
AINSLIE	1km,SF-2, wf-15	Good	Good	Good
FISHER-SIMMONS	1km, SF-2, wf-15	Good	Good	Good
THORP	1km, SF-2, wf-15	Good	Average	Good

AINSLIE	5KM, SF-2, WF-15	GOOD	GOOD	GOOD
FISHER-SIMMONS	5KM, SF-2, WF-15	GOOD	BAD	AVERAGE
THORP	5KM, SF-2, WF-15	GOOD	BAD	BAD
AINSLIE	10KM, SF-2, WF-15	GOOD	GOOD	GOOD
FISHER-SIMMONS	10KM, SF-2, WF-15	GOOD	BAD	BAD
THORP	10KM, SF-2, WF-15	GOOD	BAD	BAD
AINSLIE	1KM,SF-2, WF-25	GOOD	GOOD	GOOD
FISHER-SIMMONS	1KM,SF-2, WF-25	GOOD	AVERAGE	GOOD
THORP	1KM,SF-2, WF-25	GOOD	AVERAGE	GOOD
AINSLIE	5KM,SF-2, WF-25	GOOD	GOOD	GOOD
FISHER-SIMMONS	5KM, SF-2, WF-25	GOOD	BAD	AVERAGE
THORP	5KM, SF-2, WF-25	GOOD	BAD	BAD
AINSLIE	10KM, SF-2, WF-25	GOOD	GOOD	GOOD
FISHER-SIMMONS	10KM, SF-2, WF-25	GOOD	BAD	BAD
THORP	10KM, SF-2, WF-25	GOOD	BAD	BAD

Table 5.1 Comparison of all underwater models

The above table shows the comparison of transmitted signal, received signal, and SNR. considering different models like Ainslie model, Fisher Simmons, Thorp and different ranges by varying shipping factor and wind factor. So, it is been observed that Ainslie model gives the best results when compared to Fisher Simmons and Thorp model even after considering different ranges, shipping factor and wind factor.

CONCLUSIONS AND FUTURE SCOPE

It is well known that the acoustic underwater channel poses great challenges on the design of a communication system, especially in the present case of high speed communication in a shallow-water channel. Thus during this project the focus of the work lay on one hand on the careful design of the underwater channel, transmitter and receiver properties using MATLAB code. Despite much development in this area of underwater wireless communication, There's still an immense scope so much research as major part of ocean bottom yet remains unexplored. The main objective is to overcome present limitation and produce effective transmission of broadband signal.

With the present results, the future of current work will include the following tasks: Application of the CMA evolution strategy onto the simulation, Implementation of the electronic design, Refinement of the simulation using tests with the implemented electronics, Development of powerful signal processing algorithms using the real-world environment and simulation results.