Chapter 1

Introduction:

Now a day though wireless communication technology has turned out to be a part of regular human life, the idea of wireless UW communication system still seems to be fantastical. However, researchers have spent over ten years on structuring the mechanisms for UW wireless information transmission.

The data we could accumulate from remote undersea areas is the major source of erudition and understanding the oceans, which cover the most of the region of earth. The notable discoveries in the past few decades were achieved because of the use of cabled submersibles, e.g. hydro-thermal vents or the relics of the Titanic at the bottom of the deep sea. Wireless communication can enable new applications when combined with the sensor technology and vehicular technology e.g. environmental monitoring, marine archaeology, collecting oceanographic data and search and rescue missions.

Although from the time of World War II UW communication have been experimented, like an UW telephone was invented in 1945 and used in the USA for communicating with the submarines, on the contrary UW network technology still is an unexplored area. In UW networks the typical physical layer technology used is acoustic communication. The radio waves, as a matter of fact, travel up to long separations through conductive water of ocean, only in the frequency range of 30–300 Hz, which is called extra low frequency (ELF) range, which requires high transmission power and large antenna. Optical waves, however get influenced by scattering, but do not experience the ill effects of such a high attenuation. Moreover, high accuracy is necessary while directing the narrow laser beams for transmitting the optical signals. Thus, links in submerged networks are taking into account the acoustic wireless communications

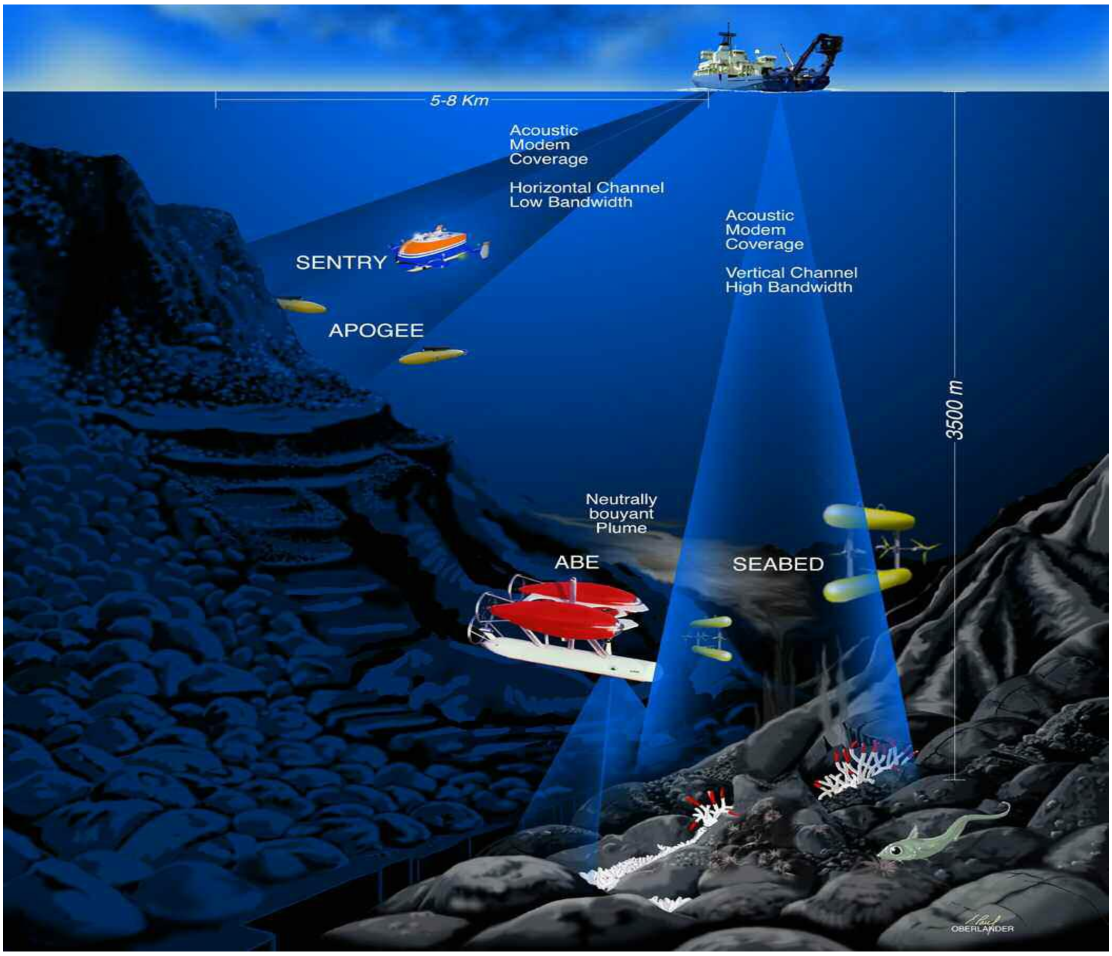


Figure 1.1Navigation, acoustic network and sensing for multiple autonomous underwater robotic vehicles

Since electro-magnetic waves can propagate over extremely short distance, radio signals are not used to carry digital data through the underwater channels. So AWs are utilized, which can travel, unlike EMWs, over long separations. Though, a UW acoustic channel introduces numerous troubles for the communication system manufacturer. This channel has three especial attributes: low speed of sound propagation, severe multipath and frequency-dependent propagation loss. In land dependent radio channels none of these attributes can be maintained nearly, this is the cause which makes UW-WL communication extremely troublesome.

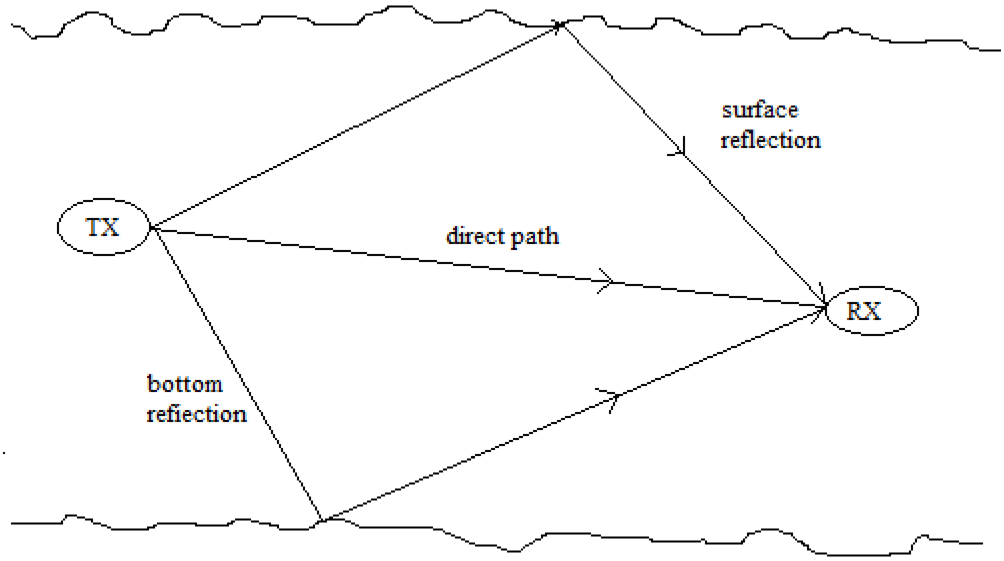


Figure 1.2: Multipath Propagation in Shallow Water Undersea

For an acoustic channel, path loss occurring over a separation **d** can be given by the expression A=dka(f)d, here the value of **k** is define between 1 and 2, and absorption factor is denote by **a(f)** the which depends upon the frequency **f**. This dependence extremely restrains the available bandwidth, e.g. on the 100 km order of distance, the bandwidth available is on the order of 1 kHz only. A larger bandwidth is accessible at shorter distance, yet practically it is constrained by the transducer. An acoustic signal, unlike the radio systems, is rarely narrowband, which means with respect to the center frequency its bandwidth is not negligible.

Underwater wireless communication is useful in pollution monitoring, disaster prevention, offshore exploration and other applications. Wireless communication is a part of our life but under water wireless communication is still a lucrative field. The environment of subsea is challenging for wireless communication because the medium in which waves are propagating is not air, it is propagating through different fractions of water having different densities. Magnetic induction (MI) is a technique which is not affected by multipath propagation, large propagation delays and fading. MI communication can be accomplished with small size coil. MI technique creates constant channel condition and This (MI) technique is very useful in reducing path loss.

1.1Under Water Wireless Network:

In the past decades, the most widely technique is used acoustic wireless communication for underwater wireless communication. Acoustic communication is use physical layer technology for UWCNs. It is use for long distance communication [1], [2], [3]. But it has many disadvantages, such as air bubbles in water and temperature gradients are effect on speed of transmission [4]. Acoustic wireless communication has poor performance in shallow water.

Optical underwater communication has high bandwidth such as gigabits per second. Cost of this technique is less. But it has many disadvantages like; it needs line-of-sight communication, required tight alignment of nodes. In addition, optical underwater communication does not cross water/air boundary [5]. This type of communication also affected particles, marine fouling, soil and rock.

Electromagnetic (EM) wireless communication is also most popular technique. It gives high bandwidth at very short range. But it suffers from high path loss. EM communication affected by fading. It have large antenna size and dynamic channel condition and etc. [5],[6].

So that above three techniques cannot be used due to poor performance. Magnetic induction technique is immune to reflection and scattering and can penetrate ice, rock, soil and water [7]. Magnetic induction is a physical layer technique for UWCNs. It is not affected by fading and multipath propagation. In shallow water, it has an important application such as text communication and diver to diver voice communication can be developed.

In addition, in sea water, conductivity is not same whole time. It is change with day and night. In this paper we built a simulation model of the MI wireless network based on the theoretical analysis and compare with previous paper [8]. And see that how to change path loss with electrical conductivity in a day and a year.

In addition, acoustic wave communication is affected by turbulence due to the tidal wave and acoustic noise [10].

In MI communication, the analysis cannot be applied directly to underwater network due to it has different propagation medium. Due to soil and rock, the communication medium is no longer. In underwater communication, medium properties and operating frequencies are different for near field communication. So that our path loss is affected by these differences.

In further, in sea water, underwater path loss is affected by induced eddy currents due to the conductive property of sea water. In MI technique, we use small size of coil for transmitter and receiver. So that we do not need large size of antennas like EM communication.

MI communication technique is in coastal areas. In underwater communication, MI technique is use for extremely low frequency (ELF) to very low frequency (VLF) range.

MI communication is prefers for shallow water and deep sea water. MI technique and EM technique give short range of bandwidth but they are used to immune to acoustic noise. MI communication is not affected by EMI.

1.2 Related Work

EM wave propagation characteristics in underwater channel have been analysis in [5] and [10]. In [5], conclude that we need large antenna size in fresh water and it has very high attenuation in sea water. So we cannot use EM wave communication in underwater environment.

Acoustic communication is use for long distance communication. It is use physical for UWCNs. But it has some limitation [11], [12]. Underwater acoustic communication has severely limitation on available bandwidth and this bandwidth depends on both transmission frequency and communication range [12].

It has high bandwidth (more than hundred KHz) for small range transmission and has low bandwidth (a few KHz) for long range transmission [10].

Chapter 2

Underwater Sensor Networks:

UW sensor networks are envisaged to enable various applications. Few to count like oceanographic information gathering, offshore investigation, pollution monitoring, natural disaster prevention and assisted navigation kind of applications. Also, numerous autonomous and unmanned UW vehicles (AUVs, UUVs), outfitted with UW sensors, may be used in exploring the underwater natural assets and collecting the scientific information in joint monitoring missions. Empowering underwater communication among submerged devices is essential to make all these applications feasible.

Submerged vehicles and sensor nodes must have self-configuration qualities, which mean they must have the ability to organize their operations by trading the information regarding design, location and movement, and to transfer checked information to an onshore station. Wireless underwater networking using acoustic channel is the empowering innovation for these applications.

2.1 Two-Dimensional Underwater Sensor Networks:

two- dimensional underwater sensor networks is represented in Figure 2.1. A sensor nodes group is tied down to the base of the sea with profound sea anchors.The method of wireless acoustic links is used to interconnect UW sensor nodes to one or more UW-sinks. Two acoustic transceivers are outfitted on the UW-sinks to achieve this goal; one is a horizontal and other is a vertical transceiver.The vertical link serves the purpose of relaying data to an onshore station. The UW-sink uses the horizontal transceiver to exchange information with the sensor nodes such as: (a)sends configuration and command information to the sensors (from UW-sink to the sensors); (b) collects monitored data(from sensors to UW-sink).An acoustic transceiver, capable of handling multiple parallel correspondences with the conveyed UW-sinks, is fitted on the surface station. A long range RF transmitter or satellite transmitter is connected to establish communication with the surface or onshore sink (OS-sink).

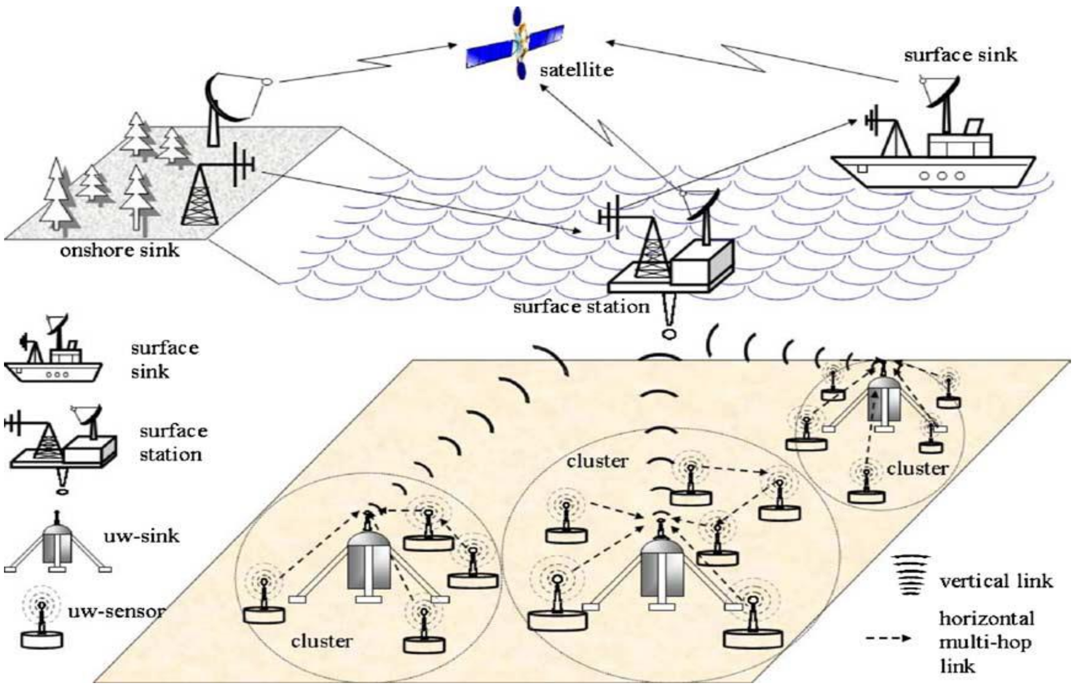


Figure 2.1. Architecture for 2D underwater sensor networks.

Sensors can be joined with the UW-sinks through multi-hop ways or by means of direct links. In the previous case, every sensor specifically sends the assembled information to the chose underwater sink. However, in UW acoustic sensor networks, the power required to transmit may rot with powers more prominent than two of the separation, and the submerged sink may be a long way from the sensor node . Though direct link connection being the easiest approach to network sensors , but it may not be the most productive solution in terms of energy efficiency. Besides, direct connections are liable to decrease the network throughput because high transmission power increases acoustic interference. If, like terrestrial sensor networks, multi-hop paths technique is used, then intermediate sensors relay the information generated by a source sensor until it reaches the underwater sink . This may save energy and increase network capacity, yet routing function's complications may also increase.

Indeed, every network device normally participates in a collaborative procedure which has the objective of diffusing topology information in a way that, for every intermediate node construction of loop free and effective routing choices is possible. Such kind of procedure includes computation and signaling. Now as we have discussed so far, the capacity and energy are two valuable assets in UW circumstances, thus in UW acoustic sensor networks the aim is to provide event features by utilizing multi-hop path techniques and simultaneously minimizing the signal over heading that is required to build submerged paths.

Chapter 3

Magnetic Induction for Underwater Wireless Communication Networks

Recent developments of UW wireless communication have empowered many scientific, military, commercial, safety and environmental applications in submerged environment, e.g. offshore exploration, marine archaeology, environmental and pollution monitoring and so on. When wire-line communication and wireless communication systems are compared, then we find that the latter has lower cost and higher reliability, while wire-lines may easily get destroyed by rocks, marine creatures or other reasons. That's why; UW wireless communication has drawn more considerations amid the previous couple of years. However, submerged environment appears to be a harsh domain for WL-communication because, in place of air, now the propagation medium can be water, soil or rock or even ice-sheets with varying densities, where the conventional techniques of terrestrial WL communication don't work admirably, e.g. radio frequency. In the past thirty years, acoustic wireless communication has become the most broadly used technique in UW wireless communication because of its long separation communication ability. Nonetheless, it experiences a few noteworthy disadvantages also, for example, in the water the transmission speed is incredibly influenced by the air bubbles and temperature gradients, the performance is restricted by the background disturbances and also noises from some submerged equipment's.

Because of the extreme scattering and absorption in submerged environment, optical wireless communication (OWC) is restricted to very short range, while OWC offers favor in point- to- point (P-to-P) communication more than a scope of a couple of kilo meters in the terrestrial communication. As a matter of fact, in the transmission path, if the rock or soil is hindered, then the OWC may not transmit signal properly.

In terrestrial communication, the radio frequency (RF) wireless communication is the most popular technique, which transmits signals by using electromagnetic waves. However, use of the conventional RF technique does not fulfill the purpose in the submerged environment because of large antenna size, dynamic channel condition, high path loss etc. The three above mentioned wireless communication techniques either cannot be utilized or show poor execution if the sensors are set up in seabed. Acknowledging the qualities of magnetic induction (MI), i.e. it can penetrate through water, ice, soil and rock and is immune to reflection and scattering, it is a trustable alternative physical layer method for submerged wireless communication. MI underground and submerged wireless communication has pulled in lots of considerations in the previous decades.

3.1 Magnetic Field Communication System:

The system of magnetic field (MF) communication adopts magnetic induction (MI) for transmitting the data, yielding a fantastic wireless (WL) communication facility within a severe environment, unlike the older system versions of WL communication which have numerous issues. Usually MF communication systems are utilized in the part of nature that contains metal, fluid and soil. A WL system for power transfer, having MI between coils of the transmitter and receiver, transfers energy. Here we are introducing a new system that contains the WL-power transfer system and MF-communication system both. The MF communication system transfers information by using magnetic fields instead of the EM waves. MF communication system is represented below in Figure 3.1.

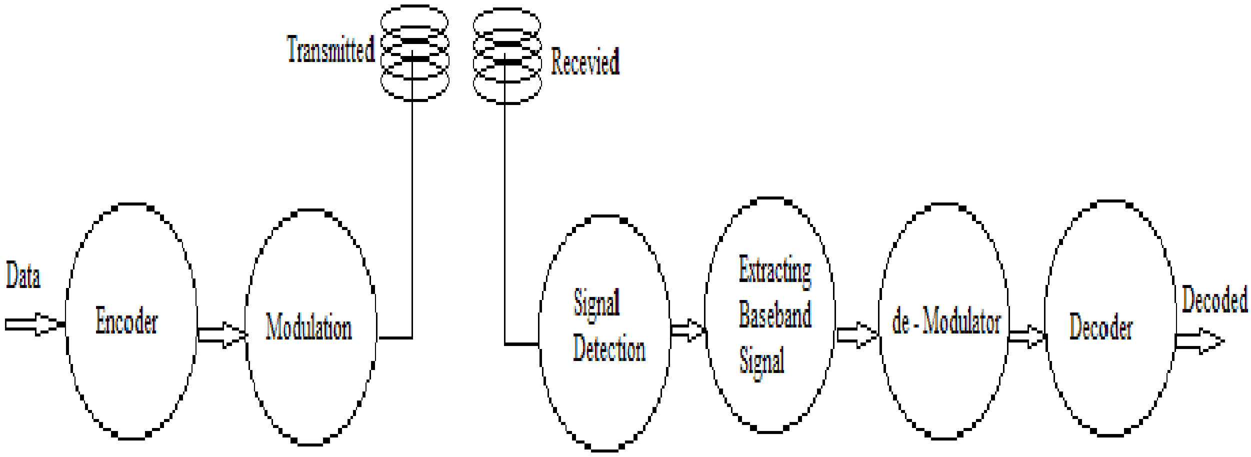


Figure 3.1. The block diagram of the magnetic field communication system

The proposed MF communication system has many similarities with the conventional system of WL communication. Here the only variation is an antenna. In contrast to the communication systems using EM wave, a current-loop-antenna is utilized by the proposed system for magnetic induction.

Chapter 4

EM Under Water Communication

Submerged electromagnetic (EM) communications were examined with intense enthusiasm for the most recent century until 1970s. Since its limits are confined by the fundamental noise and attenuation factors that must be believed to be unchangeable ecological components, so in the submarine radio communication, any significant breakthrough was not expected. Therefore, radio-communication, despite the fact when comes to the terrestrial WL network field, has eminent merits; still it has very less practical underwater relevance at present. In the existing digital world, advantages of the high-bandwidth and short-ranged communication systems have get to be common place to users. On the other hand, connector-less, reliable and also short-ranged data link relevance is demanded by the oil industries, environmental and military operations; therefore, time has come to review the EM abilities in the UW surroundings. EM signaling, combined with the signal compression methods and digital methods, has several benefits that prove it appropriate for niche UW utilizations. Latest movements in observing UW habitat have prompted a broad research on the UWSNs, a large portion of which has utilized AWs as the physical medium for transmission. Here acoustic transmission performs brilliantly.

For the vertical ranges EM presents the most suitable solution usually. Besides, reflections and thermal gradients in the shallow water and refraction in the intense water constitute operational limits and need alternative solutions. Since the transmission technique used in EM signaling is different than the acoustics, so the application arena gets extended, what's more, there is small cover in operating methodologies for both of these strategies.

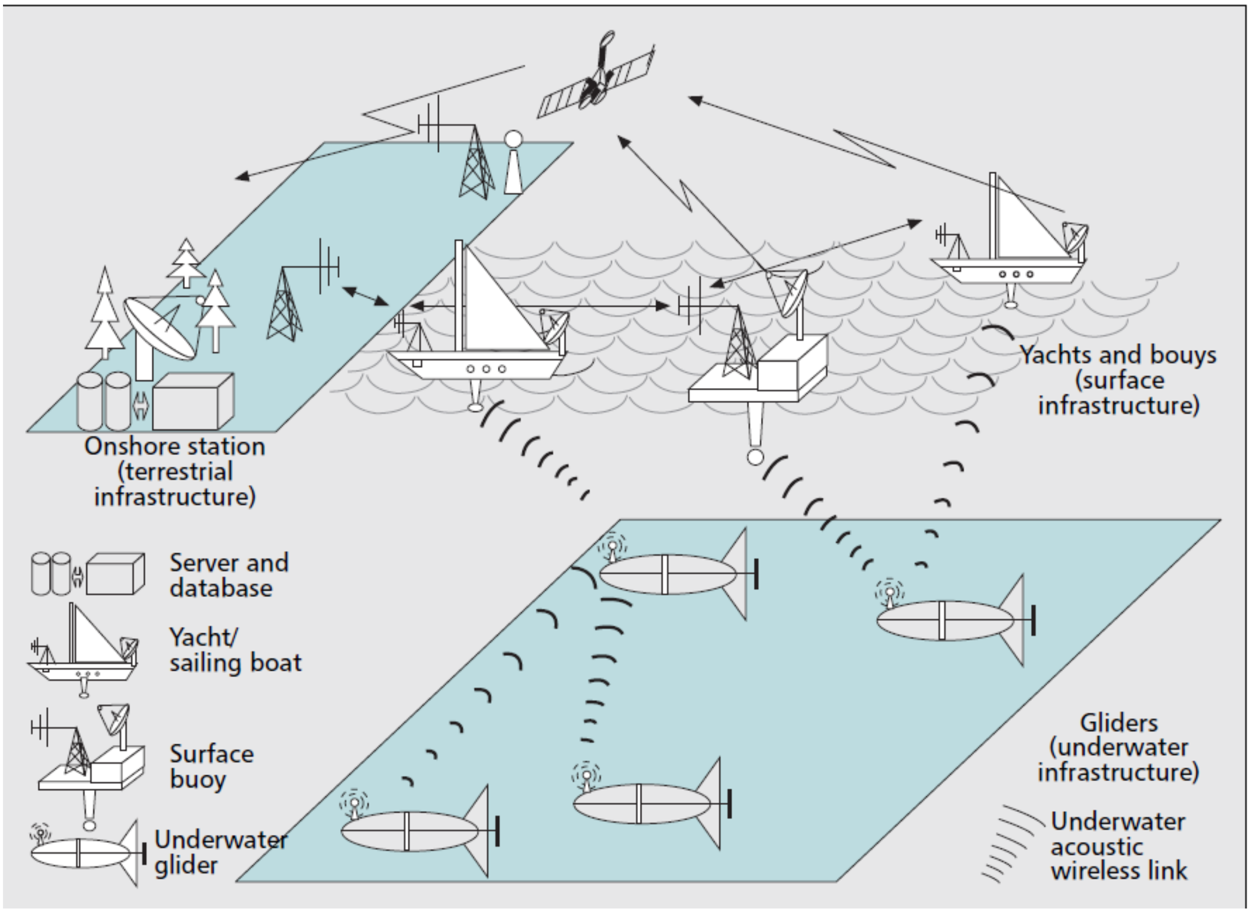


Figure 4.1Scenario of a UW-ASN composed of underwater and surface vehicles

AW and EMW procedures can be regarded as complementary procedures. Another alternative for UW-WL communication can be Optical Wave (OW) technology it has additionally as of late drawn expanding consideration from the academia, scholars, researchers and specialists. While comparing to AW and OW technologies, RF-EM technology provides extraordinary potential for the UW sensor communications. The following section in the present article gives a review of three noteworthy technologies, i.e. RF, AW and OW technologies, and also compares their advantages and their constraints. The detail of UW RF-EM methodology is then examined, alongside the benefits and abilities because of what it suit the UW operations. After that a case study is presented that utilizes the RF-EM communication technology in a UW sensor networks for on-shore monitoring application.

Chapter 5

Radio Frequency Waves

RF waves are EM waves within the below 300GHz frequency band. An EM-wave is an energy wave, having frequency within, as shown in Figure 5.1, the electromagnetic spectrum and propagates when an electric charge accelerates, as a periodic disturbance of the EM field. Submerged RF communication has been researched since the early era of radio and during the 1970sitdrew considerable attention. Besides few submerged RF systems have are developed because of salt water's high conducting nature. The effects of air/water interface, conductivity and wavelength on RF waves are discussed in this section and existing submerged systems, that utilize RF waves, are also described.

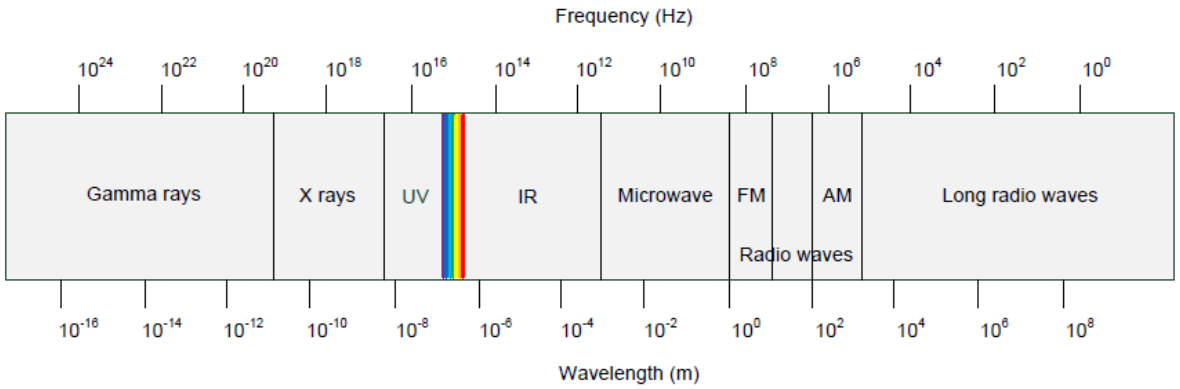


Figure 5.1: Electromagnetic Spectrum

5.1 Conductivity

Although pure water behaves as an insulator, but usually found natural water contains dissolved salts and other things that make it a partial conductor. Higher water conductivity causes higher attenuation of radio signals passing through it. The propagating waves consistently cycle its energy between the magnetic and electric fields, thus EM propagating waves get strongly attenuated because of the conduction. Ocean water has a high salt level and subsequently high conductivity, which varies from as low as 2 Siemens/meter in the cold Arctic region to as high as 8 Siemens/meter (S/m) in the Red Sea. The average conductivity of ocean water is believed to be 4 S/m though fresh water has conductivity on the order of a few mS/meter.

With increase in both conductivity and frequency, in water, attenuation of radio waves increases. Attenuation can be determined from the given formula:

$$\alpha = 0.0173\sqrt{f\sigma} \tag{5.1}$$

Where **α** stands for attenuation (in dB/meter), **σ** stands for the conductivity (in S/m) while **f** stands for the frequency (in Hertz).

5.2 Wavelength

The following formula is used to calculate wavelength in water:

$$\lambda = 1000\sqrt{10/f\sigma} \tag{5.2}$$

Where **λ** stands for wavelength (in meters), **f** stands for frequency (in Hz), and **σ** stands for conductivity (in S/m).

Wavelength of a signal considerably reduces submerged (especially in salt water), which leads to notable differences between antennas manufactured for terrestrial and UW communication.

5.3 Existing RF Systems

Since sea water's conductivity causes attenuation to the RF signals, so very less number of systems utilizing RF underwater communication have been designed to date. In military applications, (ELF) or extremely low frequency radio signals are utilized. Germany innovated radio communications for underwater submarines during WW-II, where they used the Goliath antenna that was capable of yielding power up to 1 to 2 Mega-Watt (MW) and was strong enough to transmit signals to the undersea submarines in the Indian Ocean. Later, a Russian and U.S. ELF system, to call an individual submarine, utilized 82Hz and 76Hz RF signals respectively to send a one-way `bell ring` to the surface to terrestrial radio unit for higher bandwidth communication achievement. Till past few years the use of high frequency waves was considered impractical for communication purposes. While, recent experiments with new antenna designs that uses dipole radiation with transmission powers on the order of 100W, show that radio waves in 1-20MHz range of frequency can propagate at more than 1Mbps signal rate, over separations up to 100 m. These antennas are far different from the terrestrial communication's antennas. Because unlike terrestrial antennas which have can directly with air, these antennas do not have direct contact with seawater. However the sending and receiving metal aerials are surrounded by waterproof electrically insulating material permitting an EM signal to be sent from a transmitter into the ocean-water and a distant receiver picks it up.

5.4 Medium Range Phenomenon

Several experiments done by different research teams have determined a much longer range of propagation that does not follow the conventional EM theory. The attenuation of radio signals given in and the skin depth indicates an exponential attenuaton with respect to distance. Conclusively, any long-range propagation should not be expected. Though, according to an old article from Wireless World, 1966; radio signals at a distance of almost 450 meters at 76 m depth were measured in the pacific outside San Francisco [Northrup Corporation 1966]. This article also states that with change in depth the transmission was not changing, which would be expected, had ‘sea-air-sea’ be the propagation path. This phenomenon of medium range has not been broadly investigated till date, despite the disclosure in the article of Wireless World, 1966. Within more recent time, a measured range of roughly 90 meters was disclosed, in the Liverpool marina, with output power of 5 W (+ 37 dBm) and a frequency of around 5 MHz. Though, the depth mentioned was less than 5 m, so the question that the propagation path used was through air or not, still stays unanswered.

Chapter 6

Overview of Underwater Wireless Communication Technologies

Various researches and developments have been carried out regarding UWANs so far. AW technology is a proven method for UW sensor applications that yields high transmission ranges as much as 20 km, besides some particular restrictions and challenges also has been reported. In shallow water, acoustic wave's performance become poor, as here transmission may get affected by turbidity, pressure gradients, surrounding noises and salinity; additionally, adverse effects on marine life can take place because of acoustic technology.

Several efforts at research on UW optical communications have recently been empowered because of OW technology's very high capacity. Though, OW delivers good performance only in highly clear or pure water and depends upon the tight arrangements of nodes. While using optical communication, the need for line of sight has put critical limitations over its UW applications, but endeavors are being made to overcome such restrictions. Sometimes RF-EM communication may experience the ill effects of electromagnetic (EM) interference and restricted transmission range; it likewise has some profitable qualities that can empower flexible implementation of UW sensor networks in the coastal zones. Specialists and researchers are currently working upon UW-EM communication techniques.

When compared to AW and OW technologies, the RF-EM communication technique has some distinguishable benefits because of which it is relevant for the UW conditions: (i) both AWs and OWs cannot transit smoothly from the interface of water and air. Though, EM waves can easily penetrate through water-to-earth boundaries or water-to-air boundaries, following the direction of minimum resistance. Here, both seabed and air paths will offer to make available a larger transmission range. If full advantage of this feature is taken, then a prominent contribution in network designing and implementation can be achieved. (ii) EM wave transmission, unlike AW and OW transmission, is tolerant to turbulence brought about by human activities or tidal wave. This quality is absolutely advantageous to the system execution in irregular and erratic submerged environment. (iii) Electromagnetic waves can work in filthy water, while OW is helpless to matter and marine fouling. EM wave communication becomes advantageous with this, when utilized in a water segment with an abnormal state of sentiments and air circulation. (iv) Unlike AW technology, the radiation of EM wave is insusceptible to the acoustic noise, and causes no harsh effect on the aquatic life.

Chapter 7

Benefits and Applications

In the most applications, EM signaling is an exclusive propagation technique which yields exclusive benefits, that in turn, enhances the use of present UW system. Because of the nonlinear relationship between frequency (**f**) and velocity (**v**), to lessen the effect of velocity's frequent changes in the entire band, bandwidth reduction at low-range frequencies is necessary. Various practical applications such as navigation, sensing and communication can be implemented by using UW-EM technique. Huge numbers of these applications are particularly alluring for autonomous UW vehicles (AUVs).The signal magnitude gradient present in the EM wave propagation can be advantageous for short-range navigation frameworks. For the beacon system implementation, the sonar systems must utilize the phase information to detect the wave front directions, which is affected ill by pressure gradients and multipath effects. Navigation systems predicated on the EM signaling can quantify increased strength of signal as an immediate reaction to movement toward beacon; this empowers an easy and sturdy control loop. To radiate EM signals, distributed cables are designed that transmit signals along their length.The acoustic domain has no equivalent to such distributed transducer. Right now, some of these applications are being developed, e.g. Wireless Fiber System (WFS) has clearly shown the most recent outcomes of utilizing such methodology in UW navigations. Bandwidth of EM system surpasses the counterpart AW system at very short range of frequency. Majority of the short-range applications inclines to present in deep water and such systems, due to the water columns, possess the benefit of effective protection from ecological noise. While, the applications of long-range working from ground-to-ocean floor will encounter the environment of asymmetric noise because the protection effect of sea brings down, examined in contrast to that at the surface, the noise effect experienced at the ocean bed.

Chapter 8

Digital Communication

In order to properly decode the information contained in the signal, the transferable signal containing information/bits has to be recognizable for the receiver part. Generally, one or several bits grouped together are associated with a symbol. The number of symbols has to be equal to the number of possible uniquely grouped sequence of bits. Let**S** denotes the unit of a symbol, and **n** the number of bits contained in each symbol. The number of unique sequences/symbols of the n-bits:

$$\text{Number of Symbols} = 2^n \ [S] \tag{8.1}$$

Thus modulation, is the mapping of bits onto a signal, it can be done in several different ways. E.g. assigning different voltages, power levels, or in time slots. In order to proper demodulation/retrieval of the information contained in the signal, both transmitter and receiver side must agree to the kind of modulation to be performed and that which bits the symbol represent.

The probability of demodulating a received signal into a wrong symbol is commonly denoted as **Pe**(probability of bit error). Though, the goal of any transmission is to transmit all the information from the transmitter to the receiver flawlessly. In other words, it is desirable to keep the **Pe** as low as possible, ideally zero. The trade-off here is generally energy, and/or time used for sending the signals to achieve a tolerable **Pe**. The **Pe** is a theoretical figure which can be derived mathematically for the given modulation type from a general probability theory.

When signals are transmitted through a lossy medium such as air, metal, or in this case water, the shape of the signal might be distorted or deformed due to phenomenon such as attenuation, thermal noise, etc. Due to this deformation effect, the sent symbol could look like a different symbol at the receiver side. E.g. the modulated version of a binary 0 could look like a 1, causing an error in the demodulation. Since very little information exists about the characteristics of the channel noise in sea-water, an assumption is made that the noise is white and with a Gaussian probability distribution having mean $\alpha = 0$ and standard deviation $\sigma^2 = N0/2$. Let this noise n(t) adds with the originally sent signal x(t), and sums up to the received signal y(t).

$$y(t) = x(t) + n(t) \tag{8.2}$$

This type of channel noise is often called as additive white Gaussian noise (AWGN) and is a common noise model in digital communication theory [Proakis&Salehi 2008, p. 160, 358]. Below is a graphical representation of the AWGN channel.

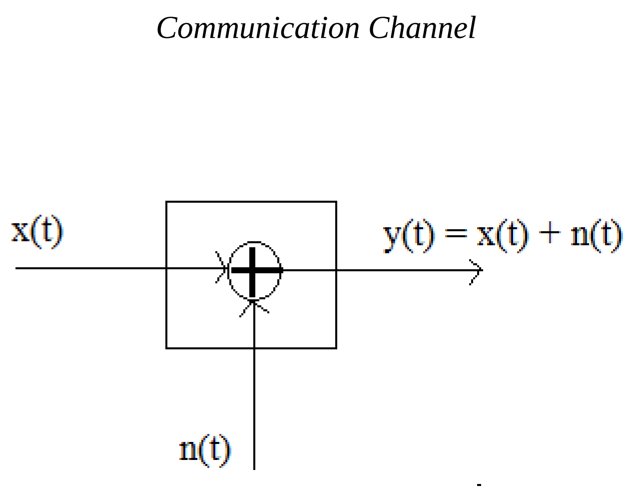


Figure 8.1: Additive White Gaussian Noise Channel.

8.1 Binary Phase-Shift Keying (BPSK)

BPSK is one of the very basic modulation schemes for wireless communication. It transmits one bit at a time and uses only two symbols i.e. '0' and '1', hence it is called 'binary'. In general, phase modulation is based on sampling the carrier wave at specific times, and by looking at the phase of the sinusoidal carrier to determine the symbol transmitted. Below Figure 8.2 represents a plot of a cosine wave with amplitude **A**, and the relative polar mapping and(or with)the constellation with two BPSK symbols. Here **A** and **-A** are being represented by '0' and '1' bits respectively. There is 180 degree phase difference between the two points, hence this is phase modulation.

Figure 8.3 represents a sample of a BPSK modulated wave(or waveform)and the respective bits. A BPSK sampled signal can be mapped in the diagram as shown below and the nearest constellation point will conclude which symbol should be assigned to it. In this modulation technique coherent detection is compulsory, which requires the sampling to be synchronized at the start when the signal first appears at the receiver.

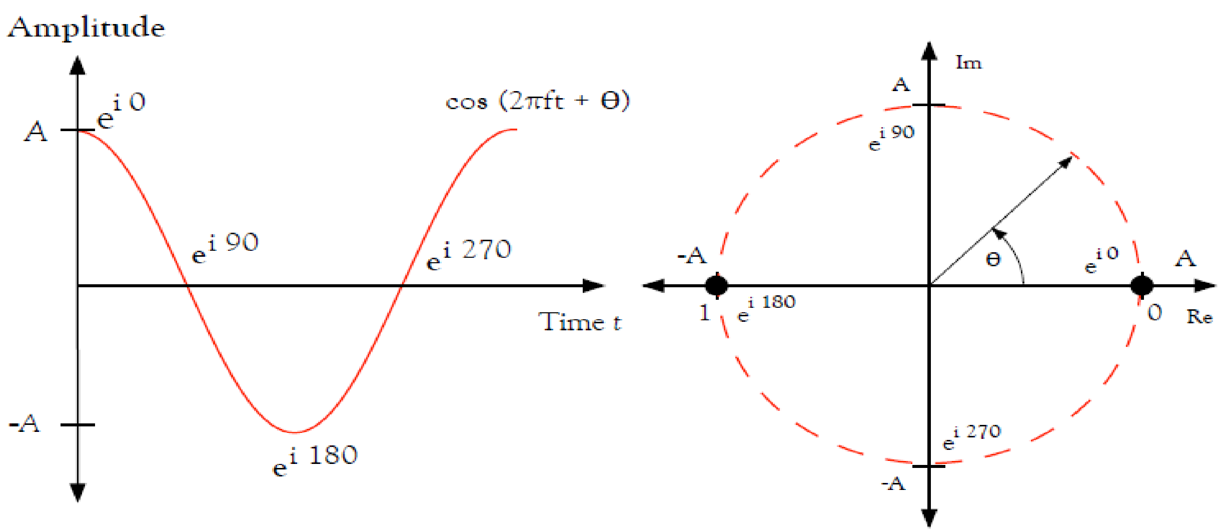


Figure 8.2: BPSK Mapping and Constellation Diagram.

For a higher order of modulation, more constellation points have to be assigned to the diagram. E.g. if another two points are added, the circle has to be divided into four equally spaced line segments and each symbol to be transmitted contains a group of two bits now. This is called 4-PSK or quadrature phase-shift keying (QPSK), where there are 4 unique symbols (ref. Equation 8.1, n = 2). The tradeoff is a lower tolerance for any communication channel.

Since the geometrical distance between constellation points is smaller now, so each transmitted symbol is more sensitive for any noise, etc. Hence the probability of detecting the erroneous symbol gets higher.

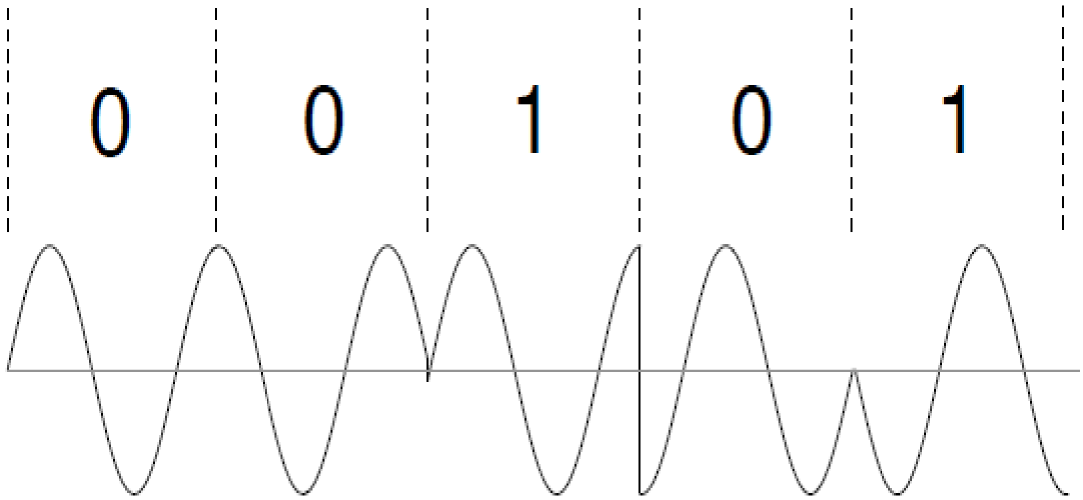


Figure 8.3: BPSK Waveform

Surprisingly, **Pe** is equipollent for both QPSK and BPSK due to the fact that two bits get transmitted in one and the symbols are orthogonal onto the most proximate symbol constellation points. The probabilities of errors for the two schemes. Increasing the amplitude of the signal, and making the circle larger can be done as a counter-measure to control the probability of symbol error. In other words, increasing the SNR ratio. In theory, it is possible to use as many constellation points as desired to transmit many bits (increasing the data rate) per symbol, as long as the SNR at the receiver is high enough.

8.2 Frequency Shift Keying (FSK)

FSK scheme of modulation is predicated upon the change in frequency inlieu of phase as in the PSK modulation. The principle of FSK modulation suggests switching between diverse carrier frequencies (f_c) to transmit different symbols. Two carrier frequencies (f_c) should be sufficiently separated, so that they are properly distinguishable and does not interfere with each other. Considering the simplest case having two carrier frequencies (f_c), each corresponds to a '0' or a '1'.This method is known as binary FSK (BFSK). To detect the different symbols, the radio frequency (RF) input can be linked up with locally generated tones with the same frequencies, and the tone that correlates best indicates the symbol transmitted at that specific time interval. Figure 8.4 represents a FSK modulated sample and respective bits. Contrary to PSK, FSK can use non-coherent detection and thus synchronization of the sampling is not necessary in FSK.

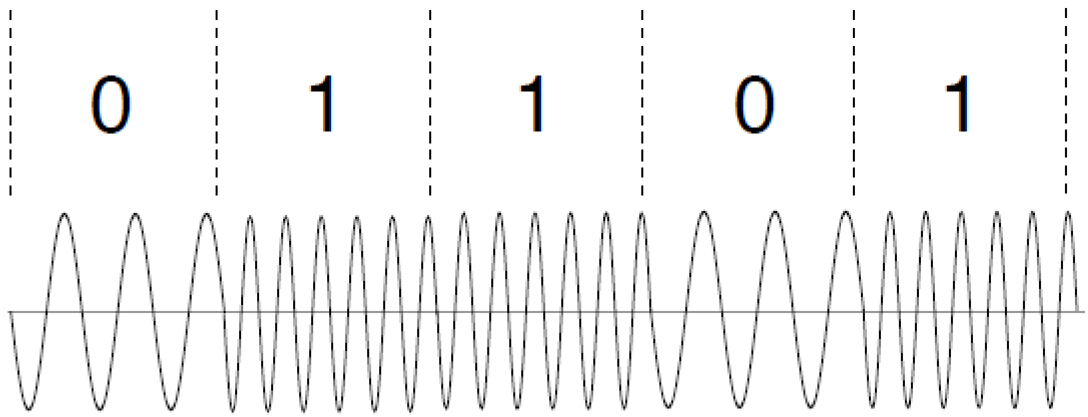


Figure 8.4: BFSK Waveform

8.3 Bit Error Rate (BER)

The **BER** is a figure of measure in the most communication systems. This parameter is predicated on the absolute statistical performance of a communication system, betokening how many bits which are erroneous in a demodulated bit stream received in a time interval. While **Pe**(probability of error) is a theoretical figure, **BER** is the absolute performance measured. This parameter can be estimated in forehand by calculating the **Pe**from a given modulation, and noise model thePe versus SNR (SNR= E_b/N0) for different modulation schemes. The **Pe** for each modulation technique can be obtained mathematically from probability theory considered generally, while assuming the channel noise is having a Gaussian probability distribution. Also assuming that all the different symbols are equiprobable, i.e. different symbols are received with equal probability.

8.4 Sampling Theory

With a view to receive and store a signal, the signal values are sampled for a given time period such that the information in signal is conserved. The carrier frequency used in the wireless communication might be in the order of GHz. Fortunately, only the modulation which has a muchsmaller frequency has to be sampled in order to retrieve the information sent over the communication channel. According to avery often known theorem in communication theory, the sampling frequency $\mathbf{f_s}$, also called the Nyquist frequency, must be at least twice the actual bandwidth of the signal so that the demodulated signal is error free.

$$F_s \geq 2BW \text{ [Hz]} \tag{8.3}$$

For BPSK scheme, the data rateof signal is half the bandwidth.

$$BW_{BPSK} = 2R \text{ [Hz]} \tag{8.4}$$

Since FSK uses two carrier frequencies, the transmission bandwidth is also dependent upon the frequency difference of them, denoted by **Δf**. Thus,for FSK effective transmission bandwidth becomes :

$$BW_{FSK} = 2\Delta f + 2R \text{ [Hz]} \quad (8.5)$$

8.5 Channel Capacity

According to the Shannon's channel coding theorem, for a given bandwidth and SNR, a maximum possible data rate exists. The channel capacity © is another name for this maximum possible data rate. This is represented as:

$$C = BW \log_2 (1 + SNR) \text{ [bits s}^{-1}\text{]} \quad (8.6)$$

This maximum capacity or channel capacity is just a theoretical limit, it does not give any denouement of a real world system can achieve this data rate. However, close convergence to this maximum data rate is possible by using complex modulation scheme and variants of coding.

8.6 Functional Schematic of the Communication System

Figure 8.5 gives a high level symbolic representation of a acoustic transmitter combined with receiver circuit. At the transmitter side, within the digital signal processor (DSP) the signal time function s(t) is generated and then a digital-to-analog (D/A) converter, converts s(t) into an analog step signal. This signal is passed through an analog low pass filter, so that the transmission power can be reduced and the amount of high frequencies appearing at the receiver can be minimized. Afterwards, the signal is amplified to the desired power level by an amplifier and then supplied to the D/70 sound projector.

The receiver starts by picking up the noisy convolution of the signal time function with the channel impulse response $r(t) = (s*h)(t) + n(t)$ using the TC4013 hydrophone. Afterwards an amplifier controlled by the dsp unit shifts the power level of r(t) in a way that it is optimal for further processing. Then the receiving analog low pass filter is used to suppress high frequencies in order to avoid aliasing by the subsequent sampling using the analog-to-digital (A/D) converter.

After that, the amplified and low pass filtered signal r(t) is discretized in time and amplitude and handed over to the DSP unit to identify the transmitted symbols.

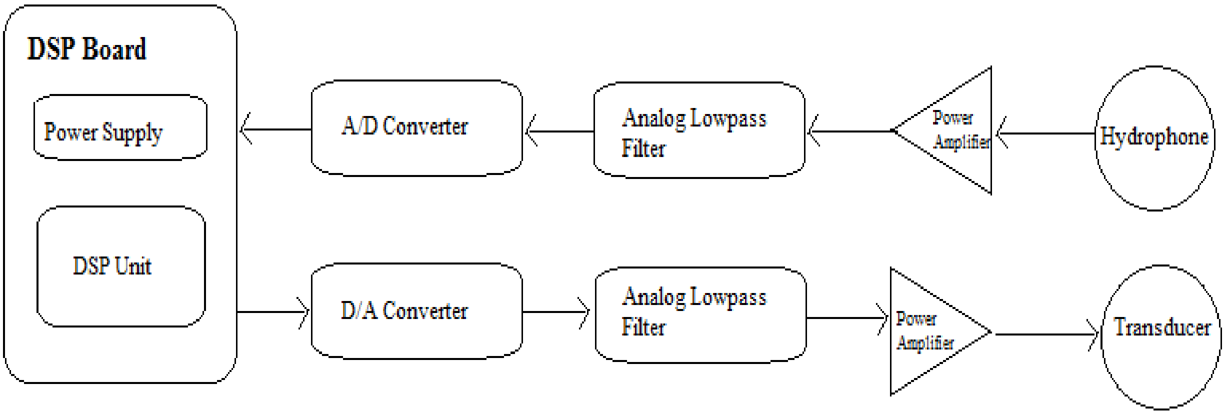


Figure 8.5: Functional schematic of a combined transmitter and receiver circuit.

8.7 DSP Unit

DSP stands for digital signal processor. This is a specifically designed processor fulfilling the purpose of signal processing. Among other things, DSP has following specific properties:

• The Harvard-architecture is used to implement the processor, in which the instruction memory is separated from the data memory. With that, simultaneous access of the instruction memory and data memory is possible and it even makes possible the multiple data memory access during the execution of one instruction.

• For data input/output, exclusive synchronous serial interfaces are available. This allows the reception and transmission of the data without causing interruptions in the processor's mathematical operations.

• There exists a multiply-accumulate (MAC) instruction which empowers parallel addition and multiplication amid one instruction. MAC instruction can be expressed as a’ = a + bc. While calculating convolutions and the FFT conversions, it is very helpful.

• It contains address generation units (AGU) which empower the automatic address generation amid data fetch/store operations. This can be utilized for instance to accelerate array handling as the handling of an array needs fetching values from succeeding memory locations. Furthermore, in FFT calculations a special address generation is used that considers the bits in the registers as they were in inverted order before augmenting the register value.

• To store intermediate values, an immense number of registers are present. E.g. for time delays implementation, this is required.

To implement DSPs, one of the fixed or floating point architecture can be utilized. The fixed point architectures use the bit representation of the values to code them. Thus they can be implemented easily and consume less power. But the fixed point DSPs may have the problem of overflow occurrence if the quantity of bits to represent a value surpasses the processor’s register size. In the floating point architectures values are symbolized using $mx2^e$ with **m** the mantissa and **e** the exponent, so they are more complex. Because of that, floating point processors experience the ill effects of higher power consumption, though they have a tremendous dynamic range. Accordingly from a user perspective- the choice must be made between algorithm complexities that is higher with fixed point architectures and power consumption that is higher with floating point architectures.

Chapter 9

9.1 MI CHANNEL CHARACTERISTICS

System Modeling

Underwater Magnetic induction technique operate very short range typically a few meters. It communicates by tight coupling, low power, and non-propagating magnetic field between devices. A transmitter coil is transmitting modulated signal which is measure by receiver coil. Underwater MI communication system is show in fig. 9.1. We assume that the underwater transmitter and underwater receiver which are made by magnetic coupled antennas are separated by a distance r. For MI communication analysis, we take help previous paper [8].

We can change dual antenna in the form of two port system as in fig. 9.2.

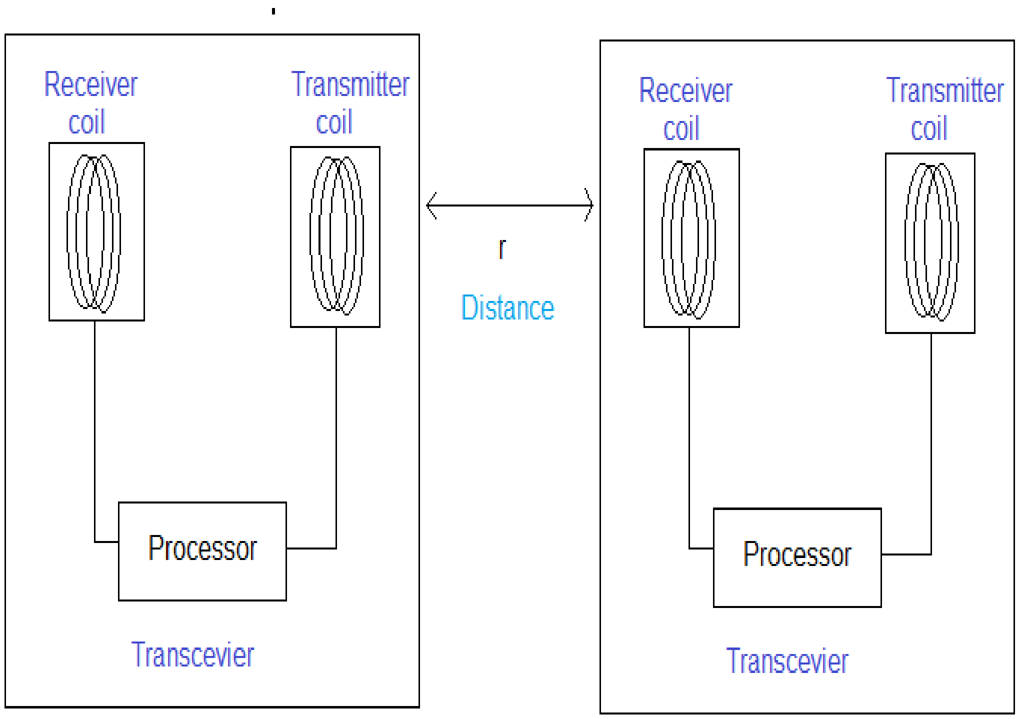


Fig. 9.1.Underwater communication system.

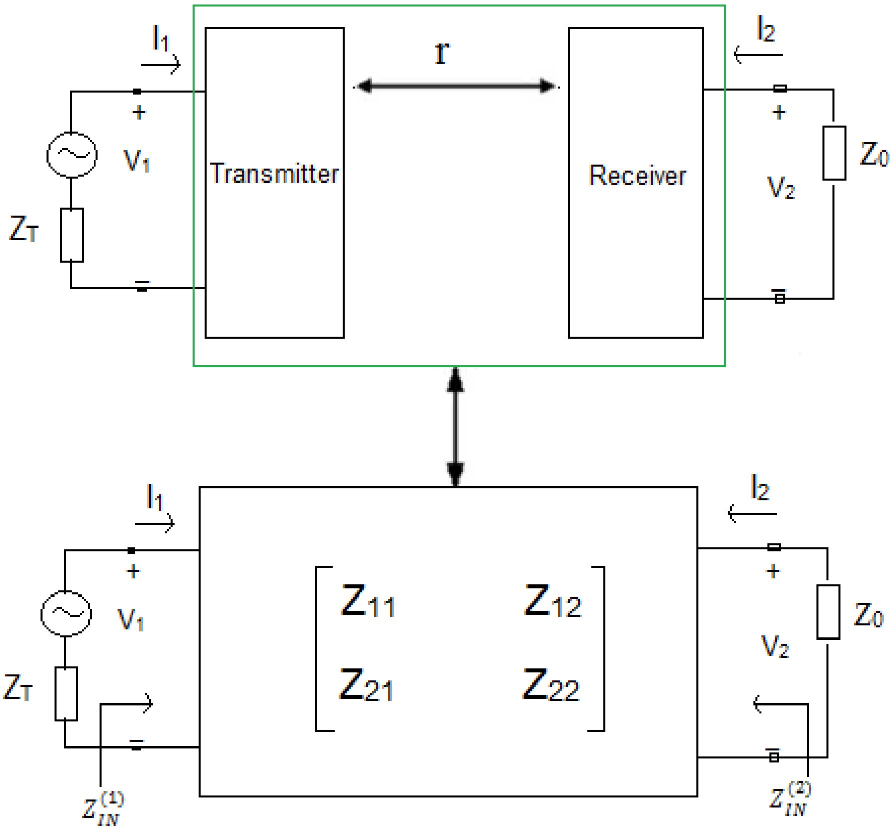


Fig. 9.2. A dual antenna system with equivalent two-port network

Path Loss for MI

Now we derived MI communication path loss. So first we assuming, there are no external losses on the dual antennas. The transmitted and received powers are calculated by

$$P_T(r) = Re(V_1 I_1^*) = Re\left(Z_{11} - \frac{Z_{12}^2}{Z_L+Z_{22}}\right)|I_1|^2 \quad (9.1)$$

$$P_R(r) = |I_2|^2 Re(Z_0) = Re(Z_0) \frac{|Z_{12}|^2}{|Z_L+Z_{22}|^2} |I_1|^2 \quad (9.2)$$

Now we can say that both powers decrease with respect to the distance. In MI system power is not lost but it is not transmitted. So that we redefined transmitted power as follow:

$$P_T(r_0) = Re(Z_{11})|I|^2 \quad (9.3)$$

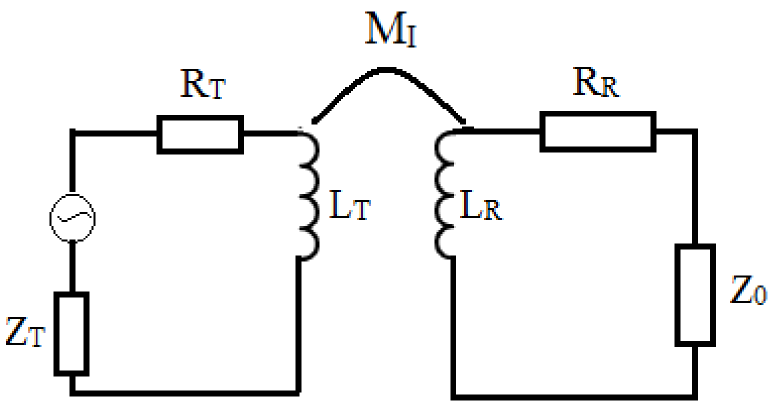


Fig. 9.3.Near-field transmission model.

where $r_0$is a very small distance and P_{TX} (r_0) is power for distance r_0. So that the path loss P_L is defined as:

$$P_L = -10 \log \frac{P_{RX}(r)}{P_{TX}(r_0)}$$

$$= -10 \log \frac{R_0(R_{12}^2+X_{12}^2)}{R_{11}[(R_0+R_{22})^2+(X_0+X_{22})^2]} \quad (9.4)$$

Now we see that the received power on the port 2 is depending on load impedance Z_L. So we need to take load impedance is equal to the complex conjugate of input impedance for maximize the received power i.e.,

$$Z_0 = \overline{Z_{IN}^{(2)}} \quad (9.5)$$

$Z_{IN}^{(2)}$ is also write as:

$$Z_{IN}^{(2)} = \frac{V_2}{I_2} = Z_{22} - \frac{Z_{12}^2}{Z_T + Z_{11}} \tag{9.6}$$

Fig. 9.3 shows the equivalent circuit of two coupled coils. Inductance of transmitter and receiver are $L_T$and L_R . Resistances of coil R_T and R_R are transmitter and receiver antennas. M is the mutual inductance. The mutual impedance (Z_{12},Z_{21}) and self- impedance (Z_{11},Z_{22}) are given as:

$$Z_{11} = R_T + j\omega L_T \tag{9.7}$$

$$Z_{22} = R_R + j\omega L_R \tag{9.8}$$

$$Z_{12} = Z_{21} = j\omega M_I \tag{9.9}$$

where $\omega = 2\pi f$ is the transmitting signal angular frequency, the self-inductances of both coil are $L_T$and L_R, and the mutual inductance represents by M_I.

The mutual inductance M_I between two coils can be calculated as:

$$M_I = \frac{\mu .\ N_T .\ a_T^2 .\ N_R . a_R^2 .\ \pi}{2\sqrt{(a_T^2 + r^2)^3}} \tag{9.10}$$

where μ is the magnetic permeability, $\mu=\mu_0\mu_r$, magnetic constant $\mu_0=4\pi x 10^{-7}$ H/m and relative permeability of water $\mu_r = 1$. The radius of the transmitting coil and receiving coil are $a_T$and $a_R$respectively. Number of turns of the transmitting coil and receiving coil are N_T and N_R respectively, and r is the distance between the coils (from the center of the coils in the x -direction).

Now the self-inductance of a coil can be determine by:

$$L_i = \frac{\mu \,.\, N^2 .\, A}{l} \qquad (9.11)$$

where the number of turns of solenoid is N, A is area of the cross-sectional of the wire where the wire's diameter is d and *l* is the length of the coil

The resistance of coil is given by

$$R_i = \frac{N \,.\, 2\pi a \,.\rho_o}{A} \qquad (9.12)$$

where a is the coil radius and electrical resistivity is ρ_o .

At the receiver , the load impedance can be obtain by using (6)–(9) in (5) and Assuming $Z_T \approx 0$.

$$Z_0 = R_R + \frac{\omega^2 M_I^2 R_R}{R_T^2 + \omega^2 L_T^2} + j\left(\frac{\omega^3 M_I^2 L_T}{R_T^2 + \omega^2 L_T^2} - \omega L_R\right) \qquad (9.13)$$

The path loss P_L is obtained

$$P_{LMI} = -\,10 \log \frac{R_0 \omega^2 M_I^2}{R_T (R_0 + R_R)^2 + R_T (X_0 + \omega L_R)^2} \qquad (9.14)$$

Due to eddy currents, there are attenuation. So that in sea water, we should be work at low frequencies of the magnetic antennas. In the salt water, the main cause of eddy currents is AC magnetic field flow. The attenuation defined as:

$$\alpha_o = \frac{1}{\delta} = \sqrt{\pi f \mu \sigma} \qquad (9.15)$$

where σ is the sea water electrical conductivity.

Therefore

$$P_{L\alpha o} = 20\log(e^{\alpha o r}) = 8.69\ \alpha_o r \tag{9.16}$$

So that the total path loss ,P_L in under water,P_{LSW} is given as

$$P_{LSW} = P_{LMI} + P_{L\alpha o} \tag{9.17}$$

Where P_{LSW} in dB.

9.2 EM WAVES PATH LOSS

Further, the Friis formula is used to determine path loss for EM waves. The received signal power is in free space as follows (logarithmic equation)[9] :

$$P_R = P_T + G_T + G_R - PL_{EM\text{-}00} \tag{9.18}$$

where P_R is transmitting power, G_T and G_R are gains of transmitting antenna and receiving antenna and $PL_{EM\text{-}00}$ is the free space path loss in dB. Which is follow as :

$$PL_{EM\text{-}00} = 32.4 + 20\log(r) + 20\log(f) \tag{19}$$

where r is the distance from transmitter to receiver in kilometer and f is the operating frequency in MHz.

Now we take a linear polarized electromagnetic wave which is propagating in the z direction. It can be written in term of electric field strength E_{x1} as

$$E_{x1}=E_0 e^{(j\omega t-\gamma z)} \tag{9.20}$$

Where$\omega = 2\pi f$ is the angular frequency of the transmitting signal and γ represent propagation constant. In further γ is divided in term of real part (α_o) and imaginary part (β_o). Where α_o is attenuation and β_o is phase constant.

For underwater wireless communication, the Friis equation (9.18) is written as :

$$P_R = P_T + G_T + G_R - PL_{EM1} \tag{9.21}$$

Where

$$PL_{EM1} = PL_{EM\text{-}00} + PL_{EM\text{-}UWC} \tag{9.22}$$

This is the total path loss underwater communication, which is combination of the path loss in free space $PL_{EM\text{-}00}$ and the path loss due to the underwater communication $PL_{EM\text{-}UWC}$. $PL_{EM\text{-}UWC}$ is written in dB as

$$PL_{EM\text{-}UWC} = PL_{\alpha o} + PL_{\beta o} \tag{9.23}$$

where $PL_{\alpha o}$ is the path loss due to attenuation with attenuation constant α_o and $PL_{\beta o} = 20\log(\lambda_0 /\lambda)$ is the attenuation loss caused by the difference of the wavelength of the underwater signal.

$PL_{\alpha o}$ can be written from equation (9.20). the path loss due to attenuation for EM wave in the underwater channel in dB)

$$PL_{\alpha o} = 20\log(e^{\alpha o r}) = 8.69\ \alpha_o r \tag{9.24}$$

Where r is the distance in meters and α_o is the attenuation constant inNp/m.$PL_{\beta o}$ is written in dB as follows :

$$PL_{\beta o} = 154 - 20\log(f) + 20\log(\beta_o) \tag{9.25}$$

Consequently, using these equations the total path loss of an underwater EM wave, PL_{EM1}, is obtained as

$$PL_{EM1} = 6.4 + 20\log(r) + 20\log(\beta_o) + 8.69\,\alpha_o\,r \qquad (9.26)$$

Where r in meter.

Chapter 10

MIMO Systems overview

Multiple-Input Multiple-Output (MIMO) is a methodology in which several antennas are utilized at the both ends of transmission usually in receiver and transmitter two or more antennas are outfitted. MIMO permits to enhance the bit rate without any need of increasing neither the bandwidth nor transmitter power per antenna. System's spatial diversity and multiplexing defines these systems, named after the number of antennas used at the transmitter and receiver ends of the system.

Spatial Multiplexing (SM) can be explained as: transmission of multiple bit streams over two or more antennas. There are two kinds of SM methods to be considered, V-BLAST (used at Bell Laboratories for the very first time) and the Space-Time Code (at receiver side, for better detection it uses orthogonal bit streams.

Spatial Diversity (SD) is founded over the structure redundancy because the transmitted signal from one antenna is caught by all other antennas. Hence SD enhances the channel capacity (while SM decreases it). If MIMO channel puts a few conditions then the true sent information can be retrieved by system from received signals.

10.1 Forms of MIMO

Figure 10.1 shows the various forms that a MIMO system can take. Latest standards, e.g. WiMAX or the IEEE 802.11, use SD that offers appreciable outcomes in terms of the bit rate and capacity. But there are many disadvantages of this technique and in the most of the standards the quantity of transmitters is often kept limited to 4. This is because of two noticeable reasons. First: because one antenna has to be kept away from another so that received signals remain uncorrelated with the others and more no. of antennas deployment increases the transmitter or receiver sizes. Second: MIMO channel and the over-multiplexing.

Single-Input Single-Output

This case should not be considered as an innovation scheme. This one serves as a conventional communication technique consisting only one transmitter and only one receiver. Yet its importance is not less in light of the fact that at present this architecture is still used by numerous systems out there.

For proper demeanor MIMO require s multipath propagation to form a specific number of independent and uncorrelated channels. Many times, both of the receiver and transmitter have a line of sight (LOS) and little SD can be created.

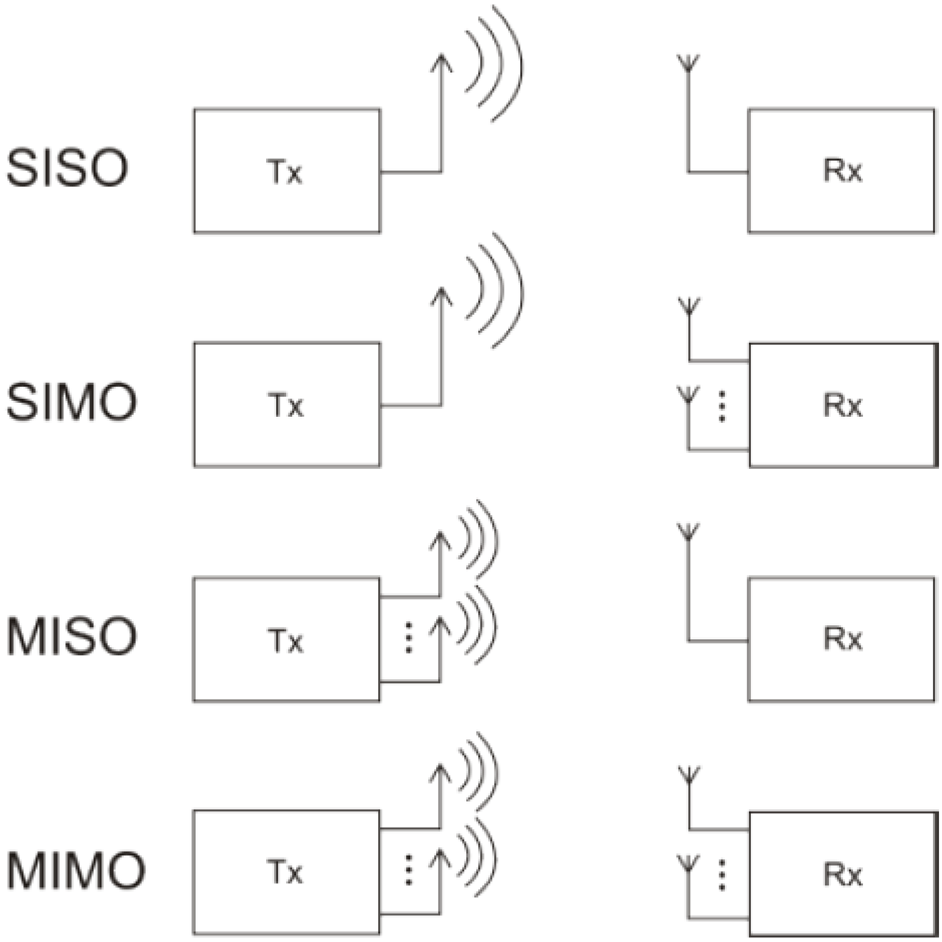


Figure 10.1 Different forms of MIMO and their configuration

Single-Input Multiple-Output

In this scenario, multiple receivers are utilized and all of them receive the signal transmitted from a single transmitter. Here, MRC or Maximal Ratio Combining can be performed at the side of receiver, thus battling with strong multipath blurs. The mixing of received signals is performed, which maximizes the resultant SNR, as well as, it is optimal for the AWGN channels.

Multiple-Input Single Output

Special coding is required in the transmitters for such kind of degenerated form. To make the signal detection possible at the receiver side, the multiple transmitters used have to transmit orthogonal streams. Though, such systems are hardly usable, where the number of transmitters used is higher than the receivers.

Multiple-Input Multiple-Output

The general form of SD systems is MIMO. Although MIMO systems have the benefits of SIMO and MISO configurations, but the system complexity additionally increases. These days, propelled forms of MIMO are being evolved; mainly utilizing multiuser, yet this document will allude to the classical methodology.

10.2 The MIMO channel

A mathematical approach is required to comprehend MIMO's principles. As figure 10.2 shows, every transmitter antenna adds to the received signals in every receiver. We will consider a flat fading, narrow band channel for a channel model and the system expressions will be written in the frequency domain.

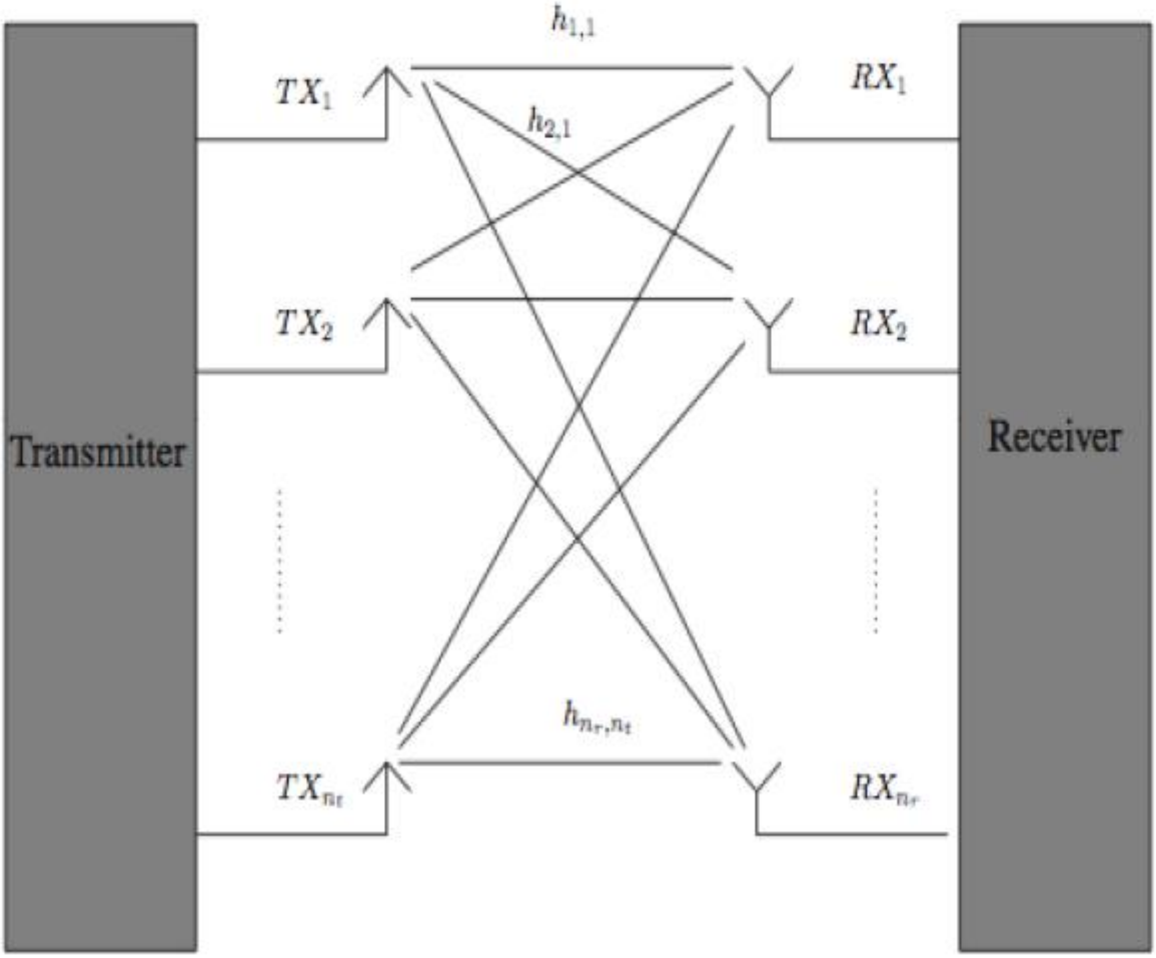


Figure 10.2 Simplified scheme of the MIMO channel

The received signal for an antenna, for instance, is being expressed as:

$$y_{f_o}^{r} = \sum_{t=1}^{M_t} H_{f_o}^{t_r}\, d^t + w_k^r \mathrm{r} = [1 \ldots M_r] \tag{10.1}$$

Here **t** and **r** depicts the transmitter and receiver index respectively and $\mathbf{f_0}$ depicts the frequency of operation. For notation simplicity, time index has been dropped. $\mathbf{M_t}$ and $\mathbf{M_r}$ represent the number of transmitters and receivers respectively used in the system. We will rewrite the previously written equation in the matrix notation for clarity. Defining the vectors:

$$y_{f_o} = [\, y_{f_0}^{1}, \ldots\ldots, y_{f_o}^{M_r}] \tag{10.2}$$

$$d = [\, d^{1}, \ldots\ldots, d^{M_r}\,] \tag{10.3}$$

$$w_{f_o} = [\, w_{f_0}^{1}, \ldots\ldots, w_{f_o}^{M_r}] \tag{10.4}$$

$$\sim H_{f_0} = \begin{bmatrix} H_{f_0}^{1,1} & \cdots & H_{f_0}^{M_t,1} \\ \vdots & \ddots & \vdots \\ H_{f_0}^{1,M_r} & \cdots & H_{f_0}^{M_t,M_r} \end{bmatrix} \tag{10.5}$$

Now, the expression given above in equation (10.1) becomes:

$$y_{f_o} = \sim H_{f_0} d + w_{f_0} \tag{10.6}$$

Once we can express the received signal in a more compact form, analysis of the equation can be done. It is clear from equation (10.6) that each transmitter contributes to all the receivers and that some conditions on the channel matrix $\sim H_{f0}$ will be necessary to demodulate the original signal **d**.

Let's take a closer view at the physical, real life representation of the equation shown above, rather than discussing the demodulation process. As, for SISO systems, Shannon has already done; the same way channel capacity can be computed for MIMO systems also. The basic principles are same, the capacity will be the maximum mutual information between the data before the channel, d and the data received, y.

About the above given equation some considerations are as following:

- If there is a deterministic channel, the value which was expected is not utilized. If there is a random channel, averages are required and the term ergodic capacity is utilized.
- The matrix Rdk shows the correlation between the sent data and fundamentally, on the transmitters, this matrix provides the power allocation.

- Channel capacity is useful only at the transmitter side. Hence, CSI or channel state information is required at the transmitter side.
- If there is no CSI available then no strategies can be performed on power allocations. Then, in each of the antennas same measure of power will be transmitted.
- To maximize the capacity, the methodology to be used depends upon the kind of fading expected for channel. Nakagami, Rician and Rayleigh channels models are utilized in typical situations.

For a MIMO channel, numerous studies have been done by the researchers and specialists. This document will mainly focus on the demodulation strategies that could be applied rather than the statistical characterizations of an underwater acoustic MIMO channel.

10.3 Space Time Coding

Space Time Coding (STC) technique is used in a MIMO link to enhance the reliability. Hoping that FEC or forward error correction at the receiver will retrieve the exact sent data, some redundancy is introduced in the transmitter. STCs can be separated in the two parts:

Space Time Block Codes (STBC) This method is in light of building an arrangement of orthogonal code-words which are sent along the antennas. Here, intricacy of STBC is very less than that of STTCs and the linear operations are required only.

Space Time Trellis Codes (STTC) This technique is much complex than STBC, this sort of codes disperses a trellis code among multiple antennas subsequently providing coding and diversity gain. The receivers depend upon the Viterbi algorithm to decode the information, since the trellis coding method is convolutional, thus expanding the system complexity.

Now, since in STTCs is complexity very much high, in a more detailed manner only STBC will be explained. Alamouti Coding was utilized in the system outfitted in SPACE'08 experiment. Where, in each of the time block, M_t symbols totally are received. These symbols can be expressed in a matrix forming a space time symbol which will define the coding type:

$$D = \begin{bmatrix} d_0^1 & \cdots & d_{N-1}^1 \\ \vdots & \ddots & \vdots \\ d_0^{M_t} & \cdots & d_{N-1}^{M_t} \end{bmatrix} \quad (10.7)$$

Where d_{ij} gives the symbol sentat the time instant **j**, on the transmitter **i**. To make the set of code-words i.e. d_{ij}, 8i orthogonal among each other, is the primary purpose of the coding. The linear, simple and optimal decoding is outcome of this at the receiver. Like many other coding techniques, the system has to sacrifice the data rate because of redundancy. The rate of the code is given by the number of encoded symbols in one time block (note that many transmitters can send the same symbol) divided by the number of time slots necessary to complete the space-block symbol, r = (number of symbols)/N. With a matrix of 2X2, the Alamouti's code is the simplest among such codes without any bit rate loss since its rate is 1 only. For this code matrix is given below:

$$D = \begin{bmatrix} d_1 & d_2 \\ -d_2^* & d_1^* \end{bmatrix} \quad (10.8)$$

We can clearly see that matrix columns are essentially orthogonal. Using optimal decoding technique, the BER of the Alamouti's code, at the receiver side, is equal to a MRC consisting 2 symbols over M_r number of receivers. This is a result of the perfect orthogonally between the symbols after receive processing: there are two copies of each symbol transmitted and M_r copies received. Most of the likelihood decoding is done with the main need of linear operations, in this way keeping up the system's complexity low. Considering that the symbols cannot be recovered after 2 slots of time (N for a regular STBC) therefore introducing a little time delay. In spite of the fact that the remarked plan was for STBCs, the STTCs are sturdier against errors, however the receiver complexity is higher because dynamic programming algorithms are required on the receivers for exact data detection. In both ways, the use of STC allows MIMO systems to work with higher number of transmitters than receivers.

10.4 OFDM Signals

OFDM is nothing but a FDM or the technique of frequency-division multiplexing, which is used as a digital multicarrier modulation approach. Here data is transmitted by using a set of independent orthogonal subcarriers. And the total BW is divided into multiple narrowband channels, in such a manner that no one channel is interfering with another.

System

Figure 10.3 represents an OFDM system below, which consists of transmitter and receiver. First, (assuming that coding and interleaving have already been performed) i/p serial bit stream is divided into **K** number of bit's streams; here **K** taken as the no. of system subcarriers. After performing the mapping of the bits, with some proper modulation like generic QAM, into the symbol's space some of the subcarriers are reserved so that pilot-symbols can be inserted. After that modulation for every band is performed with a chosen particular frequency and then guard intervals are inserted and the up-conversion is performed. At last, the signal is sent and transmitted through channel. Now, at receiver side, dual process is performed for retrieving original sequence of bits.

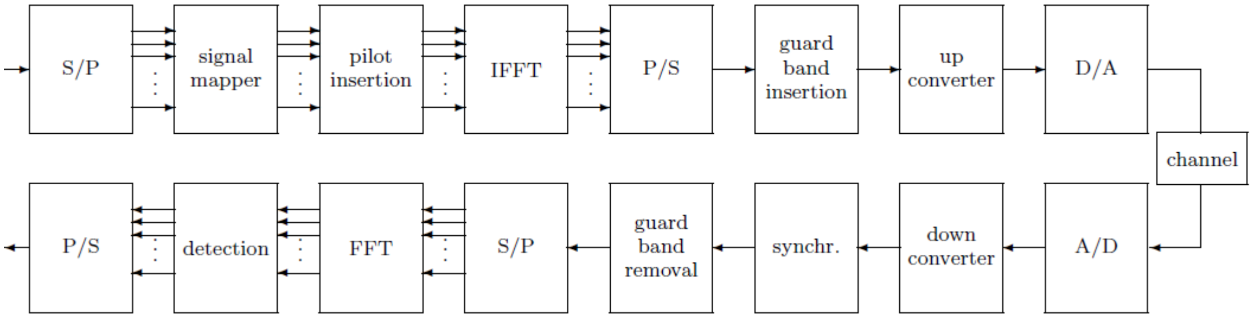


Figure 10.3 Typical block diagram of an OFDM system

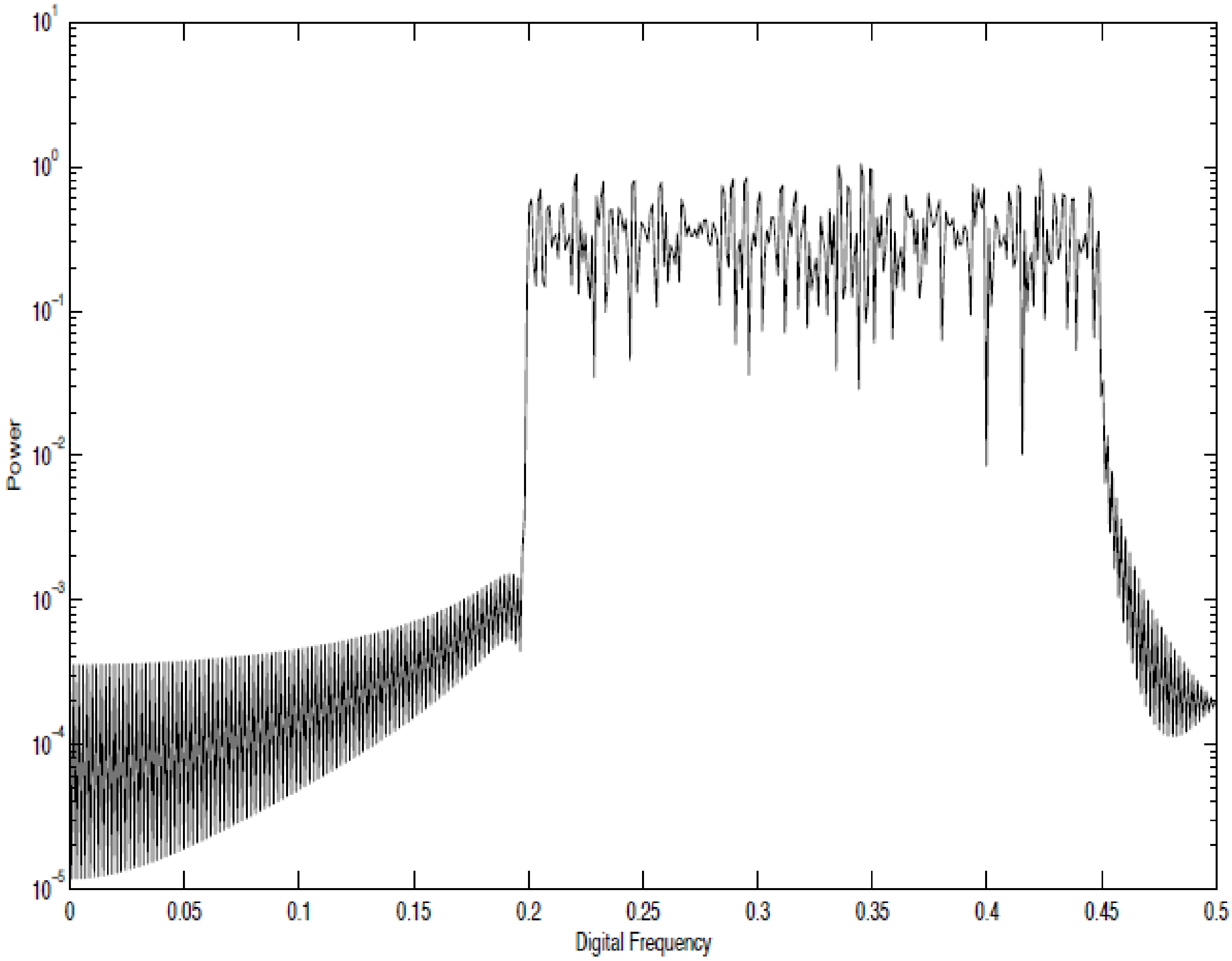


Figure 10.4 Digital Frequency

Coding and Interleaving

To keep the BER probability low and/or to get a communication free from errors, interleaving and coding methods are required so that the incorrect detections can be reduced. Usually, when utilizing a OFDM modulation methodology, the wideband system is considered. Since frequency response, for every sub-band, of the channel is not equivalent, there can be parts of the spectrum which are more error prone due to their high attenuation and low SNR ratio.

Coding

Alike other communication systems, some redundancy is added to the useful bits to be sent. The main purpose of channel coding is to protect data transmitted through the channel in the noisy environment. If the coding, with the bit stream, is properly dimensioned then it is possible to retrieve the original error-free bit sequence with the redundancy added. Thus more redundancy, with respect to the SNR ratio, has to be applied. A theoretical limit was set by Shannon for the rate of communication.

$$C = BW*\log_2(SNR+1) \text{ bps} \tag{10.9}$$

The channel capacity **C** is thus directly proportional to the BW used. At the time of system designing the coding applied has to obey this limit, if prior knowledge of SNR is available. Else error may appear at the receiver side.

Mostly used two kinds of coding method in actual system are: convolutional coding (CC) and block coding (BC). The primary distinction between them is: output of the former is formed on the basis of the bit operations while the latter changes blocks of bits into properly designed code words. To decode a BC, received bits are allotted the nearest codeword and after that original bits are recovered. Viterbi algorithm is required to decode a CC.

Interleaving

Interleaving does not assist to diminish the no. of errors yet to actually make them appear to be random. These errors normally appear in burst in communication. Due to these errors several bits are overwritten in a row, thus a conventional error correction methodology with which errors' more uniform distribution is possible, can be overpowered. The primary motivation behind interleaving is to change errors' probability distribution's function (pdf) and make errors to be seen independent from each other.

Two kinds of interleaving methods are present in OFDM: the frequency interleaving (FI) and the time interleaving (TI). FI is possible because transmission of information is done by using parallel and independent subcarriers, and TI is possible because of the mutual independence of each sent block.

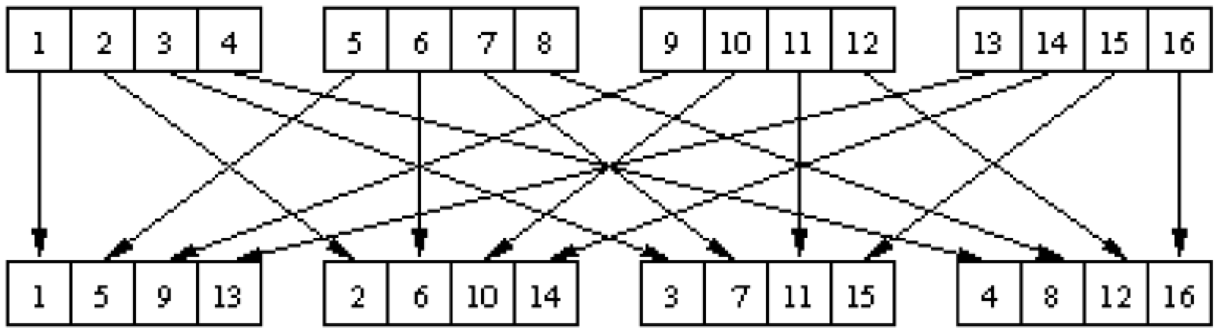


Figure 10.5 Example of time interleaving with the original and the interleaved data (top and bottom respectively)

The main disadvantage of TI is the introduction of a delay on the detection, yet as a benefit it keeps safe the information from the suddenly forced errors. FI is utilizable while dealing with an inflate channel FR, hence errors are also distributed more uniformly in OFDM without any delay expenses.

Advantages, Drawbacks and System Design

Advantages

- Can effortlessly adjust to severe channel conditions with no complex equalization
- Sturdy against Inter-symbol Interference (ISI) and fading because of multipath propagation
- Sturdy against narrow-band co-channel interference
- Spectral efficiency is high
- Using FFT, implementation is efficient
- Less sensitivity towards time synchronization error

Drawbacks

- Show sensitivity to Doppler shift.
- Show sensitivity to frequency synchronization.
- Loss of efficiency because of Guard intervals/cyclic prefixes.
- High peak-to-average-power ratio (PAPR), expecting a linear transmitter circuitry and experiences a low power efficiency.

Albeit there are some critical drawbacks, OFDM is the best procedure to achieve high rate UW communication.

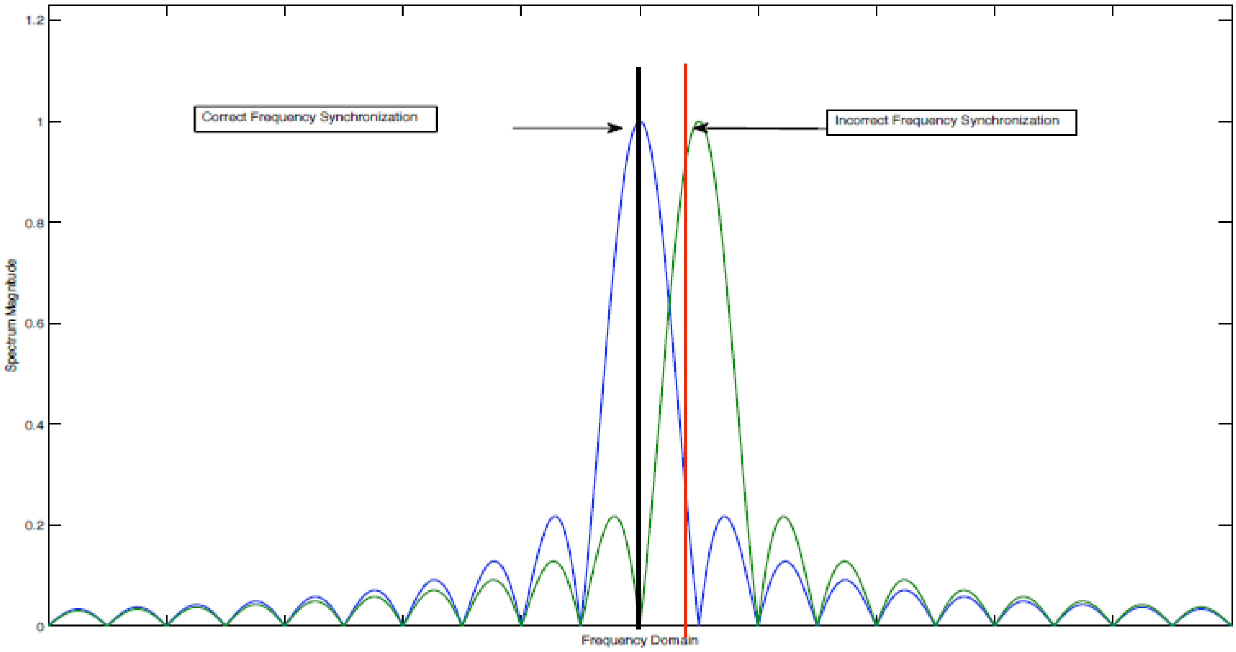


Figure 10.6 Frequency synchronization in OFDM systems

Chapter 11

SIMULATION ANDRESULTS

In general value of sea water electrical conductivity is 4.0 S/m. But it does not remain constant,it changes with time. the value of electrical conductivity varies from 3.62 S/m to 4.46 S/m. the path loss directly related to the conductivity, so that our path loss changes with the value of the electrical conductivity. Thus the path loss changes daily as well as monthly.

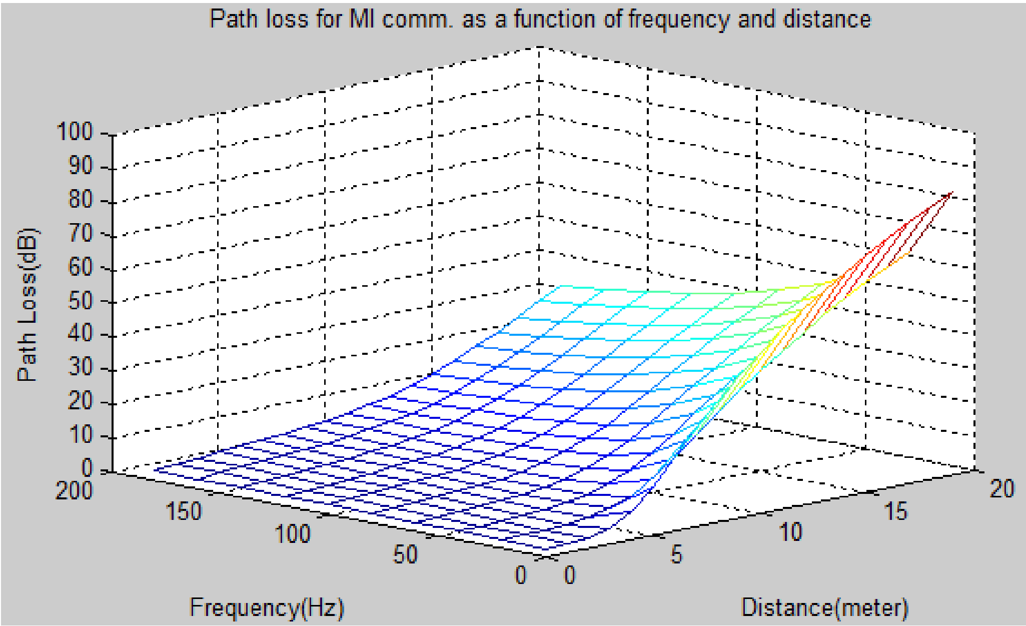


Fig. 11.1. Path loss of MI communication changing with the distance and frequency

In fig. 11.1 the path loss of Magnetic induction system is changing with the frequency and the distance between transmitting coil and receiving coil. We kept the number of turns of transmitting coil and receiving coil to 1500 and the radius of coils is 1.5m. We observed that our path loss increases with increase in the distance between transmitting coil and receiving coil. We also observed that path loss decreases with increase in the frequency. In Magnetic induction system, minimum path loss at the distance of 10 meter is received at a frequency of 140 Hz.

In fig. 11.2 the variation in the path loss by MI technique in a year for sea water is shown. This figure shows that electrical conductivity of sea water is changing every day due to variation in temperature and other atmospheric factors. The transmission range of communication is 10m and takes frequency 140Hz. Radius of coils is 1.5m and the number of turns of transmitting coil and receiving coil are 1500. Than we compared the path loss of two consecutive year and the different values of path loss occurred due to changing sea water electrical conductivity. The average path loss is minimum between January to march.

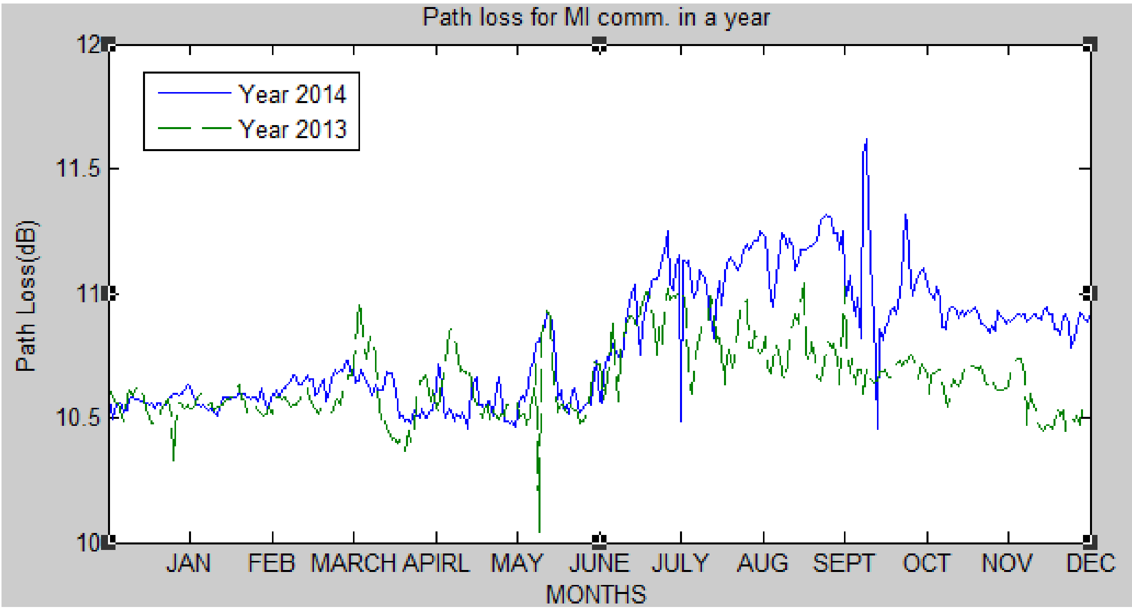


Fig. 11.2. Path loss of Magnetic induction system in a year with changing conductivity

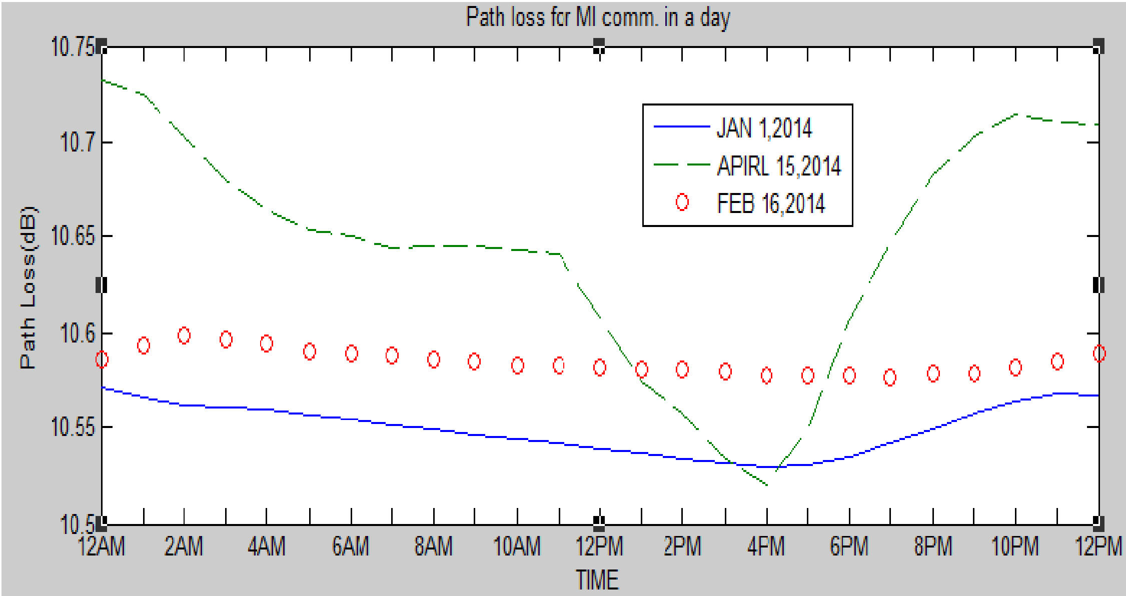


Fig. 11.3. Path loss of magnetic induction system in a day with changing conductivity

In fig . 11.3 the variation in the path loss by MI technique in a day for sea water is shown. The range of transmission is 10 m, frequency is kept at 140 Hz, the number of turns of transmitting coil and receiving coil are 1500. Coil radius is 1.5 meter. We compared the path loss of three days. The path loss occurred is minimum between 2PM to 6PM in a day. So we observe that the communication is better during this time period of the day.

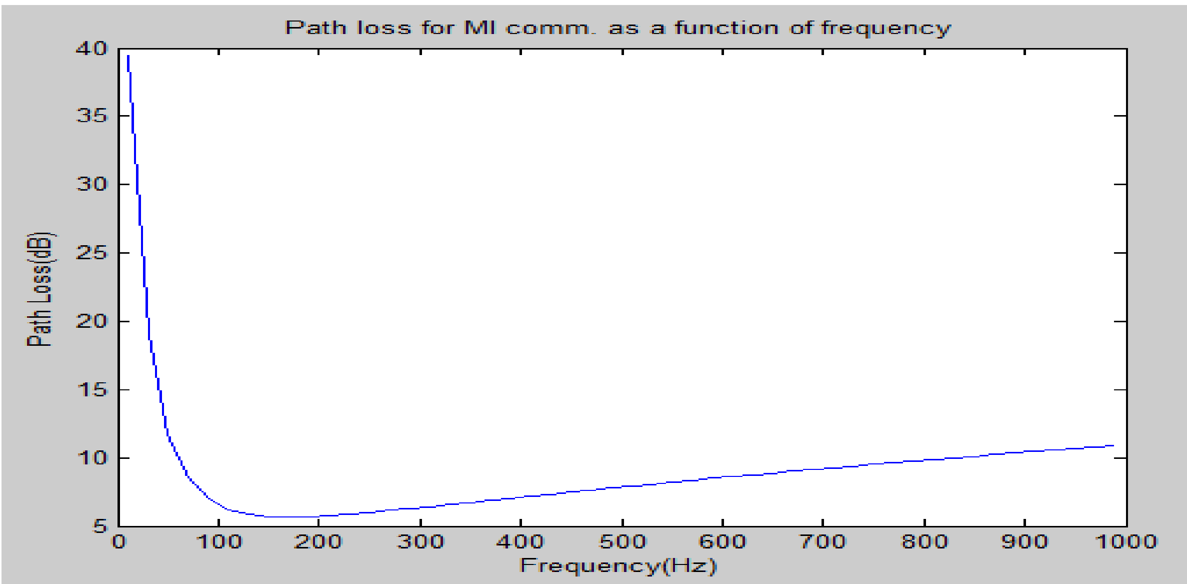
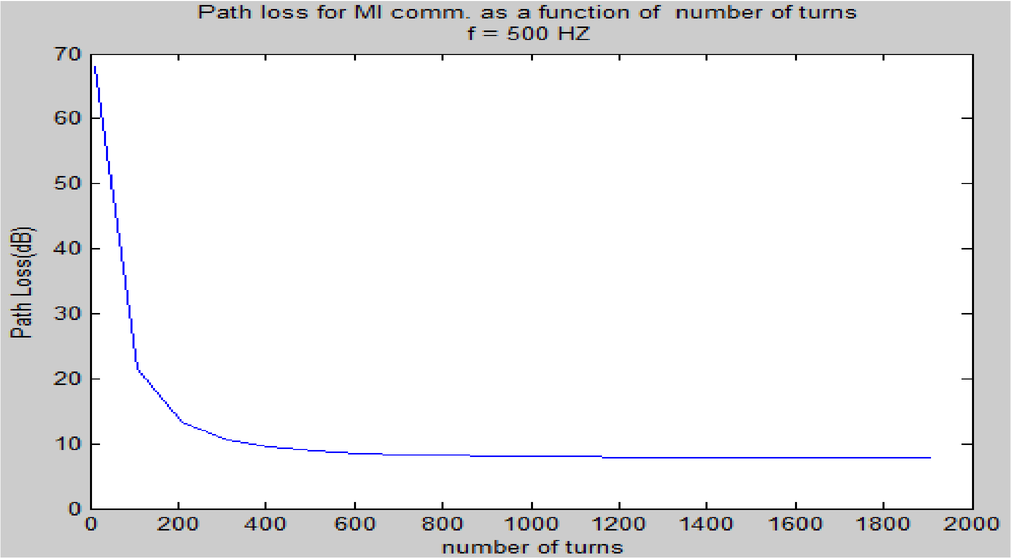


Fig. 11.4. Path loss of Magnetic induction system changing with frequency

In fig. 11.4 the path loss of Magnetic induction system is changing with the frequency between transmitting coil and receiver coil. We kept the no. of coil at 1500 and distance of transmission 10m. At very low frequency path loss is high. When we increase frequency the path loss is reduce. But at high frequency, when we increases frequency our path loss also increase. So we take medium range of operating frequencies. Now we analysis that how the number of turn effect on magnetic induction path loss.



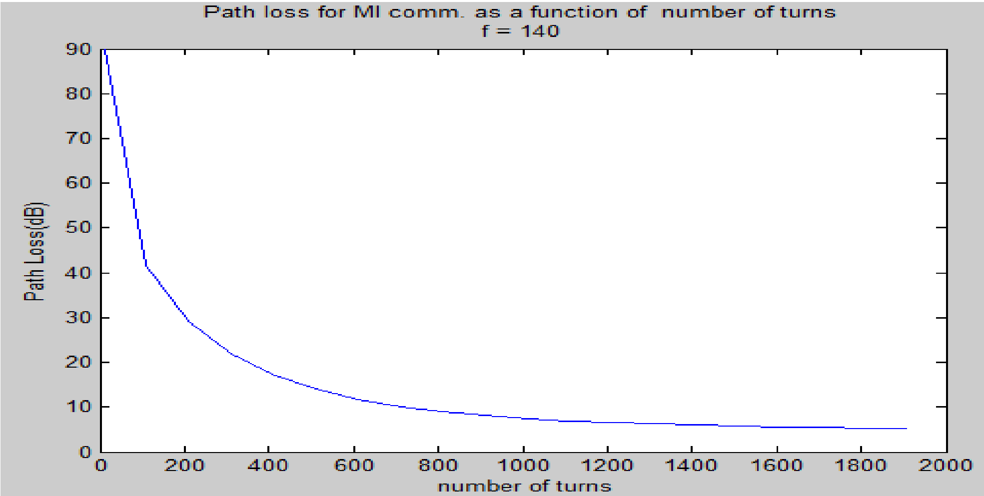


Fig. 11.5. Path loss of Magnetic induction system changing with number of turns

In fig. 11.5 the path loss of Magnetic induction system changing with number of turns of transmitting coil and receiving coil. We kept the operating frequency at 140 Hz and 500 Hz. We take distance of transmission 10m. Now we change the number of turns. When we increase the no. of turns of coil, our path loss is decreases. But we cannot take large number of turns because of size of system is increase. So we fix number of turns at 1500. We also see that when we increase frequency than path loss also increases.

According to theoretical study, the different frequencies have different path loss. We set operating frequency at 140 Hz for MI communication for near-field propagation and it reduce the attenuation due toeddy current in sea water. The eddy current is proportional to frequency in sea water. So that low operating frequencies are recommended for near-field region. Thus propagating wave suffers less attenuation. At low frequencies, we increase distance of MI communication. So that at low frequency path loss will be small.

TABLE I

PARAMETER VALUES

Parameter	New Value	Previous Value
Operating frequency: *f*	140Hz	500Hz
Number of turns (transmit coil): N_T	1500	1000
Number of turns (receiver coil): N_T	1500	1000
Communication distance : r	10 m	4.5m
Radius of transmitter coil: a_T	1.5m	1.5m
Radius of receiver coil: a_R	1.5m	1.5m
Length (solenoid):*l*	6m	6m
Electrical resistivity of copper: ρ	0.01724 ohm*mm^2/m	0.01724 ohm*mm^2/m
Diameter of the copper wire :d	1.45 mm (AWG15)	1.45 mm (AWG15)
Cross-sectional area for a copper wire of 1.45mm:A	1.65 mm^2	1.65 mm^2

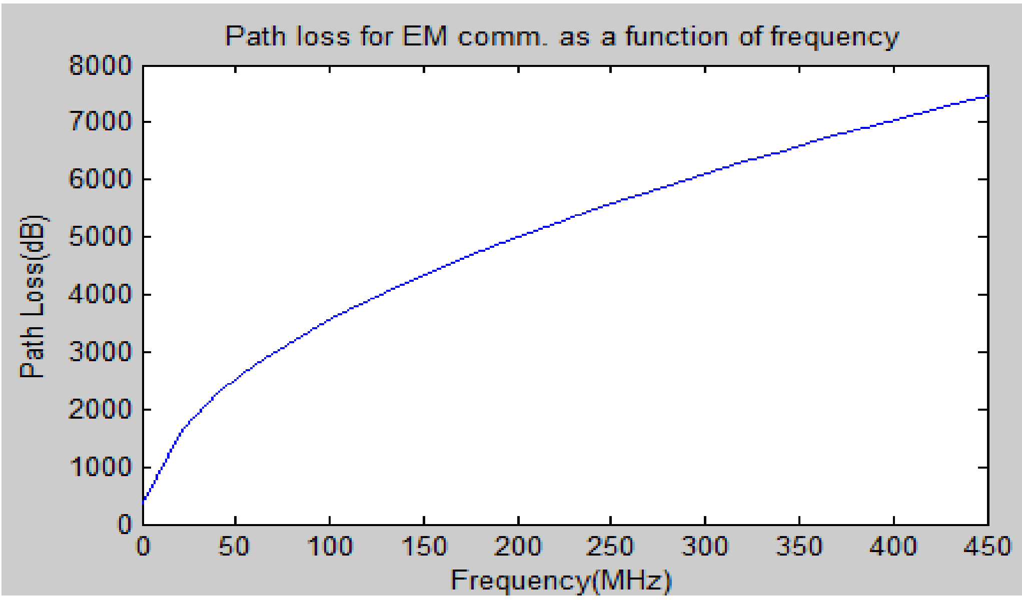


Fig. 11.6. EM wave communication path loss as a function of frequency

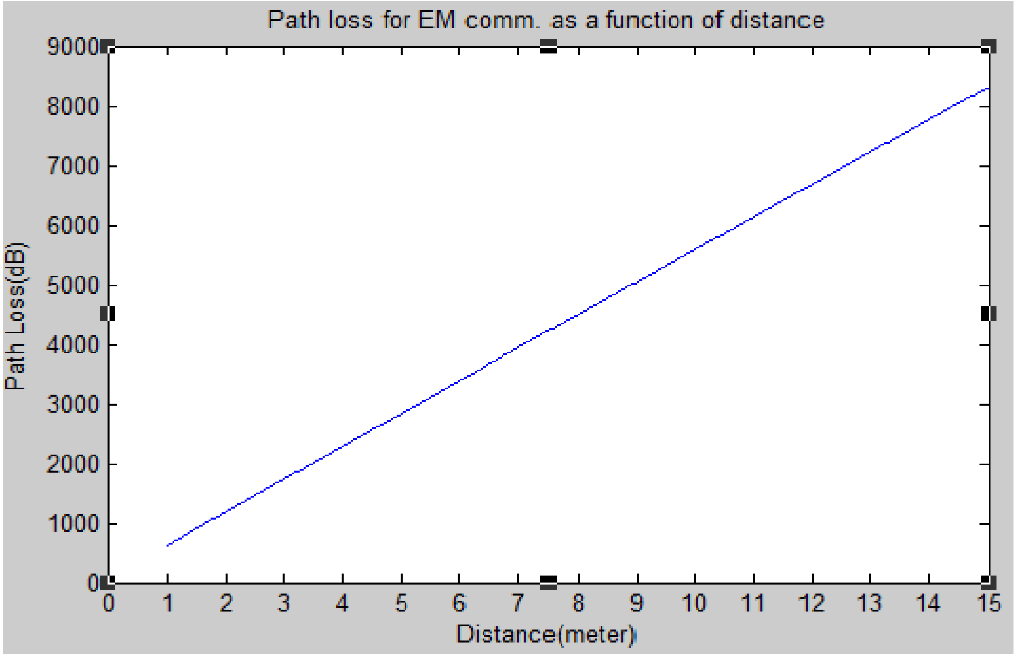


Fig. 11.7. Path loss for EM comm. as a function of distance

In sea water, value of α_o and β_o are calculated by [13] for EM wave propagation. In fig. 11.6 show variation of path loss for EM wave communication with respect to frequency. For EM wave propagation, we take the distance of transmitter and receiver 10 meter. The relative permittivity of sea water is ε_r=18. The electric conductivity of sea water higher than fresh water because of sea water is high lossy medium. In fig. 11.6, we show the operating frequency of sea water in band 1-501 MHz. So that we use high frequency for EM wave communication.

In fig. 11.7 variation of path loss for EM wave propagation as a function of distance. We take operating frequency 250 MHz. In EM wave communication path loss is linearly increase with distance. The path loss of EM communication is higher than the path loss of MI communication. The range of transmission is 5 m for EM propagation. It is also consider the solutions for the dielectric band ($\sigma/\omega << \varepsilon$) and conduction band ($\sigma/\omega >> \varepsilon$).

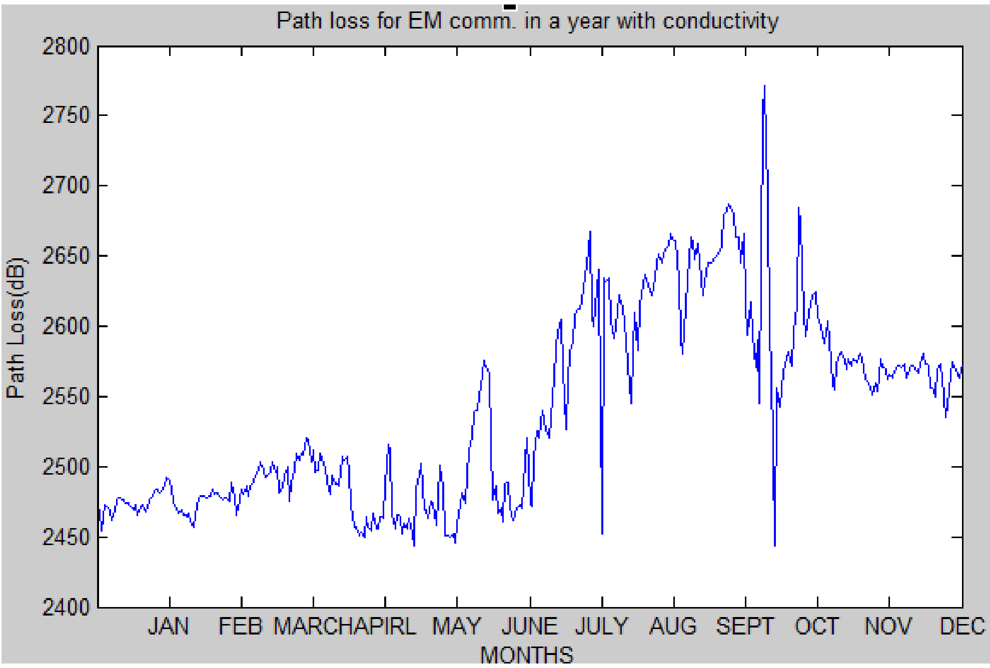


Fig. 11.8. Path loss for EM comm. in a year with changing conductivity

In fig. 11.8 show that Electromagnetic wave communication path loss in a year. The electric conductivity of sea water is not constant due to the variation in temperature and pressure. So that our path loss changes with conductivity. The path loss in august to October is very high. The average minimum path loss is obtain in month of January to march. So we observe that the communication is better during these months.

Chapter 12

CONCLUSION

In underwater wireless communication, EM wave have been three major problems: high path loss, channel fading, and large antenna size. MI technique overcomes these three problems. In this paper we studied MI communication channel theoretically and numerically. The distance between the transmitter coil and receiver coil is actually the range of transmitted signal. The path loss decreases with the increase in number of turns and increase in frequency. For near-field region we select low operating frequency in MI communication.

We also observed the variation of path loss in a year by change of electrical conductivity. The path loss occurred is minimum between 2PM to 6PM in day. The average path loss is minimum between January to march.

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