

**Design and Comparison of Modified Circular Bow-Tie Antenna for
Under Water Radio Communication by Optimizing Different
Parameter**

Thesis submitted in the partial fulfillment of requirement for the award of degree of

**Master of Engineering
in
Electronics and Communication Engineering**

**Submitted by
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**Under the guidance of
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ELECTRONICS AND COMMUNICATION ENGINEERING DEPARTMENT

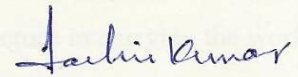
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DECLARATION

I, **Sachin Kumar**, here by certify that the work which is being presented in this thesis entitled “**Design and Comparison of Modified Circular Bow-Tie Antenna for Under Water Communication by Optimizing Different Parameters**” by me in partial fulfillment of the requirements for the award of degree of Master of Engineering in Electronics and Communication Engineering from Thapar University (Deemed University), Patiala, is an authentic record of my own work carried out under the supervision of **Mr. Sukhwinder Kumar**.

The matter presented in this thesis has not been submitted in any other University / Institute for the award of any other degree.


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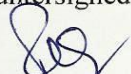
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ABSTRACT

Underwater communication systems have received much attention in recent years. For underwater communication it requires specific techniques and devices which give totally different criteria as compared to the air. In the ocean salts water provide a hindrance for electromagnetic radiation such as normal radio communication because salt water acts as thick conductors. To successfully develop radio wave based communication solutions, antenna becomes an important element regarding the propagation aspects of the electromagnetic waves in liquid. To meet a particular design goal, one possible approach is to study the parameter and geometric configuration of antennas.

Design, simulation and measurement of circular bow-tie antenna, a conventional and modified circular bow-tie antenna are reported in this thesis. The five different parameters (Height, Thickness, Width, Angle and Feeding) of antenna are optimized and analyzed. The software simulation result obtained by study of various parameters for antenna and shows the acceptable characteristics. The return losses and radiation patterns of the antennas are simulated with CST Microwave Studio and the results are compared with measurements, the comparisons show that there is an excellent agreement between the simulations and measurements for different cases. Furthermore, the radiation performance of the modified circular bow-tie antenna is verified, by simulations and measurements. Low operating frequency, small size, ultra-wide band property and low level return-loss make the efficient candidates for excellent alternative to other antenna system used in under water radio communication. The behavior of the antennas determines the electromagnetic wave propagation in water.

In addition, it is also verified that the behavior of the designed antenna will lead to a reduction in return-loss resulting improvements in radiation pattern and overall antenna efficiency.

TABLE OF CONTENTS

Title Page	
No.	
Declaration	2
Acknowledgement	3
Abstract	4
Contents	5
List of figure	8
List of table	10
List of abbreviations	11
Chapter 1: Introduction	12-16
1.1 Need for Under Water Antenna	12
1.1.1 Type of data telemetry	13
1.2 Purpose of design under water antenna	14
1.3 Objectives of thesis	15
1.4 Organization of thesis	15
Chapter 2: Literature Survey	17-32
Chapter 3: Electromagnetic Theory and Propagation of Signal in Water	33-38
3.1 Maxwell's Equations	33
3.2 Electromagnetic Waves	34
3.3 Propagation of Signal in Water	35
3.3.1 Characteristics of Electromagnetic Wave in Water	35
3.3.1.1 Conductivity	36
3.3.1.2 Wavelength	37
3.3.1.3 Intrinsic Impedance	37
3.3.1.4 Permittivity	38

Chapter 4: Antenna Theory	41-52
4.1 Introduction	41
4.2 The Heritzen Dipole	41
4.2.1 The Near-Field Region	42
4.2.2 The Far-Field Region	43
4.3 Antenna Parameter	44
4.3.1 Return Loss	44
4.3.2 Gain	45
4.3.3 Directivity	45
4.3.4 Power	45
4.3.5 Resonant Frequency and Bandwidth	45
4.3.6 Radiation Pattern	46
4.3.7 Polarization	47
4.3.8 Input Impedance	47
4.4 Under Water Antenna	47
4.5 Ultra Wide-Band Antennas	48
4.5.1 DC-to-daylight	48
4.5.2 Multi-narrowband	48
4.5.3 Modern UWB Antenna	49
4.5.4 Frequency independent antennas	49
4.5.5 Horn antennas	50
4.5.6 Reflector antennas	50
4.5.7 Small element antennas	50
4.5.7.1 Solid bow-tie	51
4.6 Characteristics for Underwater Antenna Simulations	51
4.6.1 Software Characteristics	51
4.6.1.1 The Mesh	52
4.6.1.1.1 Lines per wavelength	52
4.6.1.1.2 Refine at PEC / lossy metal edges by factor	52

Chapter 5: Design and Analysis of Under Water Antenna	53-64
5.1 Introduction	53
5.2 Circular Bow-Tie Antenna	53
5.3 Measurement of Antenna Parameters	54
5.3.1 Angle	55
5.3.2 Width	55
5.3.3 Thickness	56
5.3.4 Height	56
5.3.5 Feeding	57
5.3.5.1 Radiation pattern	58
5.4 Final shape with internal isolation	59
5.4.1 Return loss	60
5.4.2 Radiation pattern	61
5.4.3 Directivity	62
5.5 Variations in the medium	64
5.5.1 Conductivity	64
5.5.2 Permittivity	64
Chapter 6: Conclusion and Future Work	66-67
REFERENCES	68-71

LIST OF FIGURES

2.1 The over view and side view of the antenna showing the formation of the coils	18
2.2 The laboratory test tank	26
2.3 The flexible bow-tie antennas Solid bow-tie antenna and Outline bow-tie antenna	28
3.1 A point charge q has a radially symmetric electric field, E	34
3.2 Current carrying wire	34
3.3 Propagating Electromagnetic Wave	35
3.4 Intrinsic impedance on dependence of the conductivity of different frequencies in MHz	39
3.5 Dielectric permittivity and dielectric loss of water between 0°C and 100°C	40
4.1 The field components of radiating elements are often expressed in spherical coordinates (r, θ, ϕ) rather than Cartesian coordinates (x, y, z) .	45
4.2 E-plane and H-plane for a dipole antenna	46
4.3 Linear and Circular Polarization	48
4.4 The transmitter/receiver circular loop antenna and the folded dipole antenna	49
4.5 Spiral Antenna	50
4.6 Horn Antenna	51
4.7 Solid bowtie and form bowtie antenna	52
4.8 The mesh	54
5.1 The Perspective view and Top view of antenna	55
5.2 S_{11} of different Angle	55
5.3 S_{11} of different Width	56
5.4 S_{11} of different Thickness	56
5.5 S_{11} of different Height	57
5.6 (a) Studied parameters of the isolated region	58
5.6 (b) S_{11} of the different sizes of the isolated region	58
5.7 3D Radiation pattern without internal isolation	59
5.8 Antenna with internal isolation	59
5.9 S_{11} With and without internal isolation	60
5.10 3D radiation patterns at 206 MHz	61

5.11 3D radiation patterns at 325 MHz	61
5.12 3D radiation patterns at 582 MHz	62
5.13 Radiation pattern of the gain (in dB) in 2D (XZ plane) at different frequencies	63
5.14 S_{11} of with air-Teflon isolation with $\sigma = 0 S/m$ and $\epsilon = 81$	65
5.15 S_{11} of with air-Teflon isolation in different permittivity	65

LIST OF TABLES

1.1 Advantages and Disadvantage of the different types of data telemetry in the aquatic environment	14
3.1 Electrical conductivity (S/m) of sea water	38
5.1 Tested dimensions (in cm) of the air region to isolate the feeding	57

LIST OF ABBREVIATIONS

ELF	Extremely Low Frequency
V	Very Low Frequency
LF	Low Frequency
EM	Electromagnetic
UWB	Ultra Wide Band
BPDN	Basis Pursuit De-Noising
EFIE	Electric-Field Integral Equation
MOM	Method of Moments
UWSN	Underwater Wireless Sensor Networks
HED	Horizontal Electric Dipole
OFDM	Orthogonal Frequency Division Multiplexing
MIMO	Multiple Input Multiple Output
FDC	Flexible Display Center
DHS	Department of Homeland Security
QHA	Quadrifilar Helical Antenna
EIRP	Effective Isotropically Radiated Power
FCC	Federal Communications Commission
CSTMWS	Computer Simulation Technology Microwave Studio
PEN	Polyethylene Naphthalate

CHAPTER 1

INTRODUCTION

1.1 Need for Under Water Antenna

Antenna is a device which is used to transmit or receive the continuous wave energy radiated oscillates at radio frequencies. Waves are coupled to current in circuits by antennas. To design antenna for underwater communications it is necessary to know which antennas are more suitable for propagation into water. Loop antennas, Long wires and Dipoles have been successfully used underwater at very low frequencies.

The development of underwater antenna should capable for benefit from new data transmission capabilities to enable large file exchanges between autonomous entities and fixed platforms, or interactive video transfers. Current existing solutions are based on different principles with specific limitations. Acoustic waves are often used in this context, but data rate is still limited. Temporary mechanical connections are very efficient but, notably, they have to deal with sealing problems; this results in costly and still failure-prone solutions in deep water. Laser optical systems benefit from wide bandwidths, but necessitate good alignments between the emitter and receiver; they are also sensitive to electromagnetic diffusion due to the impurities in the water. Thus they are costly as well.

The sea water is the medium for radio wave propagation and the range and quality of transmission varies with water conditions, local noise level, and reverberation effects. Submarine can achieve the range more than out to 12,000 meters if the submarines are operating in a sound channel, the communication range may be many kilometers greater than that achieved by ships. Severe reverberation effects and local noise, caused by ship's movement through the water, machinery, screws, etc., can reduce the range to less than half the normal range.

The only reliable and safety communication is the ELF (Extremely Low Frequency) communications systems which make use of a principle in physics where the attenuation of radio waves (electromagnetic waves) from sea water increases with the frequency of the signal. This means that the lower the frequency a radio transmission, the deeper into the ocean a useable signal will travel with feasible sea condition but it is very difficult to construct such type of small ELF antenna which used in both ways. Radio waves in the VLF

(Very Low Frequency) band at frequencies of about 20,000 Hz penetrate sea water to depths less than the ELF waves while maintaining stealth.

1.1.1 Type of data telemetry

There are three different types of data telemetry in the aquatic environment: acoustic, optic and electromagnetic. Table 1 shows the Advantages and Disadvantage of the different technologies. This paper will concentrate on the use of electromagnetic waves as a carrier through-water, through-ice and through-ground.

Table: 1 different types of data telemetry in the aquatic environment [22]

Technology	Advantages	Disadvantage
Acoustic	Proven technology. Range: up to 20 km. Energy efficiency. Precision navigation. Low size and cost	Does not transit water/ air. Poor in shallow water. Adversely affected by water aeration, ambient noise and Unpredictable propagation. Limited bandwidth. Latency. Impact on marine life. Detectable.
Free Space Optical	Ultra-high bandwidth: Gbps. Low cost.	Susceptible to turbidity & particles. Marine fouling on lens faces. Needs tight alignment. Very short range. Difficulty transiting water/air.

<p>Electromagnetic Radio Frequency</p>	<p>Transits water/air boundary. Transits water/seabed boundary. Signal passes through ice. Unaffected by water depth. Unaffected by turbidity/bubbles. Non-line-of-sight performance. Immune to acoustic noise. Immune to marine fouling. Up to 100 Mbps data rates. Frequency agile capability. Unaffected by multi-path. No known effects on marine animals.</p>	<p>Susceptible to electromagnetic interferences. Limited range through water.</p>
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Underwater wireless communications links have up until recently almost exclusively been implemented using acoustic systems. Optical links have proved impractical for many applications for a variety of reasons. Although underwater radio links were experimentally evaluated in the pioneering days of radio they were unable to meet the requirements of the time. In light of modern operational requirements and ready availability of digital communications technology it is now time to re-evaluate the role of electromagnetic signals in the underwater environment.

1.2 Purpose for the design of an Underwater Antenna

Purpose for the design of an underwater antenna is the limited work in that kind of antennas. There are a lot of designs for under water antennas, but most of them are done for air communications. Furthermore, there are few studies of electromagnetic waves in water, but they have been done with narrow band antennas, such as dipoles or loops isolated with plastics. Hence the design of this antenna is a new challenge with a lot of possible solutions. In addition, the specifications for design antenna do not allow making bigger in size. This

restriction in size means an extra difficulty for finding a correct antenna, mainly with a good behavior in low frequencies.

The propagation of electromagnetic waves in water is very different than in the air, because of its high dielectric constant. Actually, the attenuation is much higher in water, causing a limitation on the transmission distance. However, the main problem caused by it is the variation of the impedance of the antenna. This change implies a completely variation in the return loss of the antenna when it is placed in water, increasing the difficulty of the challenge.

1.3 Objectives of the thesis

The current thesis work of designing underwater antenna is carried out to meet the following objectives:

- Analyze various underwater antennas, their basic concepts including their characteristics, applications and properties.
- To investigate the history of underwater radio communication and different antenna design for that purpose.
- To analyze wave transmission properties in water at over all distances both short and long, for successful underwater electromagnetic (EM) wave operation.
- To Design under water circular bow-tie antenna for different parameters (Height, Thickness, Width, Feed Angle, and Internal isolation).

In addition, after finding a good design for the application, the antenna will be studied and analyzed in order to understand its behavior in different conditions. These studies will be carried out varying the parameters of the antenna, and also some characteristics of the propagation medium. The goal is to find out what are the environmental conditions under which the antenna can work properly.

1.4 Organization of the thesis

The thesis is organized in six chapters.

Chapters 2 provide a brief discussion of different underwater antenna and their development in recent years also summarized. The use of antenna for underwater communication and their approach are also discussed in this chapter.

Chapter 3 introduces the basic electromagnetic concept and electromagnetic propagation of signal in water. This chapter conceptualizes the propagation and energy storage of electromagnetic wave.

Chapter 4 discusses the basic antenna theory, to understand how antenna work and the characteristics that are useful for design and optimize the antenna. The different classes of ultra-wide band antenna also discussed in this chapter.

Chapter 5 provides the simulated result and design methodology for circular bow-tie antenna. The different parameter estimating the performance of the designed antenna are calculated and presented.

Chapter 6 concludes with a critical discussion of the result of the investigation carried out. Important observations are made and useful conclusions are drawn. The thesis concludes with a list of reference books and research publications found useful during the course of investigations.

Ahmed I. Al-Shamma'a et al. [1] have studied a new approach of EM wave propagation through seawater for successful underwater electromagnetic (EM) wave operation; knowledge is required of the wave transmission properties of seawater over all distances both short and long. This information is required for such activities such as: sensor systems, imaging, position fixing, measurement of speed, obstacle detection and avoidance, guidance, communication of data/voice and remote control.

Acoustic systems are the most versatile and widely used technique. Both optical and acoustic systems, however, are unable to penetrate behind an object and suffer from shadow zones. In shallow water, the use of acoustic techniques can be severely affected by multipath propagation in water due to reflection and refraction. The comparatively slow speed of acoustic propagation in water, of the order of 1500 m/s, is another limiting factor in terms of transmission data rates. Whereas optical systems fail because of suspended matter, and acoustic systems because of high ambient noise levels, methods using electric and magnetic fields may offer an effective alternative for use over short distances.

Seawater has a molecular dipole lossy dielectric structure as well as a conductivity of approximately 4 S/m. In the near field, because of the proximity of the electrodes, conduction currents exist, while in the far field, the influence of the electrodes is minimal and under these conditions dielectric molecular dipole displacement (nullification) currents exist. Conduction is a continual loss process whilst nullification is a single and much smaller loss process in response to a change of electric field.

M. Waheed-uz-Zaman and M.A.K. Yousufzai [2] designed very low frequency (VLF) antenna they used especial method of design methodology. They used copper wires which are rewound just like a transformer core in either direction to cover the all around communication as shown in figure 2.1. The gap between the two windings is filled with mica and wood by considering the good magnetic properties especially for mica. In this construction the basic parameters are used without which it is very difficult to fulfill a good and efficient antenna. The low power modulated and amplifier circuit is design to transmit

the signal for short distance. This is an experimental effort to enquire the live data and with the passage of time and effort, it can be used for both way communications between two submarines.



(a) over view



(b) side view

Figure 2.1: The over view and side view of the antenna showing the formation of the coils

Alex Garcia Miquel [3] studied some typical UWB antennas, such as the circular dipole, the diamond and the bow-tie antenna for under water communication. Ultra-Wide Band technology is to transmit and receive information over a large bandwidth. The sizes of these antennas close to radius of 5cm. In air, the range of frequencies analyze this from 10MHz to 9GHz, with 200 samples. Otherwise, because in water the frequencies are 9 times lower, the studied range is from 10MHz to 1GHz, also with 200 samples. The reason for this choice is that the frequencies in water are 9 times lower than in air,

The characteristics required for this project:

- The antenna has to work between 100MHz and 1GHz because an UWB behavior is needed.
- It is also requested a transmission in frequencies as low as possible, because there the attenuation is less than in high frequencies.
- The antenna has to be omnidirectional because it will be placed in a device which will be moving.
- The size of the antenna has to be small (e.g. $r \leq 5\text{cm}$).

Finding a good design for the application, she studied and analyzed in order to understand its behavior in different conditions. These studies carried out by varying the parameters of the antenna, and also some characteristics of the propagation medium, such as the conductivity and the permittivity. To design the antenna she used some kind of software to simulate the response of the antennas to be able to analyze the results and to determine the best shape for each application. The most used software (CST Microwave Studio) in different conditions to determine which one is the best for underwater applications.

Chunshan Liu, Yuriy V. Zakharov, and Teyan Chen [4] studied the Broadband Underwater Localization of Multiple Sources Using Basis Pursuit De-Noising. This paper proposes an MF technique for solving the localization problem. The proposed technique exploits formulation of the localization problem in terms of sparse representation of a small number of source positions among a much larger number of potential positions. The sparse representation is formulated as the basis pursuit de-noising (BPDN) problem for complex-valued variables. The solution is found as a joint solution to a set of BPDN problems corresponding to the set of source frequencies subject to the joint support. The joint BPDN problem is efficiently solved using the Homotopy approach and coordinate descent search. For further reduction in the complexity, a position grid refinement method is applied. Using simulated and real experimental data, it is shown that the technique can provide accurate source localization for multiple sources. The proposed technique outperforms other MF techniques in resolving sources positioned closely to each other, tolerance to the noise and capability of locating multiple sources.

They formulated the underwater acoustic source localization in the framework of the MF processing as a sparse representation problem and demonstrated that its solution based on the complex-valued multi-frequency BPDN shows high localization performance. For solving the BPDN problem, we have used the Homotopy approach combined with the coordinate descent search. Grid refinement has further been used to reduce the complexity of solving the BPDN problem. Comprehensive simulation has been carried out to evaluate the performance of the proposed method in resolving sources close to each other, locating multiple sources and robustness to noise and interference. The effectiveness of the proposed method has also been verified using real ocean experimental data. It has been shown that the proposed technique outperforms other MF techniques, such as the conventional MF

processor and IAA MF processor, in resolving sources positioned closely to each other, tolerance to the noise and capability of locating multiple sources.

Hector Fabian Guarnizo Mendez [5] conducted an experiment to development of a UHF radio antenna compatible with deep underwater transmissions. It aims to allow rapid transmission of large size files and real-time video. The solution under development is based on a radiating excitation isolated from the sea water by a buffer. The system presents several advantages: lack of sensitivity to sea water variability, robustness to axial rotation and to alignment between emitter and receiver, and ease of integration into classic underwater equipment. First measurements on a simple prototype present a bandwidth of 70 MHz around 2.4 GHz, appropriate for Wi-Fi communications.

The experimental measurements confirm certain specific properties selected for applications in various seawater conditions (temperature, salinity, depth). Notably, it was not necessary to develop a circular polarization excitation to suppress any azimuthal alignment constraints between the transmitter and the receiver. Simulations for the transmission were carried out. The experimental study of the transmission in progress will make it possible to verify the hypothesis of the medium modeling and evaluate the experimental reachable distance for an underwater radio communication. It is expected to be about 10 to 15 cm with a common wireless Wi-Fi system.

Sandra Sendra, Jose V. Lamparero and Jaime Lloret [6] measured the maximum coverage distance of underwater wireless sensors when they are placed at about 15 cm underneath the water surface, without having wireless coverage from the air side. Then, we measured the number of lost packets and round trip time for 1, 2, 5.5 and 11 Mbps at different frequencies for different distances. In this paper we measure the maximum coverage distance of underwater wireless sensors when they are placed at about 15 cm underneath the water surface, without having wireless coverage from the air side. Then, we measured the number of lost packets and round trip time for 1, 2, 5.5 and 11 Mbps at different frequencies for different distances.

They performed several tests at different frequencies and modulations to check several parameters such as minimum depth, distance between devices and signal transmission characteristics. It seems that BPSK modulation has greater stability than the other ones,

although when they increased the frequency the ping delay increases. However, despite of this fact, the amount of received packets is still better than in other cases. BPSK may be better compared to other modulations because this modulation uses only 2 symbols (so it has lower error probability).

They proposed system is developed to monitor the water surface with enough accuracy. It can occur in the following cases: in ponds and rivers where some poisonous plants may contaminate the water, in swamps where the surface water quality is different depending on the season and affects to the organic material of the water, and in water close to industrial plants where there could be a chemical escape.

B.Benhables and P. Lacour [7] have studied a simple and closed-form expression for the E field in sea water is derived from two physical models, which agree but are different: the surface-wave theory and the Fresnel formulas. Three configurations of immersed receiving antennas are investigated by means of computer simulations. The scattered electric field and expected measured voltage are computed, using an EFIE (electric-field integral equation), and the Method of Moments (MOM). Then, an equivalent-circuit model of the underwater antenna is investigated, with a focus on two dominant antenna parameters: the impedance and the voltage measured between the wire terminals. Calculations and computed results are compared with off-shore measurements.

Sea water is a lossy medium (with standard conductivity 4.5 S/m), and electromagnetic fields are strongly attenuated when propagating into it. Thus, working at 15 kHz, the complex dielectric permittivity ϵ_r^* , of sea water has an important imaginary part:

$$\epsilon_r^* = \epsilon_r - j \frac{\sigma}{\omega \epsilon_0} = 80 - j5,400,000 \quad (2.1)$$

The VLF ranges are mainly used for radio navigation and submarine communication. There are actually a few frequency ranges that allow the transmission of EM waves through the air-sea interface: the VLF, LF, and ULF ranges, and the blue-green laser-frequency range.

They conclude that the structure and the value of the transmitted underwater electric field was determined, a computer code based on an EFIE and the method of moments was developed, and the scattered field and the expected voltage for three different antenna configurations have been studied.

C. Conessa and A. Joisel [8] designed Active antenna to measure electromagnetic fields in water. It combines a differential wideband amplifier and a dipole, the characteristics of which have been designed to provide a constant gain on the bandwidth of the antenna. The small size of the dipole reduces the mask effect. The designed antenna is a symmetrical reception antenna for the electromagnetic field measurement in water in the frequency range of 100 MHz to 1 GHz and it introduces few disturbances. A possible application will be the microwave imaging of immersed objects.

Using a short dipole instead of a thick wide band conventional antenna allows the mask effect to be reduced drastically. This dipole can be connected to a differential amplifier which used as a wideband matching network and ideal balun. A short antenna ($l \leq \lambda$) presents two advantages:

- its omnidirectional pattern is quite independent of the frequency and
- This antenna works like a field measurement device over a wide frequency band.

They conclude that the Active wide band antenna is smaller than the biconic system, hence resulting in fewer disturbances. Its gain is also higher than the former system. Simple, cheap and easy to build, it becomes possible to build an antenna array for immersed object imaging with low disturbance. The sensitivity is also better, especially for high frequencies. As a consequence the spatial resolution of tomographic systems using such probes can be improved. Before realizing a probe array using this principle, the prototype could be improved, by optimizing other parameters such as the dipole and differential line lengths.

Zhang Hao and T. Aaron Gulliver [9] studied the attenuation due to the conductivity of seawater limits the effectiveness of electromagnetic underwater systems. Transmission frequencies and the antenna design are examined in this paper with the goal of improving underwater communications.

They conclude that in an underwater environment, a vibrator antenna provides better performance than a loop antenna. Although a vibrator antenna may have a reduced signal to noise ratio, it can be employed over greater distances. The conductivity of seawater is nominally $\sigma=5$ S/m and a good conductor satisfies the condition $\sigma/\sqrt{\omega\epsilon} \gg 1$, so seawater is a good conductor at 7 to 30 MHz. The attenuation constant is approximately $\beta \approx \alpha \approx \sqrt{\pi f \sigma \mu}$. Thus, as the frequency increases, the attenuation also increases and the propagation

distance decreases, so water is a better conductor at lower frequencies. Therefore seawater is a good medium at frequencies around 10 MHz.

Kenneth P. Hunt and James J. Niemeier [10] investigated the propagation of radio waves underwater and between water and air to facilitate setting up hybrid wireless sensor networks with both surface and subsurface nodes. Our investigation includes signal attenuation, antenna radiation patterns, multipath due to reflections from the surface and substrate, noise, and reflection losses transmitting from one medium to another.

The study concludes that setting up a wireless sensor network in freshwater using commercial wireless motes is feasible in spite of the greater path loss due to attenuation. To improve the software for analyzing electromagnetic fields underwater, first in unbounded water and later in the presence of the surface and bottom. With they examined the electromagnetic fields due to sources at the surface, on the bottom, and at various depths in a body of water. They also evaluate underwater noise characteristics. The information from these studies specifies characteristics of underwater, water-to-air, and air to water communications channels. Finally, the antennas supplied with commercial wireless motes are designed for use in air and may not function well underwater.

Carlos Uribe and Walter Grote [11] studied Underwater Wireless Sensor Networks (UWSN) experience severe communication problems due to large acoustic or electromagnetic (EM) signal attenuation. The propagation of acoustic signals in submarine media is possible with very low frequency signal carrier only, therefore reduced bandwidth, and low transmission rates, thus extending transmission duration and diminishing battery life. They increase transmission data rates for UWSN have made it attractive to explore the possibilities of higher frequency EM transmissions. Recent experiments show that huge EM signal losses are to be expected in the near field of the transmitting antenna, however experiencing little additional reductions thereafter. Carlos Uribe study the lack of a unified simple analytical model based on Maxwell's equations that can be used as a design tool for these wireless submarine links.

Carlos Uribe and Walter Grote developed a new unified EM wave propagation model for submarine radio communications that describes the path losses between transmitter and receiver antenna quite accurately both in the near and the far field, as compared to

experimental data available. The model is robust to frequency, conductivity and distance parameter changes.

Liu C. and Zheng L.-G. [12] Investigated extremely low frequency (ELF) electromagnetic fields generated in a sea of finite depth by a submerged horizontal electric dipole (HED) are derived based on an air-water-seafloor three-layer model. Field components in seawater are computed using numerical integration technique and Euler's transform. The effects of frequency, sea depth, seabed conductivity and depth of submerged transmitting HED on the electromagnetic field distribution in a sea.

They conclude that vertical electric field component produced by a HED in a sea of finite depth is much weaker than the horizontal components, and may be neglected generally in ELF band. The vertical magnetic field component is much stronger than the horizontal components, and is the major component in underwater communication. The horizontal electric field components are more sensitive to the change of seabed conductivity than other field components, and are the components suitable for seabed prospecting application. In a shallow sea, the field strength from a HED would decay slower with the distance than that in a deep-sea. This provides a favorable condition for underwater communication. The field strength produced by a HED in a sea of finite depth is not sensitive to frequency change in ELF band. Therefore, it is necessary to further decrease the operating frequency for prospecting seabed purpose.

The presence of seabed in a sea can substantially change the electromagnetic field distributions produced by a submerged HED at the seabed. Three-layer model can only obtain apparent conductivity at seabed. It is not equipped with detailed information of seabed structure. Seabed should be modeled as a stratified medium. That means the method above can't be used to determinate the layered structure of the seabed medium. It can only be applied to determinate the apparent conductivity at seabed surface.

Brian Kelley et al. [13] describe new methods that solve well known problems associated with high throughput, robust communication in underwater environments. By robust, they imply simultaneous increases in enabled underwater communication data rates, range, and reliability. their methods borrow concepts from advanced multi-carrier modulation using Orthogonal Frequency Division Multiplexing ,multiple input multiple output (MIMO) space

time codes (e.g. Alamouti diversity), and zero carrier frequency ultra-wide band (UWB) wireless. In addition, we discuss system optimization involving the elimination of the phase synthesizer and analog mixer through direct sampling of the RF antenna port.

They estimated that underwater data rates in excess of 1MBs are possible using modern 4G transceivers properly configured for underwater communications. In essence, they use the spectral efficiency of modern communications to overcome the large near field and diffraction attenuations of 130dB. With the modular design of equipment we are capable of testing our RF underwater channel. Future research will focus upon new transceiver configurations with even high capacity and experimental modeling of underwater channels.

Frank Plonski [14] designed an electrically efficient small packaged submarine antenna that operates at the HF band using existing subminiature aperture technology.

The goal was to achieve High Radiation efficiency within a restricted Radome cylindrical size (the available space of, a max height of 92 inches and a max overall diameter of 4 inches in the GOTLAND submarine). The design principal used to achieve a Hi-Radiation Efficiency on the LOW end of the frequency spectrum (2-24 MHz) is an inductively tuned CAGE Capacity Hat antenna. The Hi end of the frequency band (24 to 30 MHz) the antenna acts like a very broadband monopole.

A. Shaw, A.I. Al-Shamma'a, [15] study the electromagnetic wave propagation through seawater at MHz frequencies. These frequencies would enable the use of high speed data rates, suitable for a wide range of sub-sea activities.

A. Shaw, A.I. Al-Shamma'a The experimental setup, the transmitter was placed at the bottom of the test tank to a depth of 1.2m and the receiver was suspended in the water from a gantry (also to a depth of 1.2m) with moveable supports allowing the separation of the antennae to be varied. To ensure there was no RF conduction path between the transmitter and receiver, the transmitter was constructed as a standalone, battery operated system with no cables either for support or to supply the RF signals. The transmitter electronics for the tank tests consisted of a series of fixed crystal oscillators filtered and amplified providing a constant RF output of +10dBm in the range 1 to 66MHz. A range of different types of antennae were investigated including single loop, multi-turn loop, dipole and folded dipole. The propagation between these antennae was initially measured as a function of distance

within the laboratory test tank. They analyze that an RF signal at frequencies up to 5MHz can be transmitted over a distance of 90m in sea water. It has also been shown that audio data, modulated on to this signal can be transmitted over these distances. These tests were carried out in relatively shallow water (<5m) which is known to be a problem with acoustic systems. Further tests are outlined to be performed at depths down to 30m at the diver center in Loch Linnhe, Scotland. These tests will be performed to eliminate the possibility of any surface effects.

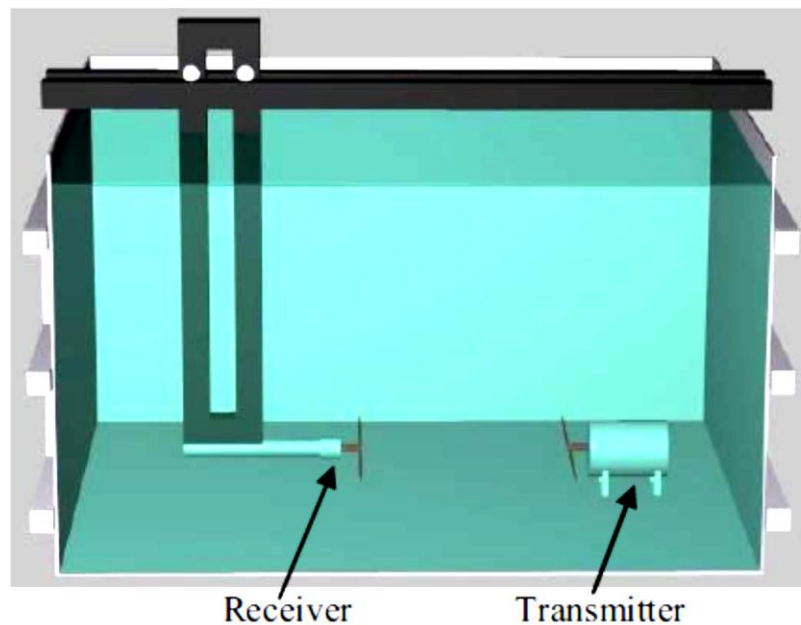


Figure 2.2: The laboratory test tank

They used transmitter was placed at the bottom of the test tank to a depth of 1.2m and the receiver was suspended in the water from a gantry (also to a depth of 1.2m) with moveable supports allowing the separation of the antennae to be varied. To ensure there was no RF conduction path between the transmitter and receiver, the transmitter was constructed as a standalone, battery operated system with no cables either for support or to supply the RF signals. Figure shows the transmitter and receiver PVC containers, which housed the electronics, and the coated single loop antennae on each. The transmitter electronics for the tank tests consisted of a series of fixed crystal oscillators filtered and amplified providing a constant RF output of +10dBm in the range 1 to 66 MHz. The receiver was an identical antenna connected to an HP spectrum analyzer via a 5m RG58 cable and a narrowband filter.

Ram Somaraju and Jochen Trumpf [16] proposed a physically realistic model; similar to the one is used in plasma physics, for the variation of the dielectric constant of water with varying frequencies and salinities. Their model is in excellent agreement with existing empirical fits for frequencies between 1 and 256 GHz.

They also studied the propagation of electromagnetic waves in seawater and explain that large propagation distances would be possible at MHz frequencies if the conductivity of seawater decreases at small field strengths due to the hydrogen bonding of water molecules. However, they were unable to experimentally verify any reduction in the conductivity of seawater.

They derived a physically realistic model for the frequency variation of the relative permittivity of seawater for varying salinities and temperatures. The model derived is in excellent agreement with existing empirical fits to experimental data. Also, the model uses only two parameters that need to be determined from experimental data as opposed to more than 10 parameters used by most empirical fits. Furthermore, the remaining parameters in our model have a physical interpretation and could hence theoretically be determined by independent experiments. Moreover, because our model has a physical foundation, they were confident that it is valid over a wider parameter (frequency, temperature and salinity) range and can be used for extrapolation in regions where no experimental data is available. . They measured no change in conductivity for electric fields as small as 12 and 1.5 $\mu\text{V}/\text{m}$ at frequencies of 50 KHz and 1 MHz respectively.

Ahmet Cemal Durgun and Constantine A. Balanis [17] study the design, simulation, fabrication and measurement of two different novel flexible bow-tie antennas, a conventional and a modified bow-tie antenna. The antennas are mounted on a flexible substrate fabricated at the Flexible Display Center (FDC) of Arizona State University (ASU). The substrate is heat stabilized polyethylene naphthalate (PEN) which allows the antennas to be flexible. The antennas are fed by a microstrip-to-coplanar feed network balun.

The return losses and radiation patterns of the antennas are simulated with HFSS and the results are compared with measurements, for bow-tie elements mounted on flat and curved surfaces. The comparisons show that there is an excellent agreement between the simulations and measurements for both cases. Furthermore, the radiation performance of the modified bow-tie antenna is verified, by simulations and measurements, to be very close to

the conventional bow-tie. The reduction of the metallization is based on the observation that the majority of the current density its performance.

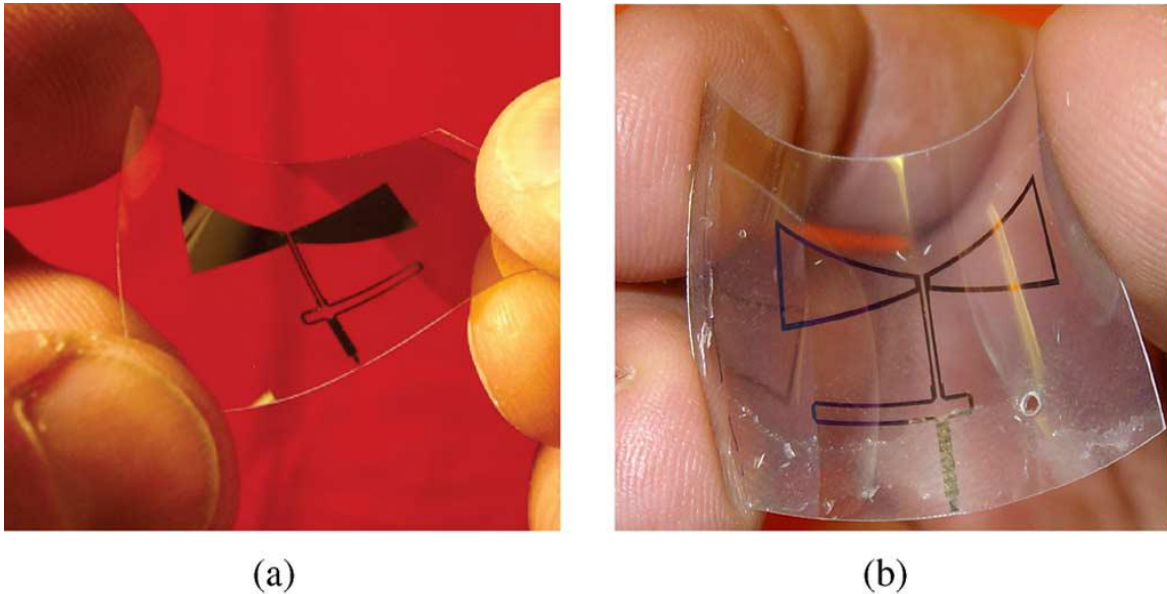


Figure 2.3: The flexible bow-tie antennas (a) Solid bow-tie antenna (b) Out line bow-tie antenna.

They found the support structure, which was used to stabilize the coax-microstrip transmission line connection, was verified to have an impact on the resonant frequency of the antennas. Although, due to the gap between the ground plane and brass, the triangular support introduced a capacitance resulting in an increase in the resonant frequency, the cylindrical brass tube had an inductive effect. This inductance was due to the currents circulating within the brass tube. Consequently, the resonant frequency of the antennas decreased after the assembly of the new support structure.

Richard K. Moore [18] has studied very low frequency (VLF) communication in the sea. Moore consider surface to submarine, submarine to surface and submarine to submarine propagation. Sea water is a good conductor and atmospheric noise is generally more of a problem in sea communication than thermal noise communication ranges are limited by the effects of depth attenuation and atmospheric noise. Ranges in the sea tens of the kilometers

are possible for antenna within five meters of the surface; bandwidth is less than 1 Hz and tens of kilowatts of power required.

The electromagnetic properties of sea water limit the communication ranges, a plane wave travelling in the sea, with electric field E is

$$E = E_0 e^{j\omega t - \gamma x} \quad (2.2)$$

The propagation constant γ

$$\gamma = \sqrt{j\omega\mu(\sigma + j\omega\epsilon)} = \alpha + j\beta = \frac{1}{\delta} + j\beta \quad (2.3)$$

At low frequency where displacement current can be neglected the propagation constant is approximately

$$\begin{aligned} \gamma &= \sqrt{j\omega\mu\sigma} = \sqrt{\frac{\omega\mu\sigma}{2}} (1+j) \\ &= \alpha + j\alpha = \frac{1}{\delta} + j\frac{1}{\delta} = \beta + j\beta \end{aligned} \quad (2.4)$$

Waves are coupled to current in circuits by antennas. All of the preceding propagation expressions have been predicated on dipole sources. In air, more elaborate sources are not feasible at the low frequencies necessary for submarine communication. Nevertheless, these electric and magnetic dipoles in the sea take on interesting forms different from those common in air, primarily because attenuation and phase shift are equal in the conducting medium; in air, attenuation between the parts of an antenna is negligible.

Moore conclude that Radio communication from, to, and between submerged antennas involves propagation paths through the highly conducting sea with segments vertically above the submerged antennas and a segment along the surface like that for a vertical antenna in air. In fact, a submerged horizontal electric dipole is equivalent in its fields to a weaker vertical quadrupole at the surface. Because of the strong attenuation in the sea, very low frequencies are required for such communication .

Lloyd Butler [19] studied communications link with the surface or perhaps in radio controlled boats and try at model submarines. On the other hand, he might just be interested in another area of experimentation field, relatively untouched by the amateur fraternity, involving different transmission techniques, different antenna designs and different equipment environmental problems. The transmission characteristics of radio waves

underwater and the extent to which the radio amateur might make use of these characteristics:

- Water in its pure form is an insulator, but as found in its natural state, it contains dissolved salts and other matter which makes it a partial conductor. The higher its conductivity, the greater the attenuation of radio signals which pass through it.
- Attenuation of radio waves in water (and, in fact, in any conducting medium) increases both with increase in conductivity and increase in frequency.

Butler conclude that Radio communication under the sea is not an attractive option for experiment by the radio amateur as it requires the use of very low frequencies, large antenna systems and very high powers. Fresh water lakes and rivers have much lower electrical conductivity than the sea and underwater transmission distances (or depths) up to 30 meters appear feasible using the lowest frequency amateur band of 1.8 MHz Even larger distances (or depths) could be achieved if a lower frequency band allocation is available. Communication between underwater stations or between a surface station and an underwater station could be achieved over much larger distances by utilizing a transmission path above the surface and tolerating the air to water refraction loss.

Cui Guoheng [20] studied Loran-C navigation system is a middle-long range low frequency radio navigation system, which use land-based transmitters and pulse phase modulation. The satellite navigation system (GPS) is emerging more and more disadvantages, the U.S. Department of Homeland Security (DHS) announced that they would continue to use the Loran-C, and upgraded it to enhanced Loran-c (eLoran) as a backup to GPS in 2008, and then the development of the Loran-C system drew the attention of the world again. Loran-C/GNSS integrated navigation becomes the hot spot of research.

Cui Guoheng concluded the propagation characteristics of Loran-C underwater and calculated the H-field and E-field, and then got the result that using H-field antenna was the best way to receive Loran-C signal under water. The variance of the underwater propagation depth for H-field and E-field with the different resolution of circuit is analyzed. Simulation results show that resolution of circuit is the key to receive the signal of Loran-C underwater. The voltage of H-field antenna was calculated. Experiments indicate that position underwater

can be feasibility (with the depth is less than 10m) when Loran-C signal is received by H-field antenna.

Andrian Andaya Lestari [21] studied, the basic design of an adaptive ground penetrating radar antenna is introduced. The antenna is able to adapt its input impedance to a variation in the antenna elevation and soil type to keep reflections at the antenna's terminal minimum. As a result, energy transfer from the generator to the antenna is maximized, which in turn maximizes the energy radiated by the antenna into the ground for different antenna elevations and soil types. The antenna is based on a wire bow-tie structure with variable flare angle for adjusting the antenna's input impedance. The flare angle variation is realized by short-circuiting the gaps separating the wires from the feed point of the antenna, for which electronic switching devices such as PIN diodes could be used to allow fast and convenient control of the antenna's flare angle.

Andrian concludes that adaptive antenna for impulse GPR applications have been proposed. The antenna is capable of adapting its input impedance against a variation in the antenna elevation and soil type for maintaining a minimum reflection at the antenna's terminal to obtain the best matched condition between the antenna and the feed line. The antenna is based on a wire bow-tie structure and the antenna adaptation is achieved by varying the flare angle of the antenna, for which the wires are separated from the feed point by narrow gaps. It has been shown that the flare angle variation can be done by short-circuiting the gaps, which would allow one to control the flare angle electronically using electronic switching devices such as PIN diodes. It has been demonstrated theoretically that the best matched condition can be achieved by at least three different effective flare angles for different antenna elevations and soil types. As a result, energy transfer from the generator to the antenna is maximized, which in turn maximizes the energy radiated by the antenna into the ground. The adaptation capability of the proposed antenna has been confirmed experimentally.

John P. Casey [22] describes a multipath-abating antenna system consisting of a linear array of four quadrifilar helical antenna (QHA) elements and an associated beam former that are installed on a buoy that floats along the sea surface for the purpose of supporting both transmit and receive communications along line-of-sight paths. The circuit and radiation

characteristics of a QHA enable an array of these antennas to provide hemispherical coverage overhead with sufficient gain and low sensitivity to multipath interference. In the receive mode, the beam former takes advantage of the spatial diversity of the array by appropriately weighting the elements in order to optimize the array signal-to-noise ratio.

Xianhui Che, and Gordon Dickers [23] study electromagnetic technology in a small-scale underwater wireless sensor network. The results demonstrate the likely effectiveness of the designated network

They investigate Underwater EM communication has very few applications to date. Communications technology and operational requirements have radically changed since underwater electromagnetism was first evaluated. An overview and comparison of the three major underwater technologies (radio, acoustic, and optical) indicate the potential of underwater EM. Investigation has revealed that EM signaling, coupled with digital technology and signal compression techniques, has many advantages that make it suitable for niche underwater applications. In the case study presented, a small-scale underwater wireless sensor network is designed to monitor coastal erosions. EM communication is used in the physical layer because it presents distinct advantages compared to acoustic and optical communication in shallow water coastal environments. The analysis of this case study has shown that EM communication in underwater environments is both feasible and effective for a specific set of applications.

ELECTROMEGNETICS THEORY AND PROPAGATION OF
SIGNALS IN WATER

3.1 Maxwell's equations

In 1864, James Clerk Maxwell recognized a symmetric relationship between electric and magnetic field and by joining four simple equations, he established the basis of electromagnetism. In differential form Maxwell's equations are:

$$\nabla \times \bar{E} = \frac{-\partial \bar{B}}{\partial t} \quad (3.1)$$

$$\nabla \times \bar{H} = \bar{J} + \frac{-\partial \bar{D}}{\partial t} \quad (3.2)$$

$$\nabla \cdot \bar{D} = \rho \quad (3.3)$$

$$\nabla \cdot \bar{B} = 0 \quad (3.4)$$

Where \bar{E} = Electric field (V/m)

\bar{H} = Magnetic field (A/m)

\bar{D} = Electric displacement (C/m²)

\bar{B} = Magnetic flux density (T)

\bar{J} = Electric current density (A/m²)

ρ = Electric charge density (C/m³)

Coulomb originally showed that a static electric charge q creates an electric field E that radiate omnidirectionllay from the point charge:

The strength of electric field decays as 1/r² where r is the radial distance from point charge:

$$\bar{E} = \frac{q}{4\pi\epsilon r^2} \hat{r} \quad (3.5)$$

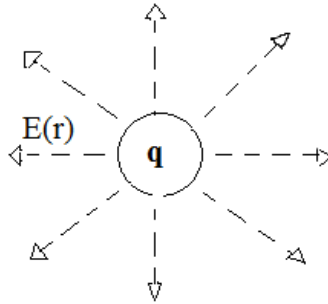


Figure 3.1: A point charge q has a radially symmetric electric field, E .

A magnetic field \vec{H} however, stems for the movement of charge, I as shown by the Bio-Savart Law:

$$\vec{H} = \int \frac{I d\vec{l} \times \hat{r}}{4\pi r^2} \quad (3.6)$$

In 1831, Faraday experimentally demonstrated that a changing magnetic field produce an electric field, a phenomenon that we refer to as Faraday's laws and constitutes the first of Maxwell's four equations. Even earlier in 1820, ampere held experimentally shown that a current on a wire produces a magnetic field that circles the wire, leading to Ampere's law which is Maxwell's second of four equations and is consistent with Bio-Savart law.

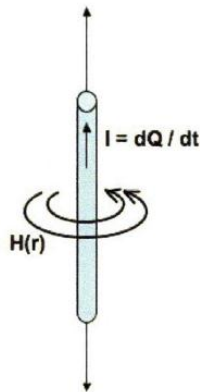


Figure 3.2: current carrying wire

Figure 3.2 shows a visual representation of Ampere's law. Maxwell appended Ampere's law to include a changing electric field, $\frac{-\partial \vec{D}}{\partial t}$. By showing that a changing electric field act as a current and induces a magnetic field, Maxwell made a symmetrical relationship between electric and magnetic fields that has forever shaped our understanding of electromagnetics.

3.2 Electromagnetics Waves

From Maxwell's equations, a time varying electric field induces a time varying magnetic field which then induces a changing electric field and so on. If a time varying electric field \vec{E} , and a time varying magnetic field \vec{H} , are coupled and propagating orthogonal to each other, they produce an energy storing electromagnetic wave which travels orthogonal for both the fields. Figure 3.3 display a propagating electromagnetic wave and its field components.

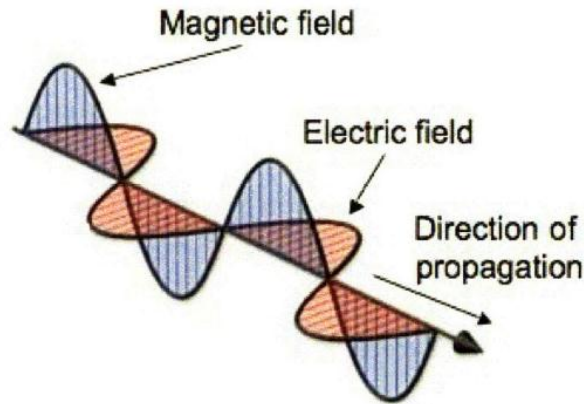


Figure 3.3 Propagating Electromagnetic Wave [23]

Electromagnetic wave travel at the speed of light, $c=3 \times 10^8$ m/s they are characterized by their wavelength λ (m) and there frequency f (1/s) which are inversely proportional to each other:

$$c = \lambda \times f \quad (3.7)$$

The energy of an electromagnetic wave is stored in the electric and magnetic fields and the wave has the “energy flux” at particular time and space proportional to the magnitude to the magnitude of its corresponding electric and magnetic field:

$$\vec{S} = \frac{1}{2} \text{Re} (\vec{E} \times \vec{H}^*) \quad (\text{W/m}^2) \quad (3.8)$$

Where \vec{H}^* is the complex conjugate of \vec{H} . Because \vec{E} and \vec{H} are time varying the Poynting vector \vec{S} as the wave's time averaged power per unit area through a surface which is normal to it. \vec{S} is also known as the power density and has unit W/m^2 .

The field strength of \vec{E} and \vec{H} are related by the permittivity ϵ and the permeability μ of the medium through which the electromagnetic wave is traveling. In free space,

$$\frac{|E|}{|H|} = \sqrt{\frac{\mu_0}{\epsilon_0}} = \eta_0 \text{ (}\Omega\text{)} \quad (3.9)$$

Where ϵ_0 = free space permittivity = 8.8542×10^{-12} (F/m)

μ_0 = free space permeability = $4\pi \times 10^{-7}$ (H/m)

3.3 Propagation of Signals in Water

The transmission of information in the form of light, sound or electric and magnetic fields (EM wave). However each of these techniques has advantages and limitations. Optical systems are generally limited to extremely short distances because of backscatter and absorption. In the Sea water, for example, visibility is often zero or at best around 1–2 meter due to suspended matter in the water. Acoustic systems (Sound Wave travel in solid, liquid and air in the form of transverse wave and shear wave the propagation occur due to the vibration of particles of the medium) are the most versatile and widely used technique. Both optical and acoustic systems, however, are unable to penetrate behind an object and suffer from shadow zones. In shallow water, the use of acoustic techniques can be severely affected by multipath propagation in water due to reflection and refraction. The comparatively slow speed of acoustic propagation in water, of the order of 1500 m/s is another limiting factor in terms of transmission data rates. Whereas optical systems fail because of suspended matter, and acoustic systems because of high ambient noise levels, methods using electric and magnetic fields may offer an effective alternative for use over short distances.

3.3.1 Characteristics of Electromagnetic Wave in Water

For successful underwater electromagnetic (EM) wave operation, knowledge is required of the wave transmission properties of water over all distances both short and long. Seawater is a poor medium for communication because it contains dissolved salts and other matter which makes it a partial conductor. The communication within the sea is limited because of attenuation due to high frequency. The most used waves to establish underwater wireless communications are the acoustic waves. However, acoustic communications are limited by two factors: low speed of sound underwater and time-varying multipath propagation.

Together, these factors result in a communication channel of poor quality and high latency. Optical systems are another alternative to take into account, but they usually fail because of suspended matter of the liquid medium.

It is better to use electromagnetic waves because their properties are more suitable. The positioning of the sensors, the system has to work fast because the position of sensors could change very fast as well, and with the acoustic waves we could make a lot of mistakes causing slow propagation. Maxwell's equations give us the speed of electromagnetic waves in a medium. While for acoustic waves this speed of propagation is over 1440 m/s in water, for electromagnetic waves this propagation works over 33.5×10^6 m/s, becoming more than 23×10^6 m/s times faster [3].

Maxwell's equations predict the propagation of electromagnetic (EM) waves travelling in seawater. A linearly polarized plane EM wave propagating in the z direction may be described in terms of the electric field strength E_x and the magnetic field H_y strength with

$$E_x = E_o \exp(j\omega t - \gamma z) \quad (3.10)$$

$$H_y = H_o \exp(j\omega t - \gamma z) \quad (3.11)$$

The propagation constant (γ) is expressed in terms of the permittivity (ϵ), permeability (μ) and conductivity (σ) by

$$\gamma = j\omega \sqrt{\epsilon\mu - j \frac{\sigma\mu}{\omega}} = \alpha + j\beta \quad (3.12)$$

Where α is the attenuation factor, β is the phase factor, and $\omega = 2\pi f$ is the angular frequency. The term $\epsilon\mu$ arises from the displacement current and the term $\sigma\mu/\omega$ from conduction current. The speed v of electromagnetic propagation in the medium is

$$v = \frac{1}{\sqrt{\epsilon\mu}} \quad (3.13)$$

3.3.1.1 Conductivity

Water in its pure form is an insulator, but as found in its natural state, it contains dissolved salts and other matter which makes it a partial conductor. The higher its conductivity, the

greater the attenuation of radio signals which pass through it. The conductivity is also dependent on the temperature, [19]

Table 3.1: Electrical conductivity (S/m) of sea water

Temperature (C ⁰)	Salinity (g/Kg)		
	20	30	40
0	1.745	2.523	3.285
5	2.015	2.909	3.778
10	2.300	3.313	4.297
15	2.595	3.735	4.837
20	2.901	4.171	5.397
25	3.217	4.621	5.974

Typical values of water conductivity

- Ultra-pure water: 5.5×10^{-6} S/m
- Distilled water: 0.001 S/m
- Drinking water: 0.005 - 0:05 S/m
- Sea water: 4.0 – 5.3 S/m
- Great Salt Lake, USA: 15.8 S/m

3.3.1.2 Wavelength

The distance of one duty cycle travelled by wave is known as the wavelength. The relation between frequency f , speed v and wavelength λ is shown below

$$\lambda = \frac{c}{f} \quad (3.14)$$

The frequency in free space is nine time faster than the frequency in the water. From the equation (2.5), it is clear that slower the frequency in water larger the wavelength.

3.3.1.3 Intrinsic Impedance

The ratio of electric field intensity E and magnetic field intensity H is called intrinsic impedance. The intrinsic impedance, η is changes due to the conductivity of water

$$\eta = \frac{E}{H} \quad (3.15)$$

With slightly electrical conductivity ($\sigma > 0$, e.g. seawater)

$$\eta = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\epsilon}} \quad (3.16)$$

With no conductivity ($\sigma = 0$, e.g. free space)

$$\eta_{\text{freespace}} = \sqrt{\frac{\mu}{\epsilon}} \quad (3.17)$$

In pure water the equation

$$\eta_{\text{pure water}} = \sqrt{\frac{\eta_{\text{pure water}}}{\epsilon_{\text{pure water}}}} \quad (3.18)$$

Figure (3.4) shows the absolute value of the intrinsic impedance at four different frequencies (50MHz, 100MHz, 150MHz and 200MHz) in water with different conductivities. It is observable that the impedance decreases with the conductivity, but increases with the frequency.

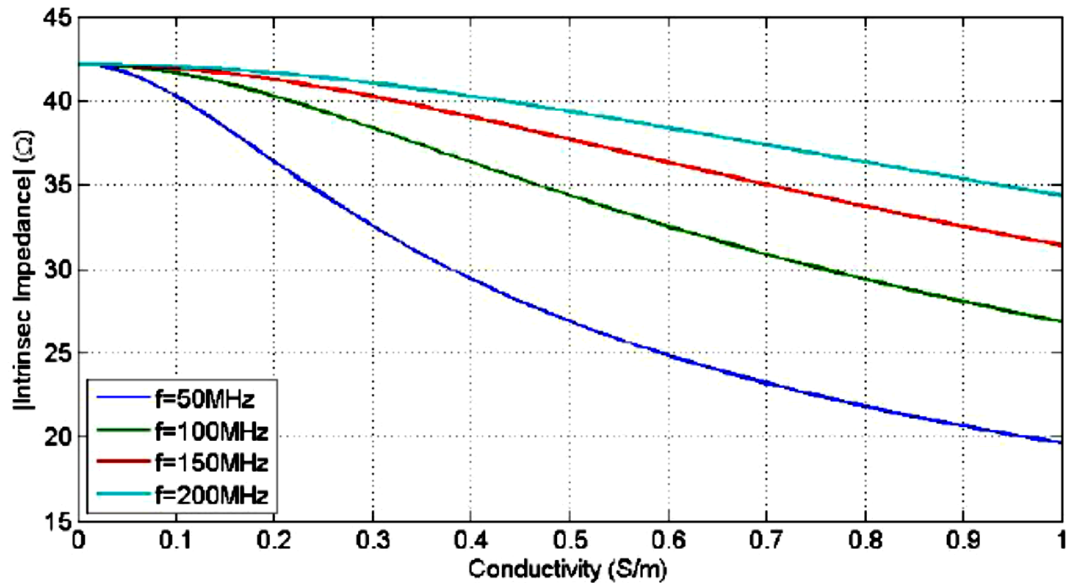


Figure 3.4: Intrinsic impedance on dependence of the conductivity of different frequencies in MHz [3]

3.3.1.4 Permittivity

Water has among the highest permittivity of any material and this has a significant impact in the behavior of the electromagnetic waves propagation. Permittivity experiences variations with the frequency and the temperature. Figure (3.5) shows the dielectric constant in dependence of the frequency and the temperature. The arrows show the effect of increasing temperature or increasing water activity [26]. The wavelength range 0.01 - 100cm is equivalent to 3THz - 0.3GHz respectively.

The permittivity in water is dependent on this relative permittivity (ϵ_r), the permittivity of the vacuum ($\epsilon_0 = 8.85 \times 10^{-12}$) and the conductivity (σ), as the equation

$$\epsilon_{water} = \epsilon_r \epsilon_0 - j \frac{\sigma}{\omega} \quad (3.19)$$

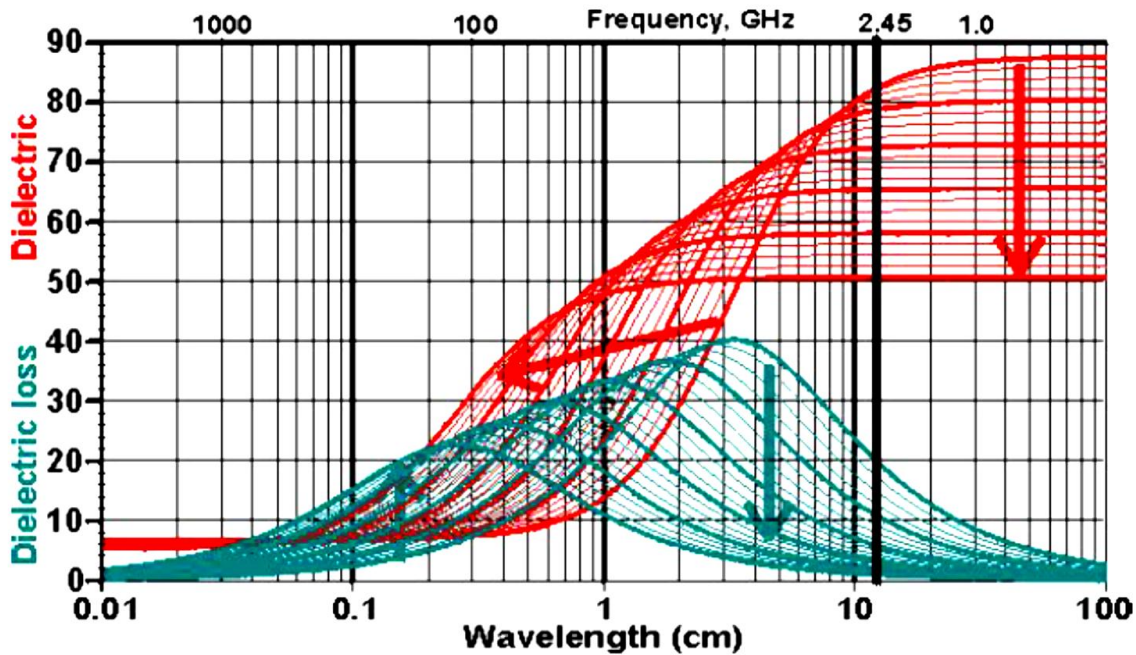


Figure 3.5: Dielectric permittivity and dielectric loss of water between 0°C and 100°C [3]

From figure 3.5 it can be noticed, for that range the dielectric constant does not vary with the frequency. Hence a constant ϵ_{water} of 81 when the temperature is about 20°C and the frequency is less than 1GHz.

4.1 Introduction

An antenna is a "transition device, or transducer, between a guided wave and a free space wave, or vice-versa". Using Ampere's Law a current-carrying element or antenna creates a magnetic field which then creates an electric field and so forth as shown in Figure 3.2. When the antenna is attached to a load, it radiates the load's information in an energy storing electromagnetic wave. The reciprocity of Maxwell's equations demonstrates that an antenna can equally receive electromagnetic energy and translate the information back into a guided wave.

All wireless technologies today- radio, 802.11g, cellular, depend on the existence and efficiency of well-designed antennas to successfully communicate information through the air. Antennas come in various shapes and sizes depending on factors such as the attached load, the operating frequency, and the desire directionality. For instance, the parabolic-shaped Dish antenna that was popularized in 1997's Contact has a high gain and is used for radio and television communication [39]. The Yagi-Uda developed in the late 1920s, is a highly effective antenna noted for its simplicity and directivity. The antenna consists of an array element: a driven dipole, a reflector, and parasitic elements.

4.2 The Hertzian Dipole

The Hertzian dipole, the most fundamental radiating element, is defined as an infinitesimal wire carrying current with uniform amplitude and phase over its length

In spherical coordinates, the field components of an oscillating Hertzian dipole of length dl , carrying current I_0 , and lying on the z -axis as shown in Figure 4.1, are:

$$E_r = -\frac{I_0 dl}{4\pi} \eta_0 k^2 2 \cos\theta \left(\frac{1}{(jkr)^2} + \frac{1}{(jkr)^3} \right) e^{-jkr} \hat{r} \quad (4.1)$$

$$E_\theta = -\frac{I_0 dl}{4\pi} \eta_0 k^2 2 \sin\theta \left(\frac{1}{jkr} + \frac{1}{(jkr)^2} + \frac{1}{(jkr)^3} \right) e^{-jkr} \hat{\theta} \quad (4.2)$$

$$H_{\phi} = -\frac{I_0 dl}{4\pi} k^2 \sin\theta \left(\frac{1}{(jkr)^2} + \frac{1}{jkr} \right) e^{-jkr} \hat{\phi} \quad (4.3)$$

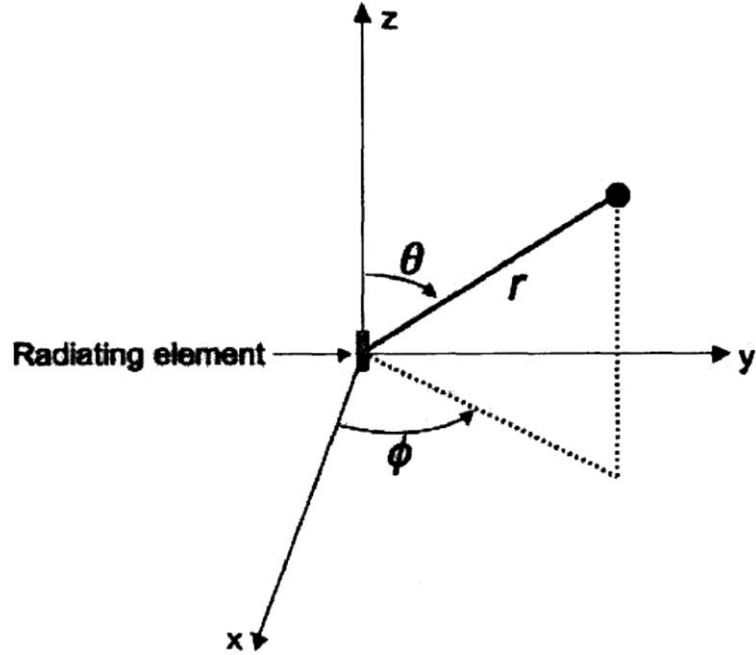


Figure 4.1: The field components of radiating elements are often expressed in spherical coordinates (r, θ, ϕ) rather than Cartesian coordinates (x, y, z) .

4.2.1 The Near-Field Region

The distance $r_{cutoff} = 1/k = \lambda/2\pi$ determines the nature of the surrounding fields and distinguishes the near-field region from the far-field region. For distances $r \ll r_{cutoff}$, the third order terms of the electric field \bar{E} dominate; the second order term of the magnetic field \bar{H} dominates, and e^{-ikr} approaches 1:

$$\bar{E}_{near-field} = j \frac{I_0 dl}{4\pi kr^3} (2\cos\theta \hat{r} + \sin\theta \hat{\theta}) \quad (4.4)$$

$$\bar{H}_{near-field} = j \frac{I_0 dl}{4\pi kr^2} (\sin\theta \hat{\phi}) \quad (4.5)$$

This region for distances $r < r_{cutoff}$ is called the near-field region. The strength of the field components \bar{E} and \bar{H} decay as $1/r^3$ and $1/r^2$ respectively, signifying the short range of the

near-field from the radiating object. Also, evaluating the Poynting vector with the given field components indicates that no real power flow exists in the near-field. Rather, because the electric field and the magnetic field are 90° out of phase with each other, energy is simply being stored and released between the two fields. High-frequency (HF) antennas operate in the near-field region where energy is transferred at close range and using magnetic coupling.

4.2.2 The Far-Field Region

When $r \gg r_{cutoff}$ the *first* order terms of the field equations dominate:

$$\bar{E}_{far-field} = j \frac{I_0 dl}{4\pi r} \eta k e^{-jkr} \sin\theta \hat{\theta} \quad (4.6)$$

$$\bar{H}_{far-field} = j \frac{I_0 dl}{4\pi r} k e^{-jkr} \sin\theta \hat{\phi} \quad (4.7)$$

The region for distances $r > r_{cutoff}$ is the far-field region. From the equations 4.6 and 4.7, the \bar{E} and \bar{H} fields are in phase, orthogonal, and decay similarly as $1/r$. Evaluating the Poynting vector in the far-field region results in a real power density signifying wave propagation. Ultra-high frequency (UHF) antennas operate in the far-field region.

4.3 Antenna Parameters

A background of the fundamental antenna parameters is presented in order to understand the physical behavior of the antenna and also to improve its performance. These antenna parameters are directly obtained by a professional electromagnetic solver and dependent on the antenna's geometry.

4.3.1 Return Loss

In a transmission line, when an incident wave propagates along it, V^+ , a fraction of the voltage amplitude is reflected, V^- due to the impedance discontinuities. The reflection coefficient, Γ , is defined as:

$$\Gamma = \frac{V^-}{V^+} = \frac{Z_L - Z_S}{Z_L + Z_S} \quad (4.8)$$

Where Z_L is the load impedance and Z_S is the source impedance. A single pair of input/output terminals, referred to one port. The corresponding scattering matrix consists on a single element, the scattering parameter or reflection coefficient S_{11}

$$b_1 = S_{11} \times a_1 \quad (4.9)$$

Where a_1 the incident is wave in the port and b_1 is the reflected wave in the port. The return loss of an antenna (RL) is calculated by:

$$RL = -10 \log_{10} |S_{11}|^2 = -10 \log_{10} |\Gamma|^2 \quad (4.10)$$

4.3.2 Gain

The gain of an antenna is defined as the ratio of the maximum power density to its average value over a sphere and it is often expressed in dBi, where i represent the gain with respect to an isotropic antenna. An isotropic antenna radiates equally in all directions and therefore, has a gain of 1. For example, the common half-wave dipole has a gain of 2.15 dBi. Thing Magic's Mercury4 reader antenna has a gain of 4.6 dBi. High gain antennas such as the Dish antenna have gains on the order of 20 dBi.

4.3.3 Directivity

The directivity in a direction measures the power density that an antenna radiates in a specific direction, relative to the power density radiated by an ideal isotropic radiator antenna radiating the same amount of total power.

This parameter is related with the power of radiation, and it is used to know the efficiency of the antenna with the equation

$$G = N \times D \quad (4.11)$$

Where G is the gain, D is the directivity, and N is the efficiency of the antenna.

4.3.4 Power

Just as gain is often measured in reference to some standard antenna, i.e. an isotropic resonator, so too is the radiated power. Radiated power is stated in terms of effective (or equivalent) isotropically radiated power (EIRP), which is defined as its input power multiplied by its gain relative to an isotropic antenna.

$$EIRP = G_t P_t \quad (4.12)$$

4.3.5 Resonant Frequency and Bandwidth

Antennas typically "resonate" or operate at a particular frequency and are size proportionally to the wavelength of the operating electromagnetic wave. For example, a half-wave dipole

antenna that operates at 915 MHz has a length of fifteen centimeters, which is half operating wave's wavelength.

An antenna's bandwidth is defined as the range of frequencies at which the antennas gain is less than 3dB of its peak gain. However, increasing bandwidth reduces antenna gain.

4.3.6 Radiation Pattern

The antenna radiation pattern is defined as the spatial distribution of a quantity which characterizes the electromagnetic field generated by an antenna [28]. It is possible to represent the radiation pattern of an antenna using three dimensions or two dimensions, on both spherical and polar coordinate systems respectively. The two dimensional radiation patterns can be used to determine the relative strength of the radiation power in the far field with regard to the direction.

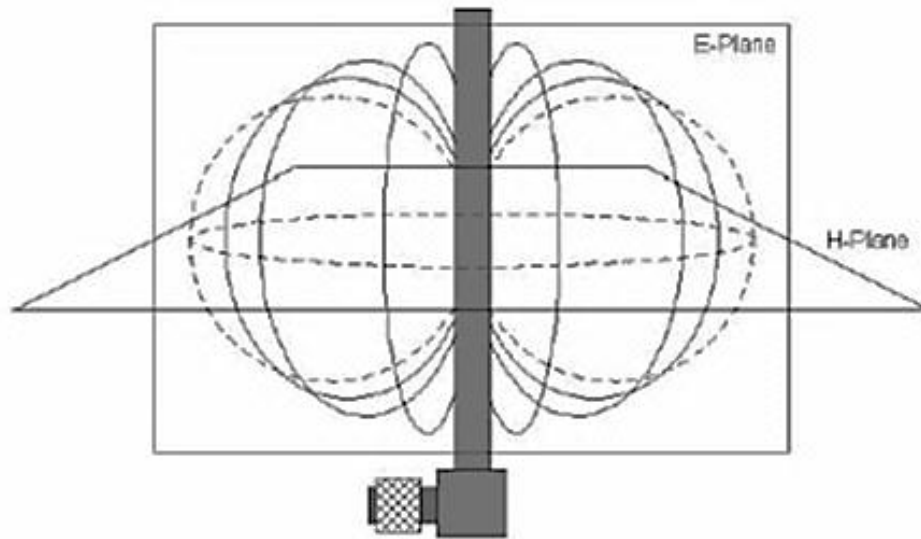


Figure 4.2: E-plane and H-plane for a dipole antenna [2]

On the spherical coordinate system two different planes are particularly interesting: the E-plane (the plane containing the electric field vector and the direction of maximum radiation) and the H-plane (the plane containing the magnetic field vector and the direction of maximum radiation).

In this I have to study the gain. The level of this parameter is related with the power of the feeding. With the directivity, it allows to know the efficiency of the antenna.

4.3.7 Polarization

The polarization of antenna is determined by the electric field of the wave emitted by the antenna. Specifically, the magnitude and phase of the electric field \vec{E} dictate the antenna's polarization. If the magnitudes and phases of the electric field components are equal, the antenna is linearly polarized. If the magnitudes are equal, but the phases differ by 90° , the antenna is circularly polarized.

The electric field components of a linearly-polarized wave project a line onto the plane where the electric field components of a circularly polarized wave project a circle as shown in Figure 4.3

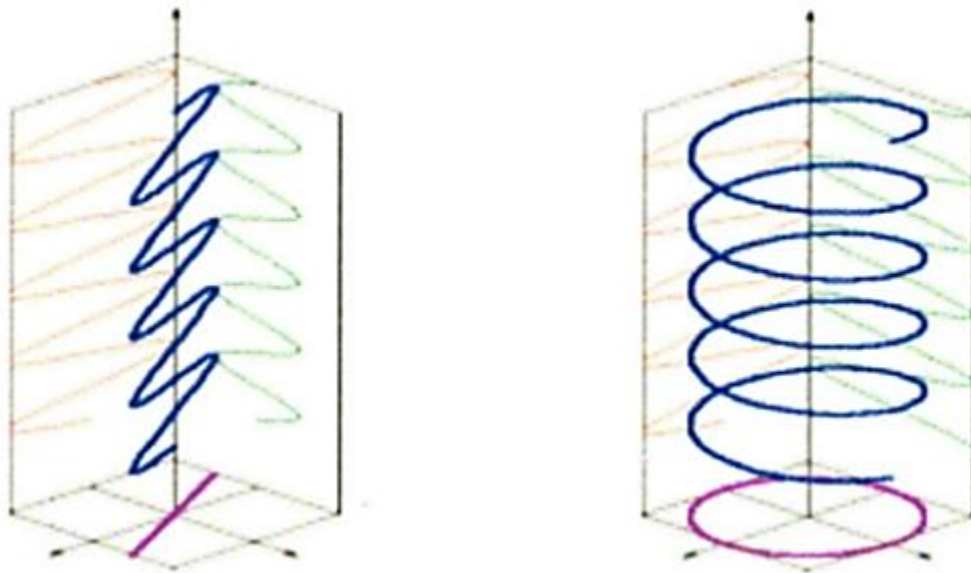


Figure 4.3: Linear and Circular Polarization [23]

In order for two linearly polarized antennas to communicate with each other, their projected electric fields must be aligned. A circularly polarized antenna however, can communicate with any linear antenna regardless of its orientation. Each polarization type has its advantage; where a circular antenna is orientation insensitive, a linear antenna radiates higher power because all the power is directed in one direction as opposed to being split among the two components.

4.3.8 Input Impedance

The input impedance of an antenna is defined as the ratio of the voltage to current at the antennas terminals. The length and size of the antenna determine its input impedance. The impedance Z has a real portion, which includes the antenna's radiation resistance R_{rad} and its ohmic losses, and a reactive portion which contains energy from the fields surrounding the antenna.

$$Z = R_{rad}R_{ohmic} + jX \quad (4.13)$$

When electromagnetic energy is transferred from one medium to another, say from an antenna to a microchip, the absorption of energy depends on the relative impedances of the two media. For maximum power transfer between the antenna and its attached load, the impedances of the antenna and the load must be conjugate matches. Their real components should be equal, while their reactive components should be equal and opposite.

More specifically, the reflection coefficient Γ , is a measure of how much of the transferred energy is reflected back into the original source

$$|\Gamma| = \frac{Z_l - Z_a}{Z_l + Z_a} \quad (4.14)$$

Equation 4.6 shows that when the load impedance of the microchip Z_l , is open or shorted, the reflection coefficient Γ equals 1 and all the energy is reflected back into the antenna. If however, the impedance of the microchip Z_l , and the impedance of the antenna Z_a are equal, Γ equals 0 and all the energy is absorbed by the microchip.

4.4 Under Water Antenna

To design antenna for underwater communications it is necessary to know which antennas are more suitable for propagation into water. Loop antennas, Long wires and Dipoles have been successfully used underwater at very low frequencies. Because of the reduction of the frequency because of their physical dimensions are lower than their equivalent in space. In the underwater communications, antenna conductors are insulated from the water to prevent leakage of direct current to the conducting medium.

Figure 4.4 (a) shows the transmitter/receiver circular loop antenna and Figure 4.4(b) shows the folded dipole antenna [2]



Figure 4.4: (a) Circular loops

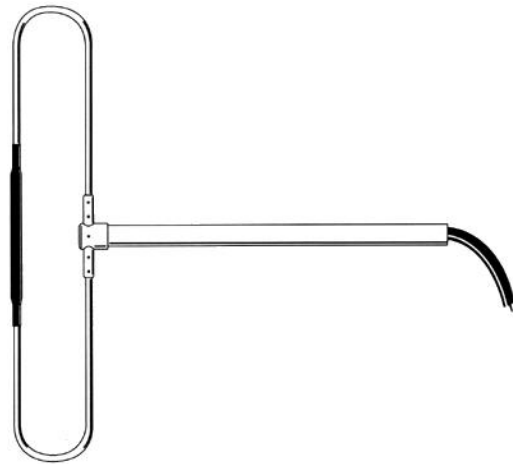


Figure 4.4: (b) Folded dipole

Figure 4.4: (a) the transmitter/receiver circular loop antenna and Figure 4.4 (b) shows the folded dipole antenna [2]

4.5 UWB (Ultra-Wide Band) Antennas

There are three different classes of UWB antennas based on different applications:

4.5.1 DC-to-daylight

These antennas are designed to have maximum bandwidth and to use as much spectrum as possible. Typical applications are ground penetrating radars, field measurements or electromagnetic compatibility, impulse radars, and shelter communication systems.

4.5.2 Multi-narrowband

The design goal of multi-narrow band antennas is similarly to grab as much spectrum as possible but to only use small sub-bands at any given time. These antennas are designed as scanner or signal intelligence antenna for receiving or detecting relatively narrowband signals through certain frequencies.

4.5.3 Modern UWB Antenna

These are antennas designed for use in conjunction with the approximately 3:1 bandwidth, as 3.1-10.6 GHz UWB systems authorized by the FCC (Federal Communications Commission). The bandwidth requirements for a modern UWB antenna are narrower than for DC to daylight antennas. These antennas have certain implications that distinguish them from the other more traditional classes of UWB antennas. First, instead of trying to grab maximal bandwidth, these modern UWB antennas must operate within a certain spectral mask. In this context, excessive bandwidth degrades system response and is counterproductive.

Some UWB Antenna technology based on their characteristics:

4.5.4 Frequency independent antennas

Antennas whose mechanical dimensions are short compared to the operating wavelength are usually characterized by low radiation resistance and large reactance. This combination results in a high quality level and consequently a narrow bandwidth. The current distribution on a short conductor is ideally sinusoidal with zero current at the free end, but because the conductor is so short electrically, typically less than $\lambda/30$ of a sine wave, the current distribution will be approximately linear. By end loading to give a constant current distribution, the radiation resistance is increased four times, thus greatly improving the efficiency but not noticeably altering the pattern. Because the effective source of the radiated fields varies with frequency, these antennas tend to be dispersive. Examples of frequency independent antennas include spiral, log periodic, and conical spiral antennas.



Figure 4.5: Spiral Antenna

4.5.5 Horn antennas

A horn antenna is an electromagnetic funnel concentrating energy in a particular direction. Horn antennas tend to have high gain and relatively narrow beams. Horn antennas also tend to be large and bulkier than small element antennas. These antennas are well suited for point-to-point links or other applications where a narrow field of view is desired. Horn antenna is usually applied to the air-launching GPR system. It is made from two tapered metal plates, including exponentially tapered or linearly tapered. There are a narrow feed point and a wide open end at both sides of transfer electromagnetic horn.

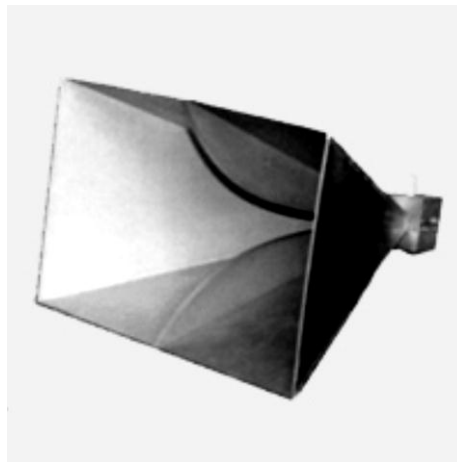


Figure 4.6: Horn Antenna

4.5.6 Reflector antennas

A reflector antenna also concentrates energy in a particular diffraction. Like horn antennas, reflector antennas tend to have high gain and are relatively large. Reflector antennas tend to be structurally simpler than horn antennas and are easier to be modified and adjusted by manipulating the antenna feed.

4.4.7 Small element antennas

Achieving high gain in a small-size antenna is a very desirable characteristic for many applications. A small element antenna is capable of attaining high gain in a simple structure. These antennas tend to be small, omnidirectional antennas well suited for commercial applications. Examples of small element antennas include Lodges biconical and bow-tie

antennas, diamond dipole, ellipsoidal antennas, and Thomas circular dipole. Figure 4.7 shows the small element bow-tie antenna.

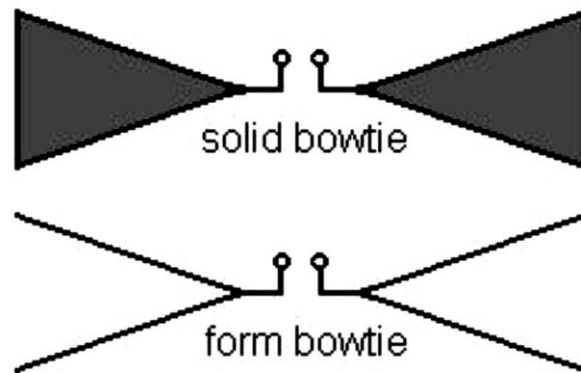


Figure 4.7: solid bowtie and form bowtie antenna [2]

4.5.7.1 Solid bowtie

It has been demonstrated that the bow-tie wire structure is a good approximation for a solid bow-tie antenna as shown in Figure 4.7. The main advantage of such a wire bow tie is that it offers the possibility for controlling the flare angle electronically [26]. By virtue of the wire structure, it would be possible to implement electronic switching devices (e.g., PIN diodes) for deactivating certain wire elements of the antenna to form the desired flare angle. This approach allows a fast and convenient way for controlling the bow-tie flare angle required in a real GPR survey, as the antenna should promptly adapt to any changes in antenna elevation and soil type.

4.6 Characteristics for Underwater Antenna Simulations

4.6.1 Software Characteristics

For antenna design some kind of software is used to simulate the response of the antennas to analyze the results and to determine the best shape for each application. However, these applications are normally for air, and the simulation tools of the software are prepared for that purpose and not for underwater applications. The most used software, CST Microwave Studio Suite 2009 determines which best condition for underwater applications. The antenna performance is simulated by CST Microwave Studio (MWS). This software has the ability to use Visual Basic scripts for program control

4.6.1.1 The Mesh

The high permittivity of the water makes the simulations more difficult. The simulations, determined by the software solve the antenna's area or volume of interest. In CST software, the mesh is three-dimensional. To determine volume of the background where the shape is placed, and analyzes all the volume with the mesh. The shape of the mesh cells is rectangular.

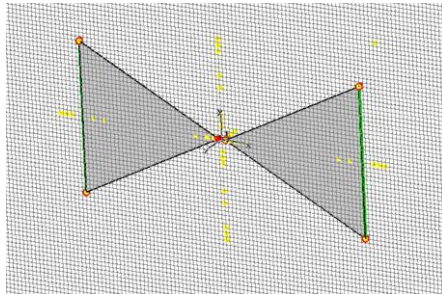


Figure (4.8): The mesh [2]

In order to choose an appropriate mesh in CST, some parameters are defined below:

4.6.1.1.1 Lines per wavelength

This value is connected to the wavelength of the highest frequency set for the simulation. It defines the minimum number of mesh lines in each coordinate direction that are used for a distance equal to this wavelength. In a way, it sets the spatial sampling rate for the signals inside of your structure. This setting has a strong influence on the quality of the results and on the calculation time. Increasing this number leads to a higher accuracy, but unfortunately also increases the total calculation time.

4.6.1.1.2 Refine at PEC / lossy metal edges by factor

This option increases the spatial sampling at PEC or lossy metal edges. At these edges additional density points are added that force the automatic mesh generator to increase the mesh density at those points by the given factor. This setting is very useful, because at metal edges you theoretically obtain singularities in the electromagnetic fields. This means that the fields vary very much near such edges and have to be sampled higher than elsewhere.

5.1 Introduction

This chapter is dealing with the analysis of the selected circular bow-tie antenna is the combination of bow-tie and circular loop antenna. The circular loop provide low loss and omnidirectional radiation pattern and also shown a good behavior in water. The bow-tie antenna is also a typical UWB antenna, used for many applications for wireless communication, with a great variety of forms. The combination of both shapes arise a new antenna. The behavior of antenna in water, because their response in air could be similar to that in water, but in a bandwidth 9 times lower, and with a different return loss level (because the impedance depends of the environment). Finally, study the parameter to choose the best shape using CST Microwave Studio software to obtain the return loss, the phase and the radiation pattern.

The feeding in both cases do not have to touch water because it is needed an electrical device to feed the antenna. In the air simulations this is not a problem, but in the water isolate the feeding is necessary. In these cases, the isolation is done by putting the feeding inside a small region with free space.

The propagation of radio waves underwater and between water and air to facilitate setting up hybrid wireless sensor networks with both surface and subsurface nodes. The investigation includes signal attenuation, antenna radiation patterns, multipath due to reflections from the surface and substrate, noise, and reflection losses transmitting from one medium to another.

5.2 Circular bow-tie antenna

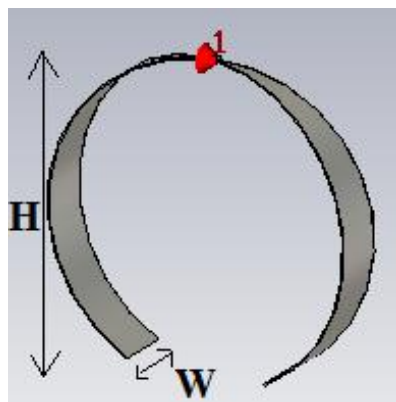
Circular loop and bow-tie antennas are the most suitable antennas for the underwater communication. Circular loop presents a better behavior in water environment than in air and also has been used in underwater communication at very low frequency as shown in figure 4.4. The bow-tie is also a typical UWB antenna, used for a lot of applications, and with a great variety of forms. The combination of both shapes arise a new antenna.

The simulations are done completely in CST Microwave Studio, using an accurate mesh to ensure reliable results. The most important characteristics taken into account are:

- The return loss must be less than -10 dB from a low frequency around 100MHz.
- The antenna has to be omnidirectional.
- The size of the shape should not be large.

The antenna size has to be as smaller as possible. This restriction is very important to determine the low frequency from which the return loss level becomes minor than -10dB.

The perspective and top view of circular bow-tie antenna is shown in figure 5.1



(a) Perspective view

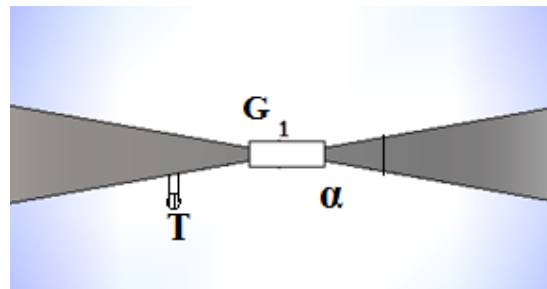


Figure 5.1: (b) Top view

Figure 5.1: the Perspective view and Top view of antenna

5.3 Measurement of Antenna Parameters

The Measurement of circular bow-tie antenna parameters suggests the analysis of geometric configuration of antenna. The final shape should satisfy different specifications such as physical size and electrical performance. The electrical performance is concerned, the antenna should be able to transmit a pulse having a bandwidth ($S_{11} \ll 10$ dB) located in the range from 100 MHz to 1 GHz (wide bandwidth implies a good resolution time). A return loss level lower than -10 dB means that more than the 90% of the energy is radiated. These parameters are:

- Angle (α)
- Width (W)
- Thickness (T)
- Height (H)
- Feeding (G)

5.3.1 Angle (α)

As it can be seen from figure 5.2, S-parameter has different value at different angles (α). It is noticed that $\alpha=20^\circ$ implicates a return-loss level less than with angles $\alpha=30^\circ$, $\alpha=34^\circ$ and $\alpha=40^\circ$, hence $\alpha=20^\circ$ gives better result. This is not possible to choose angle less than $\alpha=20^\circ$ because the width of antenna will be changed.

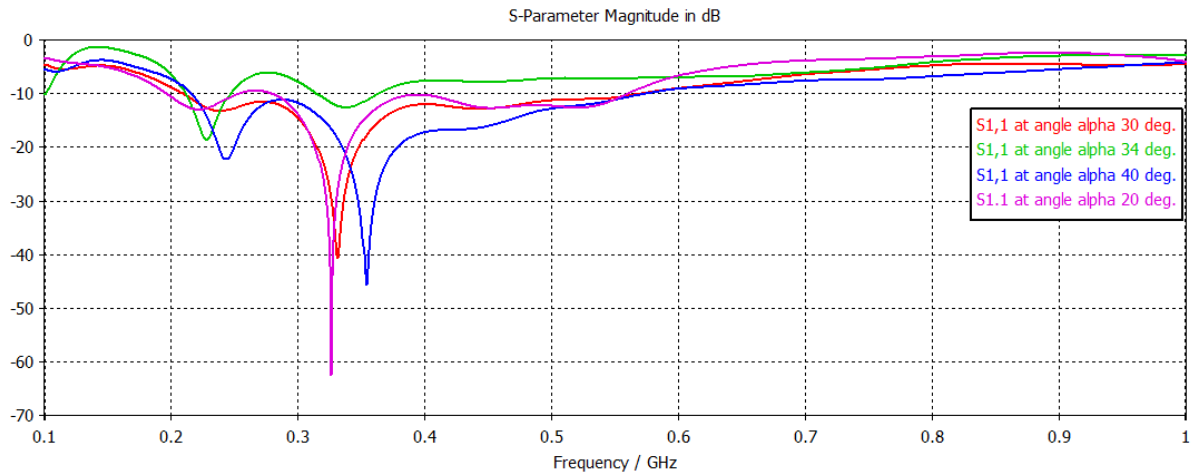


Figure 5.2 S_{11} of different Angle

5.3.2 Width (W)

In this section the width of the shape have to be studied. The angles are verifying keeping width $W= 1.8\text{cm}$ so original width is 1.8cm . The change in width is shown in figure 5.3.

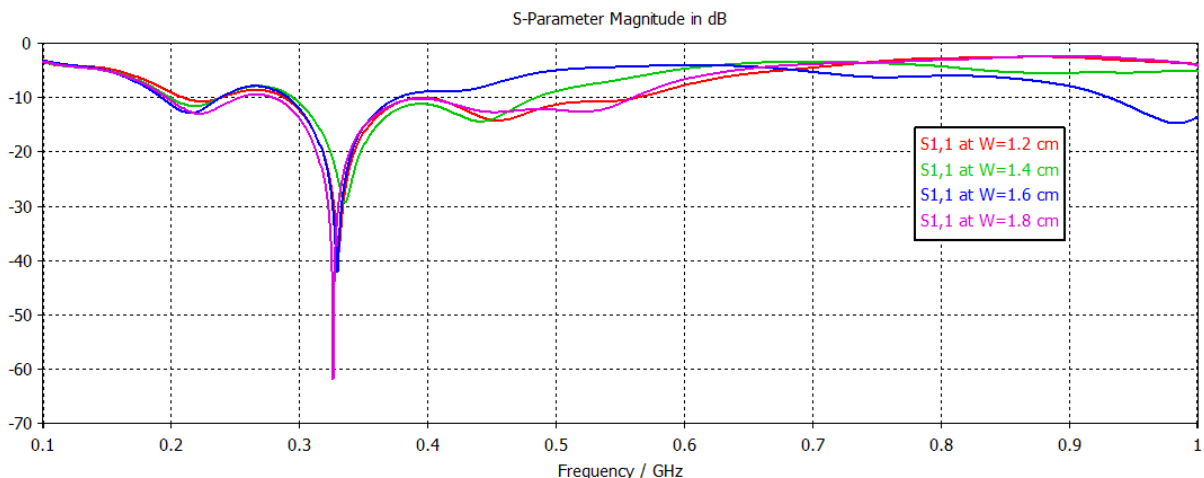


Figure 5.3 S_{11} of different Width

However, as the width of antenna increase the shape of antenna change drastically, so at width $W= 1.8\text{cm}$ the angle $\alpha=20^\circ$ provide very less return-loss. The results of the parametric

study of the angle and the width lead that it is possible to improve the return-loss changing the width and the angle at the same time.

5.3.3 Thickness (T)

It is noticed from the figure 5.4, the return-loss is very low at thickness $T=.05$ cm. so this value gives good result. As the thickness of antenna varies the return-loss value also vary and does not provide acceptable value.

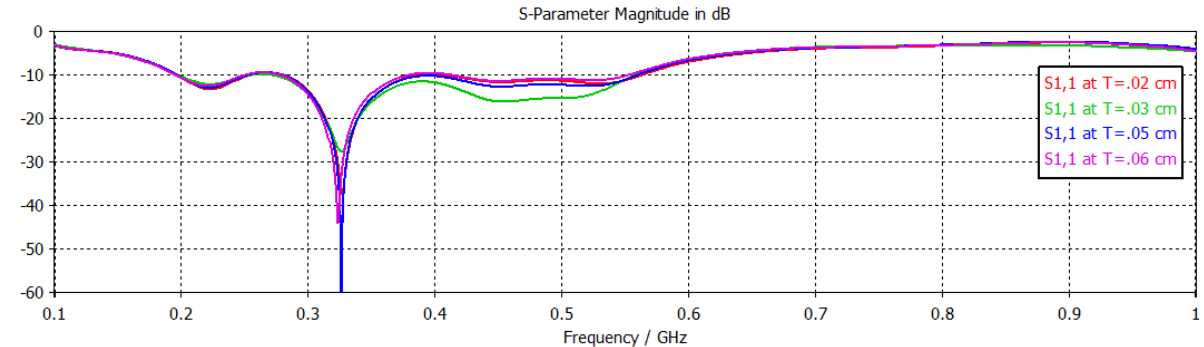


Figure 5.4 S_{11} of different Thickness

5.3.4 Height (H)

Finding the best angle, width and thickness from different value, another interesting parameter is height (H) of antenna. Figure 5.5 shows the S-parameter changes in accordance with height of antenna so $H=9.4$ cm (≤ 10 cm) provide acceptable result.

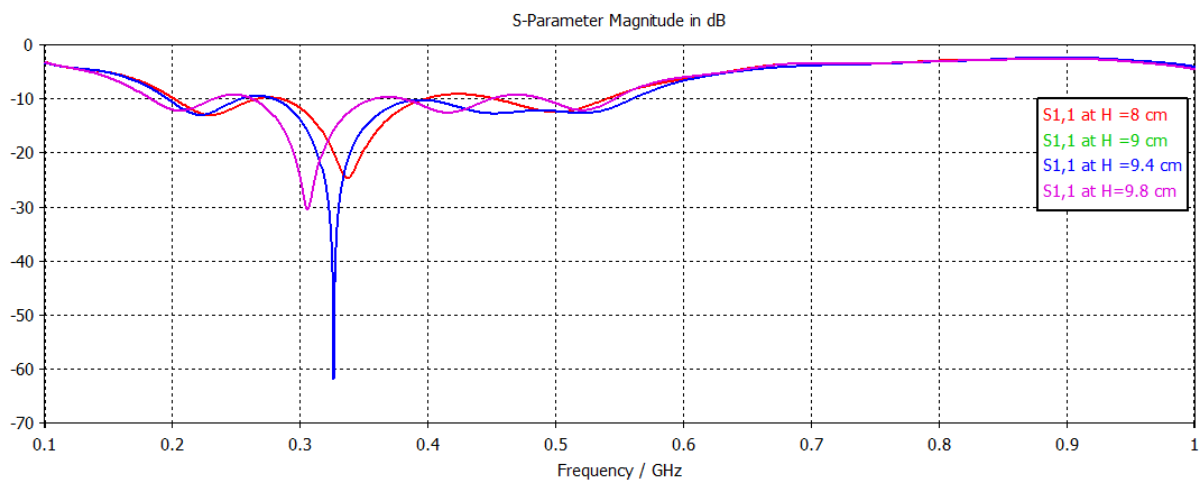


Figure 5.5 S_{11} of different Height

5.3.5 Feeding (G)

The gap of the feeding is 3 mm because the region is isolated from the water and this is the best distance. The region of the feeding has an important effect on the return loss. In this section four different sizes will be tested and the best dimensions will be including, as it can be noticed in Table.

Table 5.1: Tested dimensions (in cm) of the air region to isolate the feeding

Case	Width(FW)	Depth (FD)	Hight (FH)	Return-Loss
First Case	.30	.44	.30	-25 dB
Second Case	.40	.40	.15	-26 dB
Third Case	.30	.60	.05	-27 dB
Fourth Case	.20	.60	.20	-28 dB

As it can be seen in figure 5.6 (b), the fourth case is best for region of isolation.

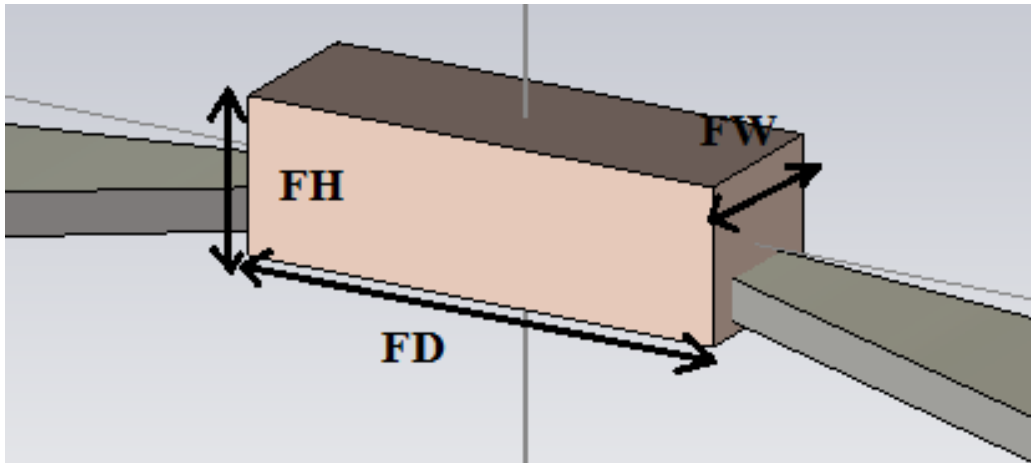


Figure 5.6 (a): Studied parameters of the isolated region

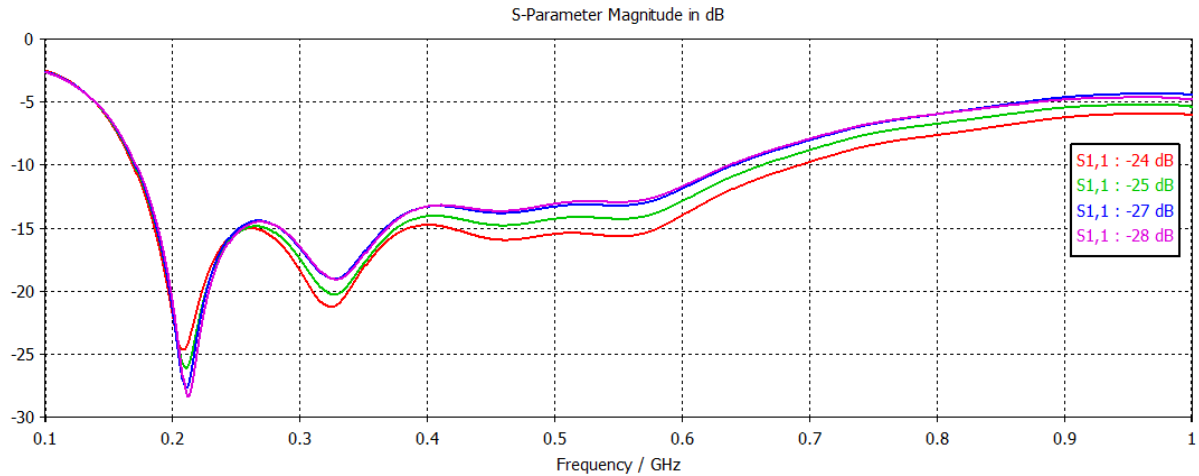


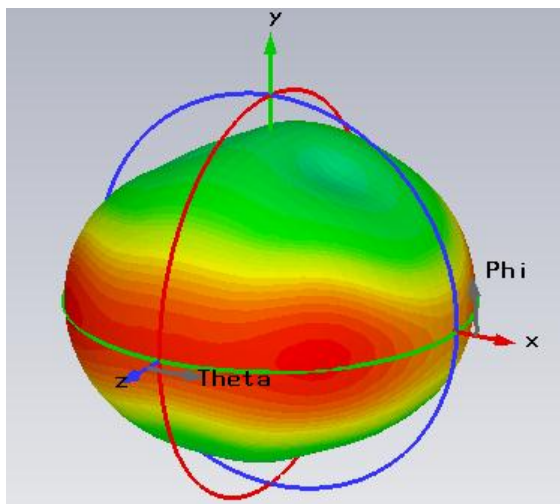
Figure 5.6 (b): S_{11} of the different sizes of the isolated region

The return loss is shown in Figure 5.6, and the radiation pattern in Figure 5.7. The results of the CST's simulation indicate:

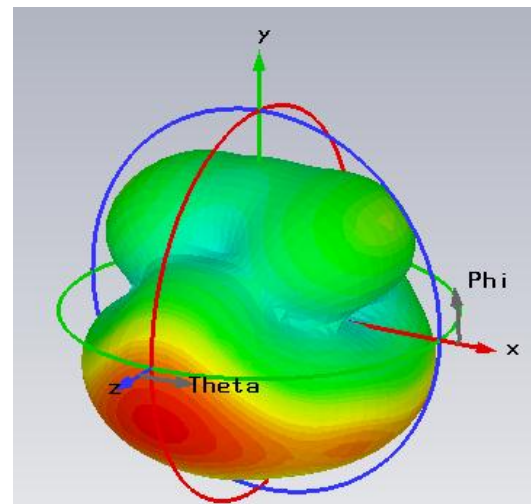
1. The return loss is less than -10dB from 180MHz (Figure 5.6), a frequency lower than the original one.
2. The behavior is UWB because the bandwidth is greater than 500MHz; it is from 200MHz to more than 1GHz.

5.3.5.1 Radiation pattern

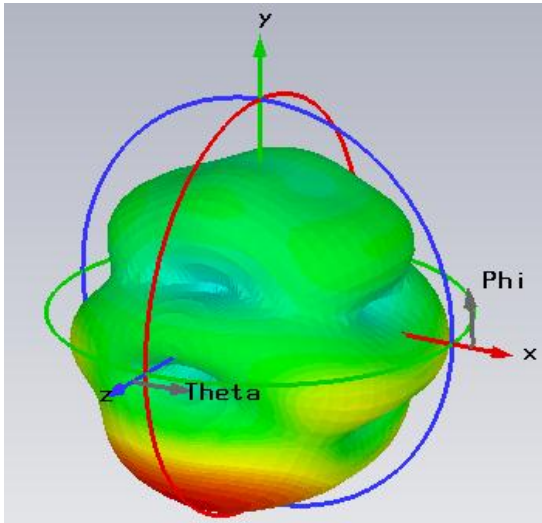
The radiation pattern without internal isolation at different frequency is shown in figure 5.7,



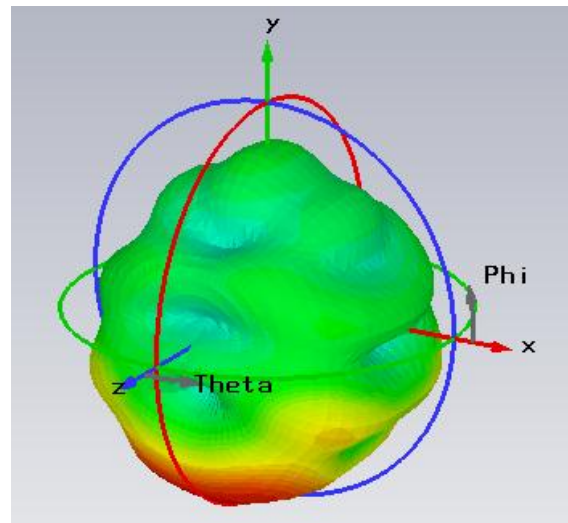
(a) 180 MHz



(b) 270 MHz



(c) 482 MHz



(d) 582 MHz

Figure 5.7: 3D Radiation pattern without internal isolation

As it can be noticed in Figure 5.7, the radiation pattern is almost omnidirectional, especially at the frequencies close to 180 MHz. However, at higher frequencies, it is not totally omnidirectional because when the length of the ring is greater than a half-wave dipole, some new nulls and some new lobes appear in the pattern.

5.4 Final shape with internal isolation

As the antenna has to work in water, an air or air-Teflon sphere is put inside the antenna to isolate the battery and the electrical circuit from the water (Figure 5.8). This isolation ball implies important changes in the behavior of the antenna; hence an analysis of these variations is presented in this section.

The boundary of the air ball in the first case is touching the antenna. On the other hand, the air-Teflon ball is almost the same, but with a half centimeter of Teflon recovering the air. This is important because air and water have to be, obviously, separate. Furthermore, the air region of the feeding has to be improved. Otherwise, in the air-Teflon ball case, it can be added one millimeter of Teflon to separate air and water.

Antenna with internal isolation is shown in figure 5.8:

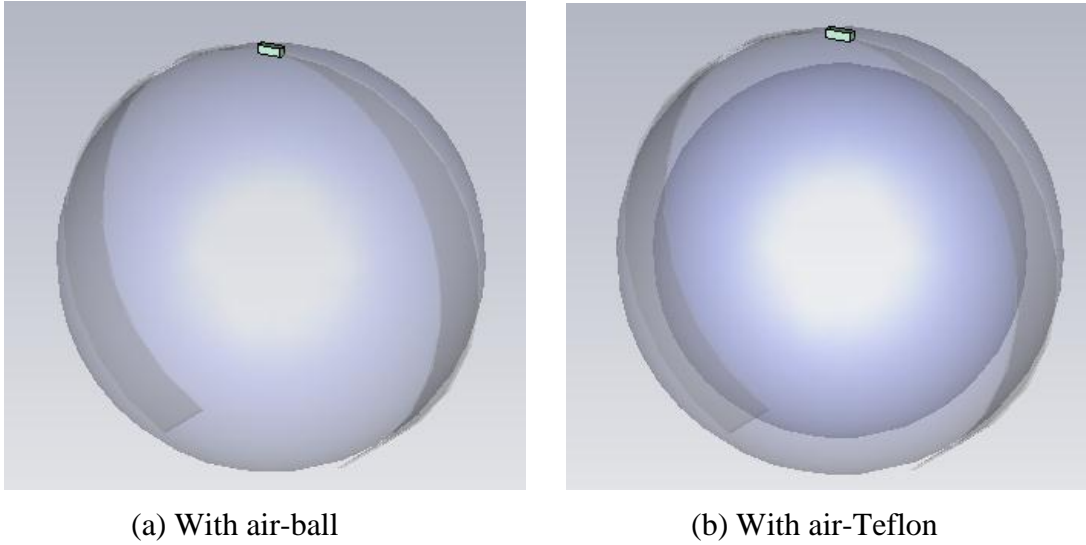


Figure 5.8: Antenna with internal isolation

5.4.1 Return loss

The return loss level of the three models: without internal isolation, with an air ball, and with an air-Teflon ball is shown in figure 5.9.

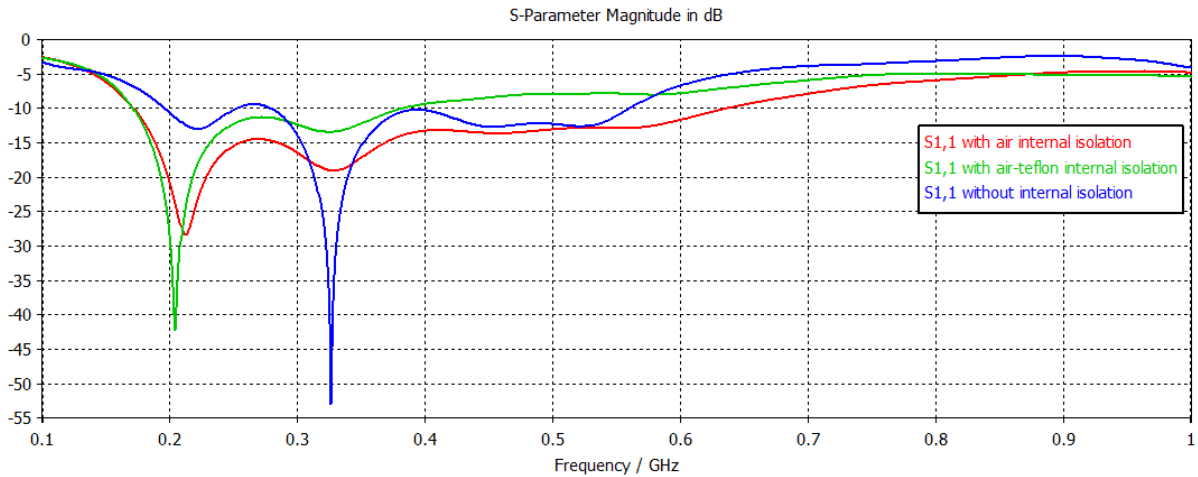


Figure 5.9: S_{11} with and without internal isolation

The results of the Figure 5.9 indicate the antenna works in a good way with the internal air-Teflon internal isolation ball, but not with the internal air-Teflon ball. The first case of air internal isolation shows the return-loss level is below -10 dB at frequency 210 MHz which very high as compared to third case. In third case the return-loss level is very less at frequency 325MHz but at high frequency the attenuation is high.

The second case with air-Teflon internal isolation provide return-loss below -40 dB at low frequency 201 MHz hence this is the best configuration of circular bow-tie under water antenna.

5.4.2 Radiation pattern

Checking the return-loss at different internal isolation the analysis of the radiation pattern in some frequencies is shown in figure 5.10:

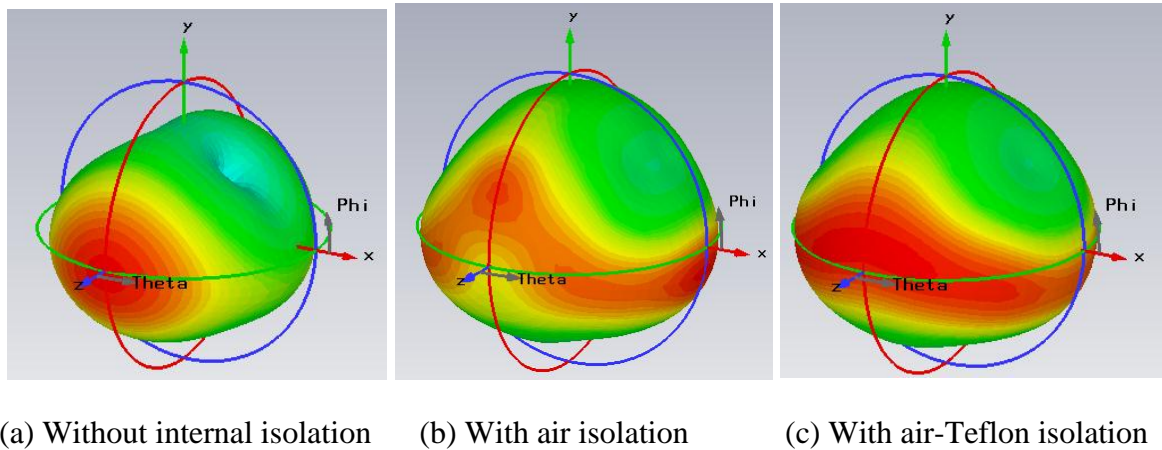


Figure 5.10: 3D radiation pattern at 206 MHz

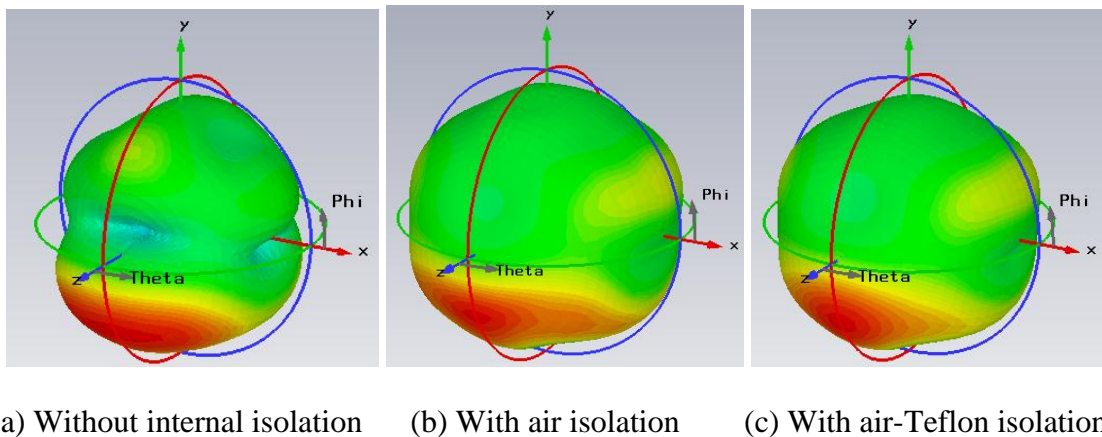
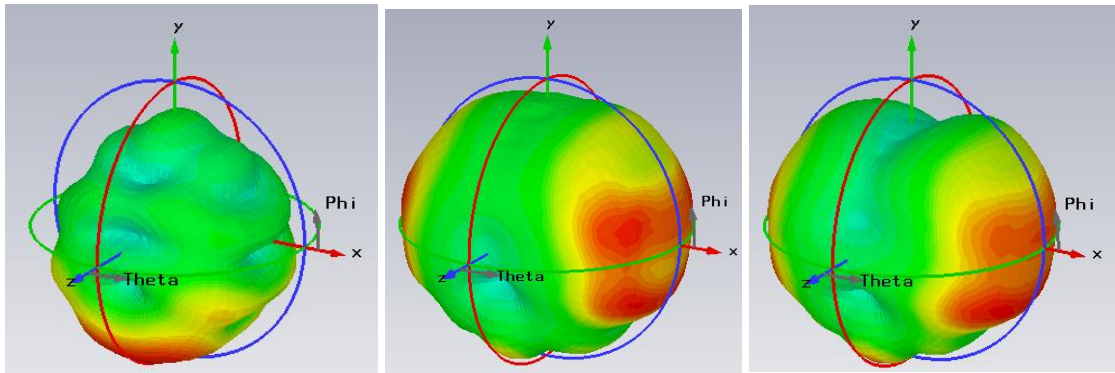


Figure 5.11: 3D radiation pattern at 325 MHz

Figures 5.10, 5.11 and 5.12 show the results in 3D, while Figure 5.13 shows the radiation pattern in 2D (XZ plane). It can be observed that:

- At low frequencies (over to 200MHz) the pattern is omnidirectional in the XY-plane.



(a) Without internal isolation (b) With air isolation (c) With air-Teflon isolation

Figure 5.12: 3D radiation pattern at 582 MHz

- At medium frequencies (over to 300MHz) the radiation of the first model is mostly in the bottom in form of circle, while in the model with the air ball is almost of all in the side bottom. In the third case it is obtained a radiation pattern totally symmetry like in the others a without internal case but radiation is more.
- At high frequencies (over 500MHz) the first model has a lot of lobes, and the energy is concentrated in the bottom of the antenna. The radiation pattern of both models with internal isolation is similar, and they have a behavior quite omnidirectional, with a maximum of transmission in the middle of the sides.

Finally, it is clear that the model without internal isolation and the model with internal air-Teflon isolation radiates correctly in almost all the directions. When the antenna will be placed in a liquid medium, it will be floating, moving and rotating all the time.

5.4.3 Directivity

The last parameter to analyze is the directivity of the antenna which is dependence of the frequency. There are three cases antenna without internal isolation with air isolation and with air-Teflon isolation. As it can be noticed in Figure 5.13, the graphic indicates:

- Without internal isolation the antenna has maximum radiation in side middle of z-direction, shown in figure 5.10 (a) at low frequency (from 70 MHz to 325 MHz) and beyond 325 MHz the energy radiated in bottom of the antenna, shown in figure 5.11 (a) and 5.12 (a). In other direction the radiation pattern is very poor.

- In case of with air isolation the antenna has maximum radiation in middle of xz-direction, as shown in figure 5.10 (b) at low frequency (from 50 MHz to 206 MHz) after 206 MHz to 325 MHz the energy radiated in side middle of antenna as in figure 5.11 (b). At high frequency above 500 MHz the antenna radiate energy in bottom, as shown in figure 5.12(b). In other direction the radiation pattern is very poor.

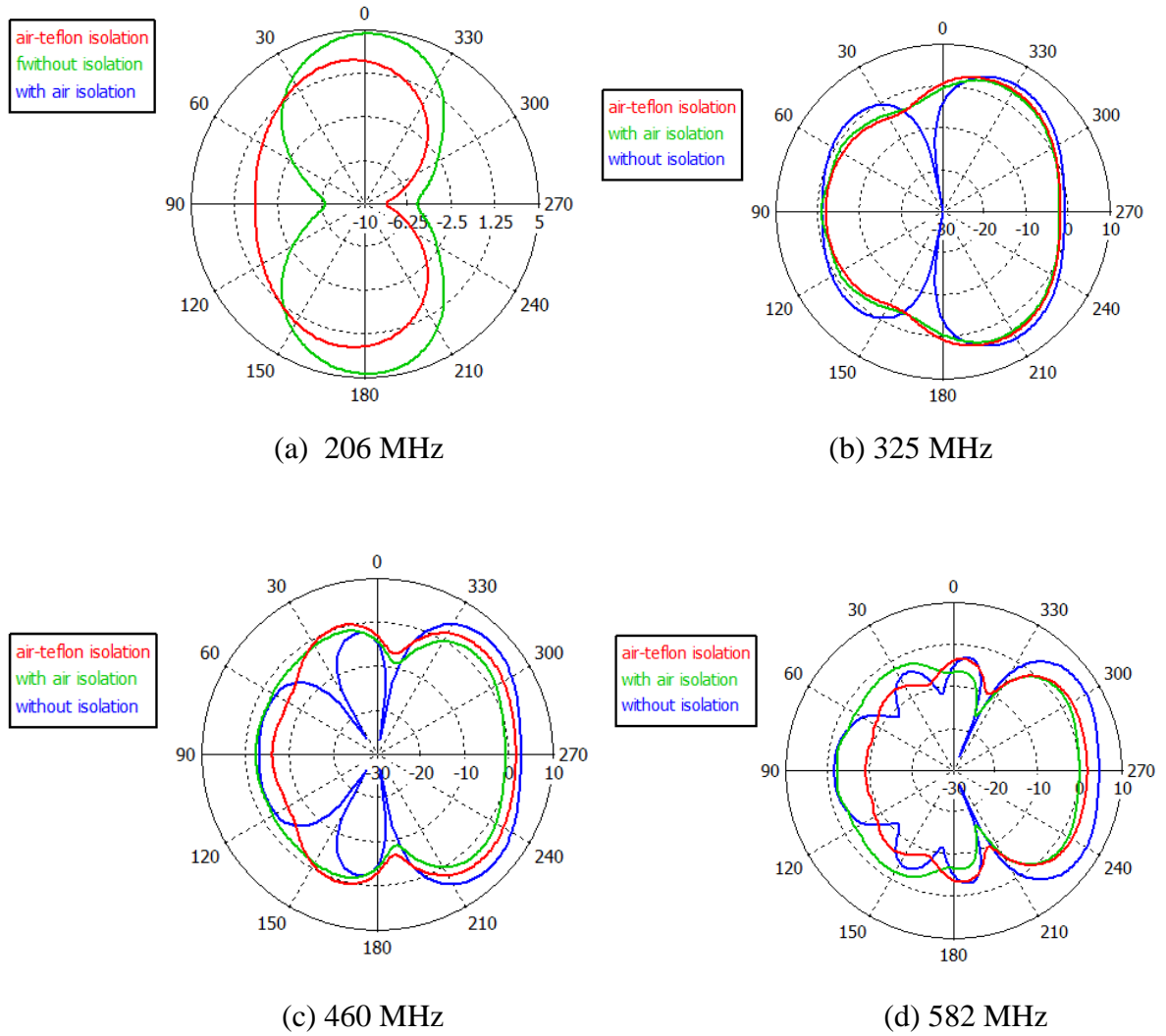


Figure 5.13: Radiation pattern of the gain (in dB) in 2D (XZ plane) at different frequencies

- In case of air-Teflon isolation the antenna has maximum radiation in middle of xz-direction, shown in figure 5.10 (c) at low frequency (from 10 MHz to 201 MHz) after 201 MHz the energy radiated by antenna in side bottom as in figure 5.11 (c). At high

frequency beyond 500 MHz the energy radiated in x-direction of the antenna as shown in figure 5.12 (c). In other direction the radiation pattern is very poor.

5.5 Variations in the medium

5.5.1 Conductivity

After finding a good shape for the application in pure water ($\sigma = 0 \text{ S/m}$), and constant relative permittivity of 81. Figure 5.14 shows the return loss of the final shape with air-Teflon isolation with conductivity $\sigma = 0 \text{ S/m}$ and permittivity $\epsilon = 81$.

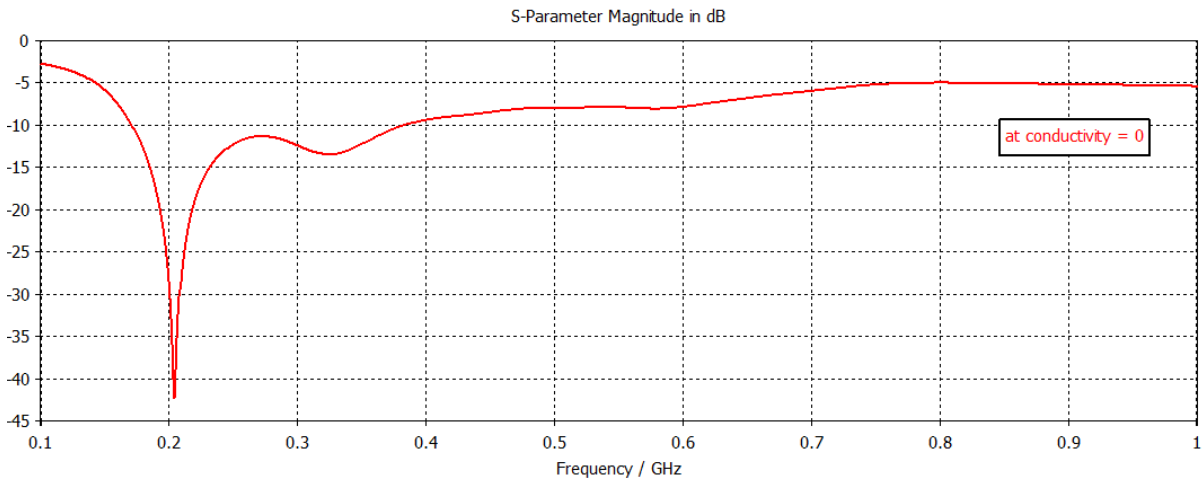


Figure 5.14: S_{11} of with air-Teflon isolation with $\sigma = 0 \text{ S/m}$ and $\epsilon = 81$

5.5.2 Permittivity

Another important issue to take into account when some communication is working in a liquid is the permittivity (ϵ) of the medium. Up to now it has only been studied the response if the antennas in water with a dielectric constant of 81. However, as it has been discussed in Section 3.3.1.4 (Figure 3.5), the permittivity of the water decreases with the temperature. In fact, at 0° C the $\epsilon = 81$ and at 100° C , $\epsilon = 50$. Thus, it is going to be studied the behavior of the final antenna with internal isolation in that range (ϵ from 50 to 88).

The return loss of the antenna in a medium with a permittivity between 50 and 88 does change a lot. The main change is that in the case of the $\epsilon = 50$ an unusual peak at 330MHz can be appreciated, due to the variation of the impedance, due to the variation of the impedance. However, this level of this peak is minor than -10dB.

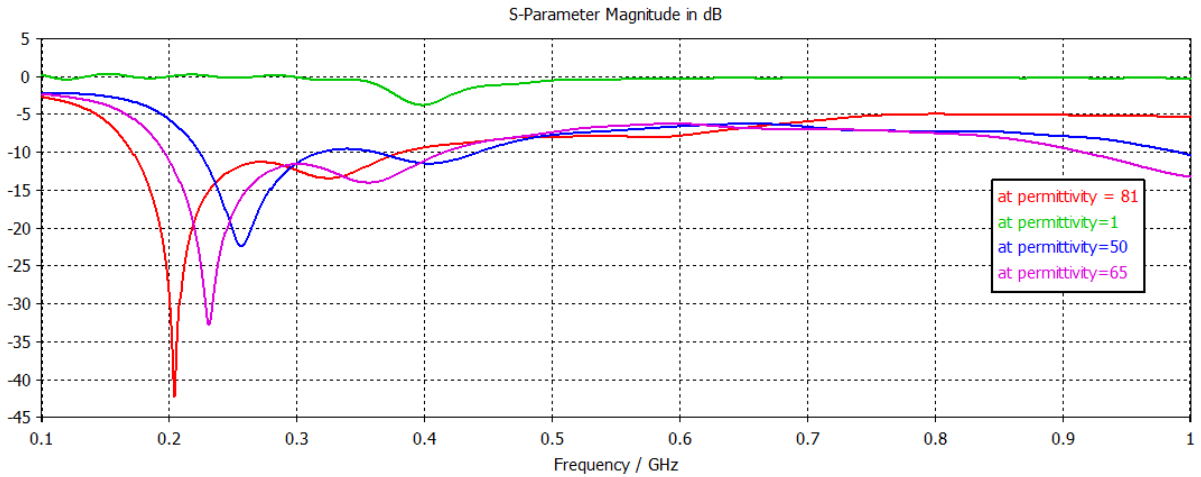


Figure 5.15: S_{11} of with air-Teflon isolation in different permittivity

It can be observed that the same antenna in air has a very bad behavior. That occurs because of the complete variation of the impedance. Thus, if it uses a liquid with a very low permittivity, the antenna will not work in a proper way.

6.1 Conclusion

In this thesis an antenna for underwater applications has been designed. The CST Microwave Studio software tool is used to analyze the parameter of antenna to find out which one is the most suitable for underwater applications. A combination of circular loop and bow-tie has resulted in a new antenna shape: the circular bow-tie antenna. An analysis of this new antenna has been presented. In addition, the isolation problem of the feeding antenna from the water has been taken into account in the design, adding also an internal isolation to be able to isolate the battery and the electrical circuit from the water.

The circular bow-tie shape is good starting points for the design. The return loss of the combination of both shapes in water shows a promising behavior. If an internal isolation (air and air-Teflon) is placed inside the antenna, shows the good behavior. The size of the antenna is an important factor to take into account. The bigger the size is, the better the return loss level in low frequencies. The changes in the medium of propagation affect at the return loss level of the antenna. However, the typical values of the conductivity and the permittivity of water do not affect this parameter too much. The transmission level in pure water is 5dB lower than in air. However, if the conductivity increases, the channel attenuation increases too.

The main conclusions are:

- The return-loss from the measurement and simulation result is obtained lower than -30 dB. The change in feed angles (α) and other parameters affects the return-loss of the designed circular bow-tie under water antenna. As long as the design of the matching network is correct, the desired return loss can be obtained.
- The radiation pattern for different parameter at different value gives an omnidirectional pattern and low return-loss value.
- By comparing the simulation result and measurement result it is notice that the return-loss of antenna varies as changes in parameter.
- The circular bow-tie antenna which have been designed are with angle $\alpha = 20^{\circ}$, Thickness $T=0.05$, Width $W=1.8$ cm, Hight $H=9.4$ cm and feed $G=0.03$ cm. The

simulation result of antenna in three cases (without internal isolation, with air isolation and with air-Teflon isolation) provides return-loss -52 dB, -29 dB and -42 dB respectively.

6.2 Future scope of work

In future work, one more area of development in under water circular bow-tie antenna design is to implement antenna into current technologies in practical situations, another area of interest worth pursuing is to analyze the mathematical aspects of electromagnetic wave propagation in water to correlate their improved characteristics as antennas with their unique geometrical properties. In design aspect at low operating frequency below 200 MHz to find the lower return-loss below -55 dB may be the good result and should provide omnidirectional pattern. The field of designing under water antenna engineering is still early stage of development, with the anticipation of much more innovative advancement to come over the months and years ahead.

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