ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and the Most Merciful. I would like to say Alhamdulillah with the hard work and determination finally I had come to the study fulfillment. Praise to the almighty for providing me capability, strength, guidance and granting me his blessing to complete this final year project.

I would like to express my deep thanks to my supervisor, Professor Ir. Dr. Mohd Fadzil Bin Ain and my examiner, Dr. Patrick Goh Kuan Lye who always gives a valuable advice, excellent assistance, continuous support and guidance throughout this project. The motivation from them gives a great impact to this project to be completely done. Without his help, this thesis would not have been made possible.

Apart from that, I would like to express my deepest gratitude to my beloved parents which are Mr. Mohd Ikhwan Kheng Bin Abdullah and Mrs. Ruzana Binti Ghazali for their endless love, prayers and encouragement throughout these four years I am studying at Universiti Sains Malaysia. I am very thankful and appreciate for those advice that they had given to me.

On top of that, I would like to extend my gratitude to my course mate and my seniors for their support and help. They always help me without hesitation and give the best suggestion when I encountered the problem. Thanks for giving me a tremendous support throughout this project.

Lastly, I would like to show my gratitude to Communication Lab technicians, Mr. Abdul Latip Bin Abd. Hamid and Mrs. Zammira Binti Khairuddin for providing me a good guidance, information and help throught out this project. Next, I would like to thank Mr. Elias Bin Zainuddin and Mr. Kamarulzaman Bin Abu Bakar who is helping me complete the PCB fabrication process. Without the help and cooperation from them, I would face a lot of problems which is hard for me to handle it on my own. To those who is indirectly contributed to this project, your kindness means a lot to me. Thank you.

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LIST OF ABBREVIATIONS

CST	Computer Simulation Technology
DRA	Dielectric Resonator Antenna
HF	High Frequency
HFSS	High Frequency Electromagnetic Field Simulation
PCB	Printed Circuit Board
PVC	Polyvinyl Chloride
RF	Radio Frequency
SMA	Surface Mounting Adapter
UHF	Ultra High Frequency
VHF	Very High Frequency

LIST OF SYMBOLS

f_1	Lower Cutoff Frequency
f_2	Upper Cutoff Frequency
G_{AUT}	Gain of the Antenna Under Test
G_r	Receive Gain
P_{AUT}	Power of the Antenna Under Test
P_{meas}	Measured Power
P_t	Transmit Power
S_{11}	Return Loss
Z_{in}	Input Impedance
Z_{out}	Output Impedance
ε_r	Dielectric Constant/Relative Permittivity
σ	Conductivity
μ_r	Relative Permeability

ABSTRAK

Antena air adalah sejenis antena cecair, yang telah menjadi yang paling popular pada tahun-tahun kebelakangan ini. Ia telah muncul sebagai alternatif kepada antena tradisional untuk banyak aplikasi terutamanya dalam tentera laut, komunikasi maritim dan komunikasi tanpa wayar. Tujuan karya ini adalah untuk membentangkan kajian yang menyeluruh tentang antena air, yang bertujuan untuk mendapatkan pemahaman yang lebih baik daripada antena air yang menggunakan cecair. Bahagian atas dan bahagian bawah antena air terdiri daripada bahan akrilik. Silinder akrilik dipilih kerana ketelusan. Spesifikasi tiub akrilik adalah; tinggi= 200 mm, ketebalan= 2mm dan diameter= 2mm. FR4 digunakan sebagai substrat dan tembaga digunakan sebagai satah bumi dengan bentuk bulat dan dimensi 100x100mm. Asas akrilik mempunyai dimensi yang sama dengan substrat dan tembaga. Sebahagian besar daripada antena air tradisional menggunakan air dan air laut sebagai medium antena kerana ia adalah kos rendah dan mudah diakses. Antena air tradisional biasanya mempunyai tahap prestasi yang rendah di mana kekerapan dan radiasi kecekapan salunan adalah rendah dan lebar jalur yang sempit. Oleh itu, matlamat untuk projek ini adalah untuk mereka bentuk antena air yang mempunyai prestasi yang lebih baik berbanding dengan antena air tradisional. Jenis pelbagai cecair disampel dan dianalisis dalam bentuk kekerapan salunan dan bandwidth seperti air tulen, air suling, air mineral, sirap gula, air garam, air laut, air hujan, air sungai dan air "zam zam". frekuensi salunan, jalur lebar, gandaan dan corak sinaran adalah kepentingan tertentu. Jumlah air di dalam tiub akrilik yang diselaraskan untuk tune frekuensi salunan. Analisis ini dilakukan dengan menggunakan peralatan RF bagi setiap 20mm dengan pelbagai paras air 0-180mm. Berdasarkan pengukuran yang telah dijalankan dengan menggunakan Network Analyzer, air suling telah dipilih sebagai medium untuk mereka bentuk antena kerana ia mempunyai jalur lebar yang paling luas dan kekerapan salunan tinggi. Sebagai contoh, dengan menggunakan 20mm air suling antena boleh mempunyai frekuensi salunan tinggi yang 2.728GHz, kembali loss pada -15.76dB dan lebar jalur lebar yang 1.101GHz. Corak radiasi dan gandaan diukur pada tiga frekuensi yang berbeza yang 2GHz, 2.5GHz, dan 3GHz. Berdasarkan hasil daripada corak sinaran, ia boleh disimpulkan bahawa yang paling tinggi menerima kuasa boleh diperolehi dengan menggunakan 20mm air suling pada 2GHz dan 20^{o} sudut putaran. Yang paling tinggi menerima kuasa, -44.76dB. Selain itu, keuntungan yang paling tinggi diukur yang -8.07dB boleh diperolehi dengan menggunakan 20mm air suling pada kekerapan 2GHz. Kesimpulannya, antena air direka menunjukkan prestasi yang baik dalam aspek-aspek seperti kekerapan salunan tinggi, kembali kerugian bawah -10dB dan lebar jalur lebar.

ABSTRACT

Water antennas is a type of liquid antennas, which have become the most popular in recent years. They have appeared to be alternatives to traditional antennas for many applications especially in naval, maritime communication and wireless communication. The purpose of this thesis is to present an exhaustive study about water antenna, aiming at obtaining a better understanding of water antennas that utilizing liquid. The upper and the bottom (base) part of the water antenna is made up from an acrylic material. The acrylic cylinder is chosen due to its transparency. The specifications of the acrylic tube are; height=200mm, thickness=2mm, and diameter=2mm. FR4 is used as the substrate and copper is used as the ground plane with a circular shape and dimension of 100x100mm. The acrylic base has the same dimension as the substrate and copper. Most of the traditional water antenna are using a pure water and sea water as the medium of the antenna because it is low cost and easily accessible. The traditional water antenna usually has a low-performance level where its resonant frequency and radiation efficiency are low and the bandwidth is narrow. Therefore, the aim of this project is to design a water antenna that has a better performance compared to traditional water antenna. Various type of liquids is sampled and analyzed in terms of its resonant frequency and bandwidth such as pure water, distilled water, mineral water, sugar syrup, salt water, sea water, rain water, river water, and “zam zam” water. The resonant frequency, bandwidth, gain, and radiation pattern are of particular interests. The volume of the water in the acrylic tube is adjusted in order to tune the resonant frequency. The analysis is done by using the RF equipment for each 20mm with a range of 0-180mm water level. Based on the measurement that had been carried out by using the Network Analyzer, distilled water was chosen as the medium to design the antenna since it has the widest bandwidth and high resonant frequency. For instance, by using 20mm of distilled water the antenna could have a high resonant frequency which is 2.728GHz, return loss at -15.76dB and wide bandwidth which is 1.101GHz. The radiation pattern and gain were measured at three different frequencies which are 2GHz, 2.5GHz, and 3GHz. Based on the result of the radiation pattern, it can be concluded that the highest receive power can be obtained using 20mm of distilled water at 2GHz and 20º angle of rotation. The highest receive power, -44.76dB. Moreover, the highest measured gain which is -8.07dB can be obtained by using 20mm of distilled water at a frequency of 2GHz. As a conclusion, the designed water antenna shows a good performance in aspects such as high resonant frequency, return loss below -10dB and wide bandwidth.

CHAPTER 1
INTRODUCTION

1.1 Research Background

We rely too much on antennas throughout our daily lives. There are many businesses conducted through devices with antennas these days such as credit card readers, laptops, and so forth. Antennas are essential electrical devices in the routine of people nowadays. However, they have their own limitations. Sometimes, the antenna could not receive the signals due to signal disruptions during the transmission.

Recently, a liquid antenna is receiving growing attention due to the development of communication. The liquid antenna has several attractive features, for instance, liquidity, transparency, and reconfigurability. Due to the liquid's fluidity and high dielectric constant, the liquid antenna is one of the best choices to design antennas (Meng et al., 2016). One of the most popular types of liquid antennas is water antennas.

According to Changzhou & Zhongxiang (2015), water antenna is likely the most admirable among the other liquid antennas owing to its low cost and easy access. Water antenna makes use of water as a medium to transmit and receive the signals. There are several attractive characteristics of water antenna such as compact in size, conformability, reconfigurability, easy transport, low-cost, transparent, and readily accessible. Hence, there are a few attractive water antennas have been designing for instance, a monopole water antenna, a broadband water antenna and a broadband saline-water antenna (Lei et al., 2015).

The performance of the broadband monopole antenna can be analyzed by dissolving salt into pure water. To maximize the bandwidth of the broadband monopole antenna, a dielectric base is placed between the water and the ground plane. Ascribed to the low loss of pure water at the low frequencies, the high permittivity, and a rectangular dielectric resonator (DR) water antenna with a compact size was designed (Changzhou et al., 2014).

Water antennas can be designed at different working operations. The water antenna can be regarded as a conducting antenna, a hybrid antenna, or a water loaded antenna. It can be designed by tuning the salt concentration, integrating the radiating and feeding structure or utilize water as a load (Lei et al., 2015).

This project is done to design, fabricate and simulate the water antenna. The antenna is made up of a clear acrylic cylinder, a ground plane which is fabricated on FR4 board, and an SMA connector. The operating frequency of the water antenna can be tuned by adjusting the height of the water in the container of the water antenna. The conductivity of the water can be adjusted by adding salt into the water. Other than that, to avoid short circuit in the water antenna, the dielectric can be inserted in the water antenna.

1.2 Problem Statement

Due to the growing of applications and standards introduced in the modern communication system, the demand of antenna increases in the wireless communication system. Mobile antenna is important for remote military movement. Water is one of resources that exist naturally. An antenna can be designed by utilizing the water as the medium to transmit and receive the signals. By using water, an antenna that are refillable and lightweight can be designed and hence it could make the movement of the military easier. Water antenna is the most popular among the liquid antennas because it is low cost and portable. Several studies and researches had been carried out to compare the parameter of the water antenna that utilizes various type of liquid especially, pure water, seawater, distilled water, mineral water, drinking water, salt water and much more. Commonly, sea water is used to design the antenna, especially in the naval or maritime communications. Instead of using the sea water, a pure water that has been added with salt into it also can be used. By adding the salt into the water, the conductivity and bandwidth of the water antenna can be adjusted (Hua et al.,2014; Hua et al.,2015). The proposed antenna has a low operating frequency and radiation efficiency. Thus, an analysis of different type of liquids that function as the medium of the water antenna is carried out in order to obtain a better performance antenna.

1.3 Objectives

This project is carried out based on objectives listed in below:

1. To design and fabricate the water antenna.
2. To characterize the water antenna based on the different samples of water antenna.
3. To measure the characteristic of the water antenna.

1.4 Scope of Research

The aim of this project is to design and fabricate a water antenna which utilizing distilled water as the medium. Before the distilled water is chosen as the medium to design the antenna, various type of liquids had been tested. The liquids include pure water, mineral water, drinking water, filtered water, tap water, salt water, sugar syrup, sea water, cooking oil, rain water, lake water, river water, "zam zam" water, and coconut water.

The important parameters in this project are return loss, resonant frequency, gain, bandwidth, and radiation pattern. These parameters are being analyzed throughout the designing process. This project consists of hardware part only. The prototype of the water antenna is done by myself except the base part that was sent to the PCB laboratory for fabrication. The experimental result is carried out at the Communication Laboratory. Most of the important parameters of the water antenna are measured by using a network analyzer, signal generator, and spectrum analyzer.

1.5 Thesis Outline

Chapter 1: Introduction

In this chapter, the thesis starts off with the brief introduction that describes the overview of project background. This is also including the problem statements, research objectives and scope of research.

Chapter 2: Literature Review

This chapter presents all the relevant theory, conceptual, fundamental background and related technique that has been used in the design. The important parameter will be shown and explained. Based on some research, the summary of several previous works has been done is explained in this chapter.

Chapter 3: Methodology

This chapter discusses the process and working procedure such as designing and testing that will be done throughout this project in a more specific way. This chapter consists of hardware part only.

Chapter 4: Design and Fabrication

This chapter presents the method used to design and fabricate the water antenna. The material, component/tool, and equipment use were listed.

Chapter 5: Result and Discussion

This chapter covers the experimental result that has been collected using network analyzer, signal generator, and spectrum analyzer. The result is analyzed and discussed.

Chapter 6: Conclusion

This chapter concludes this project. A suggestion for the future project improvement will be included at the end of this chapter.

CHAPTER 2
LITERATURE REVIEW

2.1 Overview

In this chapter, it consists of six sections which are Section 2.1-2.6. In Section 2.1 will explains the summary of this chapter. In Section 2.2 will explains the theoretical background of the antenna including its types and its characteristics. Section 2.3 will cover the general theory of the dielectric resonator antenna and Section 2.4 will explain about the water antenna with a few types of antenna that will be used in this project. Next, in Section 2.5 previous works that have been done will be described. Lastly, in Section 2.6 will conclude this chapter.

2.2 Theoretical Background

In this subtopic, the theoretical background of this project will be explained which consists of the basic parameters that are used to design the water antenna. The theory of the water antenna including basic of the antenna, type of antenna, parameters that affect the performance of the antenna. The formulae that will be used to design the water antenna is also provided in this chapter.

2.2.1 Antenna

The antenna is an important device in radar or wireless communication system. Basically, antennas are bidirectional. Thus, it can be used to transmits and receives an electric wave. Free space acts as the medium of the transmission line in wireless communications. In other words, no wiring is needed for the transmission line. A transmitting antenna will convert a guided electromagnetic wave on a transmission line into a plane wave propagating in free space.

Figure 2.1 below represents the basic operation of transmitting and receiving antennas. A spherical antenna is emitted at the transmitting antenna at large distance. A receiving antenna obstructs a part of an incident plane wave. Hence, it will send a receive power Pr to the receiver load impedance (Pozar,2012).

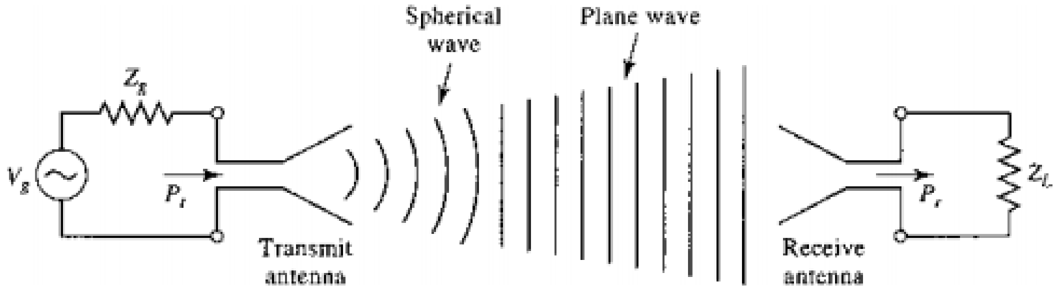

Figure 2.1: Basic operation of transmitting and receiving antennas (Pozar, 2012)

2.2.2 Type of Antennas

Pozar (2012) successfully proved that there is a various type of antennas that have been developed to be used in many types of applications. For instance, wire antennas, aperture antennas, printed antennas, and array antennas. These types of antenna are discussed as follows:

(a). Wired antenna

Wire antennas consist of dipoles, monopoles, loops, sleeve dipoles, Yagi-Uda arrays, and an associated form. The advantages of this type of antenna are light weight, simple designs, and economical. While, the disadvantages of the wired antenna are low gains and usually used at a lower frequency such as HF to UHF.

(b) Aperture antenna

Aperture antenna is most frequently been used in the millimeter wave frequencies and microwave. The gains are average to high. The aperture antennas comprise of open-ended waveguides, circular horns (also known as rectangular), lenses, reflectors and reflect arrays

(c) Printed antennas

Printed antennas can be designed with photolithographic techniques. Through this technique, both radiating elements and equivalent feed fabricated on a dielectric substrate. This type of antennas includes the microstrip patch, printed slots, and printed dipoles. Commonly, printed antennas are used at millimeter wave frequencies and microwave. Moreover, the high gain can be easily obtained by arraying the antenna.

(d) Array antennas

This type of antenna includes a systematic arrangement of antenna components with a feed network. The phase excitation and amplitude of the array elements can be modified in order, to control pattern characteristics like beam pointing angle and sidelobe levels. Phase array is one of the most commonly used.

2.2.3 Basic Antenna Parameters

There are many parameters that corresponding with the performance of the antenna. For instance, S-parameter, radiation pattern, antenna gain, and bandwidth.

(a). S-Parameter

S-parameter is a parameter set that associates to the travelling waves that are scattered when an n-port is placed into a transmission line. This parameter is used to portray connection of input-output between ports or terminals of the electrical system. Basically, S11 is the most important parameter in antenna design that represents the return loss of the antenna. The S11 are related with input impedance Z_{in}, output impedance Z_{out} , and reflection coefficient,τ_L. The Eq. (2.1) and Eq. (2.2) is used to calculate the S11. The S-parameter can be measured directly by using the network analyzer (Pozar,2012).

$$where \tau_L = \frac{Z_{in} - Z_{out}}{Z_{in} + Z_{out}} \tag{2.1}$$

$$S_{11} = -20 log|\tau_L| \tag{2.2}$$

(b) Radiation Pattern

The radiation pattern is a plot of the gain as a function of direction. It portrays how the antenna radiates when it is placed at a certain direction. The radiation pattern is also known as antenna pattern. For example, a typical antenna pattern is shown in Figure 2.2 below. The antenna pattern shown is plotted in polar form versus the elevation angle that used a horn antenna that is small size and it is slanted in the vertical direction.

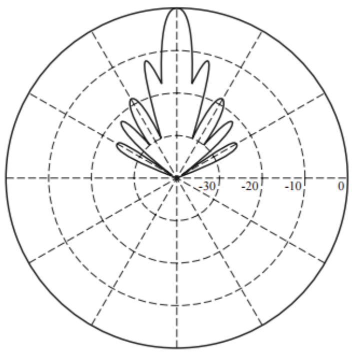

Figure 2.2: The E-plane radiation pattern of a small horn antenna (Balanis, 2005).

(c). Antenna Gain

The most important parameters that will portray the performance of the antenna.

$$G_{AUT} = P_{AUT} - P_S + G_S \quad (2.3)$$

Where;

G_{AUT} = Gain antenna under test

P_{AUT} = Power antenna under test

P_S = Power received by the reference antenna

G_S = Gain of the reference antenna

(d). Bandwidth

The bandwidth of an antenna is the range of frequencies at which the antenna's performance is following the designated antenna (Balanis, 2005). Eq. (2.4 shows the formula be used for bandwidth.

$$BW = f_2 - f_1 \quad (2.4)$$

where;

f_1: The lower cutoff frequency

f_2: The upper cutoff frequency

2.3 Dielectric Resonator Antenna

The interest of the dielectric resonator antenna has been developed due to its high radiation efficiency, good match and small physical size. Commonly, the DRAs is using low-loss solid dielectric as the materials. Precisely, ceramics is used as the materials because of its high permittivity and good loss at high frequency. A special type of DRAs, liquid antennas have become the most popular antenna among the DRAs due to its high permittivity and low loss. Liquid antennas discovered a new path for antenna design since the physical size or shape can be modified dynamically. In other words, the volume of the resonator can be tuned in order, to varies the resonant frequency. This is to make sure that the antenna is tuned closely to the transmission frequency. As the frequency of a DRA is tuned, the coupling between the probe and the DRA will change and cause the resonator not coupled in good manners. Thus, a poor return loss is obtained at the input. To overcome this problem in some way the probe must be retuned. This is done by utilizing the varactor diode. Figure 2.3 shows a schematic of the tunable DRA probe (Steven et al., 2007).

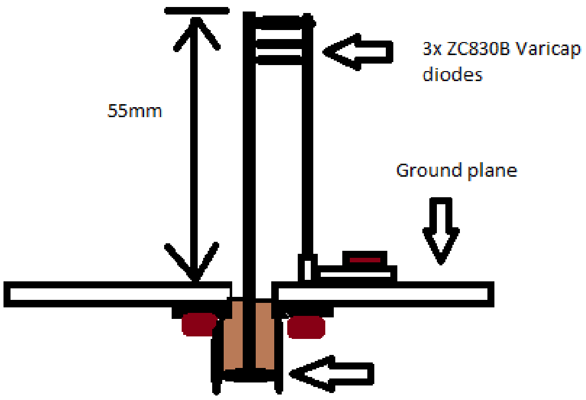

Figure 2.3: Schematic of the tuneable DRA probe (Steven et al., 2007)

2.3.1 Liquid Antenna

Liquid antenna is the fluid that transmits charged particles in the form of ions. This liquid acts as the radiating medium. Due to its fluidity and high dielectric constant, liquid antenna always is the most suitable to use as the antenna design. Water antenna is the most popular liquid antenna (Changzhou et al., 2014). There are a few advantages of water antenna that make it the most popular one which are (Lei et al., 2012):

i. Conformability
   - The antenna can be designed to the desired shape, easily compared with other dielectric or metal.

ii. Reconfigurability
   - The operational frequency and the bandwidth can be tuned by tuning or changing the length, height, and width of the liquid stream.

iii. Small radar cross section (RCS)
   - When the antenna is not in use, it can be simply turned off.

iv. Portable
   - Especially for large antenna

v. Low cost
   - If use water or seawater

vi. Improvement in electromagnetic coupling
   - An air gap between probe and dielectric can be eliminated.

2.4 Water Antenna

Water has a high permittivity. If water is used as the material to design an antenna, the antenna size can be reduced by $\sqrt{\varepsilon_r}$. Moreover, water should be good choices to design a small antenna since it is inexpensive, accessible, and eco-friendly (Lei et al., 2012). Based on the electrical characteristic of the water, it can be divided into two types of water namely as salt water and pure water (Meng et al., 2016).

i. Salt water
   - Acts as a good conductor at HF and VHF bands.
   - Use in water monopole antenna
   - Example, sea-water monopole antenna that have been used for maritime wireless communication system due to its high efficiency.

ii. Pure water
   - Acts as a dielectric with high permittivity.

According to Lei et al. (2015), based on the variety of working mechanisms, the antenna can be designed. For example, by tuning the salt concentration, integrating the radiating and the feeding structure or utilizing the water as the load. Thus, the water antenna can be deemed as a conducting antenna, a water-loaded antenna or a hybrid antenna (Lei et al., 2015).

2.4.1 Monopole Water Antenna

In the article by Lei et al. (2012), the monopole water antenna was proposed with a dielectric layer. Seawater has a relative permittivity, ε_r=81 and the conductivity, σ=4.7S/m that acts as a combination of two different properties such as dielectric and conductive. If the dielectric properties not considered, the seawater can be considered as a conductor which suitable for designing the normal conducting antenna. The conductivities of water will affect the performance of the water antenna. Additionally, if the conductivity of water is not considered the water should be utilized as good alternatives material for DRAs. Generally, the conductivity and the antenna efficiency is related to each other. For instance,

i. when conductivity is 0, the efficiency will become high
ii. when the conductivity increases, the efficiency decreases
iii. when the conductivity goes to infinity, the efficiency should be 100%.

To isolate the water from the ground plane, a water monopole antenna is designed with a layer of foam that has a relative permittivity, ε_r=1 and relative permeability, μ_r=1. Figure 2.4 shows the illustration of the water monopole antenna. A PVC tube is used to be filled with a water. In order, to maximize the bandwidth, the foam base is used. Three types of base are analyzed which are foam, teflon and paxolin in terms of its bandwidth and efficiency. Based on the results obtained, we can conclude that foam base has the highest efficiency and widest bandwidth at -10dB. In real life, even though foam base shows good performances, it is difficult to make. Thus, paxolin base is used instead of using foam base. All the results are measured by using the Network Analyzer. The broad bandwidth and high efficiency can be obtained by using the seawater monopole antenna (Lei et al., 2012).

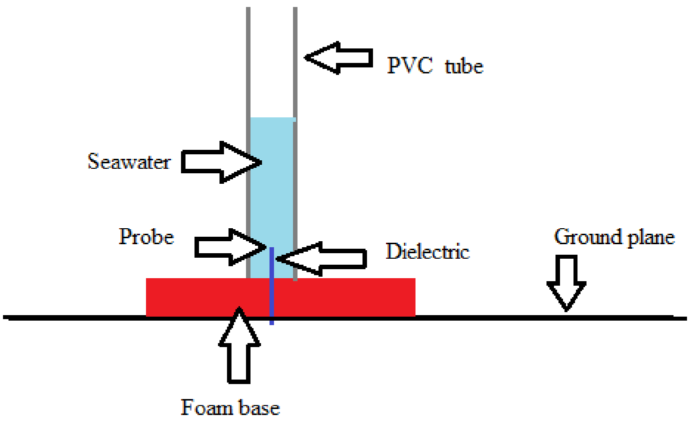

Figure 2.4: Geometry of the monopole water antenna (Lei et al., 2012)

2.4.2 Hybrid Water Antenna

Traditional water antenna designs used the resonance of water itself which yield a narrow bandwidth or low efficiencies. Hybrid resonator antenna technique is used to fix the problem. In this technique, the resonance from the water dielectric resonator and the resonance from the feeding probe is combined (Lei et al., 2015).

The hybrid antenna consists of two different type of antennas which are a seawater monopole and a distilled-water ring antenna. The seawater can be considered as a good conductor when it is operating in the frequency range of 50MHz to 300MHz and at the same time, the distilled water can be considered as an imperfect dielectric. Thus, this combination is also known as a hybrid metal monopole-dielectric resonator ring antenna.

A teflon dielectric base is used instead of foam base to place the seawater monopole antenna. A clear acrylic tube is used and it is placed vertically with the teflon base. It is also sealed with the silicon gasket. The spacing between the seawater and the distilled water is important in coupling the electromagnetic fields between this both type of antennas. Good performances of the impedance can be obtained by modifying the space between the monopole and ring antennas (Hui et al., 2015).

2.4.3 Reconfigurable Water Antenna

Changzhou et al. (2014) introduce two types of reconfigurable water antenna which are a water-grating leaky-wave antenna and sea-water monopole antenna.

i. A water-grating leaky-wave antenna

The water-grating leaky-wave antenna is used for wide-angle beam-scanning.

ii. Sea-water Monopole Antenna

The sea-water monopole antenna is used for naval maritime wireless communications. Traditionally, the water antennas were design by utilizing the fresh water. But, in a maritime environment sea water is more easily attain compared to fresh water. Thus, a reconfigurable sea-water antenna is suggested to be used for naval and maritime wireless communications. Figure 2.5 shows a graphic of the reconfigurable sea-water monopole antenna. A teflon is used as the container and a pipe is used to supply the water into the antenna. The feed probe is placed into the water through the ground plane. In order, to obtain the desired TM mode excitation, the container and the feed probe are concentric so that the structural symmetry is maintained. This antenna can be turned off. When the antenna is turned on or activated, the sea water will be pumped into the teflon through the pipe. Next, the water stream will be shooting out from the container. This will form a monopole antenna. Since the sea-water monopole antenna can be reconfigurable, it also means that the operating frequency and bandwidth of the sea-water stream (Changzhou et al., 2015).

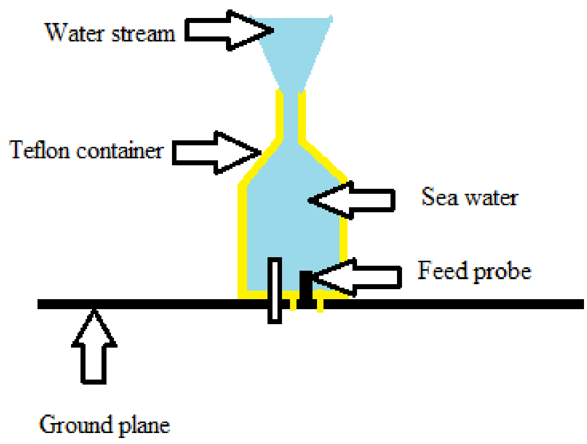

Figure 2.5: Reconfigurable sea-water monopole antenna (Changzhou et al., 2015).

2.4.4 Sea-water Antenna

In a maritime environment, fresh water is easily obtained. Table 2.1 below shows the advantages and the disadvantages of the sea-water antenna. At upper VHF and UHF bands, the efficiency of the sea-water monopole antenna is low. This is because the sea water stream is thin and it is not an efficient radiator. The size of the stream will affect the loss resistance and the radiation efficiency. As the stream becomes thinner, the loss resistance is larger and the radiation efficiency is lower.

Table 2.1: The advantages and disadvantages of the sea-water antenna

Advantages	**Disadvantages**
Dynamic	Low efficiency
Reconfigurable	Low radiator efficiency

Generally, sea-water antenna can be grouped in two types which are;

i. Static-type Sea Water Antenna

   The static-type water antenna is simpler. It consists of a transparent plastic tube that acts as the holder for the sea-water cylinder and a top-loaded feeding probe. The tube that commonly used is a clear acrylic tube. Figure 2.6 shows the geometry of the sea-water monopole antenna mounted on a ground plane. The sea-water antenna can be reconfigurable (Changzhou et al., 2014). There are a few practical limitations of static-type sea water antenna. For instance, at an HF band, a very long tube is needed to hold the water and this has caused the antenna difficult to carry and assemble. Therefore, a dynamic-type sea water antenna is introduced so that this problem can be overcome (Changzhou et al., 2015).

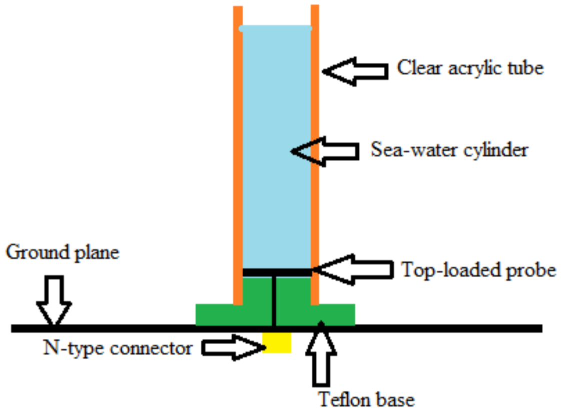

Figure 2.6: The geometry of the sea-water monopole antenna (Changzhou et al., 2014).

ii. Dynamic-type Sea Water Antenna

A dynamic-type sea water antenna is designed by using a current probe to excite a thin sea-water stream. The advantages of the dynamic-type sea water antenna are dynamic in a real-time and rapid reconfigurability. While, the disadvantages are low efficiency because the toroidal ferrite core is lossy at VHF band, and low-efficiency radiator due to the thin sea-water stream. Figure 2.7 shows one of the examples of a dynamic-type sea-water antenna (Changzhou et al., 2015).

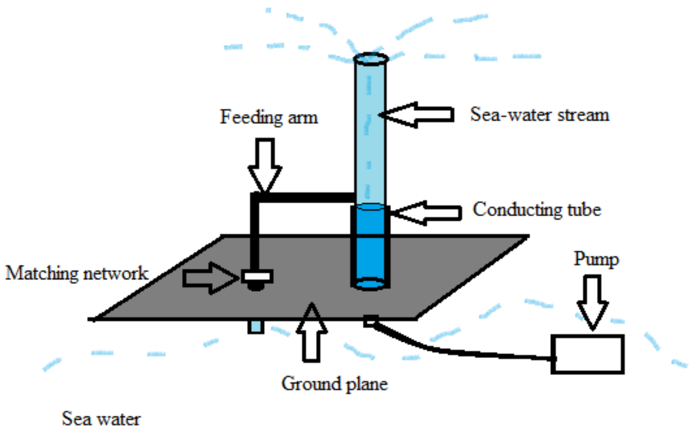

Figure 2.7: Example of dynamic-type sea-water antenna (Changzhou et al., 2015)

2.5 Previous Work Done

In this section, the overview of the researched regarding this water antenna project that has been done previously is discussed.

2.5.1 A Monopole Water Antenna

Lei et al. (2012) have investigated the water antenna in this paper a monopole water antenna with a relative permittivity, μ_r=81 and conductivity that has been varied is studied. There are 3 objectives of this paper and the objective are as follows:

i. To investigate the relationship between the conductivity and antenna radiation efficiency.
ii. To design a new feeding design for the water antenna with a good return loss, radiation efficiency, and radiation pattern.
iii. To conduct the experiments in the anechoic and reverberation chambers and evaluate the performance of the water antenna.

The aim of Lei et al is to design an alternative antenna that can be used for various applications. With variety of conductivity, the antenna can be regarded as a dielectric resonator antenna (DRA), a conducting antenna or their combination.

A. The relationship between the conductivity and radiation efficiency

Water is good choices to design an antenna especially small size antenna since it is inexpensive, easily accessible and eco-friendly. In this paper, seawater is used and it has a relative permittivity, μ_r=81and conductivity σ=4.7 S/m. It means that the seawater has the combination of two different properties which are dielectric and conductive. The seawater can be considered as the conductor if the dielectric properties are neglected and hence it is suitable to design a normal conducting antenna. Whilst, the sea water can have a high permittivity if the conductivity is not considered hence it is suitable to become an alternative material for DRAs. The conductivity and antenna efficiency are closely related to each other. The simulation is done by using CST Microwave 2014. By analyzing the efficiency and conductivity of the antenna through simulation process, the function of the antenna can be determined whether it acts as a high permittivity dielectric antenna (DRA), combination of dielectric and conducting antennas or a normal conducting antenna (Lei et al., 2012).

B. The Design of Water Antenna

A prototype of the water antenna is designed. The prototype consists of a layer of foam that has a relative permittivity, ε_r=1 and relative permeability, μ_r=1. The foam layer is used isolate the water from the ground plane. Table 2.2 shows the parameters that are used to design an antenna that operates at 1.8GHz. A PVC tube is used as the holder of the water that has design parameters as shown in Table 2.3 below. To maximize the bandwidth of the antenna, a foam base is used. In this article, three types of base are simulated which are foam, Teflon and paxolin base. Through the simulation, the reflection coefficient, S11 and efficiency can be obtained. Moreover, to avoid short circuit the dielectric foam base is used (Lei et al., 2012).

Table 2.2: List of design parameters for a 1.8GHz antenna (Lei et al., 2012)

Parameter	**Value**
Water antenna height	50 mm
Seawater relative permittivity	81
Seawater relative permeability	1
Seawater conductivity	4.7 S/m

Table 2.3: The PVC tube parameters (Lei et al., 2012)

Parameter	**Value**
Permittivity	4
Conductivity	0
Relative permeability	1
Tube height	100 mm
Diameter	25 mm
Conducting ground plane thickness	1mm

C. Water Antennas Measurement

Even though foam base shows the better performance, in real life it is quite difficult to be done. Therefore, in this article (Lei et al., 2012) the paxolin base is used as an alternative so that the measured and simulated results can be compared. The water antenna is measured by using a network analyzer. The efficiency of the antenna is measured in a reverberation chamber whilst the radiation pattern is measured in an anechoic chamber. To control the conductivity and bandwidth of the water antenna, salt can be added to the water.

2.5.2 High-Efficiency Sea-Water Monopole Antenna for Maritime Wireless Communications

According to Lei et al. (2012), the efficiency of the sea-water monopole antenna is low at the VHF and UHF bands. This is because the thin sea-water is not an efficient radiator. A new transparent and sea-water monopole antenna that operates at VHF bands is proposed. This type of antenna is suitable for maritime environments and it is simple. Mainly, this antenna consists of a transparent plastic tube that is filled with sea-water and a top-loaded feeding probe. The proposed antenna has a higher efficiency. This is because the feeding structure and the thick sea-water cylinder used is efficient. Due to the small surface resistance of the sea-water monopole, the radiation efficiency of the proposed antenna is higher than the radiation efficiency (Lei et al., 2012). A clear acrylic tube is used as the sea-water holder and it is placed on the Teflon base vertically.

The center frequency and bandwidth of the antenna can be modified that is by changing the height and radius of the sea-water cylinder. In other words, the sea-water is reconfigurable. The limitation of this sea-water monopole antenna is the electrical properties of sea water that depends on its chemical composition. This limitation is due to the electrical properties of sea water that varies with the temperature, frequency, and pressure (Changzhou et al., 2014).

2.5.3 Sea-Water Half-Loop Antenna for Maritime Wireless Communication

Generally, the sea-water half-loop antenna may be limited to complex and poor marine environment such as a storm. This antenna consists of a capacitive coupling feeding structure and a stream of a sea water that is formed by using a water pump. The antenna is designed using a metallic tube with a tilt angle, θ, a feeding post and a dielectric-filled parallel-plate capacitor. Once the antenna is activated, the water pump will pump the sea water into a metallic tube, and then water stream shoots out from the tube. Hence, a half loop is formed. The result was taken in a real side environment which is at the sea. The simulation and measurement are done to obtain the reflection coefficient, S_{11} and the bandwidth. The limitations of this type of antenna are, it has narrower impedance bandwidth if compared with the water monopole (Lei et al., 2012). Another limitation is on it measured the maximum gain of the sea-water half-loop placed above the sea surface is smaller than the gain above the perfectly conducting ground. This is due to the lossy conducting ground of the sea surface (Changzhou & Zhongxiang, 2015).

2.5.4 Summary of the previous work done

The comparison of the results for the different type of water antenna is shown in Table 2.4. Based on Table 2.4, it is observed that all those water antennas operate at a frequency below 2GHz and the lowest operating frequency is the sea-water half-loop antenna (Changzhou&Zhongxiang, 2015). The bandwidth of the monopole water antenna is the widest with a value of 35.7%. The monopole water antenna also has the highest operating frequency which is approximately 1.4GHz. Among the three types of antennas that have been discussed, the sea-water antenna has the highest radiation efficiency that varies between 30% and 65% at a frequency range of 1.25GHz to 2.70GHz.

Table 2.4: Comparison of the discussed previous work done

Title and References	Parameter			
	Operating frequency	Bandwidth	Reflection coefficient	Radiation efficiency
A monopole water antenna (Lei et al., 2012)	Approximately 1.4GHz	35.7%	-14dB	Varies between 30% and 65% (frequency range 1.25GHz to 2.70GHz)
Reconfigurable water antenna (Changzhou et al., 2014)	0.065GHz	27.8%	-29dB	Varies between 50.2% and 72.3% (frequency range 40MHz to 200MHz)
Sea-water half-loop antenna for maritime wireless communications (Changzhou&Zhongxiang, 2015)	0.11MHz	27%	-24dB	35%

2.6 Summary

Based on the literature review that has been discussed in this chapter, a useful information and guidance for this project are obtained. The performance of the water antenna was analyzed which involves the reflection coefficient S_{11}, return loss, resonant frequency, bandwidth, radiation efficiency and radiation pattern. By analyzing the performance metrics of the water antenna, the resonator and performance can be studied. Therefore, the previous research that has been carried out can be the benchmarked for this project.

CHAPTER 3
METHODOLOGY

3.1 Introduction

This chapter describes the procedure in designing a water antenna. The design stage can be divided into one main part only which is hardware. The hardware part will focus on the fabricating and testing of the water antenna. From the previous chapter, all the important antenna parameters had been discussed.

To design a water antenna a liquid is needed and sea water is commonly used as the medium of the antenna. But for this project, a few liquid samples had been tested and characterized in terms of its performance such as resonant frequency, return loss and bandwidth. There are 15 samples of liquid that has be tested and analyzed. The liquid with the widest bandwidth and a high resonant frequency was chosen. Furthermore, the dielectric constant of the chosen liquid sample was measured by using the network analyzer and software 85070.

After the analysis of the liquid sample with the best performance has been carried out the water antenna was designed. Thus, the measurement of radiation pattern and gain can be carried out by using the RF's equipment which are the signal analyzer and spectrum generator.

The design that gives the best performance is chosen to be fabricated as the prototype of the water antenna. Only ground plane need to go for fabrication process at the PCB laboratory. After the prototype has been fabricated, the water antenna is tested and measured.

3.2 Project Implementation Flow

The project implementation flow for the entire project is shown in Figure 3.1. Firstly, the prototype of water antenna design fabricates. Next, a few samples of liquid are measured in term of its bandwidth, return loss and resonant frequency. Based on the result obtained, the liquid sample with a wide bandwidth and high resonant frequency was chosen to design the antenna. After the liquid sample with the best performance was determine, the radiation pattern and gain of the water antenna was measured. If the result obtained matched the desired specification, thesis and technical paper writing can get started. If not, the prototype of the water antenna need to be fabricated again and measurement also need to be done once again until it matched with desired specification.

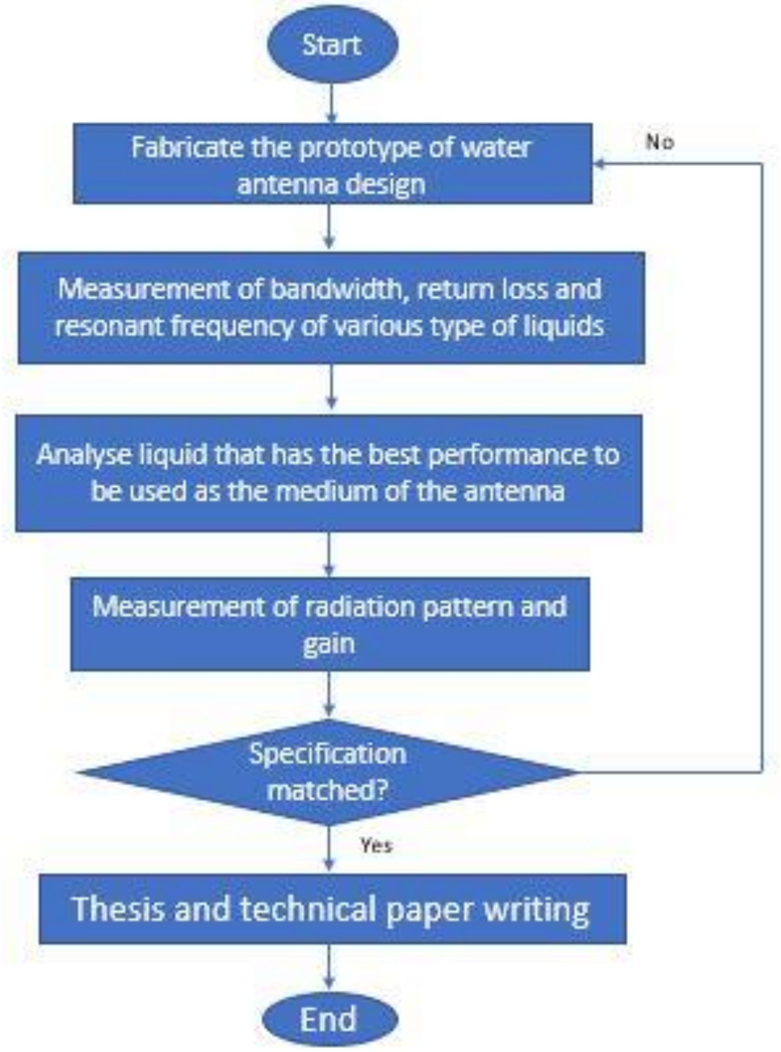

Figure 3.1: Flowchart of overall methodology

3.3 Hardware Data Collection/Measurement Method

A. Measurement of Resonant Frequency, Return Loss, and Bandwidth by using Network Analyzer:

Network analyzer which is used to measure the performance parameter is shown in Figure 3.2. Remember that the network analyzer need to calibrate first before a measurement is taken. The reason of the calibration is to lower the internal and external error that is present in the network analyzer or cable port. Figure 3.3 shows a set of calibration kits that is used for calibration of the network analyzer which is open, short and load 50Ω terminations. The connector that is used to connect the port cable of network analyzer device and calibration kits is shown in Figure 3.4. Make sure that the gender of the connector and calibration kits are the same gender. The water antenna is connected to a network analyzer to measure the return loss, resonant frequency, bandwidth, and gain. Many samples are tested which are pure water, tap water, distilled water, sea water, sugar syrup, salt water, cooking oil and so on. The procedure for this experiment is simple, just connect the SMA connector of the water antenna with the cable port of the network analyzer. A connector interface is used to connect the SMA connector with the cable port of the network analyzer. The prototype is placed on the standing rack so that it is stable. The experimental setup is shown in Figure 3.5.

Figure 3.2: Network Analyzer

Figure 3.3: Network Analyzer Calibration kits

Figure 3.4: Connector interface

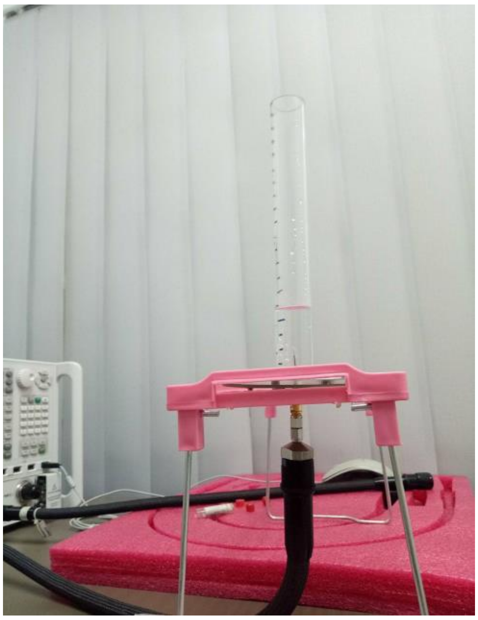

Figure 3.5: Experimental setup of water antenna and network analyzer