UNIVERSITI PUTRA MALAYSIA

HIGH GAIN COMPACT ANTENNA DESIGN FOR UNDERWATER COMMUNICATION

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HIGH GAIN COMPACT ANTENNA DESIGN FOR UNDERWATER COMMUNICATION

By

SAMA FOUAD MAJEED

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

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DEDICATION

This thesis is dedicated to my parents Awatif Hussien and Fouad Majeed

For their endless love, support and encouragement…
To my lovely sisters and brother (Rawaa, Sura and Aws)…
To all my supportive friends

To every striving muhsin person who is constantly improving aspects of life…
To those who are compassionate towards achieving perfection (ihsaan)…
To the consistent pursuers of knowledge aiming for positive change…

A special contribution to my home country Iraq and to Malaysia;
With lots of gratitude…

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

HIGH GAIN COMPACT ANTENNA DESIGHN FOR UNDERWATER COMMUNICATION

By

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Chairman : Alyani Ismail, PhD
Faculty : Engineering

Nowadays, communications technology is developing rapidly and becoming more advanced each day. In turn, the demand for this technology is also increasing. Underwater communication is not an exception; it has received the attentions of scientists working in the communications and telecommunication field. Two types of waves have been used in underwater communications and systems mostly. These are known as electromagnetic and sonar waves. Research findings show that electromagnetic waves yield more promising results when submerging communication devices in water. However, electromagnetic wave applications have also issues on it is own to address.

The performance of electromagnetic waves degrades exponentially when submerged in a medium such as water. Due to this reduction in wave energy, many hubs and transceivers should be used to cover an area for transferring data from one station to the other. In addition, the demand for free licensed frequency bands such as industrial scientific and medical (ISM) and wireless local area network (WLAN) has forced users to require more band width (BW) and a higher data transfer rate. Thus, higher frequency bands such as microwave (MW) frequency bands are required. However, higher bands than microwave bands also degrade in water, where the wave distance will become too short. Hence, a higher data transfer rate and smaller dimensions of the microwave instruments are required for underwater communications compared to electromagnetic waves in a lower band, sonar and ultra-sonic waves, and microwave, which can be a promising technology to apply for submerged communications.

A compact-sized high gain photonic band gab (PBG) structure stack antenna resonating at 2.4 GHz and also a compact high gain ultra wide band antenna (UWB) resonating at (1.65–6.8) GHz for ISM band and WLAN are presented in this thesis. Simulation and measurement results have been investigated and then the behaviour of the antennas on the reflection coefficient, antenna pattern and gain are also studied. The proposed microstrip antenna is designed at 2.4 GHz, achieving a miniaturized size by almost 20%, a higher gain, and higher efficiency at the desired harmonics in air and water compared to similar previous experiments. However, not many antennas have been designed for underwater communications and most are quite bulky. The performance of the antenna submerged in water was measured in three ways: with both antennas submerged in water, one at the surface, and the other inserted in water, followed by depth valuation. When both are submerged in water, the reflection coefficient is shifted to a lower frequency band (0.86 GHz) with an increase in distance between the antennas. The proposed antenna is working at an ISM lower band (0.91 GHz) when both are in water. Besides that, at distances of more than 350 mm, some more resonances occur at 1.5 GHz, 1.8 GHz, and even 2.4 GHz at 500 mm distance. The depth variation of the antenna was performed in a depth from 3–25 cm.

The same procedure is applied to the UWB antenna for measurement in water. When the antennas are inserted in water or even face the water, the broad BW of the antennas is degraded, especially at higher frequencies higher than 4 GHz. There is not much of a difference between the measurements when both are positioned in water and when one is put on the surface only. However, keeping one antenna on the surface and inserting another in the water can cause the antennas to resonate like three-band antennas working at lower bands. The differences between them occur when both antennas are inserted and one at the surface is the middle band. The middle band is more effective when both antennas are inserted in water and degraded with distance increment.

For future work and further studies in underwater communications, the size of the testing medium can be increased. Thus, further distances can be considered in the testing procedure and investigations. Besides that, the number of antenna arrays can be increased to achieve increased range of transmitted data.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

REKABENTUK ANTENNA DENGAN KENAIKAN YANG TINGGI UNTUK KOMUNIKASI DALAM AIR

Oleh

SAMA FOUAD MAJEED

Disember 2017

Pengerusi : Alyani Ismail, PhD
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Pada masa kini, teknologi komunikasi berkembang pesat dan menjadi lebih maju setiap hari. Sebaliknya, permintaan untuk teknologi ini juga semakin meningkat. Komunikasi bawah air bukan pengecualian; ia telah menerima perhatian saintis yang bekerja di bidang komunikasi dan telekomunikasi. Dua jenis gelombang telah digunakan dalam komunikasi dan sistem bawah laut. Ini dikenali sebagai gelombang elektromagnetik dan sonar. Penemuan penyelidikan menunjukkan bahawa gelombang elektromagnet menghasilkan hasil yang lebih menjanjikan apabila peranti komunikasi penyerapan di dalam air. Walau bagaimanapun, aplikasi gelombang elektromagnet juga telah memperkenalkan lebih banyak masalah.

Persembahan gelombang elektromagnet merendahkan secara eksponen apabila tenggelam dalam medium seperti air. Disebabkan pengurangan tenaga gelombang ini, banyak hab dan transceiver harus digunakan untuk menutup kawasan untuk memindahkan data dari satu stesen ke stesen yang lain. Di samping itu, permintaan untuk band frekuensi berlesen percuma seperti ISM dan WLAN telah memaksa pengguna untuk memerlukan lebih banyak BW dan kadar pemindahan data yang lebih tinggi. Oleh itu, mereka memerlukan band frekuensi tinggi seperti band frekuensi MW. Walau bagaimanapun, band yang lebih tinggi daripada band MW juga merosot di dalam air, di mana jarak gelombang akan menjadi terlalu pendek. Oleh itu, kadar pemindahan data yang lebih tinggi dan dimensi yang lebih kecil daripada instrumen MW diperlukan untuk komunikasi bawah air berbanding gelombang elektromagnetik dalam gelombang rendah, sonar dan gelombang ultra sonik, dan MW, yang boleh menjadi teknologi yang menjanjikan untuk memohon komunikasi yang terendam.

Reka bentuk struktur PBG keuntungan bertingkat tinggi yang bersaiz padat berukuran 2,4 GHz dan juga keuntungan tinggi padat UWB berseri pada (1.65-6.8) GHz untuk band ISM dan WLAN dibentangkan dalam tesis ini. Hasil simulasi dan pengukuran telah diselidiki dan kemudian tingkah laku antena pada koefisien pantulan, corak antena dan keuntungan juga dikaji. Antaramuka microstrip yang dicadangkan direka pada 2.4 GHz, mencapai saiz miniatur dengan hampir 20%, keuntungan yang lebih tinggi, dan kecekapan yang lebih tinggi pada harmonik yang diinginkan di udara dan air berbanding eksperimen sebelumnya yang serupa. Walau bagaimanapun, tidak banyak antena direka untuk komunikasi bawah air dan kebanyakannya agak besar. Prestasi antena yang tenggelam dalam air diukur dalam tiga cara: dengan kedua-dua antena tenggelam dalam air, satu di permukaan, dan yang lain dimasukkan ke dalam air, diikuti oleh penilaian mendalam. Apabila kedua-duanya tenggelam di dalam air, pekali refleksi dipindahkan ke band frekuensi rendah (0.86 GHz) dengan peningkatan jarak antara antena. Antena yang dicadangkan ini berfungsi pada band rendah ISM (0.91 GHz) apabila keduanya berada di dalam air. Di samping itu, pada jarak lebih daripada 350 mm, sesetengah resonans berlaku pada 1.5 GHz, 1.8 GHz, dan juga 2.4 GHz pada jarak 500 mm. Variasi kedalaman antena dilakukan secara mendalam dari 3-25 cm.

Prosedur yang sama digunakan untuk antena UWB untuk pengukuran dalam air. Apabila antena dimasukkan ke dalam air atau menghadapi air, BW luas antena dihina, terutama pada frekuensi yang lebih tinggi lebih tinggi daripada 4 GHz. Tidak banyak perbezaan di antara pengukuran apabila kedua-duanya diposisikan di dalam air dan apabila seseorang diletakkan di permukaan sahaja. Walau bagaimanapun, menjaga satu antena di permukaan dan memasukkan satu lagi di dalam air boleh menyebabkan antena menghidupkan seperti antena tiga jalur yang bekerja pada band yang lebih rendah. Perbezaan di antara mereka berlaku apabila kedua-dua antena dimasukkan dan satu di permukaan adalah band tengah. Band tengah lebih berkesan apabila kedua-dua antena dimasukkan ke dalam air dan terdegradasi dengan kenaikan jarak.

Untuk kerja masa depan dan kajian lanjut dalam komunikasi bawah air, saiz medium ujian boleh ditingkatkan. Oleh itu, jarak selanjutnya boleh dipertimbangkan dalam prosedur ujian dan penyiasatan. Selain itu, bilangan susunan antena boleh ditingkatkan untuk mencapai rangkaian data yang semakin meningkat.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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Signature: ______________________________

Name of Chairman of Supervisory Committee: Associate Professor Dr. Alyani Ismail

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Name of Member of Supervisory Committee: Associate Professor Dr. Aduwati Sali

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

SYMBOL	DEFINITION
MW	Microwave
ISM	Industrial, scientific and medical
FCC	Federal Communication Commission
LIMR	Low-intensity microwave radiation
TL	Transmission Line
VSWR	Voltage Standing Wave Ratio
AR	Axial Ratio
BW	Bandwidth
FDTD	Finite Difference Time- Domain
Q	Quality factor
MSA	Microstrip Slot Antennas
PBG	Photonic Bandgap
DGS	Defected Ground Structure
RFID	Radio Frequency Identification
SAW	Surface Acoustic Wave
AIA	Active Integrated Antenna
MMIC	Monolithic Microwave Integrated Circuit
WLAN	Wireless Local-Area Network
WiMAX	Worldwide Interoperability for Microwave Access
CPW	Coplanar Waveguide
UWB	Ultra wide band

CHAPTER 1

INTRODUCTION

1.1 Study Background

The communications industry is progressing dynamically towards innovative thinking and increased creativity, stretching the effort to achieve the impossible and to go beyond common demands of compactness, high quality and performance, and economy and cost. As a crucial player in the industry, the antenna requires speedier advancement to accelerate the industry's vision of inventing sophisticated appliances for radar, TV and radio broadcasting, satellite communications, point-to-point communications, and current wireless communications including underwater communications and their related devices. Therefore, special attention has been put on the efficiency of converting electric current to electromagnetic (EM) waves and vice versa, for which transmitting and receiving signals is given top priority [1].

Underwater communication and localisation systems are receiving huge research interest due to the role of these systems in exploration and rescue missions, such as the discovery of natural resources and search operations in the event of plane crashes. In underwater environments, acoustic systems have many drawbacks such as long propagation delay, narrow bandwidth, multipath fading, and susceptibility to propagation characteristics from background media [2]. Moreover, these systems are broadly utilised for applications that include seaward oil and gas field monitoring, coastline security and surveillance, as well as oceanographic information gathering, which will require information return between the two. This is only the tip of the iceberg of self-sufficient submerged Vehicles (AUVs). Furthermore, submerged ecological perception is also investigated in this study [3].

1.2 Statement of Problems and Motivations

Due to electromagnetic wave losses in water, the vast majority of remote networks are now essentially contingent upon sound waves. Therefore, the use of sound waves is preferred to that of electromagnetic waves [4]; however, scientists are forced to use many sonic transmitter/receiver systems to cover more areas, so using sound waves can be costlier than using electromagnetic waves. Thus, current technology is now relying on electromagnetic waves because of their significant high-speed propagation, which results in high speed transfer of data. Furthermore, due to the inflated cost of designing and the maintaining acoustic and optical systems, some standards for working in microwave (MW) regions such as Wireless Local-Area Network (WLAN) with the IEEE 802.11 Standard are applied as a reliable solution. WLAN offers ease of use throughout the world and rather low cost, but it also requires working knowledge and experience. Another free band, which is unlicensed and free, is the Industrial, Scientific and Medical (ISM) band. ISM can contribute to bringing down the cost of WLAN. Moreover, the ISM frequency band is now being used rapidly, especially in low-power and short distance communications.

Nowadays, the greater part of researchers' focus is on enhancing the distances between the nodes, whilst achieving a high BW network with high data rate transitions [5]. Furthermore, underwater propagation methods such as optical, electromagnetic, acoustic or ultrasonic signals have some advantages and disadvantages, as illustrated in [3]. However, optical signals might still propagate exceptionally. Ocean water comprises particles that diffuse these signals. Thus, the optical method is not reliable over long distances. Acoustic signals are not as susceptible to sea particles in comparison with optical signals. This is because its signal capability is dependent upon 20-km distances, so it can be utilised broadly.

Electromagnetic signals over very short distances can promise higher data rates of up to 10 Mbps. EM waves are highly dependent on the material characteristics (permittivity) of the environment around the sensor networks [6]. On the other hand, underwater communication is not only limited to communication within the underwater environment itself but might also involve communication paths that cross the air-water boundary. Besides that, when only underwater communication is required, sonic systems cannot be used due to their being too bulky and costly. Thus, for other types of communication other than underwater communications such as trans-air-to-water underwater communication, electromagnetic waves are the best choice, since these waves are not adversely affected by the air-water boundary, and could even be either air-seawater or air-freshwater interfaces.

The above are examples of problems that researchers face while using frequency ranges other than MW, as transmitters/receivers should have a broad BW to cover more frequency bands. Thus, wide bands and ultra-wide band (UWB) systems are seen as promising devices. The recent narrow-band [76-80] antennas with lower gain and bigger size showed complicated structure while the photonic band gab (PBG) structure could be promising to compensate those drawbacks. Besides, wide-band and ultra-wideband antennas [81-86] with less working BW, lower gain along with larger dimensions compared to the operating frequency for underwater communications have demonstrated more complicated design in terms of patch shape since the elliptical shape patch is one of simplest shape can be consider for UWB antennas.. Besides that, similar works on antennas for underwater communications have proposed designs that are very complicated and difficult to fabricate besides being heavy and bulky.

1.3 Objectives of study

The primary goal of this study is to design a high gain compact antenna for underwater communications followed with an analysis of the antenna characteristics.

1. To design a narrowband compact microstrip antenna with high gain at a single operating frequency of 2.4 GHz
2. To design a high gain compact ultra-wide band antenna
3. To investigate the performance of the designed antennas for underwater applications

1.4 Study Scope

The scope of this study is to simulate and design two antennas with different frequency bandwidths (BW) for underwater communications. The first one is a microstrip antenna with high performance at 2.4 GHz while the second is a UWB antenna. Figure 1.1 outlines the scope of this study in more detail. In reference to Figure 1.1, the solid lines depict the directions followed in this study to obtain the research objectives, while the dashed-lines indicate the other research areas that are covered in this work.

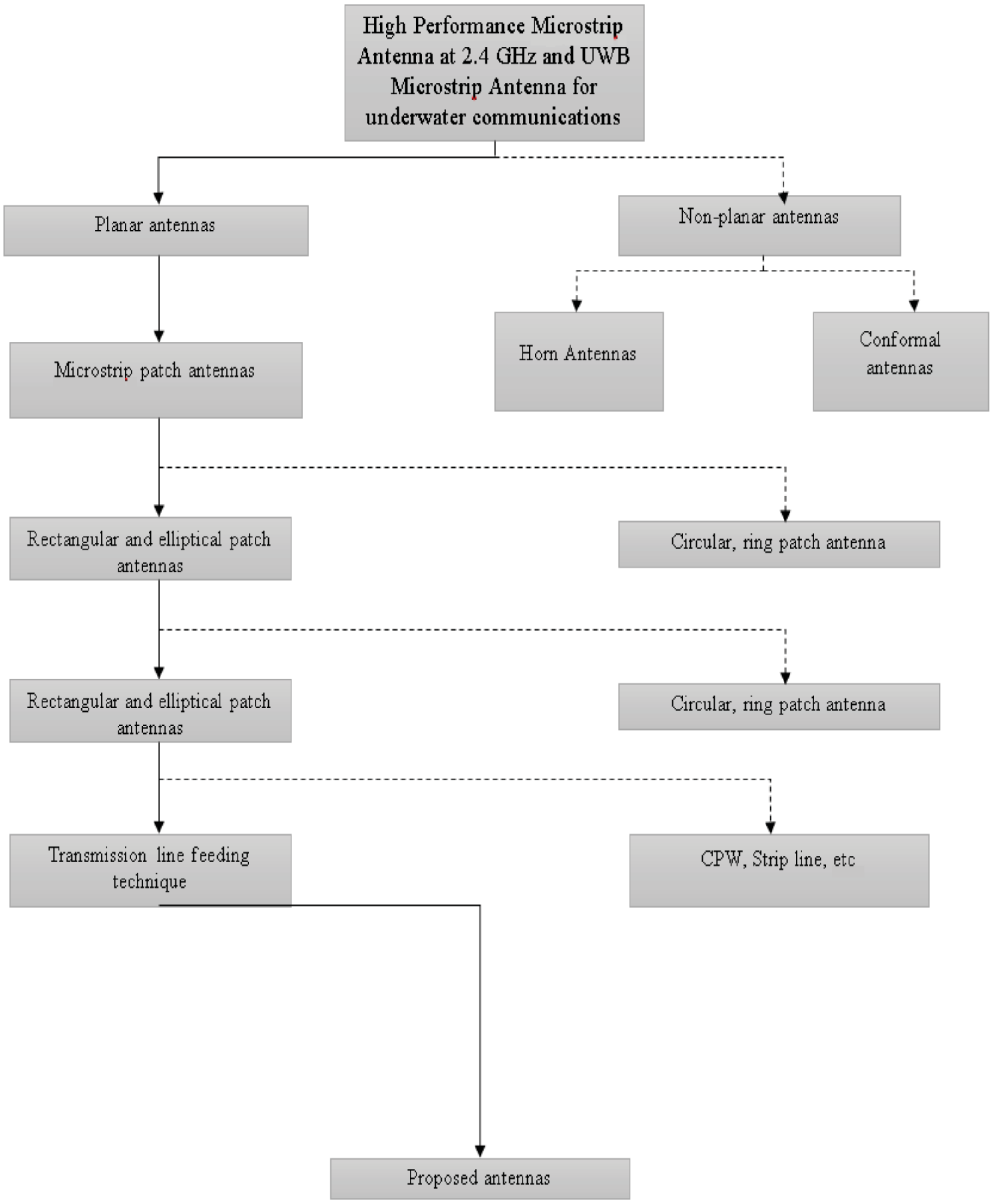

Figure 1.1 : Study scope

1.5 Research Methodology

At 2.4 GHz, the narrowband antenna is designed on an RT/Duroid 5880 substrate with a permittivity of 2.2 and thickness of 0.787 mm, so as to lower permittivity and increase the BW and radiation efficiency. The design processes are presented as follows: firstly, a rectangular patch is designed to resonate at 2.4 GHz according to the transmission line theory, which is L_p = 41.5 mm [7]. For the initial calculations to obtain the actual antenna dimensions, the transmission line technique [8] for the rectangular patch was used. Then, three periodic rectangular photonic band gap structures are etched from the rectangular patch. These rectangular slots have the same width (W_1), which is the period of our PBG structure. Moreover, the length of these slots decreases periodically and follows a pattern of a filling factor of the PBG structure. A PBG structure is required to decrease surface waves, which is a serious problem for the microstrip antenna. Surface waves are excited on microstrip antennas whenever the substrate permittivity ε_r>1 [9]. Apart from the end-fire radiation, surface waves have some undesirable features such as edge diffraction, and spurious coupling between different antenna elements. Besides that, surface waves reduce antenna efficiency and gain, limit the BW, increase the end-fire radiation, and increase the cross-polarisation level. In the next step, a small rectangular slot is cut from the ground layer located next to the feed line. This slot is used for suppressing the back radiation from the antenna [10]. This shows that the current density on the edge of the patch has been reduced and distributed to its centre by PBG.

Next, the second layer is added to the first one with a 1.71 mm thick air layer in between. This air layer is required to increase the efficiency and the gain of the antenna. Increasing air layer thickness augments resonant frequency. Two cross elliptical rings are subtended on the second layer as the second resonator to improve antenna performance. This layer’s substrate is called the Rogers 3210 with a permittivity of 10.2 and a thickness of 1.28 mm. Eventually, two layers of RT/Droid 5880 with a thickness of 3.15 mm are used to cover the second layer stack antenna.

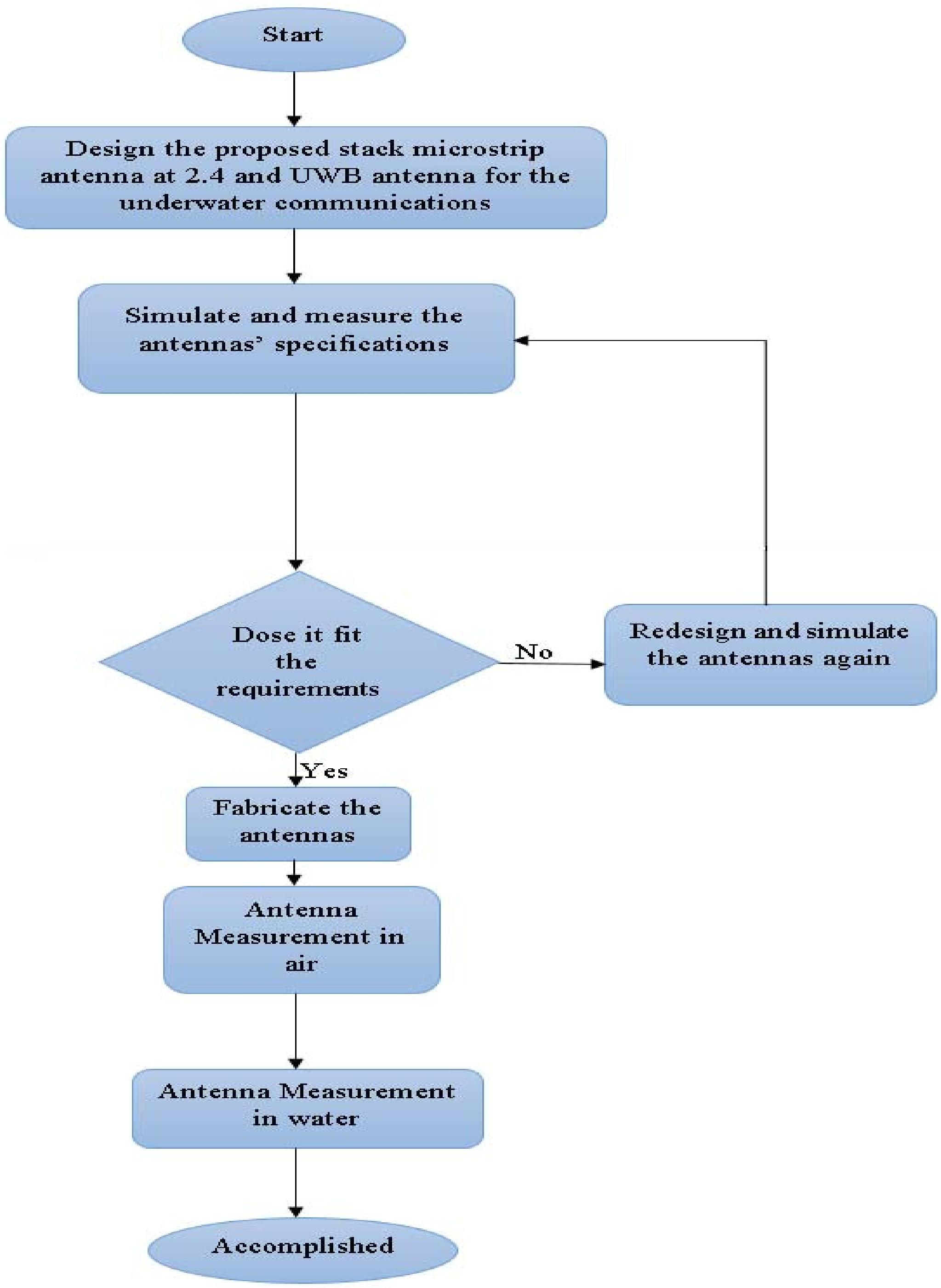

Figure 1.2 : Methodology flowchart

Last but not least, two proposed antennas were exploited in water with a permittivity of 78 and maintaining the same size (after checking the results, the water dimensions increased by 10 mm) and then the distances enhanced. Afterward, the antenna radiation characteristics were investigated within a distance range of 15 to 45 mm based on the wavelength changes and impacts of the medium (air and water) and certain materials (normal water). Hence, the wavelength restrictions in these two mediums—air and normal water—should be around $\lambda/4$, which are almost 31 mm and 3.5 mm, respectively.

To design the second antenna, the same principles, equations, and feeding technique apply for obtaining the first dimensions of the antenna. An elliptical shape was used as a patch because of its simplicity in design and fabrication. Thereafter, some techniques are exploited to increase the BW and the characteristics of the antenna, for example, radiation efficiency. In the design process, it is best to keep the antenna small even at a lower frequency band.

1.6 Thesis Configuration

This study consists of five chapters, with the details of each summarised below:

Chapter 1 presents the research area, and identifies the present issues in planning microstrip antennas to investigate advances in the field. It also presents the research goal, objectives, methodology, scope for exploration, and antenna proposal in this study.

Chapter 2 outlines the literature review on remote correspondence applications, microstrip radio wire outlining procedures, as well as UWB antennas. The principle theories and historical background of microstrip antennas are also discussed. Secondly, UWB radio wire shapes and their provisions are described. Then, the strategies on expanding the design of microstrip antennas are explored. Finally, this chapter is concluded in the summary section.

Chapter 3 first shows a new design of the microstrip antenna at 2.4 GHz as well as their geometric parameters, and discusses the constitutive effective parameters retrieved from the transmission and reflection coefficients in each step of the design. After obtaining the results from the first antenna, a new simulation structure of the UWB antenna is provided for testing and validation in underwater communications. Both antennas are designed in air first and then simulated in water. Finally, after fabrication and measurement in both water and air, their results are compared.

Chapter 4 discusses the complete results for both the PBG rectangular stack antenna and the proposed elliptical UWB antenna. First, the simulation results of these antennas are presented in air and then their medium is changed to water. Finally, their fabrication results are compared with the simulation results in both mediums—air and water.

In Chapter 5, the entire study is summarised and concluded and then followed with the major contributions of the study. Eventually, potential ideas for future work are suggested.

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