Investigation of Buffer Layer Parameters for Underwater Wideband Antenna

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***Abstract*- Underwater wireless systems require highly efficient underwater antennas to realize high data rate communication between underwater nodes. This paper presents a study on buffer-equipped underwater wideband antennas to realize high speed underwater wireless transmission. Since most underwater environments are lossy mediums affecting the characteristics of conventional antennas, a buffer-layer configuration is considered. In this study, the proposed buffer layer parameters was in terms of the relationship between its dielectric constant and conductivity and RF characteristics of the antenna, by means of 3D-electormagnetic simulation. A microstrip circular patch ultra wideband (UWB) antenna operating at 500 MHz was used as the base antenna, to provide wider bandwidth capability for underwater communication, as most researchers only concentrate on narrow bandwidth. This study proposes buffer layer, with dielectric constant value calculated using geometric average formula. Simulation results indicated that the proposed formula produced the best return loss at 500 MHz.**

Keywords-component: UWB, underwater Antenna, buffer layer, geometric average;

I. INTRODUCTION

Nowadays, almost everything in this world are connected by wireless technologies, either on land or deep space. Surprisingly, the ocean that occupied 75% of the earth, has been left out, where electromagnetic waves have reduced penetration depth. Although acoustic wave is the most effective means for underwater applications, it has many drawbacks such as of long propagation delay, narrow bandwidth, multipath fading and susceptability to propagation characteristics from back ground media [1]. Because of the disadvantages of the acoustic wave, it is better to use electromagnetic waves due to more access to wider bandwidth, hence increase data capacity [2].

Underwater electromagnetic transmission is quite different from the conventional land-based communication, where there are various challenges such as, high transmission loss, severe multipath fading and propagation delay. Hence, designing a underwater wireless communication system is extremely difficult, and necessitates dedicated system design.

Several research on underwater communication based on electromagnetic wave transmission were reported in literature, covering topics on propagation characteristics [4, 5], as well as devices dedicated for that purpose. Many researchers investigate new method and techniques to increase the frequency to the MHz and even GHz [5, 6], however, with only limited transmission distance. This can only be improved by using dedicated optimized transmission device such as the antenna.

Some underwater antenna solutions that were proposed include antenna configuration isolated from the water or transmission medium using isolating frames or buffer. The idea of combining antenna and the isolation frame were reported in works regarding implanted antenna in biological tissues [7-9]. The buffer layer was found effective in improving the radiation characteristics due to manipulation of the dielectric constant at the antennas near field region [10]. Wi-Fi compatible deep underwater antenna has been developed in 2011 [7, 11, 12], detail investigation on the buffer layer parameters were presented.

Based on the previous work done by the above researches, our aim in this study to improve what the previous researchers have done, by wider the bandwidth, through a rigorous investigation on the buffer layer of the antenna. The main concept of this study is to implement a new design of buffer layers for underwater wideband antennas, based on optimized parameters obtained through numerical calculations and electromagnetic wave simulations.

Because of the high attenuation of electromagnetic (EM) waves with increasing frequency in underwater, underwater communication is limited to very low frequency (VLF) and extremely low frequency (ELF) bands. In this study, a buffer layer around the antenna will be proposed and investigated to get better bandwidth, preferably up to 500 MHz of bandwidth, so that ultra wideband (UWB) [3, 4] wireless systems can be applied.

The objectives of this project are, to investigate the effects of buffer layer properties on RF characteristics of wideband antenna and to propose suitable buffer layer parameters for wideband antenna operating in underwater environments.

II. METHODOLOGY

The main concept of this study is to carry out parametric studies investigating the properties of buffer layer for wideband antenna affecting the S_{11} (return loss) of the antenna. Initially, a wideband microstrip antenna operating at 500 MHz were designed as the base antenna, followed by design of buffer layer containing the antenna. Parametric studies was done by varying various RF properties of antenna, buffer layer and tranmission medium. Optimization was done to obtain the best combination that produce the optimum antenna characteristics at 500 MHz, followed by calculation of buffer layer solution properties using a proposed calculation formula to determine its dielectric constant value.

A. ANTENNA DESIGN

UWB antenna was chosen in this study because the aim of this investigation is to improve the bandwidth up to UWB. Figures 1a and 1b show the basic UWB antenna design.

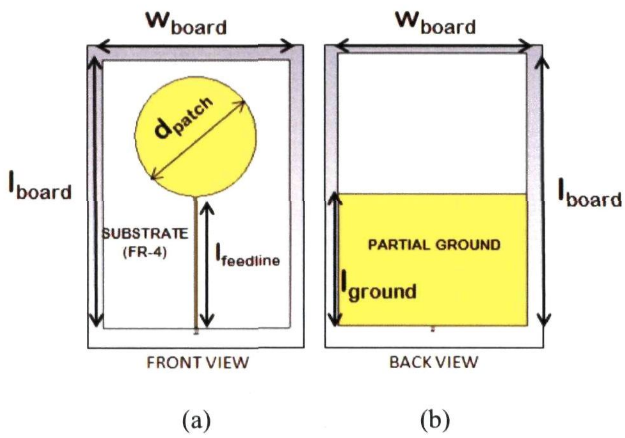


Fig. 1: Circular Patch UWB Antenna (a): Front View (b): Back View

TABLE I
DIMENSION OF THE ANTENNA

Parameter		Label	Dimension (mm)
Patch	Diameter	d_{patch}	130
Feedline	Width	$w_{feedline}$	2.5
	Length	$l_{feedline}$	143
Partial Ground	Width	w_{board}	200
	Length	l_{ground}	140
Substrate FR-4	Width	w_{board}	200
	Length	l_{board}	290
	Thickness	h	1.6
	Dielectric constant	ε_r	4.7
SMA Connector	Impedance	-	50 Ω

The antenna is designed at 500 MHz, as it will operate underwater. For circular patch UWB antenna, the radius patch calculation are shown in Eq. 1:

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{1/2}} \quad (1)$$

where

$$F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}} \quad (2)$$

h – thickness of the patch (copper)
ε_r – substrate dielectric constant (FR-4)
f_r – resonant frequency (500 MHz)

Initially, this antenna is analysed under normal condition, which means, air is the transmission medium before adding buffer layer and setting the transmission medium to water. It is important to assure that the antenna is working very well under normal condition. After some optimization on the physical design of the antenna, the best antenna size as shown in Table 1.

B. BUFFER LAYER AND TRANSMISSION MEDIUM CONFIGURATION

Next, the buffer layer design. Figure 2 shows the antenna design of the antenna with buffer layer. The length and height were chosen to contain the whole antenna in the buffer, while the thickness was set to 20 mm so that it was within the reactive near-field region of the antenna. The dimension of the buffer layer is shown in Table 3. The medium tested in the buffer layer was varied from distilled water, sea water and water. Detail specification of the material is shown in Table 2.

TABLE 2
PROPERTIES OF DISTILLED WATER

	Distilled Water
Dielectric constant, ε_r	78.4
Mue, μ	0.999991
Electric Conductivity, σ	5.55×10^{-6} S/m
Resistivity, ρ	998 kg/m^3
Thermal Conductivity	0.6 W/K/m
Heat Capacity	4.2 kJ/K/kg
Diffusivity	1.43143×10^{-7} m^2/s

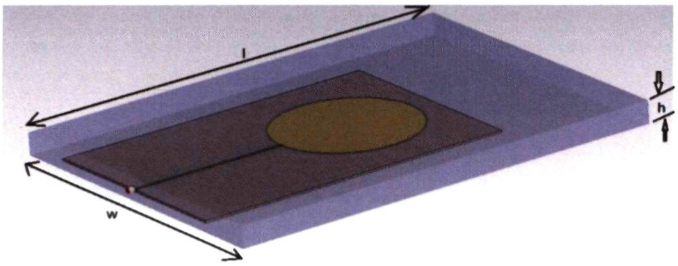


Fig. 2: Buffer Layer for UWB Circular Patch Antenna

TABLE 3
DIMENSION OF THE BUFFER

Parameter		Dimension (mm)
Buffer	Width (w)	300
	Length (l)	400
	Thickness (h)	20

At this stage, we want to see how the antenna react in term of return loss with different types of material.

The last step in this study is setting the transmission medium. Distilled water is used as the transmission medium material. This setting has been done by creating a large box within the farfield boundary in the CST, since CST does not allow changing the background to a lossy medium. Figure 3 shows the arrangement of the antenna, buffer layer and the transmission medium.

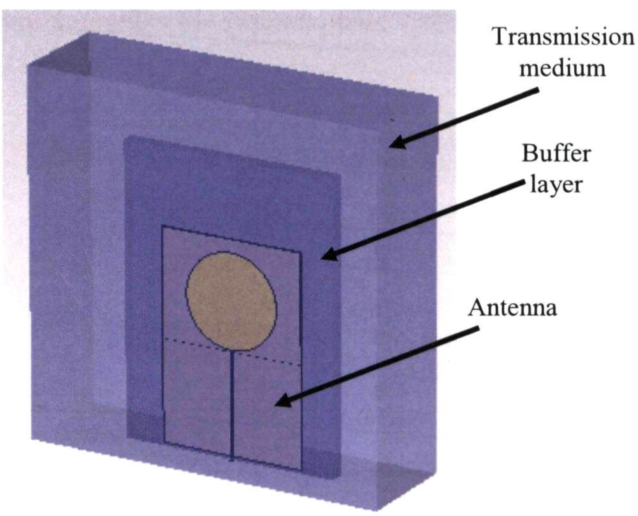


Fig. 3: Arrangement of the Transmission Medium, Buffer Layer and the Antenna

For this investigation, the transmission medium is fix with distilled water, but the buffer layer parameter will be changed to investigate its effects on the antenna performance.

Theoretically, the value of the dielectric constant or relative permittivity (ε_r) of the buffer layer should take a value between that of an air and of the transmission medium, which were 1 and 78.4, respectively, expressed by:

$$\varepsilon_{r(air)} < \varepsilon_{r(buffer)} < \varepsilon_{r(dis.water)}$$

This paper proposes that $\varepsilon_{r(buffer)}$ is determine by taking the geometric average of the two mediums, based on the following equation.

$$\left(\prod_{i=1}^{n} \varepsilon_{r1}\right)^{1/n} = \sqrt[n]{\varepsilon_{r1}\varepsilon_{r2} \dots\dots.\varepsilon_{rn}} \qquad (3)$$

where n is the number of mediums to be considered. The antenna performance based on this calculation will be compared with other values of ε_r obtained from a series of parametric study, in the range from 1 to 80, in intervals of 10.

III. RESULTS AND DISCUSSIONS

First, we observe the result of the antenna when air is set as the transmission medium. Figure 4 shows the S_{11} for the UWB antenna. It can be observed that the bandwidth for this antenna is around 330 MHz, which falls in the wideband category. In this stage, it is important to know that our antenna operate well in the air before we put buffer layer and setting the transmission medium other than air. As a benchmark, the gain of this antenna when operate in air is **2.573 dB.** We are going to compare this gain when the antenna has buffer layer and the transmission medium change to other material.

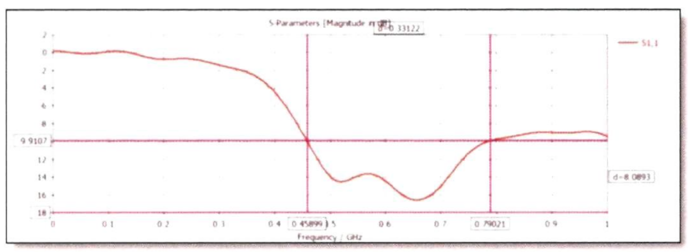


Fig. 4: S_{11} for UWB Antenna in Air as Transmission Medium

Figure 5 shows the S_{11} for three types of materials in the buffer layer, distilled water, sea water and fresh water. As we can see that only the buffer layer filled with distilled water has resonant frequency nearly 500 MHz. Therefore it was chosen as the medium in the buffer layer for the rest of the simulation.

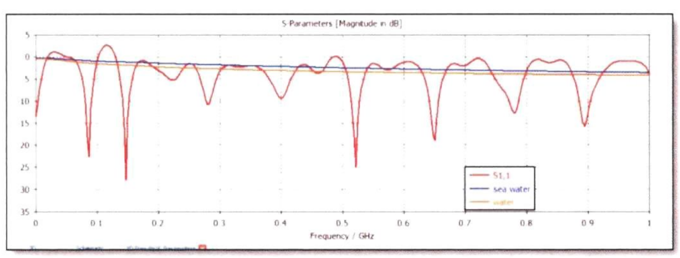


Fig. 5: S_{11} for Three Types of Material in Buffer Layer

For the analysis of the ε_r of the buffer layer, firstly we simulated the design based on the geometric average, considering two parameters, $\varepsilon_{r(air)} = 1$ and $\varepsilon_{r(dis.water)} =$

78.4, so the geometric average based on Eq. (3) gave ε_r of 8.85.

Then, S_{11} of the antenna was plotted by varying the value of ε_r from 1 to 70, comparing the results based on that of the geometric average. The results shown in Table 5, Table 6 and Table 7 shows that decreasing in ε_r will improve the antenna S_{11} at 500 MHz. Most of the better S_{11} results were obtained at lower ε_r values of the buffer layer, where the ε_r approximated the value calculated using geometric average formula. While the S_{11} were more or less similar, the geometric average gave better gain and the bandwidth also within the wideband range. This indicated that the importance of controlling the value of ε_r of the medium, which was not studied by many previous works such as in [11, 12].

TABLE 5
SIMULATION RESULTS FOR EACH BUFFER LAYER WITH DISTILLED WATER AS THE TRANSMISSION MEDIUM

ε_r buffer	Freq. (MHz)	BW (MHz)	S_{11} (dB)	Gain (dB)
78.4 (distilled water)	-	-	-	-23.08
1 (air)	-	-	-	-11.18
8.85	**563**	**117.92**	**-19.24**	**5.41**
10	529	103.3	-18.62	-6.597
15	499	21.63	-24.36	1.424
40	552	11.83	-11.37	-10.89
70	-	-	-	-9.925

TABLE 6
SIMULATION RESULTS FOR ANTENNA WITHOUT BUFFER AND AIR AS THE TRANSMISSION MEDIUM

ε_r buffer	Freq. (MHz)	BW (MHz)	S_{11} (dB)	Gain (dB)
NA	656	322.27	-16.62	2.573

TABLE 7
SIMULATION RESULTS FOR ANTENNA WITHOUT BUFFER LAYER AND DISTILLED WATER AS THE TRANSMISSION MEDIUM

ε_r buffer	Freq. (MHz)	BW (MHz)	S_{11} (dB)	Gain (dB)
NA	-	-	-	-9.91

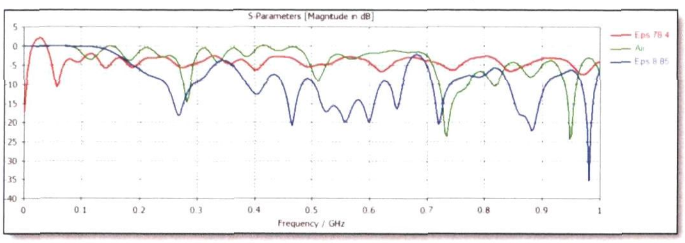


Fig. 6 S_{11} for Three Differents ε_r Buffer Layer in Distilled Water Transmission Medium

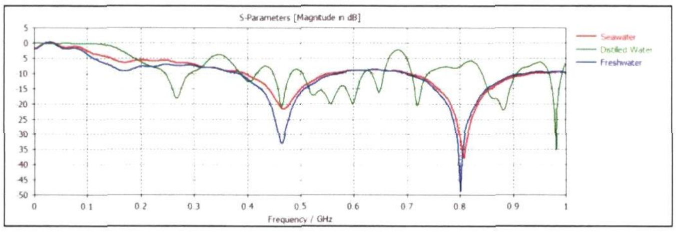
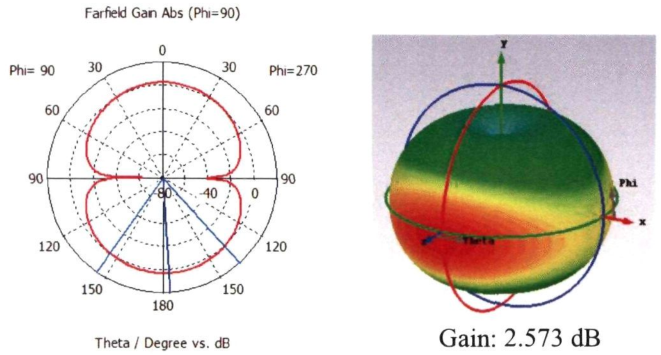


Fig 7 S_{11} - Different Transmission Medium with ε_r Buffer = 8.85 in Distilled Water

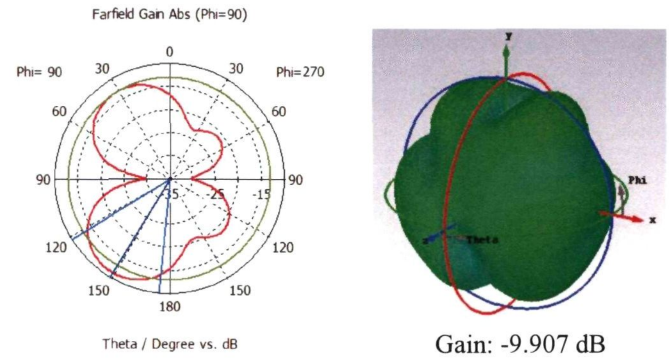
Figure 6 shows S_{11} for five differents buffer layer, where the legends show the value of $\varepsilon_{r(buffer)}$ where the buffer layer has the properties of distilled water except the dielectric constant. Figure 7 shows S_{11} for three differents transmission medium while maintaining the $\varepsilon_{r(buffer)} = 8.85$.



Gain: 2.573 dB

(a) (b)

Fig. 8 Radiation pattern of antenna in air: (a) E-plane, (b) 3D



Gain: -9.907 dB

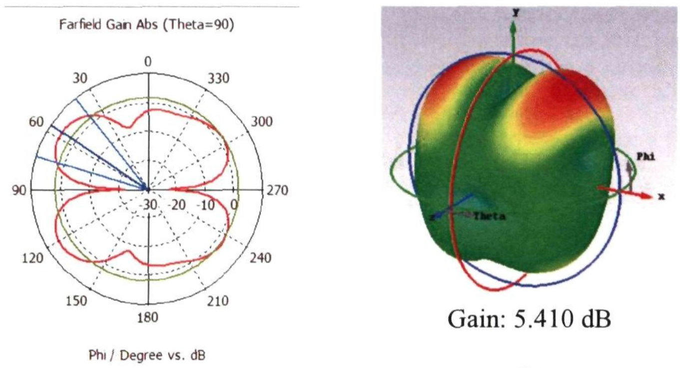
(a) (b)

Fig. 9 Radiation pattern of antenna submerged in distilled water without buffer layerr: (a) E-plane, (b) 3D

Figure 8 shows the radiation pattern in normal antenna which operate in air condition. E-plane in Figure 8(a) shows the doughnut shape.

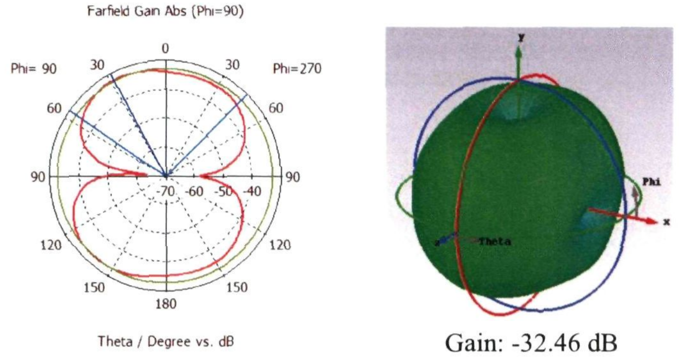
Figure 9 shows the radiation pattern for the same antenna in Figure 8 but it submerged in distilled water without a buffer layer. The E-plane shows the shape of butterfly.

Figure 10 shows the antenna with distilled water buffer layer where the ε_r = 8.85 and disstilled water as the transmission medium where the ε_r = 78.4.



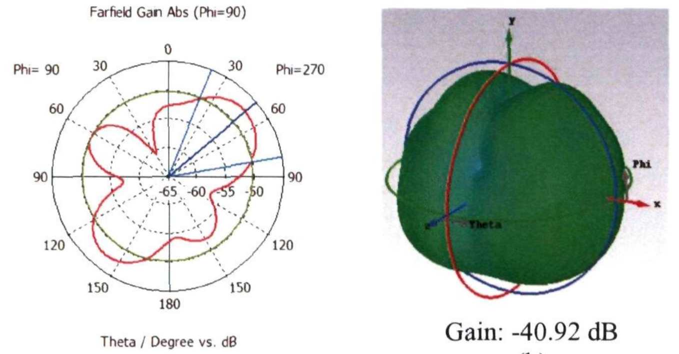
(a) (b)

Fig. 10 Radiation pattern of antenna with buffer layer in distilled water (ε_r =8.85) and distilled water (ε_r = 78.4) as the transmission medium: (a) E-plane, (b) 3D



(a) (b)

Fig. 11 Radiation pattern of antenna with buffer layer in distilled water (ε_r =8.85) and fresh water (ε_r = 78.8) as the transmission medium: (a) E-plane, (b) 3D



(a) (b)

Fig. 12 Radiation pattern of antenna with buffer layer in distilled water (ε_r =8.85) and sea water (ε_r = 74) as the transmission medium: (a) E-plane, (b) 3D

Figure 10 – 12, shows the different radition patterns in different backgrounds and the buffer layer still in distilled water conditions with ε_r =8.85. The summary of this radition pattern is shown in Figure 13.

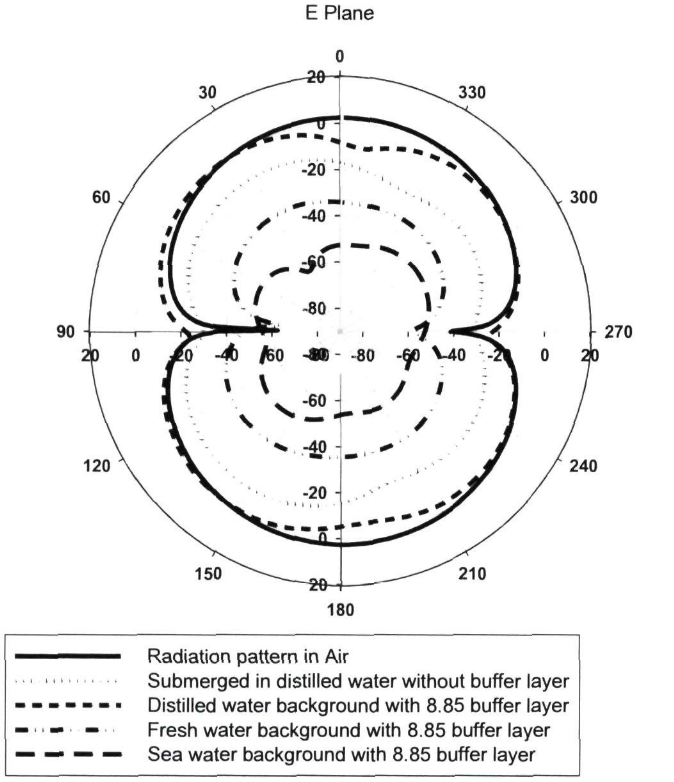


Fig 13 Summary of radiation pattern (E-plane) in five (5) differents conditions.

IV. CONCLUSION

The objective of this project to investigate and propose the most suitable buffer layer antenna for underwater applications. For the purpose of fundamental investigation and validation of the concept, the buffer layer characteristics based on distilled water parameters, while changing the ε_r. The value ε_r of was proposed to be determine by taking the geometric average of the ε_r of air and the transmission mediums. For the case presented in this paper, ε_r = 8.85 was chosen for the buffer layer. Parametric simulations confirmed that the underwater antenna produced the highest gain as well as commendable bandwidth and return loss at ε_r= 8.85. In future works, further investigation will be carried out using buffer layer cover material, or multi layer buffer material.

V. REFERENCES

[1] Sameer Babu, T.P. Kumar, S.S. "Underwater Communications", in Underwater Technology (UT), 2015 IEEE, pp. 1-3.

[2] Aleix Garcia Miquel, UWB Antenna Design for Underwater Communications, 25 May, 2009

[3] Code of Federal Regulations, Title 47 – Telecommunications, Chapter 1: Federal Communication Commissions, Part 15.503, October 1, 2015.

[4] Paul A. van Walree, and Roald Otnes, "Ultrawideband Underwater Acoustic CommunicationChannels" in IEEE Journal Of Oceanic Engineering, Vol. 38, No. 4, October 2013, pp. 678-688

[5] B. Kelley, K. Manoj, and M. Jamshidi, "Broadband RFCommunications In Underwater Environments Using Multi-Carrier Modulation," in *Systems,Man and Cybernetics, 2009. SMC 2009. IEEE International Conferenceon*, Oct 2009, pp. 2303–2308.

[6] H. D. Trung and V. D. Nguyen, "An analysis of mimo-ofdm for underwater communications," in *Ultra Modern*

Telecommunications and Control Systems and Workshops (ICUMT), 2011 3rd International Congress on, Oct 2011, pp. 1–5.

[7] Karmakar, N.; Singh, M, "Investigations into a circular patch antenna in a cylindrical cavity enclosure" Singapore ICCS'94. Conference Proceedings, Vol.2, 1994, pp 446 – 450.

[8] J. Kim, Y. Rahmat-Samii "Implanted Antennas Inside a Human Body:Simulations, Designs, and Characterizations", IEEE Transactions on Microwave Theory and Techniques, Vol. 52, No. 8, August 2004, pp 1934-1943.

[9] Tutku Karacolak, , Aaron Z. Hood, Erdem Topsakal, , "Design of a Dual-Band Implantable Antenna and Development of Skin Mimicking Gels for Continuous Glucose Monitoring", IEEE Transactions on Microwave Theory and Techniques, vol. 56, No. 4, April 2008.

[10] Gareth A. Conway and William G. Scanlon, "Antennas for Over-Body-Surface Communication at 2.45 GHz" in IEEE Transactions on Antennas and Propagation,Vol. 57, No. 4, April 2009

[11] Hector Fabian GUARNIZO MENDEZ, Christian GAC, François LE PENNEC, Christian PERSON, "High Performance Underwater UHF Radio Antenna Development", OCEANS, 2011 IEEE – Spain, pp 1-5

[12] Hector Fabian GUARNIZO MENDEZ, Christian GAC, François LE PENNEC, Christian PERSON, "2.4 GHz Radio Transmission Measurementsin a Basin filled with Sea Water", OCOSS – 2013.