

Water effects on Body-Centric communication radio channel

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Abstract—Nowadays, the trend in communication technology is gathering clothing with electronic technology. There are two factors despite each others, the convenient of On-Body antennas power supply on the cloth and the power combined with the biological lossy tissues for the human; therefore, efficiency is important when considering Body-Centric communication systems. In this work, the experiments conducted in the study of Off-Body radio with water in the channel are described. To manage the searching properties of water two techniques were studies. The first was a simulation of multilayeres human model with and without a water layer in aspect of transmission coefficient and antenna reflection, the second was to use a gel to absorb water, Polyacrylamide, within special box underneath the On -Body antenna measuring the s11 in frequency 2.1 GHz

Keywords—Water; wireless off-body communication; polyacrylamide gel

I. INTRODUCTION

NOWADAYS, the trend in communication technology is gathering clothing with electronic technology[1],[2]. There are two factors despite each others, the convenient of On-Body antennas power supply on the cloth and the power combined with the biological lossy tissues for the human; therefore, efficiency is of importance when considering Body-Centric communication systems [3]-[5].

There are some groundplane used to reflect energy away from the skin and shield it like copper groundplane[1], but in this paper a new concept of using groundplane with water has been explored. As many people know that water has high relative permittivity also has benefit aspects to radio propagation. The effect of water has been reported with small dBs because it is difficult to isolate the fading for the Off-body which is may be greater than 40 dBs. However in modern wearable communication a few dBs are valuable.

The Off-Body effects with water in the channel have not been studied. For simplicity, we will call radio propagation over water ‘Water Surface Propagation (WSP)’[6] and impedance matching effects due water surface propagation ‘Water Surface Matching (WSM)’[7].

Many papers illustrated antennas with water effects as in [8] by manipulating the shape and size of water with reconfigurable antennas for different frequencies and

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polarizations. Also in [9] a seawater antenna was broad the bandwidth impedance by using multiple close resonances.

In general, there are some changes in S21 for channels involving water as water, have high relative permittivity when compared to Off-Body radio channels having other materials. These changes increase the wave’s reflected component which gives more transmitted energy at the receiver [10],[11]. An important work that looked at water between mobiles and base stations is in [11]. As, The human body tissues have a similarity in electrical properties with water, the electromagnetic propagation in human tissue [12],[13],[14]-[22] is demonstrated in these studies.

In this work, for fresh water radio, Body-Centric WSP and WSM are researched in a simulation of electromagnetic plane wave multilayer.

A plane wave model of human tissue was provided to a flat area of human body. In the first section, the frequency and the electrical properties of the plane wave with their incident angle were analyses for each layer; skin, fat, muscle and bone. With these parameters interacts with the body, it can be calculate the transmitted and the reflected proportions of an incident plane wave. Therefore, the water effect can be examined on the human tissues in the Off-Body channel.

Later in this work, the experiments conducted in the study of Off-Body radio with water in the channel are described. To manage the searching properties of water two techniques were used. A Polyacrylamide, water absorbent gel, [23], used in bespoke antenna.

Using Polycrylamide gel [23]-[25] in this research is novel application of a gel that is most often seen in baby products for keeping children dry. The gel can be used with deionised or tap water to make a temporary good electrical insulator with high permittivity and low loss. It has the following properties; (i) take the shape of any design easily, (ii) has the gel elasticsolidity, (iii) similar to water in some characteristics such as transparent, (iv) available in many places with low cost, and (v) prevent wetting the antenna or the volunteer as it absorb water.

II. THE THEORETICAL MODEL

Human tissues with a water layer simulation model of the reflection and transmission coefficient is shown in Figure 1. This model designed to work for frequency range between (0-6 GHz) and incident wave angles (0°- 85°). The flat model of tissues layers thickness were taken as; skin (2mm), fat (10mm), muscle (28mm) and bone layer (12mm)[12],[23] as shown in Figure 1.



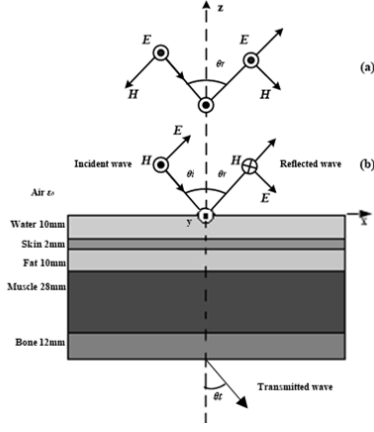


Fig.1. Homogeneous multilayers human flat model with incident wave and water layer

The water layer in the simulation was 10mm. From Snel's law of reflection[13], the incident angle can classified the plane waves polarization to parallel and perpendicular. The perpendicular polarization of the reflection coefficient for layer i and the next layer ($i+1$) is

$$\Gamma = \frac{\cos(\theta_{in}) - \sqrt{\frac{\epsilon_{i+1}}{\epsilon_i}} \sqrt{1 - \frac{\epsilon_i}{\epsilon_{i+1}} \sin^2(\theta_{in})}}{\cos(\theta_{in}) + \sqrt{\frac{\epsilon_{i+1}}{\epsilon_i}} \sqrt{1 - \frac{\epsilon_i}{\epsilon_{i+1}} \sin^2(\theta_{in})}} \quad (1)$$

The perpendicular polarization of the transmission coefficient for layer i and the next layer ($i+1$) is

$$T = \frac{2 \cos(\theta_{in})}{\cos(\theta_{in}) + \sqrt{\frac{\epsilon_{i+1}}{\epsilon_i}} \sqrt{1 - \frac{\epsilon_i}{\epsilon_{i+1}} \sin^2(\theta_{in})}} \quad (2)$$

where θ_{in} is the incident angle.

The parallel polarization for multilayer reflection and transmission coefficients expression are

$$\Gamma = \frac{-\cos(\theta_{in}) - \sqrt{\frac{\epsilon_i}{\epsilon_{i+1}}} \sqrt{1 - \frac{\epsilon_i}{\epsilon_{i+1}} \sin^2(\theta_{in})}}{\cos(\theta_{in}) + \sqrt{\frac{\epsilon_i}{\epsilon_{i+1}}} \sqrt{1 - \frac{\epsilon_i}{\epsilon_{i+1}} \sin^2(\theta_{in})}} \quad (3)$$

$$T = \frac{2 \sqrt{\frac{\epsilon_i}{\epsilon_{i+1}}} \cos(\theta_{in})}{\cos(\theta_{in}) + \sqrt{\frac{\epsilon_i}{\epsilon_{i+1}}} \sqrt{1 - \frac{\epsilon_i}{\epsilon_{i+1}} \sin^2(\theta_{in})}} \quad (4)$$

Figures 2 to 5 illustrate the total reflection loss for flat human tissues with and without water layer for perpendicular and parallel polarization with incident angle in 3D regarding to reflection loss (dB), Theta (degree) and Frequency (GHz). These figures demonstrate the effects of water layer on reflection loss in different frequencies and angles.

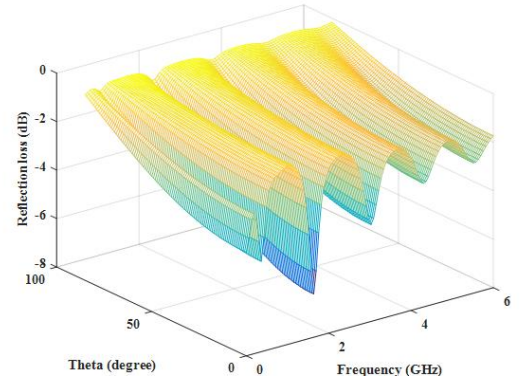


Fig.2. The total reflection loss for flat human tissues with water layer for perpendicular polarization with incident angle

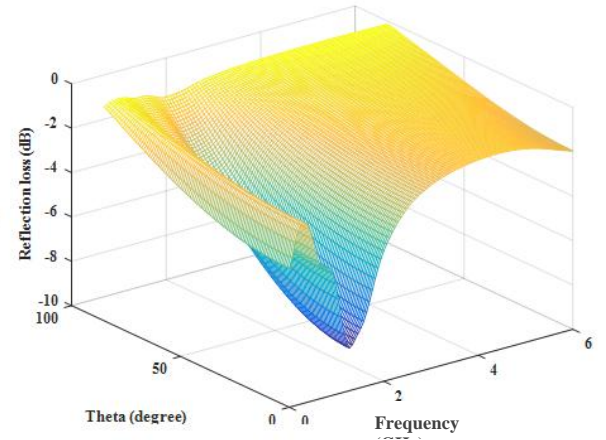


Fig.3. The total reflection loss for flat human tissues without water layer for perpendicular polarization with incident angle.

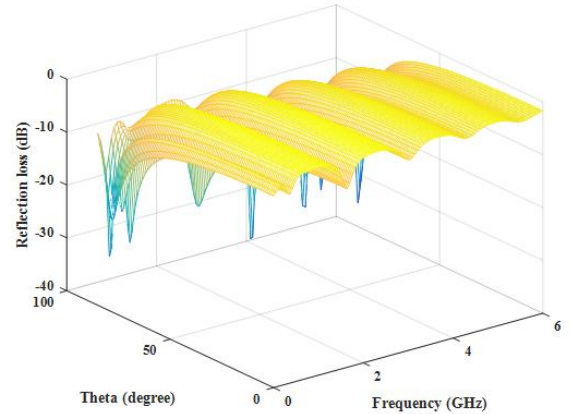


Fig.4. The total reflection loss for flat human tissues with water layer for parallel polarization with incident angle

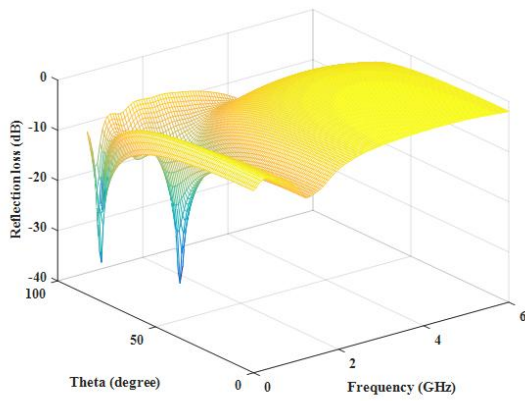


Fig.5. The total reflection loss for flat human tissues without water layer for parallel polarization with incident angle.

From the above figures, the present of water layer above the human tissues affect the reflection loss regarding to the increasing frequencies with different theta angles. As frequency increases, human tissues permittivity tends to decrease while conductivity rises. The impedance contrast interface changes, so incidence wave reflection generally changes slightly, but losses in the near field increase because both water and tissue are more conductive at the high frequencies.

III. PROCEDURE FOR MEASUREMENTS

In order to take into account the benefit of using water layer in real life, four different boxes were made, to examine different water layers underneath the antenna. An antenna was designed using cst and manufactured by Loughbrough university workshop to works at S Band (2-4 GHz) where S band is more commonly used for wireless body area networks (WBAN) that transmit around the body [2]. This antenna was a new design as a fork patch antenna as shown in Figure 6. The proposed antenna ground plane had a one sided copper FR4 substrate.

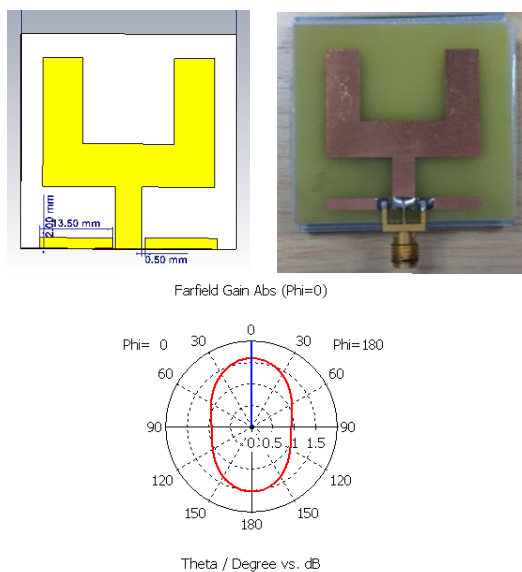


Fig.6. A 2.1 GHz patch antenna and its radiation pattern

Four different 3D printed boxes were used underneath the antennas and above the volunteer’s chest. Their dimensions are: Box 1 (length 40mm, width 40mm, height 5mm), Box 2 (length 100mm, width 100mm, height 5mm), Box 3 (length 100mm, width 100mm, height 10mm), Box 4 (length 150mm, width 150mm, height 50mm). These boxes were filled with the hygroscopic gel (Polyacrylamide Gelatin [23]).The reason behind using this gel is because high absorption water and it is acting like real water characteristics[24],[25]. Figure 7 shows a one crystal volume with and without absorbing water. Also, this figure shows the crystals sit in the 3D box used in the experiment to make sure that either the antennas or the volunteer chest get wet. In other hand, a cst simulation were done to simulate water layers and human tissues with the 2.1GHz antenna as shown in Figures 8, 9,10 and 11 Also, A set of measurements were done with these boxes, The reflection coefficient s11 was measured using the portable VNA (Anritsu MS2026A) with and without the volunteer. The volunteer was a male with 1.77 height and about 73 kg his weight, he was laying down on a wooden table, wearing a cotton shirt with the 3D printed box filled of gel once and other is empty.



Fig.7. A comparison between one crystal of the Polyacrylamide gel with a one that absorbed water and how the water absorbed gel lay out in the 3D box with its cover underneath the used antenna

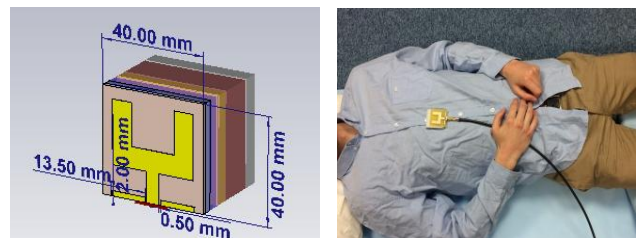


Fig.8. An antenna 2.1 GHz with 40x40x5mm water layer with human (box1) simulation in cst and with the volunteer.

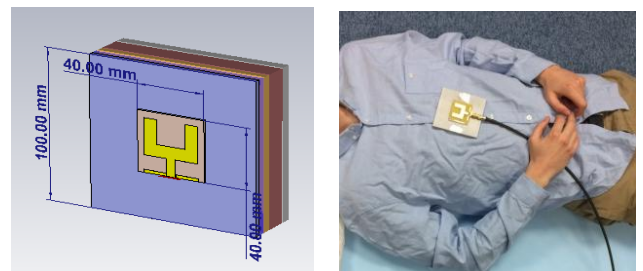


Fig.9. An antenna 2.1 GHz with 100x100x5mm water layer with human(box2),simulation in cst and with the volunteer.

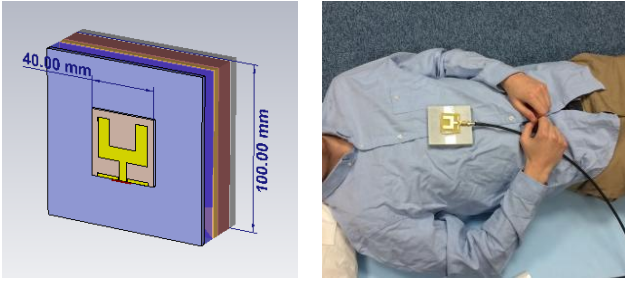


Fig.10. An antenna 2.1 GHz with 100x100x10mm water layer with human (box3), simulation in cst and with the volunteer.

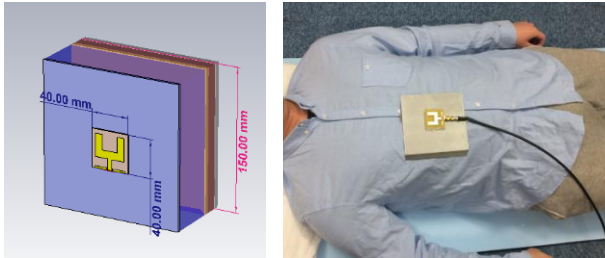


Fig.11. An antenna 2.1 GHz with 150x150x50mm water layer with human (box4), simulation in cst and with the volunteer.

IV. RESULT AND DISCUSSION

In this paper two scenarios were illustrated the first one a simulated and measured 4 boxes underneath the antenna filled with absorbed gel and human tissues, the other on the same previous scenario but without human tissues.

The results of free space, simulated and measured signals with all four boxes are shown in Figures 12 and 13. Tables 1 and 2 show the results from the simulated and measured signals with and without the volunteer.

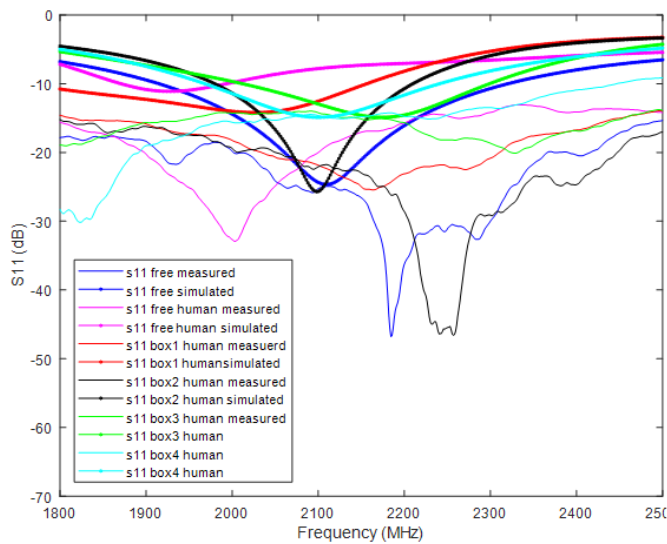


Fig.12. Simulation and measurements results with the 4 boxes underneath the antenna filled with absorbent gel and human tissues

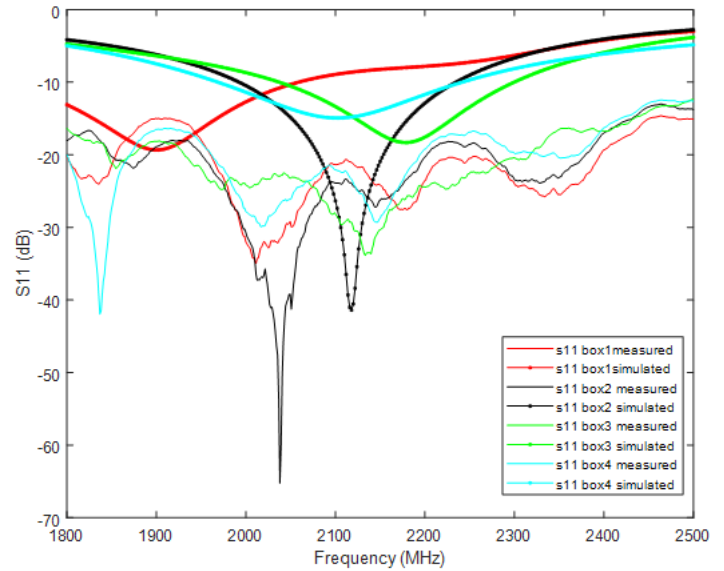


Fig.13. Simulation and measurements results with the 4 boxes underneath the antenna filled with absorbent gel without human tissues

The water boxes work as a ground layer or a separated layer between the human skin and the antenna, therefore the radiation waves will be away from the human skin which reflects on the human health and the effect of electromagnetic waves on the human.

Figure 12 shows many cases dealing with the antenna that used in the experiment in present the human, first case a free space without boxes simulated s_{11} (-24.6 dB) and measured s_{11} (-26.12 dB), the second case is the free space with human without boxes simulated s_{11} (-8.5 dB) and measured s_{11} (-20.6 dB), the other four cases of the antenna with the boxes are shown in Table 1.

In Figure 13 the same cases repeated but without human present. The results for this figure are in Table 2. There is an enhancement in reflection coefficient s_{11} with boxes filled with water gel rather than without gel in both simulation and measurements which gives a conclusion that using a water pad underneath antennas used for body-centric communication gives an advantage of enhancement the received signal and human health issues.

V. CONCLUSION

This paper is the first in the literature to study water effect on the body-centric channels. In addition, flat human tissue model with plane wave multilayer simulation was presented. It was shown that the amount of power lost could decrease power in the receiver through losses in tissue by adding a layer of water. Additionally, an experiment was tested to study the effect of water in the body-centric communications; four different boxes were made, to examine different water layers underneath the antenna. This experiment shows that in the present of water has an advance effect on communication near humans. As a future research, use trials with more volunteers or testing with different environmental conditions.

TABLE I
RESULTS SIMULATION AND MEASUREMENTS IN FREE SPACE (WITHOUT WATER LAYER), WITH HUMAN (WITHOUT WATER LAYER),
AND WITH HUMAN AND WATER IN THE BOXES. (Figure 12)

| Set | S11 at frequency 2.1GHz Simulated (dB) | S11 at the minimum Simulated (dB) | S11 at frequency 2.1GHz Measured(dB) | S11 at the minimum Measured(dB) |
|-------------------------------------|--|-----------------------------------|--------------------------------------|---------------------------------|
| Free space antenna without boxes | -24.6 | -25.2 at 2.12 GHz | -26.12 | -45.6 at 2.18GHz |
| Free space with human without boxes | -8.5 | -10.8 at 1.96 GHz | -20.6 | -32.8 at 2GHz |
| Antenna with box 1 | -11.8 | -14.1 at 2.12 GHz | -21.2 | -25.6 at 2.15 GHz |
| Antenna with box 2 | -25.3 | -25.3 at 2.1 GHz | -21.3 | -46.2 at 2.26 GHz |
| Antenna with box 3 | -11.8 | -15.2 at 2.185 GHz | -12.3 | -20.1 at 2.33 GHz |
| Antenna with box 4 | -14.5 | -14.5 at 2.1 GHz | -14.5 | -30.0 at 1.825 GHz |

TABLE II
RESULTS SIMULATION AND MEASUREMENTS WITH WATER LAYER IN THE BOXES BUT WITHOUT HUMAN (Figure 13)

| Set | S11 at frequency 2.1GHz Simulated (dB) | S11 at the minimum Simulated (dB) | S11 at frequency 2.1GHz Measured(dB) | S11 at the minimum Measured(dB) |
|--------------------|--|-----------------------------------|--------------------------------------|---------------------------------|
| Antenna with box 1 | -9.2 | -19.5 at 1.91GHz | -20.2 | -34.8 at 2.02GHz |
| Antenna with box 2 | -20.5 | -41.2 at 2.12GHz | -20.45 | -66.1 at 2.04GHz |
| Antenna with box 3 | -13.1 | -18.2 at 2.18 | -27.2 | -34.3 at 2.14 GHz |
| Antenna with box 4 | -15.0 | -15.0 at 2.1 GHz | -21.5 | -41.9 at 1.84GHz |

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