Analysis of the Antenna Performance for Wireless Implantable Body Area Network Applications

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***Abstract*—Wireless implantable body area network (WiBAN) is useful in health monitoring systems especially for the purpose of medical diagnoses, such as breast cancer, heart attack and high blood pressure. The performances of implantable antenna in a selected part of the human body are presented in this paper. The antenna performances, in terms of gain, efficiency, return loss and specific absorption rate (SAR), were investigated at selected parts of human body (hand ,chest, leg, heart and skull) by using human voxel model inbuilt in the CST Microwave Studio software. Investigations have shown that the human hand model is the most suitable place for implanting the antenna. The antenna is implanted under the skin so that the signal propagation path length to the base station at free space environment is considerably short. Besides, human hand model has a less complex structure as it consists of skin, fat, muscle, blood and bone. The antenna's gain, efficiency and Specific Absorption Rate (SAR) are -11.92dBi, 1.30 % and 0.09 W/kg respectively; which confirms the safety of the antenna usage. The results of performance evaluations have shown that the proposed antenna is a suitable candidate for WiBAN applications.**

***Index Terms*— Implantable Antenna; Small Printed Antenna; Wireless Implantable Body Area Network Application (WiBAN).**

I. INTRODUCTION

Recently, a lot of research efforts have been concentrated on the exploration of the implantable device, due to its applicability especially in health monitoring systems, biotelemetry, hyperthermia, breast cancer detection and others [1]-[3]. Wireless networks through in-body are used to monitor the patient's vital signs and can provide real-time feedback. They can also be a part of the diagnostic procedure, maintenance of chronic condition, supervised recovery from a surgical procedure and to monitor effects of drug therapy [4]. This device also can be used in such applications as home/office security, finding missing pets/kids and in the military sector.

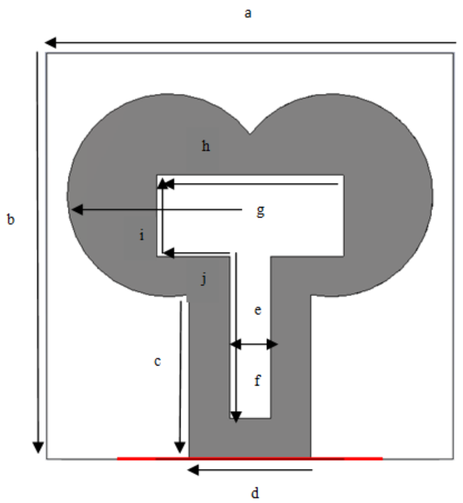
The design of an implantable antenna is very challenging compared to the antenna at free space condition. Since the antenna is implanted in a lossy environment (for example, human body), so the antenna efficiency is reduced and it also encounters very strong multipath losses. There are difficulties in using the human body to characteristics act as a medium for signal propagation due to the dissimilar tissue and organ. Attenuation occurs due to the weakly conducting tissue and reflection at each of the boundaries of dissimilar tissue. The implantable antenna is required to have a small size for ease of implantation in the human body. The power consumption should also be very low in order to ensure the safety of users.

WiBAN offers a lot of advantages for personal communication and medical application; and in order to operate as such systems, the antenna must be compact, small in size and with better performances [5]-[10]. Based on the previously reported research works, printed monopole antenna has become the major field of interest due to its compact and small size, omni-directional radiation patterns, large bandwidth (BW) and high radiation efficiency [11]-[12]. The printed monopole antenna has therefore been chosen for the WiBAN application, due to the aforementioned characteristics.

This paper continues the previous work which has been published in [13] whereas the design and performance evaluation of an implantable small printed monopole (ISPM) antenna for the WiBAN application. In this work, the antenna has been tested in selected parts of human body (hand, chest, leg, heart and brain). The antenna performances have been investigated in terms of gain, efficiency, return loss and SAR. The human voxel model in CST Microwave Studio software has been used throughout in this work for all the simulations.

II. THE ANTENNA CONFIGURATIONS

The antenna is composed of a single metallic (copper) layer with 0.036 mm thickness, and it is printed on one side of the surface of FR4 substrate. The dielectric constant of the substrates is ε_r=4.7, while the loss tangent and thickness are 0.019 and 1.6mm respectively. The proposed antenna's optimum configuration and prototype are shown in Figure 1. The antenna's dimensions are 10 mm ×10 mm ×1.6 mm. The antenna's radiating elements is composed of two overlapping shapes of a circle with a T-shaped slot at the center and feed line. The radiator is center fed by a microstrip line with length and width of 4.1 mm and 3 mm, respectively. It should be noted that no ground plane is added in the proposed design, since the body (or any lossy material) will act as a reflector to the antenna. The antenna's optimized dimensions are: a = 10.0 mm, b = 10.0 mm, c= 5.0 mm, d = 3.0 mm, e= 1.0 mm, f= 4.0 mm, g= 2.5 mm, h= 4.6 mm, i= 2.0 mm and j=1.8 mm.



(a)

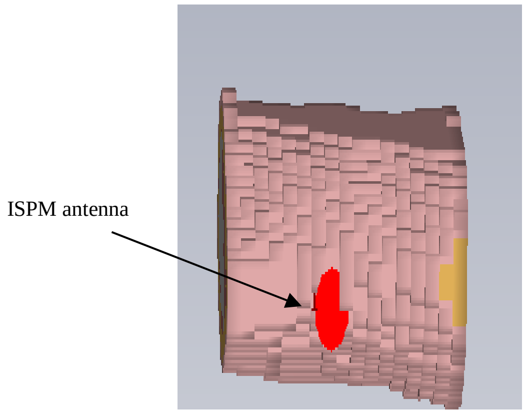
(b)

Figure 1: The antenna design (a) Simulated (b) Prototype

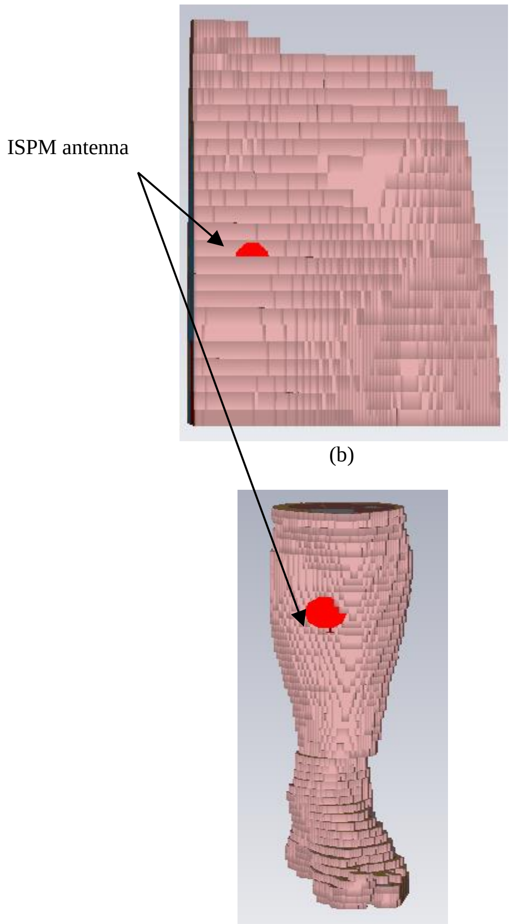
III. Investigation Of The Antenna Performances In The Human Voxel Model

The proposed ISPM antenna is designed in a free space environment and further implanted in the human breast tissue model. This work has been published in [13] whereas the antenna is operated at 6.8GHz in free space environment and tuned to 6.0GHz while operating in canola oil (represents human breast tissue model). Detuning of resonance frequency was observed, which could be attributed to the effects of the surrounding tissue. The antenna performances were also evaluated in terms of resonant frequency, return loss, gain, efficiency and SAR.

This paper continues the previous work whereas the antenna is implanted in human voxel model using the CST Microwave Studio Software. Several parts of human body (hand, chest, leg, heart and brain) are selected to evaluate the antenna performances. The antenna cannot be simulated using the whole human body phantom, a limitation encountered while evaluating the antenna performance. This is due to the limited capacity of the computer processor when simulating the antenna performance. For this reason, the antenna is only implanted in selected parts of the human body. The input reference power of an implantable antenna is 0.1W. In this investigations, there is only simulation completed as there appear some difficulties on measured the antenna performance in a real human body. However, the results can be used as a reference and guidance for designing wireless body area network in future. The implantations of antenna in some selected parts of human voxel model are shown in Figure 2.



(a)



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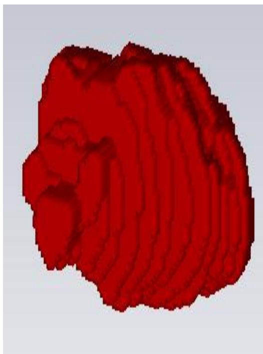

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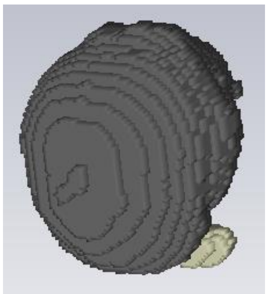

(e)

Figure 2: Implanted antenna in human voxel model (a) hand (b) chest (c) leg (d) heart (e) brain

IV. Experimental Results

The antenna is implanted under the skin in the cases of chest, leg and hand, while it is implanted approximately 3mm from the surfaces of heart and brain. The resonant frequency of each part of human body is illustrated in Figure 3. The observed results have revealed that the antenna offers the highest stability when implanted in hand, compared to other parts. Simulation result shows that the antenna is excited at 3.4 GHz with a – 10dB impedance BW of 800 MHz (3.0 - 3.8GHz). In the chest, the illustrated results have shown that the antenna operates at 7.0 GHz with impedance BW of 1400MHz (7.9-6.5) GHz. The other parts (leg, heart and brain) provide less stability as the antenna cannot perform well in these complex structures. Besides, a longer distance is needed for signal propagation from inside the tissue to the base station in free space environment. There were different resonant frequencies for the different human parts when the antenna was tested due to the effect of complex human body structures. Attenuation also occurs due to differences in boundary layers, thus resulting in some negative effects in the antenna performances.

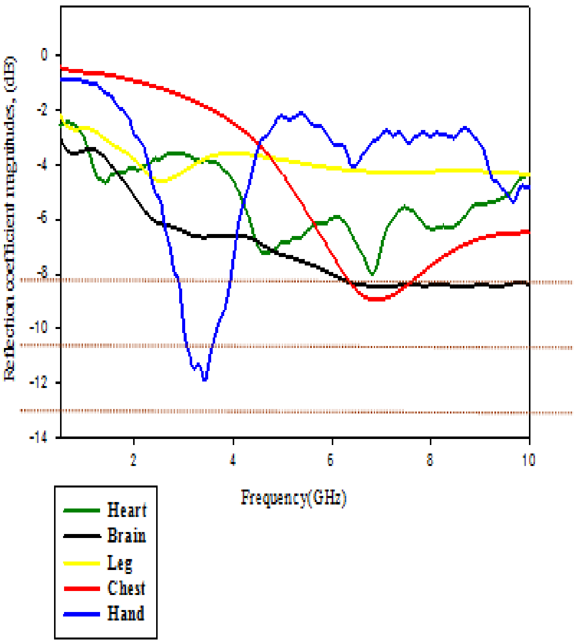

Figure 3: Antenna resonant frequency for several parts of the human body

Since the antenna is used for implantation in the human body, a safe value of specific absorption rate (SAR) is very important in order to ensure human safety. Up till now, no specific SAR standards applicable to any specific parts of human body can be found in the literature; hence the SAR standards for mobile applications have been adopted. According to the European Union standards [14], the SAR limit is 2 W/kg averaged over 10 g of tissue. Table 1 shows the gain, efficiency and SAR for antenna implanted in hand, leg, chest, heart and skull.

Human part	Gain(dB)	Efficiency	SAR(W/kg)
Hand	-11.92	1.30%	0.09
Chest	-17.36	0.48%	0.48
Leg	-17.73	0.46%	0.33
Heart	-14.57	0.04%	0.32
Brain	-28.63	0.08%	1.85

Table 1
The Gain, Efficiency and SAR for Selected Parts of Human Body

The results presented in Table 1 have shown that antenna implanted in human hand voxel provides the highest gain and efficiency, compared to other organs. This is because the human hand voxel has the least complex structure (mainly composed of skin, blood, fat and bone) and the propagation path length is short since the antenna is placed under the skin. The value of SAR in a human hand, as illustrated in Figure 4, does not exceed the standard limit which thus shows that the antenna is safe to implant in the hand. It should be noted that it is not suitable to implant the proposed ISPM antenna in the human brain and heart, as very poor performances are obtained. The reason might be due to the complex structures of these organs (brain and heart). Future works shall explore possible modifications of the antenna in order to enhance its performances on the brain and heart.

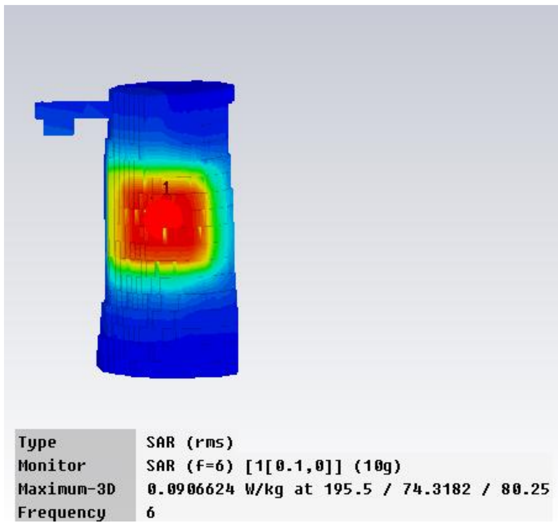

Figure 4: Simulated of SAR in human hand model

V. Conclusion

The performances of ISPM antenna in a selected part of human body is presented in this paper. The antenna is capable of operating at different frequencies in different propagating environments. For example, it can operate at 6.8 GHz (in free space environment); 6.0 GHz (when submerged in canola oil); 3.4 GHz (when implanted in human hand voxel) and 7.0 GHz (when implanted in human chest voxel). It is observed that the antenna, when implanted in the human voxel model (human hand), offers good stability in terms of return loss, gain, efficiency and SAR, compared to other organs. This is because the human hand voxel has the least complex structure (mainly composed of skin, blood, fat and bone) and the propagation path length is short since the antenna is placed under the skin. Future works shall explore the possibilities of modifying the antenna in order to enhance its performances on the skull and heart.

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