Design of a Chip Printed Antenna at 4.8GHz for Wireless Implantable Body Area Network Applications

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***Abstract*— The health monitoring system is improved by wireless implantable body area network technologies especially for medical diagnostic for instance blood pressure, breast cancer and heart attack. The objective of this paper is to design an implantable chip printed antenna at 4.8GHz for WiBAN applications. The antenna performances are evaluated in term of return loss, gain, efficiency, radiation pattern and operating bandwidth at different environments. In this experiment, the antenna is tested in three types of environments which are in homogeneous layer, non-homogeneous layer (skin, fat and muscle) and the real human hand voxel model from CST Microwave Studio Software. The simulations results of the antenna performances have been analyzed. Results proved that the resonant frequency and return loss are approximately similar for all environments. All the results will be guidelines in designing implantable antennas in futures.**

***Index Terms*— Chip Printed Antenna; Human Voxel Model; Implantable Antenna; Wireless Body Area Network Application (WBAN).**

I. Introduction

Lately, wireless implantable body area network (WiBAN) has been an interesting topic for researchers since the systems are applied to improve and support the quality of human lives. There are some implantable medical devices have been used such as temperature monitors, pacemakers, blood glucose sensor and cardioverter defibrillators [1]. As the technologies are continuous developing, the small size of the implantable antenna is a necessity to make it reliable in the system [2]-[4].Therefore, the application of WiBAN could be practical for a different kind of application such as a home or office security, finding lost pets and in the military sector.

There is some challenging to design an implantable antenna compared to the antenna which operates at free space condition. The implantable antenna is a necessity to have a small size to make it easy and possible to implant in the human body. Moreover, the implantable antenna faces very strong effect of multipath losses as the lossy environment (such as the human body) has a different layer of boundaries thus reduced the antenna efficiency. Attenuation is happened because of the weakly conductive tissue and reflection at each of the boundaries of dissimilar tissue in the human body. Therefore, the human body is challenging to act as a medium for the signal to propagate. To make sure the safety of the user, the value of power absorption by the human body is required to follow the standard. As WiBAN compromises a lot of advantage for personal communication and medical application, the compact, small size and better performance are need for an antenna to operate at such systems [5]-[6]. Based on the previous research, there is some technique applied to reduce the size of the antenna such as adding a shorter pin, adding a slot, folded the antenna design, used high substrate and eliminate the ground plane [7]- [14].

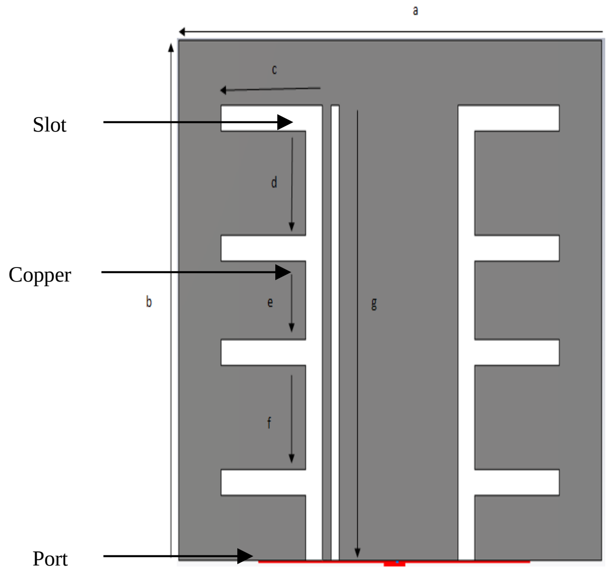
Earlier work has been published in [15] where the size of the antenna design is 10mm. The antenna performances are investigated in canola oil as it represents human breast fat. Slot technique is used to reduce the antenna size. Results proved that the antenna is reliable to use for wireless body area network.

In this paper, an implantable chip printed antenna for WiBAN application at 4.8GHz is presented. Several techniques are applied to reduce the size of the antenna as much as 50 % from the previous work in [15]. The antenna is simulated in three environments which are in homogenous layer, non-homogeneous layer (skin, fat and muscle) and the real human hand voxel model .The effects of antenna performances are studied in term of gain, efficiency, return loss and radiation pattern. The results of this work are successfully simulated by using CST Microwave Studio software.

II. The Antenna Configurations

For this project, the implantable printed chip antenna is comprised of a single metallic layer which is known as copper. The copper has 0.036 mm thickness and it is printed on both side surfaces of the substrate. The FR4 material is chosen as a substrate which has ε_r=4.7 with loss tangent 0.019 and 1.6 mm thickness. The optimum configuration of the proposed antenna is illustrated in Figure 1. Commonly, the antenna has a size of 5 mm × 5 mm × 1.6 mm dimension. There are several radiating elements in the antenna design which composed of rectangular shape with multiple E-slots at the center and feeding line. The radiator is center fed by microstrip line with 4.1 mm length and 3 mm width. The optimized dimensions of the antenna are: a = 5 mm, b = 5 mm, c= 0.8 mm, d = 0.8 mm, e= 0.5 mm, f= 0.7 mm and g= 4.5 mm.

While designing the antenna, some techniques are applied to reduce the size where the slots are added in radiating element, and then the antenna design is folded. There is no ground pin added as the antenna is too small to create a hole.



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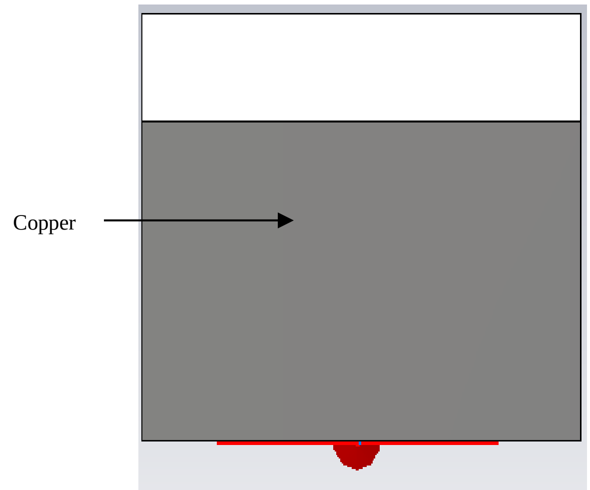

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Figure1: Geometry of the simulated proposed antenna (a) front view (b) back view

III. Experiment Setup

Generally, the antenna performances are evaluated in three surroundings which are homogeneous layer (fat layer), non-homogeneous layer (skin, fat and muscle) and the real human hand voxel model. The main objectives of this analysis are to investigate the antenna performances at different complexity of surroundings structure. The antenna performances are valued in term of return loss, resonant frequency, efficiency, gain and SAR (for the real human hand voxel model only). Firstly, the proposed antenna is implanted in a homogeneous and non-homogeneous layer which composed of skin, fat and muscle. Figure 2 shows the antenna implanted in the fat layer model. The antenna is positioned approximately 3 mm from the top. The size of a fat layer is 50 mm × 30 mm × 50 mm with dielectric properties; conductivity: 0.209 S/m and relative permittivity: 5.048 at 4.8 GHz.

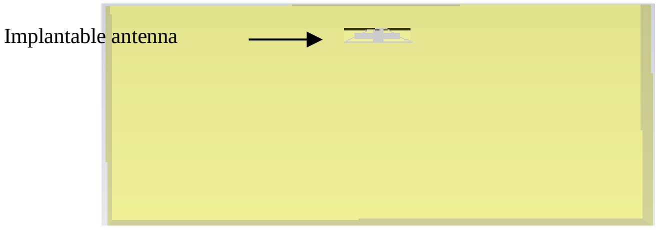


Figure 2: The proposed antenna in the homogeneous layer model

The antenna implanted in non-homogeneous layer model is illustrated in Figure 3. Table 1 shows the conductivity and permittivity for each layer at frequency 4.8GHz. The antenna is positioned approximately 3mm from the surface (in the fat layer).

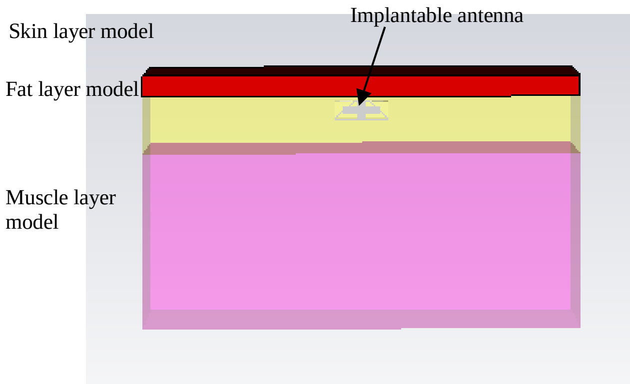


Figure 3: The proposed antenna in the non-homogeneous layer model

Table1
Dielectric Properties of Selected Human Body at 4.8 GHz

Type of layer	Conductivity (S/m)	Relative Permittivity
Skin	2.907	35.936
Fat	0.229	5.048
Muscle	3.827	49.800

Next, for more complex structure, the antenna is inserted into the real human hand voxel model by CST Microwave Studio Software as presented in Figure 4. There has limitation while evaluating the antenna performance by using a human voxel model from the CST Microwave Studio Software where the antenna cannot be simulated using the whole human body phantom. This problem is due to the limitation of computer processor when simulating the antenna performances. Consequently, the antenna is embedded in the human hand model only. The input reference power of an implantable antenna is 0.1W. The chosen input power 0.1W is to obtain higher performances in term of gain and bandwidth but at the same time to reduce the power absorption by the human body. Similarly with the antenna implanted in the non-homogeneous layer, the proposed antenna is positioned in the fat layer.

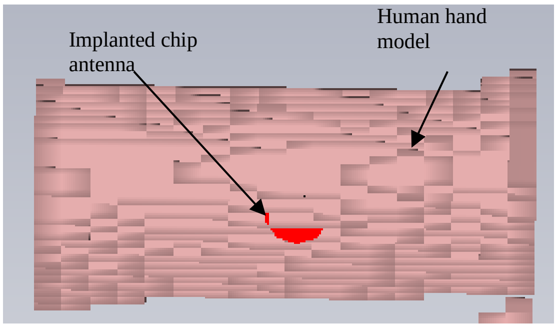


Figure 4: The proposed antenna in the real human hand voxel model

IV. RESULTS AND DISCUSSION

The simulated results of the implantable antenna in different models have been illustrated in Figure 5. It can be realized that while the antenna is embedded in the homogeneous model, the resonant frequency is tuned at 4.85 GHz with the impedance bandwidth of 450 MHz (4.6 GHz-5.03 GHz) at -8 dB. However, as the antenna is inserted in the non-homogeneous model, the resonant frequency of the antenna is shifted to 4.77 GHz with the impedance bandwidth of 340 MHz (4.60 GHz- 4.94 GHz). Whereas the antenna is embedded in the real human hand voxel model, the antenna is operating at 4.87 GHz with the impedance bandwidth of 710 MHz (4.46 GHz- 5.17 GHz). Based on the observation, the operating frequency of the antenna is shifted to a lower frequency and the bandwidth is increased when working in non- homogeneous model and human hand model. The antenna implanted in the human hand shows the lowest reflection coefficient magnitude (-16 dB) and higher bandwidth (710 MHz) compared to others. This situation is happening due to the impact of impedance matching. The value of input impedance of the antenna depends on the electrical properties of human body thus detuning the operating frequency. However, the operating frequency of the proposed implantable printed antenna at those surroundings is nearly similar. This is because the implantable antenna is implanted in fat layers for every environment. Therefore, it is proved that the implantable antenna with multiples E- slots are stable to work in human body model especially in the fat layer.

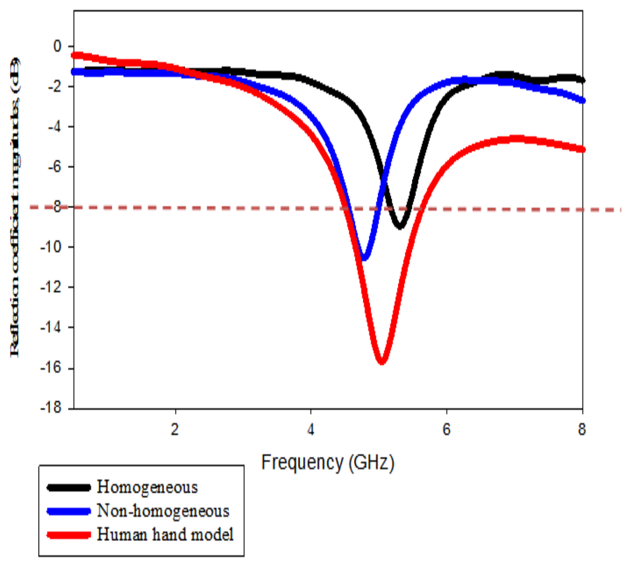


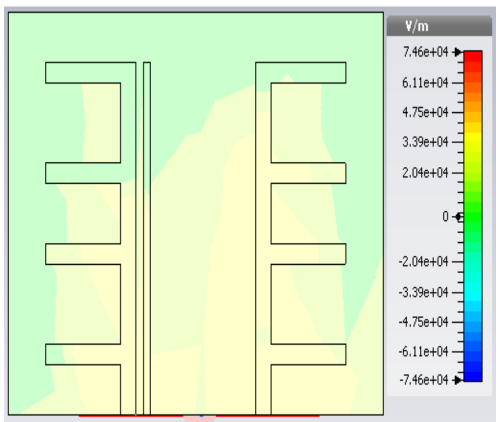
Figure 5: The evaluations of return loss between both surroundings

Table 2 tabulates the data of efficiency, bandwidth and gain of the implantable antenna in all models. According to the results, it can be noticed that the implantable antenna implanted in homogeneous layer offers the highest gain and efficiency (a reasonable value for implantable antenna) compared to the implantable antenna implanted in the real human hand model provides higher operating bandwidth. The gain and efficiency of the proposed antenna are high in a homogeneous layer because it is having less complexity of structure compared to non-homogeneous and the human hand model. Further discussions are explained by referring to Figure 6.

Table 2
The Gain, Efficiency and Bandwidth for Both Environments at 4.8GHz

Model	Gain (dB)	Efficiency	Bandwidth
Homogeneous	-5.98	5.83%	430MHz
Non-homogeneous	-11.78	1.75%	340MHz
Human hand model	-25.42	0.08%	710MHz

The magnitude distributions of the electric field of an antenna in three models are illustrated in Figure 6. From the observation, it can be seen that the electric field of the antenna is strongest in the homogeneous layer while the lowest in the human hand model. This situation has occurred as the antenna is easier to propagate in homogeneous layer (less complex of structure) compared to in human hand model due to different layers and boundaries (complex structure). A less complex of the medium structure will have a lower attenuation coefficient while a complex structure will have a large attenuation coefficient. A large attenuation coefficient signifies that the energy is fast "attenuated" (weakened) as it passes through the medium. The attenuation is occurring when there are differentiations of boundary layers. Therefore, as the structure of the environment is getting complex (having a lot of boundary layers); the value of attenuation is getting higher. So the gain and efficiency of the antenna will be reduced.



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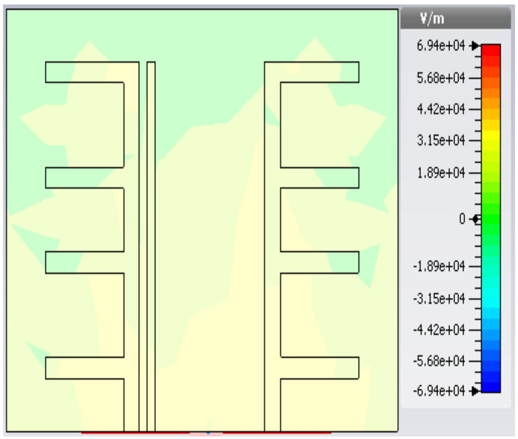

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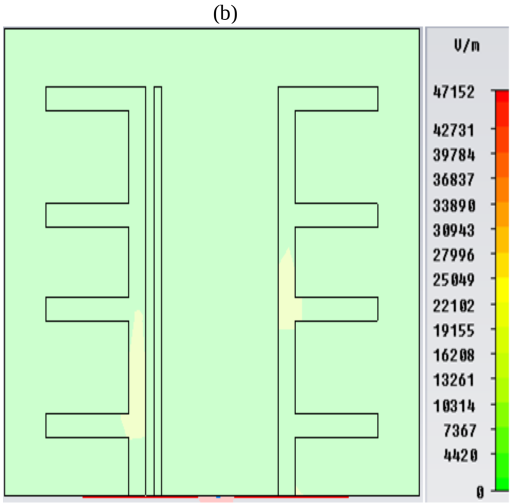

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Figure 6: The |E|- field plot of the implantable antenna in (a) homogeneous layer (b) non- homogeneous layer (c) human hand model

The radiation pattern of the implantable antenna in the fat layer model is shown in Figure 7 while Figure 8 shows the normalized radiation pattern of the implantable antenna in three models. When the antenna is implanted in the homogeneous layer (fat only) the maximum direction of the radiation pattern is direct to the back of the antenna structure. It can be seen that there is no reflection occurred. As the antenna is implanted in the non-homogeneous layer, there is reflection is occurring. It is being noticed that the skin layer and muscle layer be a reflector for the antenna. While the antenna is implanted in the human hand voxel model, the radiation pattern is totally reflected to outside the body. The things are happening since the human hand model is composed of lots of layers such as skin, fat, muscle, blood and bones. This indicates that the human body is a reflector to the antenna.

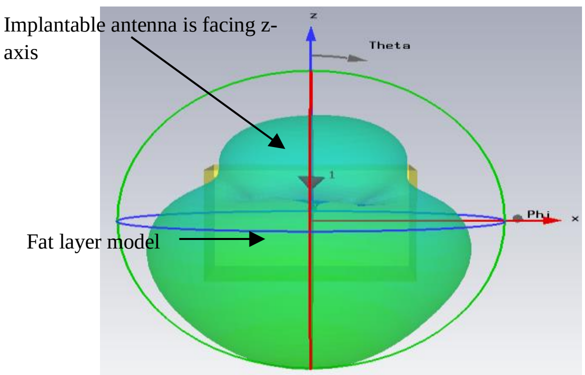
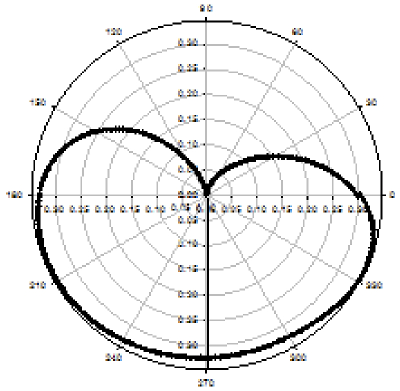


Figure 7: The simulated 3-D radiation pattern of the implantable antenna in fat layer mode



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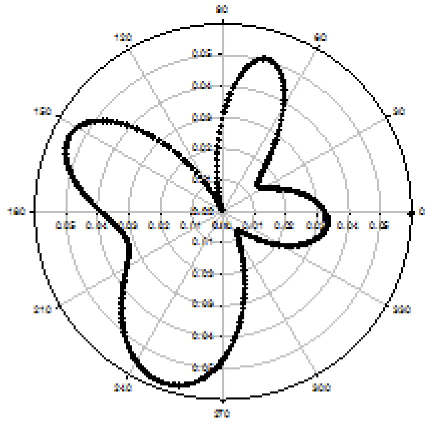

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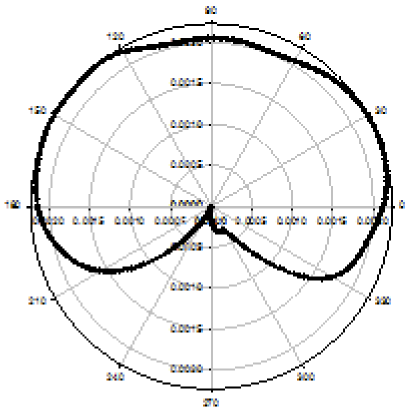

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Figure 8: The normalized simulated radiation patterns (a) homogeneous layer (b) non-homogeneous layer (c) the real human hand voxel model

V. CONCLUSION

As conclusions, an implantable chip printed monopole antenna fed by microstrip lines is presented in this paper. The printed antenna is simulated in three surroundings which are in a homogeneous layer, non-homogeneous layer (fat, skin and muscle) and human hand voxel model by CST Microwave Studio Suite. The antenna is operating at 4.8GHz for all environments. The gain, efficiency and operating bandwidth of the antenna are changed depending on the complexity of the structure of the environment. Therefore, the results from this paper are very useful in some aspects of designing implantable antenna in future.

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