

Numerical Investigation of a Chip Printed Antenna Performances for Wireless Implantable Body Area Network Applications

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Abstract. Recently, wireless implantable body area network (WiBAN) system become an active area of research due to their various applications such as healthcare, support systems for specialized occupations and personal communications. Biomedical sensors networks mounted in the human body have drawn greater attention for healthcare monitoring systems. The implantable chip printed antenna for WiBAN applications is designed and the antenna performances is investigated in term of gain, efficiency, return loss, operating bandwidth and radiation pattern at different environments. This paper is presents the performances of implantable chip printed antenna in selected part of human body (hand, chest, leg, heart and skull). The numerical investigation is done by using human voxel model in built in the CST Microwave Studio Software. Results proved that the chip printed antenna is suitable to implant in the human hand model. The human hand model has less complex structure as it consists of skin, fat, muscle, blood and bone. Moreover, the antenna is implanted under the skin. Therefore the signal propagation path length to the base station at free space environment is considerably short. The antenna's gain, efficiency and Specific Absorption Rate (SAR) are -13.62dBi, 1.50 % and 0.12 W/kg respectively; which confirms the safety of the antenna usage. The results of the investigations can be used as guidance while designing chip implantable antenna in future.

1. Introduction

Recently, the wireless communication through human body is catching the attention for researcher. The system is applied to enhance and support the quality of human lives. There are lots of implantable devices for medical systems are already used such as pacemakers and cardioverter defibrillators, temperature monitors, blood glucose sensor, cochlear and retinal implants and functional electrical stimulator [1].

The development of the technology gives high impact to the size of the antenna. Consequently, there are necessities to design small size and low power consumption of antenna for wireless implantable body area network application [2-4]. Designing an implantable antenna is very challenging compared to the antenna at free space condition. The antenna efficiency is reduced and



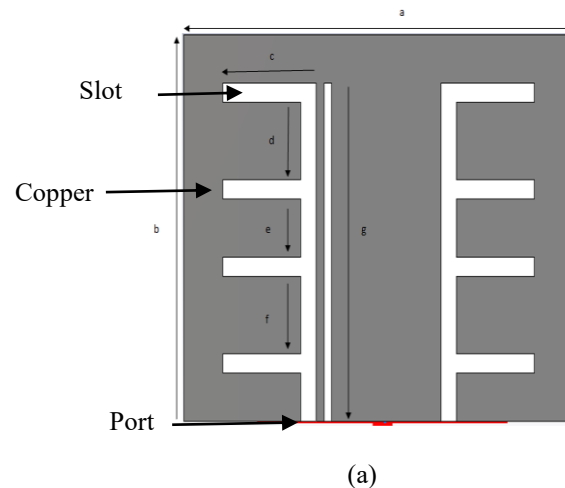
faces very strong effect of multipath losses since the lossy environment (such as human body) has a different layer of boundaries [5-14]. Attenuation is occurred due to the weakly conductive tissue and reflection at each of the boundaries of dissimilar tissue. There are also difficulties for human body to act as a medium for signal to propagate due to dissimilar tissue and organ. The value of power absorption by human body is necessity to follow the standard in order to confirm the safety of user.

Previous work is presented an implantable chip antenna for WiBAN application at 4.8 GHz. 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.

2. Antenna configurations

The implantable antenna is composed of a single metallic layer which is copper with 0.036 mm thickness and it is printed on both side surfaces of the FR4 substrate. The dielectric constant of the substrates is $\epsilon_r=4.7$ with loss tangent 0.019 and 1.6 mm thickness. Figure 1 shows the optimum configuration of the proposed antenna. In general, the size of the antenna is 5 mm \times 5 mm \times 1.6 mm dimension. The radiating elements of the antenna are 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 is added as the antenna is too small to create a hole.



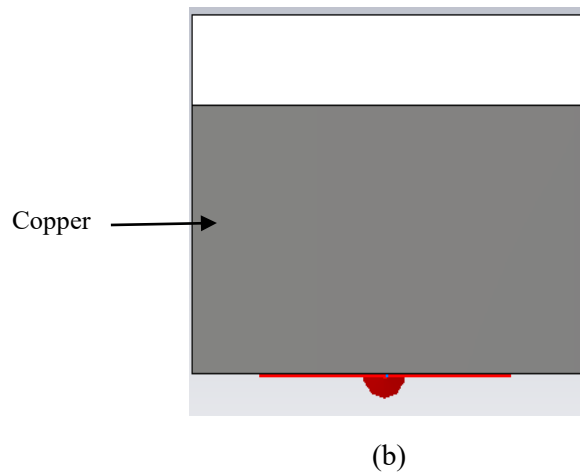


Figure 1. The configuration of the antenna (a) Front view (b) Back view

3. Experiment setup

In this section, the antenna is implanted in the human voxel model by using the CST Microwave Studio 2012. The antenna is implanted in five selected parts of the human body which are hand, chest, leg, heart and brain. The antenna performances are evaluated in term of operating frequency, bandwidth, gain, efficiency and SAR. The main purpose of this study is to analyse the antenna performances at different part of the human body and to determine the best location for antenna to operate. The input reference power of an implantable antenna is 0.1W. The implantations of antenna in some selected parts of the human voxel model are shown in Figure 2.

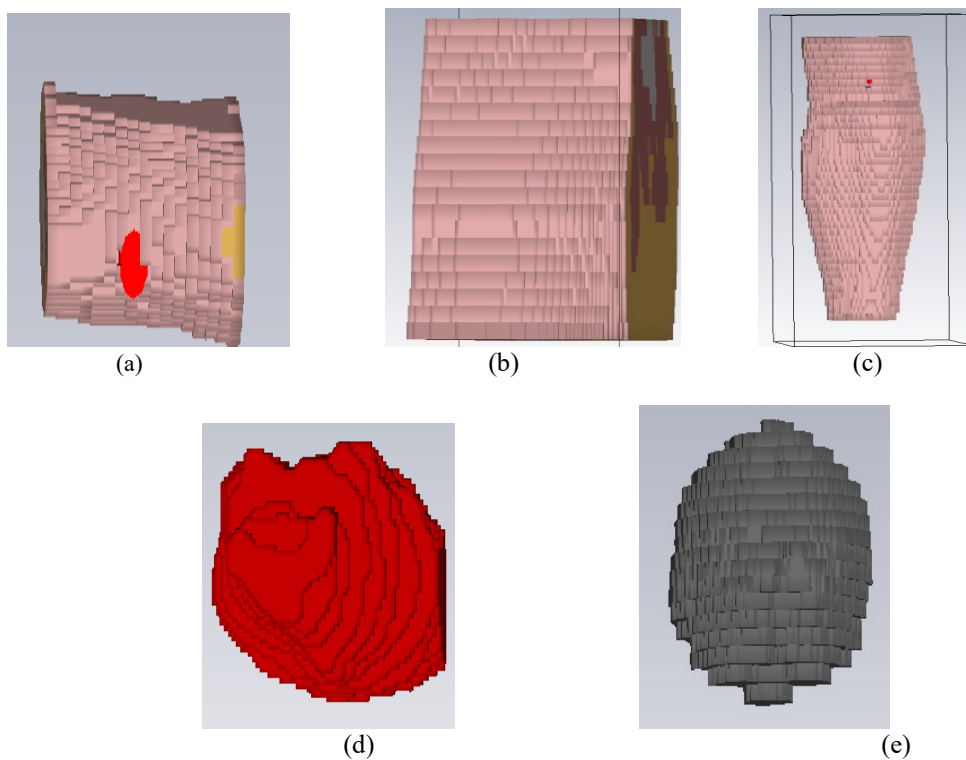


Figure 2. Antenna implanted in the human voxel model (a) hand (b) chest (c) leg (d) heart (e) brain

The antenna is coated with a thin layer of plastic in order to preserve the antenna's biocompatibility. Subsequently, the antenna is implanted under the skin in the cases of hand, leg and chest part. For the cases of heart and brain, the antenna is implanted approximately 3 mm from the surfaces of the organs.

4. Results and discussions

The reflection coefficient magnitudes of antenna for several parts in the human body are presented in Figure 3. The observed results have revealed that the antenna offers the highest impedance bandwidth and lowest reflection coefficient magnitude when implanted in the hand model, compared to other models. The results demonstrate that the antenna is tuned at frequency 5.0 GHz with a -10 dB impedance bandwidth of 900 MHz (4.6-5.5 GHz).

However, when the level of reflection coefficient magnitude is remarked below -6 dB (useful for certain application), the antenna implanted in the chest and leg model is acceptable to apply for communication. In the chest model, the illustrated results have shown that the antenna operates at 4.2 GHz with impedance BW of 300 MHz (4.1-4.4) GHz while the antenna implanted in the leg model is tuned at 5.0 GHz with impedance BW 500 MHz (4.5-5.5) GHz. The antenna implanted in heart and brain presents less stability as the antenna cannot perform well in these complex structures. Based on the results, it can be seen that the operating frequency of the antenna is detuned for each part of the human body due to the effect of different electrical properties thus mismatched the input impedance.

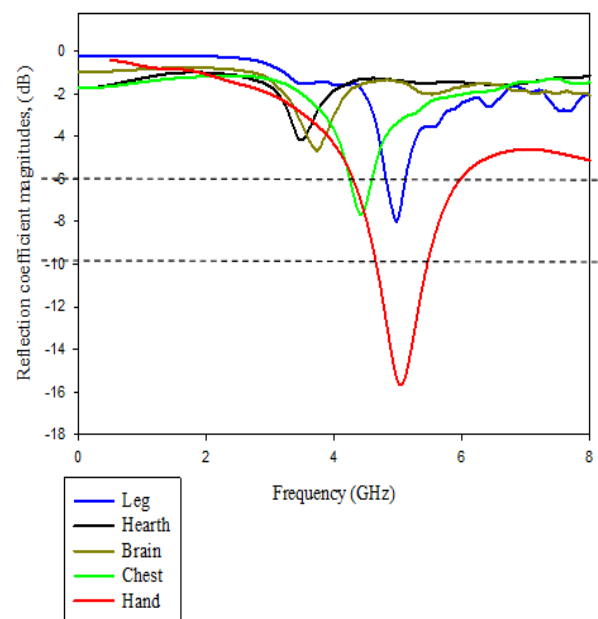


Figure 3. Comparisons of resonant frequency of each part of human body model

The electrical properties of material may affect the input impedance of the antenna as its value is depending on electrical properties thus tuned the resonant frequency. According to the equation 1, input impedance is defined as

$$Z_A = R_A + jX_A \quad (1)$$

Where:

Z_A = antenna impedance

R_A = antenna resistance

X_A = antenna reactance

In general, the resistive part of the equation 2 consists of two components which are

$$R_A = R_r + R_L \quad (2)$$

Where:

R_r = radiation resistance of an antenna

R_L = loss resistance of the antenna

According to the equation 3, the loss resistance of the antenna is represents the conductivity and dielectric losses associated with the antenna structure. Hence, this indicates that the different electrical properties of the human body model provide different input impedance, thus detuned the operating frequency of the antenna.

$$R_L = \frac{l}{p} \sqrt{\frac{\omega \mu_0}{2\sigma}} \quad (3)$$

Since the antenna is used for implantation in the human body, the value of specific absorption rate (SAR) is very important in order to protect human from any harm. Up to now, there is no specific SAR standard applied to any specific parts of the human body, thus the SAR is based on the SAR standard for mobile application. According to the standard from the European Union, 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 brain.

Table 1. The gain, efficiency and SAR of antenna for several parts of human body model (input power = 0.1 W)

Human part	Gain (dB)	Efficiency	SAR (W/kg)
Hand	-13.62	1.50%	0.12
Chest	-15.86	-23.16%	0.33
Leg	-13.35	-21.47%	0.31
Heart	-16.66	-26.08%	0.21
Brain	-17.78	-25.78%	0.17

Based on the data in Table 1, an antenna implanted in the human hand voxel model provides the most reasonable gain and efficiency compared to others organ. This factor may happen since the human hand voxel has less complexity of structure (skin, blood, fat and bone) thus providing lower attenuation. Besides, the antenna is placed under the skin, hence the distance for a signal to propagate to the base station is short. Although the value is lower, the gain and efficiency of the antenna are still in reasonable rate since the antenna is placed in lossy environment.

5. Conclusion

The implantable chip printed antenna with multiple E-slots operating at frequency 4.8 GHz is presented. Generally, the size of the antenna is 5 mm x 5 mm x 1.6 mm and it's composed by FR4 substrates and copper as radiating element. The antenna is implanted in five selected parts of the human body which are hand, chest, leg, heart and brain. The antenna performances are evaluated in term of operating frequency, bandwidth, gain, efficiency and SAR. The main idea of this investigation is to evaluate the antenna performance at different part of the human body and to verify the best location for antenna to operate. The observed results have proven that the antenna offers the highest impedance BW when implanted in hand, compared to other parts. This factor could be happened as the impedance matching of the antenna is changed from each part of the human body due to the material that composed of human body part. The gain and efficiency of implantable antenna are also high in human hand model. This is because the human hand voxel has less complexity of structure (skin, blood, fat and bone) and antenna is placed under the skin hence the distance for a signal to propagate is short. The results of the investigations can be use as guidance while designing chip implantable antenna in future.

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