Design A CPW Fed Implantable Antenna at frequency 2.4 GHz for Wireless Implantable Body Area Network

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Abstract. Designing implantable antenna is quite challenging due to the effect of lossy environment, necessity of small size and low power consumption and sequence of multipath losses. Thus, compact, small size and better performance are required for an antenna to operate in such systems. In this paper, the implantable antenna is designed by implemented coplanar waveguide (CPW) fed technique to enhances the antenna performances at frequency 2.4 GHz. The antenna performances are evaluated in term of return loss, gain, efficiency, radiation pattern. As the antenna is designed for wireless implantable body area network, hence, the antenna is tested in lossy environment. In this case, the antenna is submerged into a canola oil as it’s dielectric properties represent a human breast fat. The propagation links between antenna inside human body phantom and antenna in free space environment are evaluated. The simulated and measurement results are in good condition. The results of the investigation can be a references in the future.

1. Introduction

Nowadays, various types of wireless technology and networks allow devices to speak (send data) to each other and to the web without cables. Recent technological advances in wireless networking, microelectronics integration and miniaturization, sensors, and the internet allow us to fundamentally modernize and change the way health care services are deployed and delivered. The range of medical devices and systems being used on and into the human body are increasing rapidly and implanted device are the special interest in new sensing and monitoring device for health-care.

The implantable antenna for wireless implantable body area network (WIBAN) provides an excellent opportunity to enhance the quality of health-care [1]-[8]. The medical implanted technology delivers mobility, comfort, and higher levels of patient care. The use of implantable devices in the treatment of chronic diseases and disorders, including pain management and inner organ images, is growing at a remarkable pace [9]-[10]. The main purpose of health-care platforms is to help patients in their current life. Indeed, the related-patient always needs to move from side to side and to practice his or her normal life without any barriers including sports and any other usual activity like shopping for instance and that is one of the important reason of using wireless body area network in medical field. [12]-[15].

Since the bodies have a variety of tissues and organs, so it contains their own unique conductivity, dielectric constant and characteristic impedance. There are totally
different with the standard wireless communication where the body needs to be characterized as a medium for wave to propagate in order to create a reliable wireless communication link from base station to human body [11]. The electrical properties of each tissue and organs should be identified for the interest frequency in order to characterize the human body as a medium for frequency wave propagation. The designing antenna process for WIBAN applications is very challenging due to the reduced of antenna efficiency, effect of the environment towards the antenna, necessity of small size and lower power consumption and the very strong effect of multipath losses [16]-[27].

Therefore, in this paper, the implantable antenna is designed in a lossy environment, which is in body phantom that represent human breast fat from the CST Microwave Studio Suite software by considering the size of antenna, operating frequency, power consumption, specific absorption rate (SAR), efficiency, gain and radiation pattern. The measurements processes are implemented by submerged the antenna into the materials that mimic the electrical properties of human tissue such as canola oil is mimics a human breast fat tissue to determine the antenna performances in a lossy environment. The body link measurement between the antenna inside the canola oil and antenna placed on body is evaluated in order to analyze the characteristic of wave propagation.

2. Antenna Design and Configurations

The antenna comprises of a double metallic layer and single substrate layer. A copper with 0.036 mm thickness is used as a metallic layer and it is printed on both surfaces of the FR4 substrate. The FR4 dielectric constant is designed to operate at 2.4 GHz in free space environment. Figure 1 illustrates the antenna prototype. Generally, the size of the antenna is 28 mm × 20 mm ×1.6 mm. The radiating element of the antenna consists of the T-slot and feeding line. The dimension of the half ground plane is 28 mm × 4mm. The SMA connector is used for the antenna power input device.

Figure 1. The Antenna prototype (a) front view (b) back view
Modification of the geometrical parameters has been done in order to enhance the performance of the antenna. The performance of the antenna is a satisfying and good agreement between simulation and measurement results. So the optimized dimensions of the antenna are as shown in Table 1. Figure 2 shows the geometry of the proposed antenna fabrication.

Table 1. Dimension of CPW fed implantable antenna

| Parameter                  | Values (mm) |
|----------------------------|-------------|
| Radius, \( r \)            | 7.00        |
| Length of T Slot           | 8.00        |
| Width of T Slot            | 4.00        |
| Length of FR4 Board        | 20.00       |
| Width of FR4 Board         | 28.00       |
| Length (ground plane)      | 20.00       |
| Width (ground plane)       | 4.00        |
| Length of Feed Line        | 18.00       |
| Width of Feed Line         | 4.00        |

Figure 2. Geometry of the proposed antenna designed in CST (a) front view (b) back view
3. Results and Discussions

The printed circular antenna is tested at free space environment and lossy environment (implanted in human body phantom) in order to analyze the antenna performance. For measurement, the designed circular antenna is connected to the vector network analyzer (VNA) by using N-type male connector and coaxial cable, while simulation process is by using the CST Microwave Studio.

a) Antenna performances in free space environment

Figure 3 shows a comparison of reflection coefficient magnitudes between simulated and measured results for the printed circular antenna in the free space environment. As illustrated in the figure, both of the simulated and measured results prove that the proposed antenna is able to operate at the 2.4 GHz in the free space environment although is a slightly discrepancy in terms of the resonant frequency. This situation occurs due to error during the fabrication process, such as reducing of ground size during cutting process [15]. Power transmit for the simulated result for the circular antenna is 99.75%, while for measured result is 98.31%. The gain for the printed circular antenna is 0.8878 dB. Therefore, it can be said that the proposed antenna is able to work at the 2.4 GHz unlicensed ISM band in the free space environment.

(a)
Figure 3. Comparison of reflection coefficient magnitudes between (a) simulated and (b) measured results of the circular antenna in free space environment

The simulated radiation pattern in 2-Dimension and 3-Dimension of the printed circular antenna at the frequency of 2.4G Hz in the free space environment is illustrated in Figure 4. It clearly show that the radiation pattern of the circular antenna is omni directional.

Figure 4. Radiation pattern of circular antenna in free space environment (a) 2-Dimension pattern (b) 3-Dimension pattern
b) Antenna performances in lossy environment

Basically, there are two methods to design an implantable antenna either designing the antenna in the free space and then refining it for the tissue implantation or directly designing the antenna within the lossy environment. In this paper, the antenna is designed in the free space and then implanted it into the lossy environment. The experiments are implemented in the lossy environments in order to evaluate the antenna performances in complex structure which is canola oil. Figure 5 shows the antenna in canola oil.

![Antenna in Canola Oil](image)

Figure 5. Antenna is placed in the canola oil (a) simulated (b) measured

![Reflection Coefficient Comparison](image)

Figure 6. Comparison of reflection coefficient between (a) simulated and (b) measured results of the printed circular antenna when submerged in the canola oil.
Figure 7 demonstrates the 2-Dimension and 3-Dimension radiation pattern of the printed circular antenna in the canola oil. From the observation, it can be seen that the main radiation pattern of the antenna is directed to the back of antenna structure. Compared to the radiation of the antenna in the free space environment, the maximum radiation is bi-directional. It can be noticed that the presence of the canola oil minimizes the main radiation of the upward form the free space environment.

Figure 7. The (a) 2-Dimension and (b) 3-Dimension radiation pattern for circular antenna in canola oil

c) Evaluating of the antenna propagation

Since a bodies has a variety of tissue and organs, the body needs to be characterized as a medium for wave to propagate in order to create a reliable wireless communication link from and to the human body. The location of implantable antenna is fixed in one position. The location of the antenna 2 is changed as shown in Figure 8. For each location, the antenna 2 rotates to two positions, where the (i) radiating element of the antenna 2 facing the implantable antenna (in face), (ii) ground element of the antenna 2 facing the implantable antenna (out face).

Figure 8: Antenna’s position to test communication link
For measurement setup, the implantable antenna is submerged into the canola oil as shown in Figure 8 and connected to the VNA. The antenna 2 is also connected to the vector analyzer as a port 2 in order to get the value of $S_{21}$ [28]. The wireless propagation between both of the antennas is evaluated in terms of path loss, $S_{21}$ (dB).

![Implanted Antenna](image)

**Figure 9. Path loss measurement setup of antenna from the left side**

As shown in Table 1, the location 1 (top) demonstrates the best condition for both in face and out face. The location 1 has a smaller insertion loss, $S_{21}$ compared to other locations. This could help the antenna 2 to be well-connected with the implantable antenna in the canola oil and thereby yielding more stable polarization. Meanwhile, the location 4 shows the worse result as the antenna 2 facing the back of the implantable antenna’s structure. However, the other locations still offer stable values of insertion loss, which are still below the threshold level (-100 dBm). Therefore, the implantable antenna is suitable and reliable for wireless communications application, as it provides a good performance in terms of link communications.

### 4. Conclusion

The implantable antenna for wireless implantable area body network is successful designed at the frequency of 2.4GHz with compact, small size and better performance are required for an antenna to operate in such systems. Based on the results, the antenna has a good comparison between simulation and measured results. The antenna performances are evaluated in term of return loss, gain, efficiency, radiation pattern. As the antenna is designed for wireless implantable body area network, hence the antenna is tested in lossy environment. The antenna is submerged into a canola oil as it’s dielectric properties represent a human breast fat. The propagation links between antenna inside human body phantom and antenna in free space environment are evaluated. The results of the investigation can be a references in the future.
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