Compact Magnetically Symmetric Antenna Design for Implantable Biomedical Applications

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***Abstract*—This paper proposes a coplanar waveguide feed (CPW-fed) based patch antenna for implantable biomedical applications operating at Industrial, Scientific, and Medical (ISM) band. The antenna has a magnetically symmetric configuration with dimensions of 30 mm × 30 mm. In free space, the proposed antenna covers a wideband ranging from 2.39 - 2.57 GHz, thereby posing a -10 dB bandwidth of 180 MHz with a peak gain of 2.23 dB. For implant case, the antenna is simulated by creating a three-layered human tissue model in CST MWS 2019. The proposed design also offers -10 dB bandwidth covering the ISM band after implanting inside muscle layer with a peak gain value of -6.46 dB. A prototype of antenna is fabricated for measurement proposes. An ex-vivo testing of proposed design was performed by placing the fabricated antenna inside a fresh pork slab. The measured and simulated results demonstrate the significance of proposed antenna for wearable and implantable biomedical applications.**

Keywords—implantable antenna; coplanar waveguide (CPW) antenna; industrial scientific medical (ISM) band

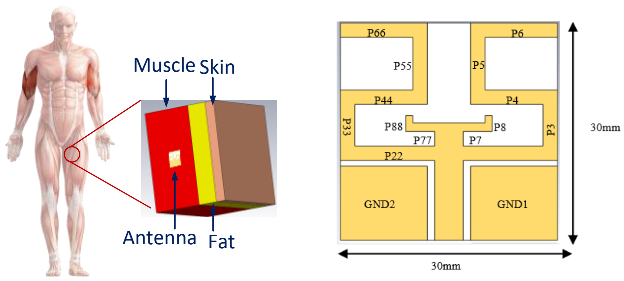
I. Introduction

The design and applications of antennas is a new hot topic in recent years, e.g. wireless biotelemetry, wireless capsule endoscopy [4], etc. On-body communication and in-body communication is made up of antennas (wearable antennas [1] and implantable antennas [2]) and external devices. For on-body implantable antennas, the main challenges of its design in medical systems are antenna miniaturization and security. In [3], a decrease in the dimensions of the antenna is realized using a radiating element. This radiating element is a spiral structure made of copper foil wound on a flexible magnetic sheet. The miniaturization of the antenna in [4] is achieved by the meander line technology to extend the current path. A reduction in the size of the proposed antenna in [5] is also achieved through a radiating element. The interdigital capacitors are added to the stub on radiating elements. Besides, the complexity of the work environment of implantable antenna should be considered like the various conditions of different human tissues.

In this paper, a CPW-fed patch antenna working in the ISM band is proposed. This antenna is suitable for biomedical applications. We consider the compromise between miniaturization, security, and manufacturing difficulty. For simulation, the antenna is tested in free space and inserted in a designed human phantom model. For measurement, the fabricated antenna is measured in free space and inside meat mince.

II. Antenna Design

In this work, a CPW-fed patch antenna operating at 2.45 GHz is designed. The configuration of this antenna is depicted in Fig.1, based on the design in [6]. The patch antenna designs with FR-4 as a substrate (ε_r =4.3) and dimensions of 30×30×0.8 mm^3. Copper is used as radiating material. The size of the antenna is indicated in Table I.



(a) (b)

Fig. 1(a) Simulated body Model (b) The layout of the CPW patch antenna.

To check the antenna performance inside the human body, a three-layer model (as shown in Fig. 1(a)) in [7] is applied to the simulation. This model is made up of a skin layer in the top (ε_r=69.45), fat layer in the middle (ε_r=6.07), and muscle layer in the bottom (ε_r=65.97). This antenna is tested in the muscle layer with a depth of 4mm. The thickness of each layer is 8mm, 4mm, and 1.6mm for muscle, fat, and skin, respectively.

Table 1. Dimension of the proposed antenna

Dimension	Size(x,y) mm	Dimension	Size(x,y) mm
P1	4, 16.2	P5/P55	2, 11.25
P2/P22	11.2	P6/P66	10, 2
P3/P33	2, 9.75	P7/P77	4, 1.2
P4/P44	8, 2	P8/P88	1, 2.2
GND1/2	12,10.25		

III. Simulation and Measurement Results

The S_{11} in free space and the human model are shown in Fig. 2. In free space, the proposed antenna resonates at 2.47

GHz covering the ISM (2.4-2.4835 GHz) band. And the -10 dB bandwidth is 180 MHz which can be observed from the figure. In the human model, the – 10 dB bandwidth is around 1 GHz at the center frequency of 3 GHz.

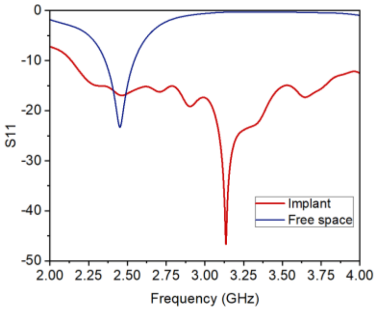
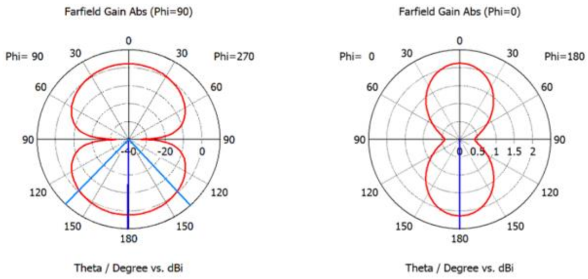


Fig.2. Simulated S11in the free space and human tissue model

The 2D radiation patterns are provided in Fig.3 The xoz plane and yoz plane cuts are taken at 2.45 GHz. The pattern indicates that the antenna has omnidirectionality. The main direction magnitude in the xoz plane and yoz plane is 180 degrees. The antenna gain is 2.18 dB and -5.82 dB in the free space and human model, respectively. And efficiency is -0.44 dB and -12.43 dB in the free space and human model, respectively.

SAR analysis of the antenna for the three-layer model is also covered and shown in Fig.4. In 2.45 GHz, the 1-g SAR value for 1W input power is 216.10 W/kg. Considering the security of the antenna, the delivered power should be decreased to a proper value, 7.6 mW for this antenna.



(a) (b)

Fig. 3. Radiation pattern at 2.45 GHz (a) xoz plane (b) yoz plane

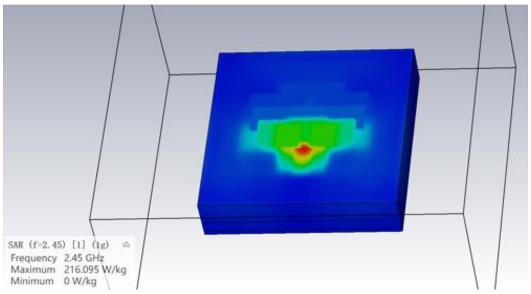


Fig .4. Simulated 1-g SAR value for the proposed antenna at 2.45 GHz when input power is 1W

The fabricated prototype of CPW-fed implantable antenna is shown in Fig. 5. The S_{11} parameter of implantable antenna is done by placing it inside a fresh pork meat slab. Fig. 6 shows the measured S11 of this design that is well below -10 dB in the implant case, that are well matched with the simulated one (as depicted in Fig.2)

Fig. 5. Fabricated implantable antenna

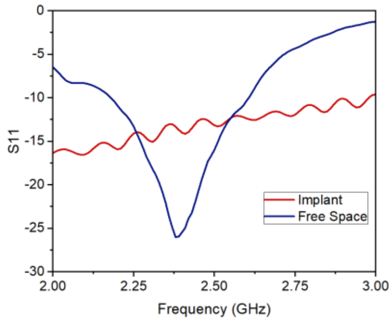


Fig. 6. Measured S_{11} of the proposed implantable antenna

IV. Conclusion

A CPW-fed implantable patch antenna is proposed in this paper. This antenna shows a good performance in free space on-body and implant case with a -10 dB bandwidth of 180 MHz covering the ISM band. Moreover, this design offers a peak gain of 2.23 dB and -6.46 dB for free space and implant case, respectively. A prototype of antenna was fabricated and tested to prove simulation results. An ex-vivo test of proposed design was performed by placing the antenna inside a fresh pork slab. The measured results match well with simulated results, which demonstrate the suitability of the antenna for implanting inside the human body for biomedical applications.

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