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Design and development of dual-spiral antenna for implantable biomedical applications.

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Abstract

The objective of this paper is to design a miniaturized dual-spiral antenna for implantable bio-medical application in the frequency range 2.41 GHz of ISM band. A parametric model of a skin, fat and muscle implantable antenna is designed and analysed their parameters such as return loss, impedance matching, gain, VSWR and radiation patterns etc. The total size of the proposed antenna is 30 mm and the thickness is 1.6 mm. To make the proposed antenna is suitable for implantation and the proposed antenna is made up of alumina (Al_2O_3) substrate. The proposed antenna is fed by coplanar waveguide method for high frequency response. It shows the lower return loss, good impedance matching and high gain compared to other antennas. The proposed antenna design methodology can be applied to optimize antenna for several implantation scenarios and ISM band applications.

Keywords: Implantable dual-spiral antenna, Coplanar waveguide method (CPW), Industrial, Scientific and medical (2400 MHz to 2480 MHz), Bio-medical application.

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Introduction

Implantable Medical Devices (IMDs) are used nowadays to perform an expanding variety of diagnostic and therapeutic functions [1]. Bidirectional telemetry between the implantable medical device and exterior monitoring/control equipment is most commonly performed wirelessly, by means of an integrated implantable antenna.

Implanted antennas are important parts of the devices used for biotelemetry, i.e., biomedical wireless communication, to transfer physiological information such as blood pressure, cardiac beat, hyperthermia etc., aiming to provide highly precise diagnostic information for prevention and/or timely treatment of diseases [2]. The performances of the antennas implanted in the body or positioned on it are of fundamental importance in the validity and accuracy of the transmitted information that will reflect on the quality of the diagnosis and treatment in turn. The design of implanted antennas is subject to additional challenges that reflect both in the link budget, due to high loss, and corrosion in time, due to the harsh environment surrounding the transmitter [3].

For bio-medical applications, medical implant communications service allotted certain bandwidth for operation i.e.) 402-405 MHz [4,5]. Implantable antenna provides a better means of communication from human body.

The ever advancing miniaturization of electronic devices is leading to the making of various personal information and communication appliances which can be attached to (or) implanted inside the bodies of patients [6-8]. One of the important design aspects of an IMD (Implantable medical device) is the transmitter as the specification determines if it will be able to operate in a ISM band is in the range of 2400-2480 MHz [9-12]. Implantable antennas are electrically small antennas similar to typical antennas used for common wireless applications such as mobile phones, but with the additional complication that the implant will be located in a complex lossy medium [13].

Most of the research on implantable antennas for medical purposes has focused on therapeutic applications such as hyperthermia, balloon angioplasty, etc. or on sensing applications. In both cases, the antennas works in its near field and propagation over a certain distance is not an issue [14]. In biomedical telemetry applications on the other hand, the system is unlikely to be in the near field therefore it should have the capacity to transmit data over a longer distance. In this case, features like the radiation efficiency and the bandwidth are essential in order to provide transmission over a large enough range with a high enough data rate to be able to operate in wider environments like those experienced in the day-to-day life of the user. CPW feeding method [15] is used to simplify the fabrication and to reduce the radiation loss. The radiation characteristics of tissue implantable antenna mounted over human body is simulated and analysed.

Antenna Design

The geometrical view of proposed antenna is shown in Figure 1. The proposed antenna is designed with the substrate of bio-compatible alumina ceramic (Al_2O_3) substrate εr=9.9; tanδ=0.0002 with the thickness of 1.6 mm.

A parametric model of a skin, fat and muscle are designed as per the electrical properties of human tissues. Table 1 shows the electrical properties of skin, fat and muscle. The thickness of the human tissues is shown in Figure 2. Antenna design with phantom model is designed which is shown in Figure 2.

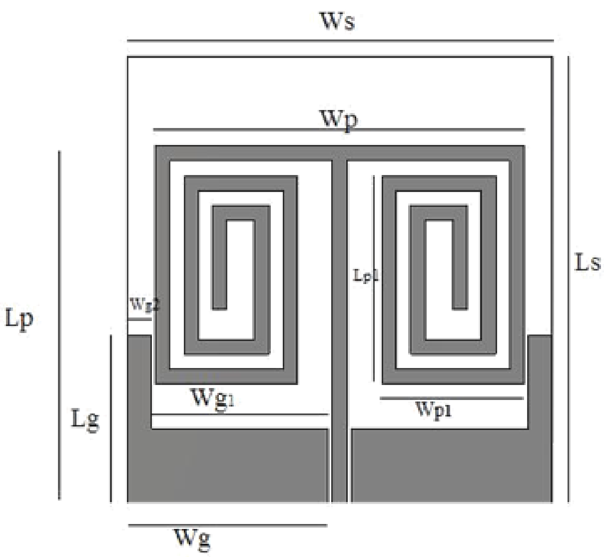

Figure 1. Geometrical view of proposed antenna.

Table 1. Electrical properties of tissues.

Dimensions of proposed antenna									
Ws	Ls	Wp	Lp	Wg	Lg	Wg1	Wg2	Wp1	Lp1
30	30	26	24	14.2	11.3	12.5	1.7	10	14

Tissue	Permittivity	Conductivity
Skin	$\varepsilon_r = 38$	$\sigma = 1.46$
Fat	$\varepsilon_r = 5.28$	$\sigma = 0.10$
Muscle	$\varepsilon_r = 52.7$	$\sigma = 1.73$

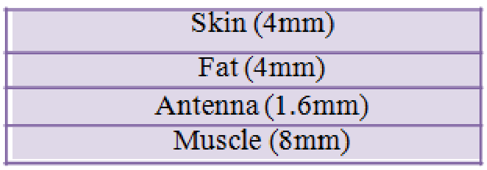

Figure 2. Proposed antenna measurement setup model.

Results and Discussion

The following results are obtained from CST software and the simulation of proposed implantable antenna. The results of parametric studies of proposed antennas are measured such as return loss, Voltage Standing Wave Ratio (VSWR) current distributions and radiation patterns. The same properties are measured for phantom model.

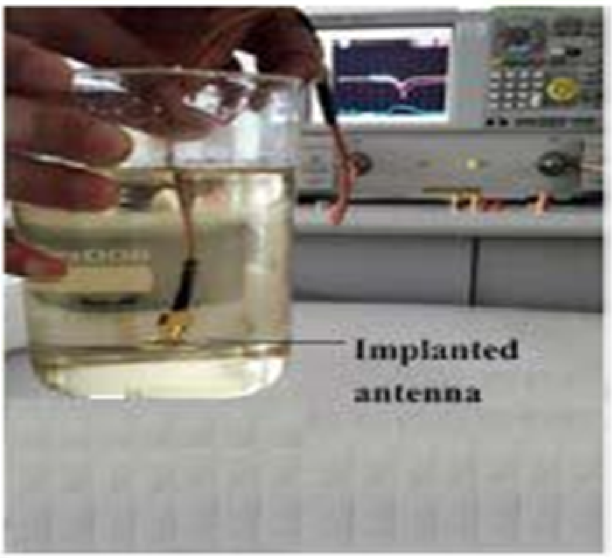

Figure 3. Measurement analysis.

Return loss

The radiation characteristics of proposed antenna and radiation characteristics of tissue implantable antenna mounted over human body phantom is presented in Figure 3.

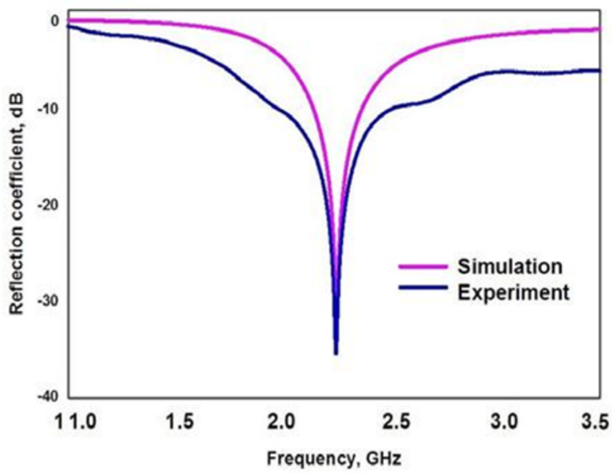

Figure 4. Return loss of proposed antenna with human phantom.

The return loss value of the proposed antenna is -36 dB at 2.41 GHz. The value of return loss for human phantom model is -26 dB at 2.41 GHz as shown in Figure 4.

Voltage standing wave ratio (VSWR)

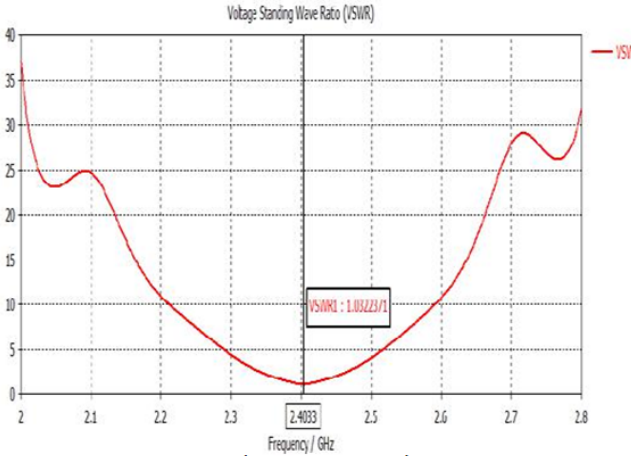

Figure 5. *VSWR graph.*

Voltage Standing Wave Ration (VSWR) is the ratio between maximum voltage and the minimum voltage along transmission line. The VSWR can be derived from the level of reflected and incident wave. The value of the proposed antenna is 1.05 so 90% power is transmitted. The VSWR graph is shown Figure 5.

Radiation pattern

The radiation patterns of the dual-spiral antenna were measured and it shown in Figure 3. The E-plane of the proposed antenna with cross polarization and co polarization is shown in Figure 6 and H-plane with cross polarization and co polarization is shown in Figure 7.

The total radiation efficiency of the proposed antenna is -8.131 dB and the value of directivity is 4.8 dB in isotropic view. So it has higher directivity than other implantable antenna.

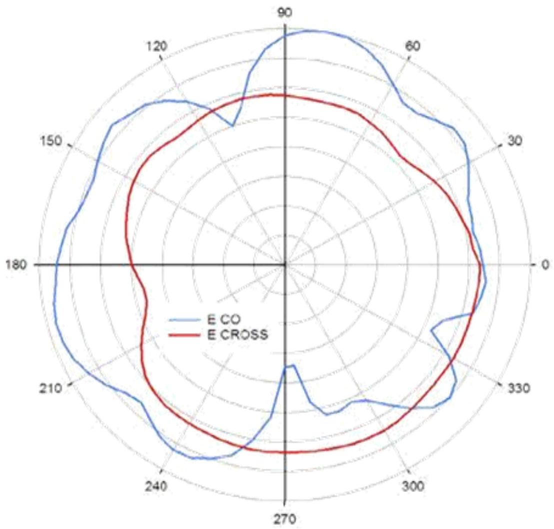

Figure 6. *Radiation pattern of E-plane (a) cross polarization (b) co polarization.*

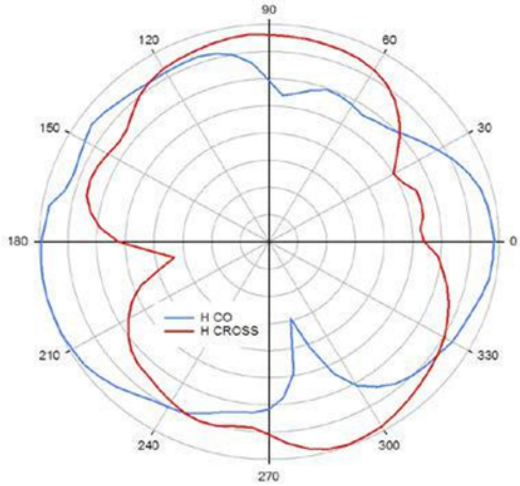

Figure 7. *Radiation pattern of H-plane (a) cross polarization (b) co polarization.*

Figure 8 depicts the simulated EM characteristics and current distribution of the proposed antenna at 2.45 GHz.

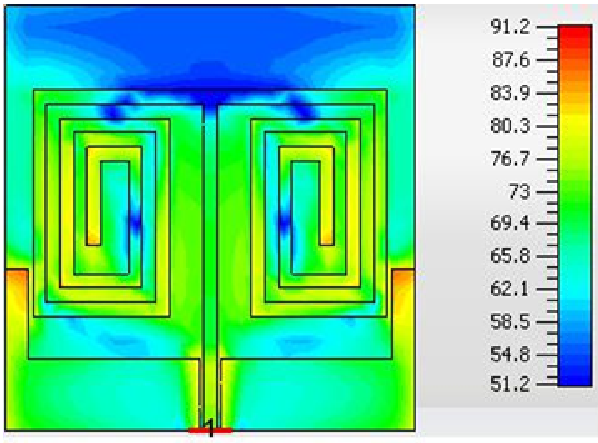

Figure 8. *Current distribution.*

Conclusion

An implantable dual-spiral antenna for ISM band bio-medical application is presented with a compact size of 30 mm × 1.6 mm was designed to resonate at 2.41 GHz. Human body influence is studied and simulations and results were carried out with a human tissue model. CPW fed ground planes and high impedance has their own merits and their physical structure makes them to suitable for bio-medical application at 2.41 GHz. The CPW fed has the advantage such as to simplify the fabrication and reduces the radiation loss. The alumina ceramic substrate increases the influence of body parameter and shows the less dispersion of biological tissues. The proposed antenna shows the lower return loss, good impedance matching and high gain compared to other implantable antennas. The proposed methodology is used for several implantation scenarios and ISM band applications.

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