A Serpentine PIFA Antenna for Implantable RFID Tag

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***Abstract*— A serpentine planar inverted-F antenna (PIFA) is designed for Medical Implant Communications Services (MICS) band (401-406MHz) and presented in this paper. Resonance frequency of implantable antenna is generally detuned towards lower frequency due to the proximity effect of high permittivity human tissue. In addition, biocompatible coating material on the antenna also leads frequency shifting of the antenna. To overcome this frequency detuning problem, the proposed serpentine PIFA is sealed in a high dielectric constant (Silicon, ε_r =11.9) material. The proposed PIFA antenna is predicted to be functional in MICS band under IEEE standard safety regulation. Gain of the antenna is -33dBi.**

***Keywords*— Serpentine PIFA antenna, implantable RFID tag, Wireless Bio-telemetry, MICS band.**

I. Introduction

Planar inverted-F antenna (PIFA) is a low profile, compact antenna. However, its narrow operating bandwidth which in turn dictates low transmission data rate represents a noticeable shortcoming. To overcome this aspect, various schemes have been proposed and applied to design PIFA antennas with enhanced bandwidth. In our proposed PIFA, improvement of the antenna bandwidth is obtained by connecting the RFID tag's ground plane with the antenna ground plane so that the PIFA overall ground plane becomes larger. Considering the specific application, once implanted in human/animal body, the antennas suffer from frequency detuning due to the effects of human/animal tissue surrounding the antenna (skin, fat etc.). Dielectric constant and conductivity of human/animal tissue may change for various reasons, for example ageing, diseases. This also leads shifting of the antenna resonance frequency. Research on the use of PIFA antennas for implantable medical devices (IMD) have received a considerable attention, as it is demonstrated by the large number of publications. Design and performances of a fabricated prototype of an UHF implantable antenna for an RFID tag is presented in [1]. Two Implantable PIFA antennas are explored in [2] for Medical Implant Communications Services (MICS) band (401-406MHz). Mutual coupling effects of PIFAs are described in [3] for a MIMO terminal with the array of antennas. In [4], a frequency tuning technique is illustrated for a PIFA to operate for multiple frequency bands. A compact and proximity-fed PIFA is presented in [5] for wireless medical applications. A low profile and small size PIFA antenna for UHF RFID tag is presented in [6].

In our recent work [1], an I-PIFA is designed and implemented for 900MHz Australian ISM band and effects of fresh rat tissue samples (collected from local hospital) on the antenna is studied. In this paper, we present an implantable PIFA antenna for an RFID tag to be implanted in human body.

The manuscript is organized as follows: Section II presents the geometry and design of the proposed antenna. Section III presents the predicted results in human body tissue environment followed by the conclusion in Section IV.

II. Antenna Geometry And Degign

Geometry and design of the proposed PIFA antenna is shown in Fig. 1. Parametric study of the antenna is performed by numerical analysis using CST Microwave Studio software. The overall dimensions of the final design are 27.5mm×16mm×5.44mm. The total thickness (5.44mm) of Rogers RO3210 substrate is constructed by placing four substrates together. Three of them are Rogers RO3210 (each 1.28mm thick) and other one is FR4 substrate (1.6mm thick).

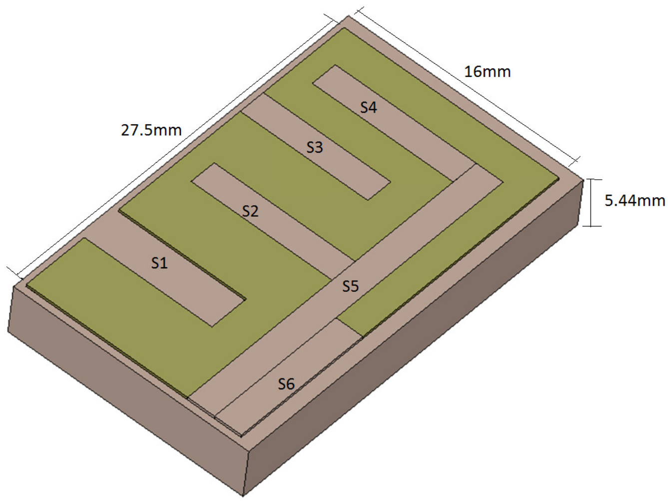

Fig. 1. Antenna geometry and leading dimensions

The radiating patch on the top is printed on a 1.28mm thick substrate (Rogers RO3210, dielectric constant, ε_r = 10.2).

Proximity capacitive feed copper printing is placed on 2nd substrate (RO 3210) (located below the 1st substrate containing radiating patch). The antenna ground plane is traced on the upper side of 3rd substrate (RO 3210) between 2nd and 4th (FR4, dielectric constant = 4.3) substrates. The antenna is fed by a strip-line which is printed on the bottom face of 4th substrate (FR4). This feed strip-line is connected to the proximity feed plate (close to the radiating patch) through a pin (via). A shorting pin is used to reduce the size of the proposed antenna. It is connected between starting end (left corner near to slot S1) of the serpentine radiating element and the antenna ground plane (Fig. 1). The antenna ground plane is connected to the RFID circuit board ground (20mm×33mm) through a via. The radius of shorting pin and feed pin has been optimized by parametric simulation. The dimensions of slots located on the radiating patch (Fig. 1) are S1= 9.5mm×3mm, S2 = 10.5mm×2mm, S3 = 9.5mm×2mm, S4 = 10.5mm×2mm and S5 = 25mm×2mm and S6 = 10mm×2mm.

III. Human Tissue Model For Parametric Study

A human tissue model is developed and included in the antenna design and optimization process as shown in Fig. 2. In the model, the proposed antenna is sealed (coated) in a bio-compatible material (silicon) to reduce the effect of human tissue on the resonance frequency. The sealing of the antenna also protects it from damaging due to conductive human tissue which may lead short-circuit between signal and ground terminals.

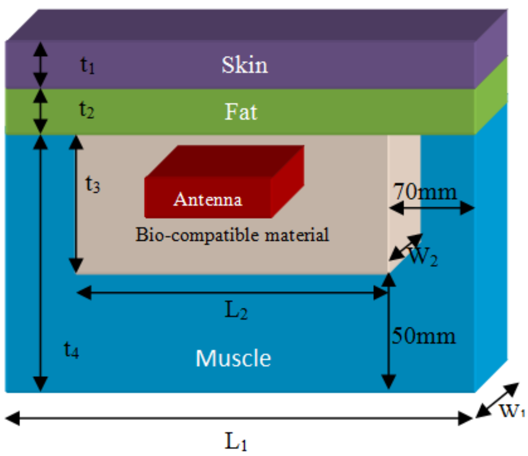

Fig. 2. Human tissue model for parametric study

The electrical properties of the human tissue are reported in Table I, while Table II exemplifies antenna environment (human tissue) model parameters.

TABLE I ELECTRICAL PARAMETERS OF HUMAN TISSUE [9]

Name of the tissue	Dielectric constant (ε_r)	Electrical cond. (σ), S/m
Skin	46.7	0.69
Fat	5.58	0.04
Muscle	57.1	0.84

TABLE II HUMAN TISSUE MODEL DIMENSIONS

Environment model parameters of antenna	Symbol	Value (mm)
Skin thickness	t_1	2
Fat thickness	t_2	2
Bi-compatible material thickness	t_3	7.8
Skin length	L_1	200
Skin width	W_1	60
Fat length	L_1	200
Fat width	W_1	60
Muscle length	L_1	200
Muscle width	W_1	60
Muscle thickness	t_4	57.8
Bi-compatible material length	L_2	33
Bi-compatible material width	W_2	20
Bi-compatible material permittivity	ε_s	11.9

IV. Numerical Results And Discussions

The reflection coefficient of the implantable PIFA antenna is shown in Fig. 3. It is found that impedance bandwidth at -10dB return loss is 9% (390 - 420MHz) when the slot length (S6) is 10mm. At resonance frequency (402.7 MHz), the return loss is -46dB indicating good impedance matching. MICS bandwidth requirement is 1.25% (401 – 406 MHz). Therefore, the entire MICS bandwidth is covered by the designed PIFA antenna. In Fig. 4, the 3D radiation pattern of the antenna is illustrated for S6=10mm. Maximum directivity of 2.3dBi is observed at 400MHz.

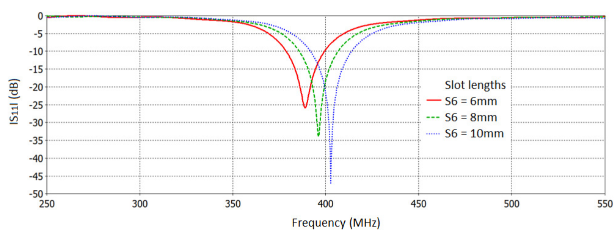

Fig. 3. Reflection coefficient of the antenna for different length of the S6 slot.

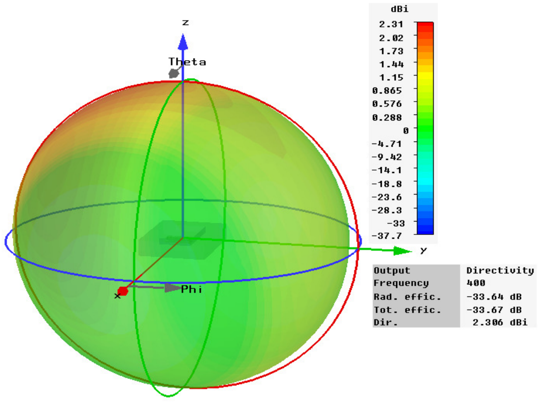

Fig. 4. 3D radiation pattern of the antenna

Efficiency of the antenna is given in Fig. 5. At 400MHz radiation efficiency is 0.04% which is in agreement for an implantable antenna [2]. However, the overall size of this antenna is slightly larger than our previous designed antennas [1], [8]. Total efficiency of the antenna is maximum at 400MHz when the radiation efficiency converges towards total efficiency.

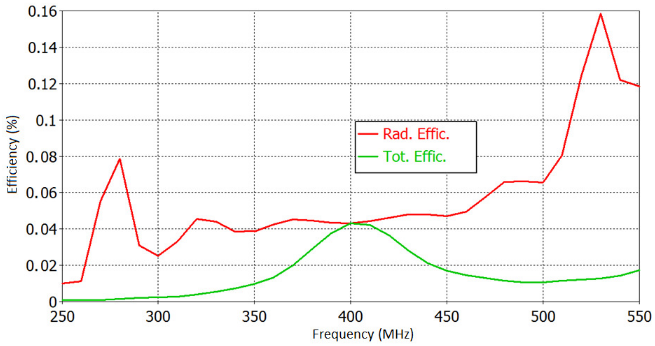

Fig. 5. Efficiency of the antenna

TABLE III MAXIMUM SAR VALUE CALCULATED, WITH 1 W INPUT POWER, IN HUMAN TISSUE MODEL AND MAXIMUM ALLOWABLE INPUT POWER AT 400MHZ [10 -12]

Standard Max SAR	Max SAR (W/Kg)	Max input power (mW)
C95.1-1999 (1-g avg)	157.42	10.16
C95.1-2005 (10-g avg)	33.16	60.31

Predicted maximum 1-g and 10-g specific absorption rate (SAR) values are 157.42 W/Kg and 33.16 W/kg (Table III) at 400 MHz, respectively. This prediction is obtained when the input power is of the antenna is1.0W. Maximum allowed SAR values of IMDs with antenna for patients' safety are: 1-g average SAR is less than 1.6 W/kg and 10-g average SAR is less than 2 W/kg [10]–[12].

V. CONCLUSIONS

An implantable PIFA antenna for MICS band is designed and parametric study is conducted in human tissue environment. Resonant frequency of the antenna can be easily tuned just by varying a single slot length (S6). Due to the presence of high dielectric biocompatible coating around the antenna, resonance frequency shifts negligibly when placed in human tissue model. At -10dB input reflection coefficient, the impedance bandwidth of ~9% is obtained while radiation efficiency is 0.04% at 400MHz.

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