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Design of dual-band (MICS and ISM) implantable antenna for wireless medical telemetry applications

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In this paper, a dual-band implantable antenna for wireless medical telemetry applications is designed. It supports both wireless information communication and wireless energy transmission at the MICS (Medical Implant Communications Service; 402 - 405 MHz) and the ISM (Industrial, Scientific and Medical; 2.40 - 2.48 GHz) bands. Numerical analysis of the implant antenna is carried out using High Frequency Structure Simulator (HFSS) software. The effects of human body and different tissues on the resonant frequencies in the MICS and ISM, and the reflection coefficient magnitude at these frequencies are considered in this study. Results have clearly indicated that the human body has notably shifts the antenna resonant frequency and modifies the radiation pattern at the frequency investigated. The dual-band antenna has a bandwidth of 9.45 % at 403 MHz and 11.4 % at 2.45 GHz in MICS and ISM bands, respectively.

Keywords: Implantable antenna; Medical telemetry; MICS and ISM bands; Dual band; Optimization; Human tissue.

1. Introduction

With the rapid development of wireless technologies, wireless communication is making inroads into every aspect of human life. One important application field of wireless communication technologies is the medical telemetry application [1]. Currently, promising implantable systems have been proposed for therapeutic and healthcare monitoring purposes to improve the lifestyle of the patients [2]. Medical devices that are implemented inside patient’s body by means of a surgical operation are called implantable medical devices (IMDs) [3]. Millions of people worldwide with critical medical conditions use implantable medical devices (IMDs) to ameliorate their life styles as well as to control chronic illnesses and complications [2]. IMDs can be used for various applications such as diagnostic, monitoring and therapeutic applications. Pacemakers, defibrillators, neurostimulators, glucose monitors, and cochlear implants are typical examples of the implantable medical devices [4 - 6]. Medical devices with wireless telemetry have gained great interest in recent years.

Antennas have major role in implantable systems since they provide communication of the implant with the external equipment [7, 8]. Unlike antennas that operated in free space, implantable antennas should consider many kinds of requirements as implantable antennas are placed in human body. So designing implantable antennas is a challenging task since there are many factors need to be considered, such as miniaturization, dual band (Medical Implant Communications Service (MICS) 402 - 405 MHz, Industrial, Scientific and

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Medical (ISM) 2.40 - 2.48 GHz) operation, biocompability, good radiation efficiency and low specific absorption rate (SAR) [9].

Dual band operation permits the power conservation by allowing the implanted device to stay in the sleep mode until an ISM wake-up signal was received [8, 10]. The antenna then uses the MICS band to transmit data to a base station located outside the tissue. The antenna radiates in MICS band for data transmission related to patient monitoring, to check the device conditions and battery health where the antenna will only transmit data until it is acknowledged by a wake up signal in the ISM band.

Miniaturization of antenna is essential to realize wireless devices where various functional components are loaded for multifunctionality [8]. Use of dielectric materials with high relative permittivity can be a proper solution for the size reduction, while side effects such as narrow bandwidth are accompanied by field confinement in high permittivity region, causing characteristic impedance difference between background and the antenna material [11, 12].

Implantable antennas must also be biocompatible in order to preserve patient safety and prevent rejection of the implant. Furthermore, human tissues are conductive, and would short-circuit the implantable antenna if they were allowed to be in direct contact with its metallization [13]. The greatest difficulty in design and manufacture antennas for bio-implantable communication devices is the effect of the host environment (biological tissue) which reduces the antenna performance, particularly in terms of bandwidth and efficiency [14].

The human body behaves differently with the various electromagnetic waves existing, it have electromagnetic properties witch change if the waves change in amplitude or frequency [15]. Biological tissues usually have high permittivities, this will change the resonant frequency of the implanted antennas [16, 17].

Many types of antennas have been proposed throughout research in order to satisfy miniaturization and good performance for implantable medical devices. Many designs and shapes have been proposed: a compact implantable PIFA antenna that operates in ISM band has been proposed in [10]. In [18, 19], a miniaturized circularly polarized microstrip patch antenna was designed for the ISM band biomedical applications. Microstrip patch antennas are widely used like in [20 - 22]. For instance, by deploying shorting pins and slots in the ground plane or radiation patch,dual-band is realized in 403 MHz MICS band and 2.45 GHz ISM band in [22 - 27].

Considerable efforts have been expended on investigating how health conditions can be monitored with wireless telemetry. Several physiological parameters can be observed as precursors to continuous monitoring such as glucose level, blood pressure, temperature, heart rate, etc. For these telemetry devices, antennas play a critical role in the communication between the implant and the base station located outside the human body.

The data could be transmitted to the main controller by using the implantable antenna. Exterior monitoring would then be provided using an external wearable device or personal computer placed close to the patient. Figure 1 illustrates a block diagram of an implant biomedical monitor system.

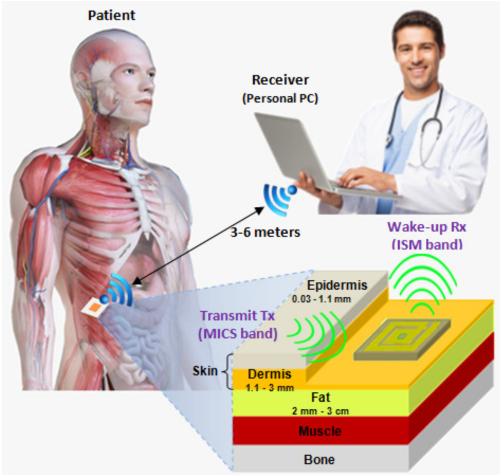


Figure 1 : A block diagram of an implant biomedical monitor system.

In this paper, our main focus is to design a dual band implantable antenna operating in MICS and ISM bands which could implantable on the human body. Proposed parametric antenna and design steps are explained in Section 2 and measurement results are provided in Section 3. The paper concludes in Section 4.

2. Proposed antenna and design methodology

The geometry of the proposed dual-band implantable antenna is shown in Figure 2. The antenna consists of a ground plane, a patch, a substrate between them, and a superstrate over the patch. The superstrate layer preserves the biocompatibility of the structure. A shorting pin (S) connects the patch to the ground plane in order to increase the electrical length of the antenna and further miniaturize its size.

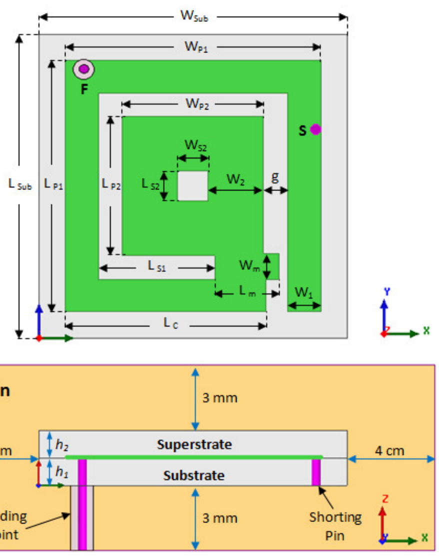


Figure 2 : Proposed antenna geometry.

The structure is fed by a 50-Ohm coaxial cable (F). The substrate and superstrate are made from the same material: resistivity silicon (ε_r = 11.9, σ = 0.02–0.05 s/m). The superstrate where the patch resides is 1.83 mm thick. The substrate is 1.27 mm thick. The use of high permittivity is readily explained by the reduction in wavelength within the structure and thus shifts to lower the operating frequency band.

A systematic, three-step, flowchart of the methodology is proposed for rapid and optimized design of dual-band implantable antenna as shown in Figure 3. The purpose is to quickly adjust antenna design in order to optimally suit the requirements of the fabrication procedure and medical applications.

In the first Step, we initialize the antenna design parameters (antenna dimensions (W_i and L_i), relative permittivity of the dielectric (ε_r), and thickness of the substrate (h_1)). Antenna design parameters are manually updated in order to achieve desired resonance characteristics, with optimal return loss results, at MICS and ISM bands. Return loss of -10 dB and below is acceptable for optimal transmission.

In the second Step, an initial version of the antenna is obtained. A superstrate dielectric layer is introduced in order to achieve biocompatibility and different dielectric parameters (Relative permittivity (ε_r), Conductivity (σ (s/m)) and Mass densities) are considered to achieve further miniaturization and improved performance characteristics. Table 1 lists related materials for implantable antenna design. These parameters are manually updated in an iterative way until the magnitude of the return loss in the MICS (402 MHz) and ISM (2450 MHz) bands is better than -10 dB.

As a final Step, all intended antenna parameters are optimized since its values enhance the facility of inserting implant inside human tissue and have a significant impact for decreasing the power loss. Antenna parameters are manually updated, the optimization process terminates when the magnitude of the return is better than -15 dB.

Table 1: Electrical properties of related materials for implantable antenna design [28].

Dielectric	Relative permittivity (ε_r)	Loss tangent tan δ
Teflon	2.10	0.0010
Alumina	9.20	0.0025
Rogers RO3210	10.2	0.0030
Silicon	11.9	0.0016
Gallium_arsenide	12.9	0.0015

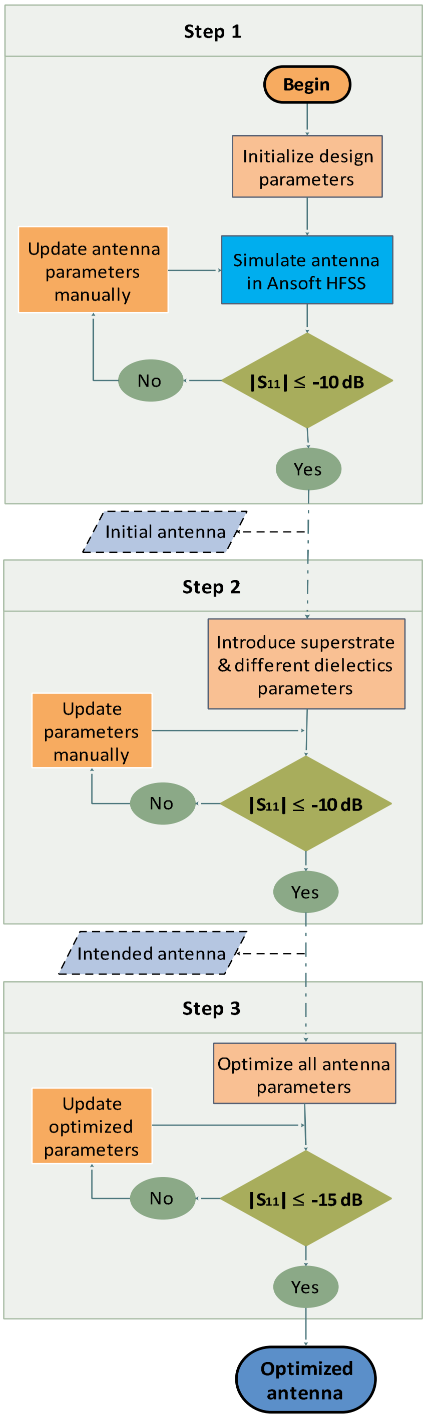


Figure 3 : Flowchart of the proposed methodology for optimized antenna.

Values of the initial and optimized parameters are summarized in Table 2. The initial parameters are randomly selected, manual update of these parameters results in the values of initial Antenna, which form a dual-band implantable antenna design that satisfies return loss better than -10 dB. Subsequently, initial parameters are optimized based en Step 2 and 3 of the optimization algorithm. Finally, the final optimized parameters are obtained. The 3D model view of the optimized antenna is shown in Figure 4.

Table 2: Geometry parameters of the proposed antenna, "Initial Antenna" and "Optimized Antenna".

Parameters	Initial Antenna (mm)	Optimized Antenna (mm)
L_{Sub}	14	14
W_{Sub}	14	14
L_{P1}	12	11.6
W_{P1}	12	11.6
L_{P2}	6.4	6.4
W_{P2}	6.4	6.4
L_C	9.2	9.0
L_{S1}	7.4	5.3
L_{S2}	2.8	1.4
W_{S2}	2.8	1.4
L_m	1.8	3.0
W_m	1.0	1.1
W_1	1.8	1.5
W_2	1.8	2.5
g	1.0	1.1
h_1	1.5	1.27
h_2	1.5	1.83
$F(x, y)$	(1.5, 12)	(2, 12.6)
$S(x, y)$	(12, 10)	(12.6, 9.7)

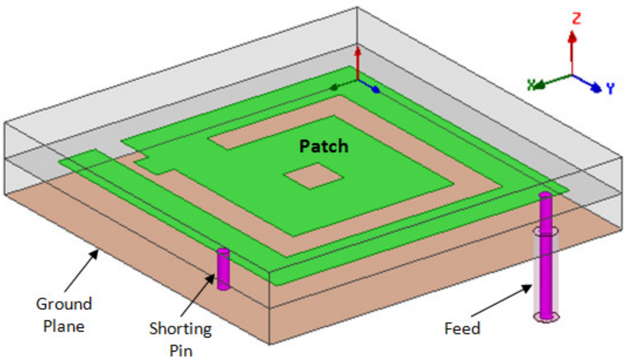


Figure 4 : 3D model view of the proposed antenna.

3. Simulation results

Figure 5 shows the return loss S11 of the optimized antenna. It is observed that antenna resonates at 403 MHz and 2.45 GHz with a return loss of -23.70 dB and of -18.42 dB respectively. The proposed antenna can cover both MICS (402 - 405 MHz) and ISM (2.40 - 2.48 GHz) bands simultaneously and it has a smaller structure. The proposed antenna has a bandwidth of 9.42 % for the MICS band and 11.4 % for the ISM band. Proposed antenna is simulated on HFSS (High Frequency Structure Simulation).

The 2D and 3D far-field radiation pattern at 403 MHz and 2.45 GHz of the proposed patch antenna are respectively shown in Figure 6 and Figure 7. Clearly, the proposed antenna operating at 403 MHz the radiation patterns are both bidirectional at both the H-plane and E-plane. At 2.45 GHz, on the other hand, exhibits omnidirectional pattern at the H-plane and bidirectional pattern at the E-plane.

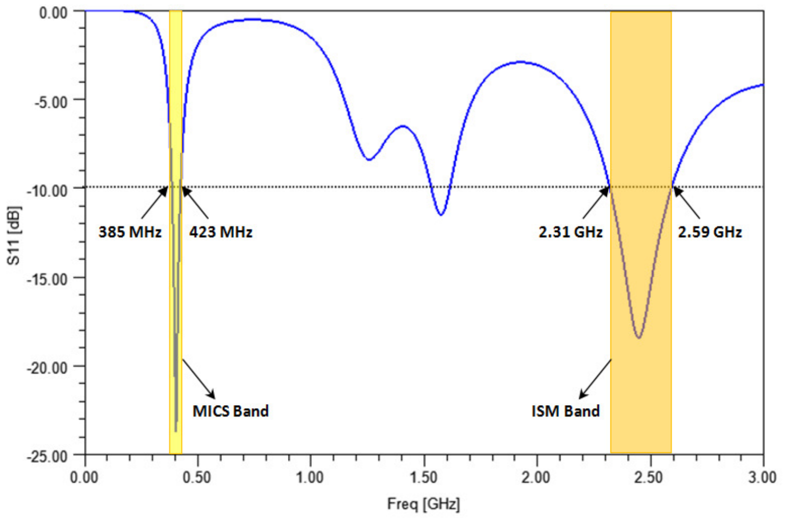
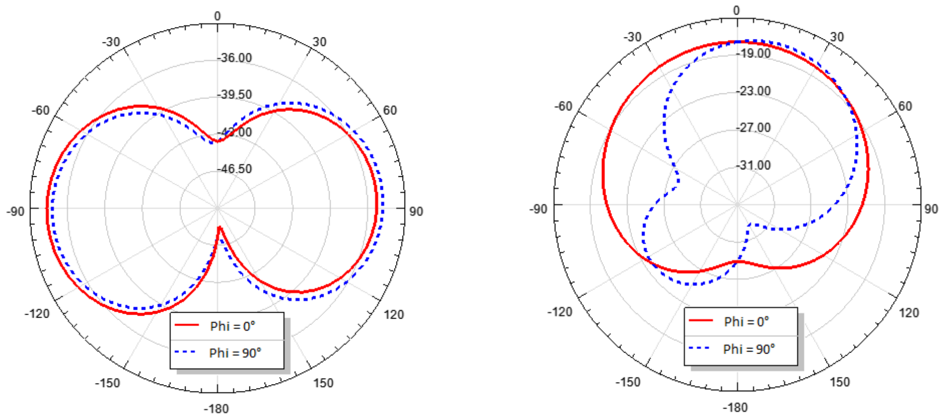
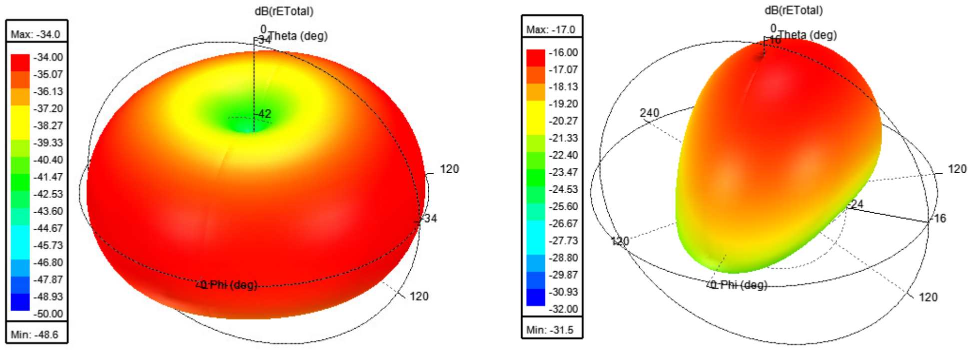


Figure 5 : Simulated return loss S11 of the proposed antenna.



(a) (b)

Figure 6 : 2D radiation patterns of the proposed antenna in the E-plane and H-plane, (a) at 403 MHz, (b) at 2.45GHz.

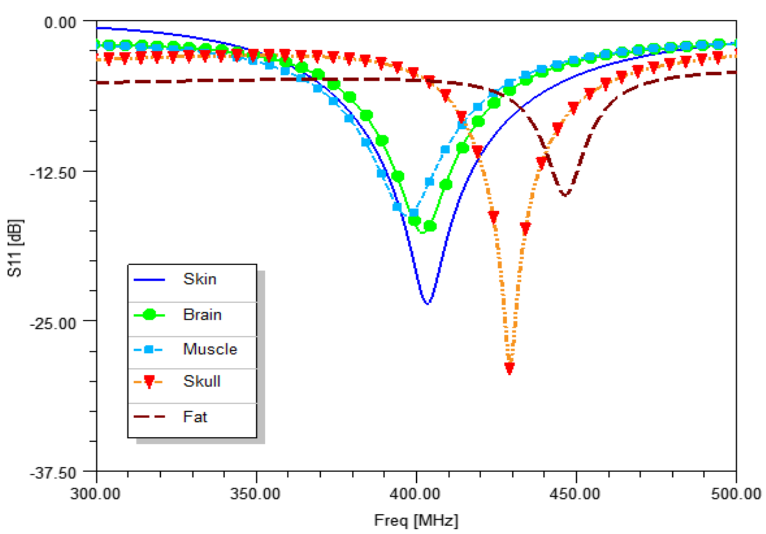


(a) (b)

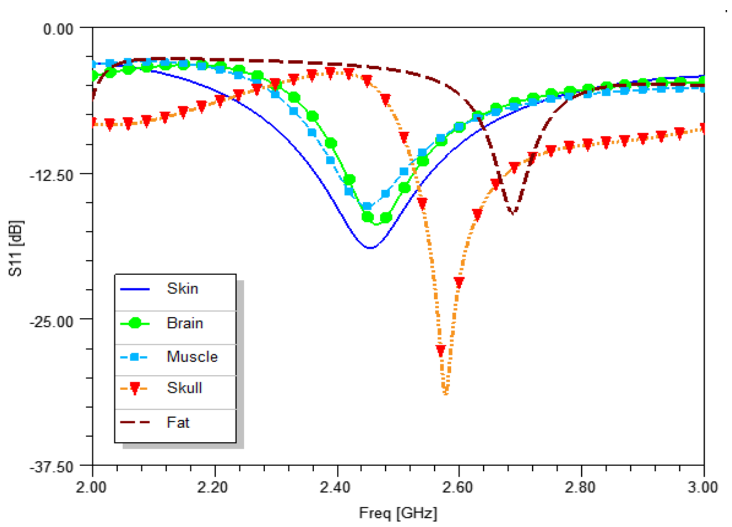
Figure 7 : 3D radiation patterns of the proposed antenna, (a) at 403 MHz, (b) at 2.45 GHz.

3.1. Effect of variation of implantation position

To demonstrate the effects of variation of implantation position in the human body on antenna performance, we simulate now the return loss S11 of the proposed antenna for different human body tissues, as shown in Figure 8.



(a)



(b)

Figure 8 : Simulated return loss S11 for different human body tissues,

(a) In MICS band, (b) In ISM band.

Dielectric properties (Relative permittivity (ε_r) , Conductivity, σ (s/m)) and Mass density) of the body tissues at 403 MHz and 2.45 GHz are shown in Table 3 [16, 17].

Table 3: Electrical properties of body tissues at the different frequency bands.

Dielectric	MICS band (403 MHz)		ISM band (2.45 GHz)		Mass Density (kg/m^3)
	ε_r	σ	ε_r	σ	
Skin	46.74	0.688	38.01	1.464	1125
Fat	5.578	0.041	5.280	0.105	916
Muscle	57.11	0.796	52.73	1.739	1047
Skull/Bone	13.14	0.091	11.38	0.394	2200
Brain	49.70	0.590	42.53	1.510	1030

It has been observed from simulation results of S11 shown in Figure 8(a) and Figure 8(b) that with varying body tissue layer (skin, Brain, Muscle, Skull/Bone, and Brain) the antenna response point change for both MICS and ISM bands . The desired operating frequency over MICS and ISM bands was obtained using Skin layer. The body tissue affects not only the operating frequency value but also affects the S11 level.

3.2. Effect of substrate and superstrate materials

The choice of substrate and superstrate materials is critical in the design of long-term biocompatible antennas. Figure 9 depicts a simulation analysis of how different substrate and superstrate materials affect on the antenna performance by monitoring simulated return loss (S11) variations over MICS and ISM bands. A comparison of five dielectric materials

(Teflon, Alumina, Rogers RO3210, Silicon, and Gallium arsenide), each 3.10 (1.27 + 1.83) mm thick, is presented. The implantable antenna is located inside the human skin layer.

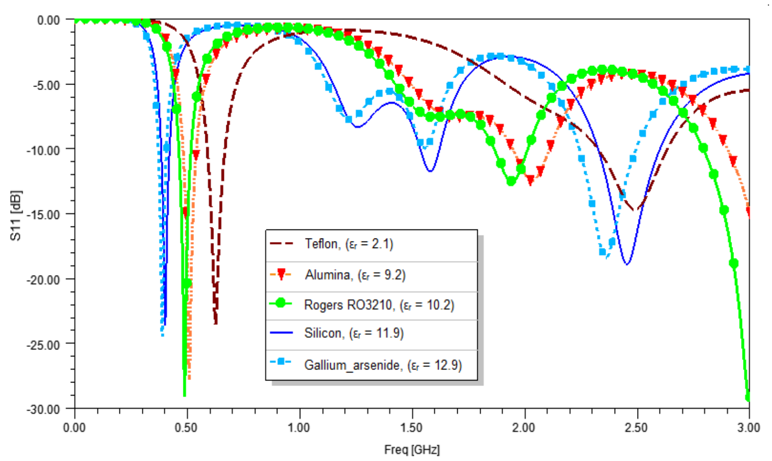


Figure 9 : Simulated return loss S11 for different dielectric materials.

As can be observed from Figure 9, Silicon material introduces the desired characteristics over MICS (402 - 405 MHz) and ISM (2.40 - 2.48 GHz) bands. All the other materials also offer satisfactory S11 return loss characteristics (S11 below -10 dB). However, these materials introduce a undesirable resonant frequency shifts for MICS and ISM bands. We see clearly that higher permittivity results in lower resonant frequency because the effective wavelength is shorter.

Figure 10 shows Voltage Standing Wave Ratio (VSWR) for two resonating frequencies. It can be seen that the value of VSWR at MICS and ISM band are 1.14 and 1.79 respectively. So it can be inferred that the proposed antenna radiates more efficiently in the MICS band then the ISM band which is the prime requirement for data transmission in MICS band.

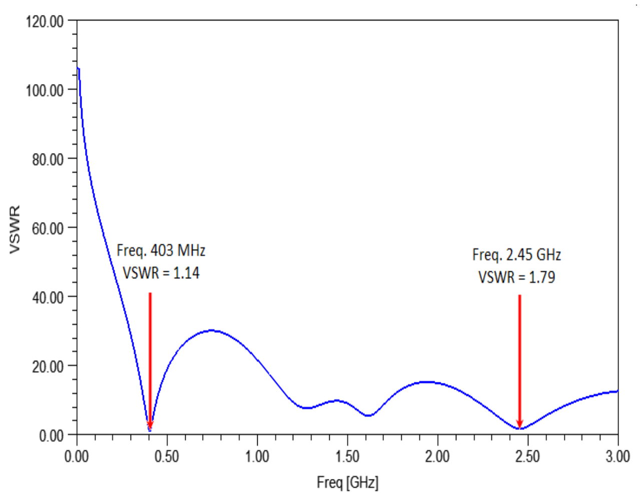


Figure 10 : VSWR for two resonating frequencies in MICS and ISM bands.

The surface current distributions at the resonance frequencies in MICS and ISM bands are shown in Figure 11 (a) and Figure 11 (b) respectively. At 403 MHz, the highest current density is found to have concentrated mostly on the outer element. At 2.45 GHz, on the other hand, the current peaks mostly on the outer element around the shorting pin.

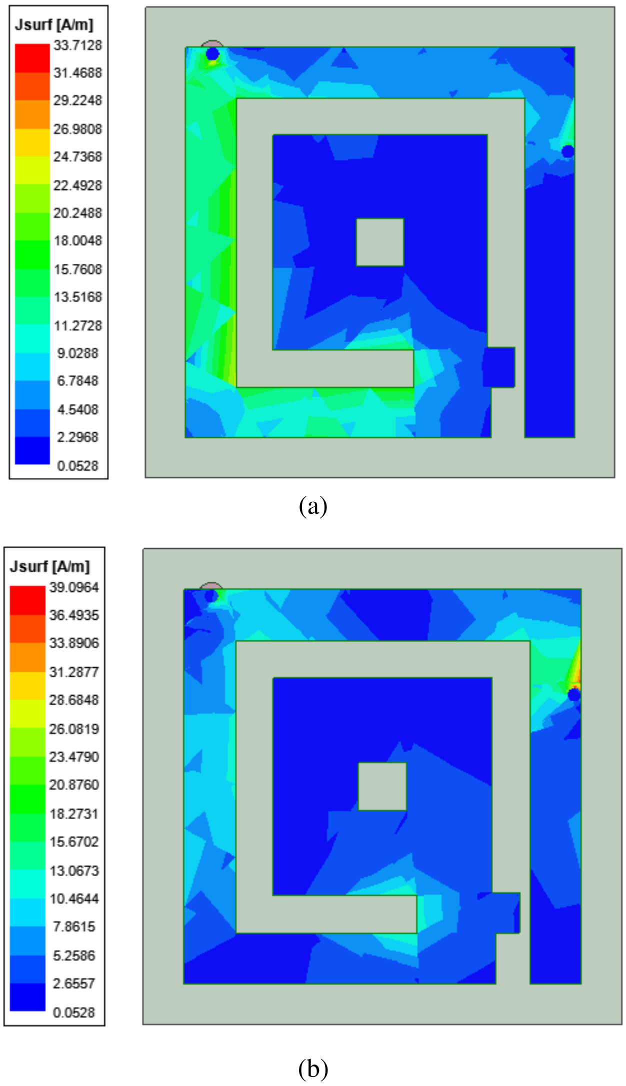


Figure 11 : The electric field distribution, (a) at 403 MHz, (b) at 2.45 GHz.

5. Conclusion

In this paper, an implantable microstrip antenna design with small geometry for the dual-band operation in MICS and ISM band wireless medical telemetry applications is presented. Designed antenna has a simple geometry and resonates at the MICS band with a reflection coefficient of -23.70 dB at 403 MHz, and a bandwidth of 9.45 %. Moreover, it resonates at the ISM band with a reflection coefficient of -18.42 dB at 2.45 GHz, and a bandwidth of 11.4 %. A three-steps methodology was proposed for the design of dual-band (MICS and ISM) implantable antennas which optimally suit the requirements and limitations of the antenna fabrication procedure and medical application.

Proposed antenna is simulated in different body tissues to achieve miniaturized and high bandwidth characteristics. In addition, various dielectric materials are considered and simulated to achieve biocompatibility. It was demonstrated that the use of Silicon material enhances better antenna characteristics over MICS and ISM bands. Such design results in noticeable reduction in antenna size in comparison with the previously available designs operating in the MICS and ISM bands.

The proposed antenna design has a wide bandwidth characteristic at both operating bands; such a wider bandwidth is preferable in case of tissues properties variation. The small size, the sufficient bandwidth as well as the acceptable radiation pattern at resonance frequencies make the antenna as a good candidate for medical implantable systems.

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