Novel Microstrip Patch Antenna for implantable medical telemetry devices

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In recent years, close collaboration has been forged between telecommunications and medicine, which has enabled the birth of medical telemetry and therefore implanting medical devices on the human and animal body. The latter is based on implantable antennas design in the MICS (Medical Implant Communication Service) band (402-405) MHz. The frequency band is explored to design mobile and comfortable communication systems to support human life. The objective of this paper is to design and optimization of implantable printed antennas in human body for medical telemetry. The proposed antenna operates in the MICS band between 402 and 405 MHz. The antenna is simulated using HFSS software. The proposed antenna resonates at 404 MHz with a return loss of -32.58 dB, bandwidth of 26 MHz and gain of 6.5 dB.

Keywords: Microstrip antenna, Medical telemetry, Implantable antenna, MICS, Optimization, HFSS

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1. Introduction

Science has experienced such a rapid development in all fields (medicine, agriculture, architecture, biology etc ...). Telecommunications have not been lacking and have taken such an important place in people's lives that it is becoming unthinkable to do without.

Among the various branches in which telecommunications are concerned, we can cite antennas. These are essential to ensure an operation of emission or reception of electromagnetic waves in the Earth's atmosphere or in space.

Printed antennas have known such a wide field of use that they are applied in medical field. Since their completion, research in this field has continued to evolve in order to exploit the many advantages of this type of antenna [1].

Combining telecommunications (printed antennas) with medicine has been very interesting and beneficial for patient and for the nursing staff. This is how medical telemetry was born, which uses telecommunication transmission of medical information [2, 3].

Biomedical telemetry allows the measurement of physiological signals through either wired or wireless communication technologies. Physiological signals are obtained by means of appropriate transducers and eventually transmitted to exterior monitor control equipment. Implantable medical devices (IMDs) are one of the most recent developments of biomedical telemetry. Low-frequency inductive links have long been the most popular method of biotelemetry for implantable medical devices. However, they suffer from low data rates (1-30 kbps) and limited communication range (10 < cm) [4, 5].To overcome these limitations, research is currently moving towards radio-frequency (RF)-linked implantable medical devices.

Implantable devices with RF communications, in particular, offer a number of advantages over their predecessors which communicated over an inductive link [6]. The device is implanted while the base station resides outside the patient's sterile field. This eliminates the need for an inductive wand which would need to be sterilized and placed close to the implant. Thus, patient safety is improved.

RF communications allow for less invasive checks during follow up clinic visits. The inductive link which would normally be placed in direct contact with the patient is replaced with the RF base station which can be placed at a distance where it is out of the view of the patient [5].

Many people are affected by heart disease and suffer from chronic diseases such as pain, diabetes, and hypertension. So that doctors can provide the necessary medical treatment, and patients can save their life before the condition worsen, it is important to diagnose a chronic disease early. Different RF-linked implanted devices such as pace-makers [6], neurostimulators, implanted cardiac defibrillators (ICD) have been used in the human body [7, 8].

One of the main components of RF-linked implantable medical devices is the integrated implantable antenna, which enables bidirectional communication with the exterior control equipment. Many wireless implantable medical devices operate at the Medical Implant Communications System (MICS) frequency band of 402-405MHz [4].

With miniaturization and therefore design of micro-antennas that can be implanted in the human or animal body, it has been possible to diagnose, treat and prevent in real time certain diseases that in the near past were impossible [4].

The design of implantable patch antennas has attracted high scientific interest for fulfilling the requirements of bio-compatibility, miniaturization, patient safety, and high-quality communication with exterior equipment [5]. The greatest difficulty in design and manufacture antennas for bio-implantable communication devices is the effect of the implant medium (human or animal body tissues that surrounds the implanted antenna) which reduces the antenna performance, particularly in terms of bandwidth and efficiency [9].

Implantable antennas must 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 [4].

The purpose of this paper is to propose a microstrip structure operating in the MICS band which could implantable on the human body. This band has good conductivity in the human body, a higher data rate, and a communication range up to 2 m [3]. The aim is to reduce the size of the antenna at the operating frequency, while still maintaining adequate electromagnetic performance.

Many types of antennas have been proposed throughout research in order to satisfy miniaturization and good performance for implantable medical devices [10–12]. Many designs and shapes have been proposed specifically for patient monitoring system, so an implantable miniaturized circular microstrip antenna has been proposed in [13, 14] a meandered Microstrip patch antenna was used as well in [15]. Microstrip patch antennas are widely used like in [16–19].

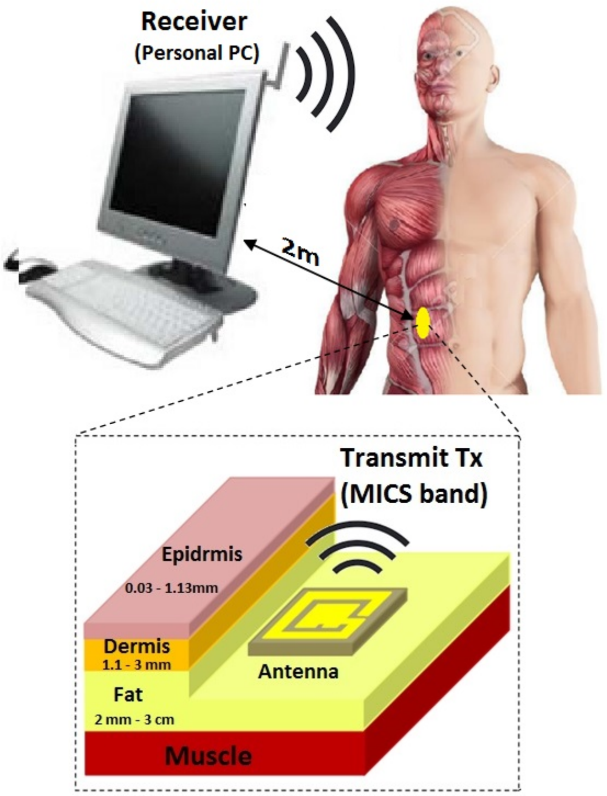

Fig. 1. Implantable antenna intended for medical telemetry applications.

The remainder of this paper is structured as follows: Section 2 provides a brief overview of the effect on the human body due to the radiation of the antenna. In Section 3, we describes the proposed antenna geometry while Section 4 presents and discusses the simulation results and the effects of some important parameters on the proposed antenna performance. Finally, the paper concludes in Section 5.

2. Antenna radiation effects in human body

Wireless transmission systems are increasingly used in biomedical applications inside and outside the human body in medical diagnosis and therapeutic monitoring for various applications. Among these systems we find the pacemaker [6], implantable defibrillator [7] and endoscopic capsule [8] which work inside the human body.

To establish the necessary communication links for biomedical circuits, antennas which are placed inside of the human body must be characterized through numerical and experimental techniques [20]. 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. Biological tissues usually have high permittivities, this will change the resonant frequency of the implanted antennas. Table 1 shows the relative permittivity value for the different body tissues at 403 MHz [5].

Table 1. Relative permittivity value for the different body tissues at 403 MHz.

Name of body tissue	Relative permittivity (ε_r)
Fat	5.58
Muscle	58
Skin	47
Blood	64

Absorption of electromagnetic energy by the outer tissues of the human body is very complicated. As frequency is increased, the penetration depths of these tissues change such that the largest part of the incident energy may be transmitted at one frequency and absorbed at another. Lower frequencies will allow deeper penetration and hence a volumetric interaction with absorbing tissues in the body [21].

The most important antenna radiation effects in human body is the increase of temperature, it is a very important factor due to the fact that a high increase of temperature might cause dangerous effects to human tissues. The increase of temperature of human tissue cells can be explained because a part of the microwaves transmitted by an antenna are absorbed by the body [5].

The tool that measures the rate of energy absorption in human body is called Specific Absorption Rate (SAR). The latter have been adopted especially at RF frequencies (between 100 kHz and 10 GHz) and expressed in Watt per kilogram (W/kg) [21].

For the health of the patient, the local SAR averaged over a cube of 10 g of tissues should not exceed 2 W/Kg for head and trunk and 4 W/Kg for limbs (guidelines given by ICNIRP: International Commission on Non-Ionizing Radiation Protection) [22]. These values have been accepted by the International Telecommunications Union (ITU) and by the World Health Organization (WHO). Studies on antenna radiation effects have not indicated any health risks at exposure levels below the ICNIRP-limits [23].

3. Antenna Design

The geometry of the proposed antenna is shown in Fig. 2. It is designed with respect to the miniaturization and biocompatibility factor. The antenna is composed of two concentric square elements and a metal pad placed between them with a coaxial feeder cable. The concentric structure can reduce antenna size by increasing the length of the current-flow path.

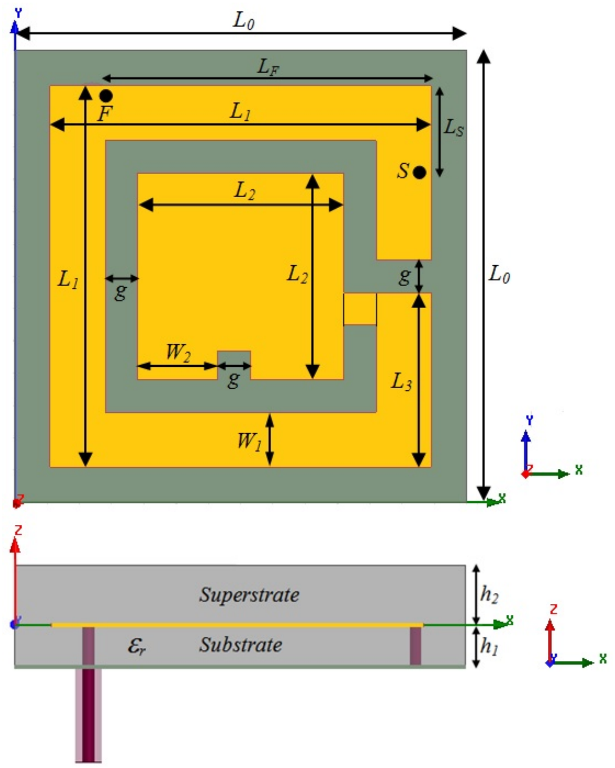

Fig. 2. Proposed antenna geometry.

A shorting pin also directly connects the outer annular element to the ground plane. Inserting a shorting pin between the ground and patch increases the effective size of the antenna, and, in turn, reduces the required physical dimensions.

The separation between the outer ring and the inner square is 1mm. The antenna is designed on a high-permittivity silicon dielectric (ε_r = 11.9, σ = 0.02-0.05 s/m) is used for both the top (Superstrate) and the bottom substrate (Substrate). The superstrate where the patch resides is 1.83 mm thick. The substrate is 1.27 mm thick.

The superstrate is used for preserving the biocompatibility of the antenna while at the same time separating the metal radiator from human tissue and high-permittivity dielectric is selected for because it reduces the effective wavelength and result in lower resonance frequencies, thus assisting in antenna miniaturization.

The geometry parameters of our proposed antenna are shown in Table 2. The proposed antenna is designed to operate at 404 MHz.

Table 2. Geometry parameters of the proposed antenna.

Parameter	Value (mm)	Parameter	Value (mm)
L_0	14	W_2	2.7
L_1	12	L_F	10.6
L_2	6.4	L_S	3
L_3	5.5	g	1
W_1	1.8	h_1+h_2	1.27+1.83

To preserve biocompatibility, while separating the metallic radiator from human tissues, the most widely used approach is to cover the structure with a dielectric superstrate layer. The 3D model of the proposed antenna is shown in Fig. 3.

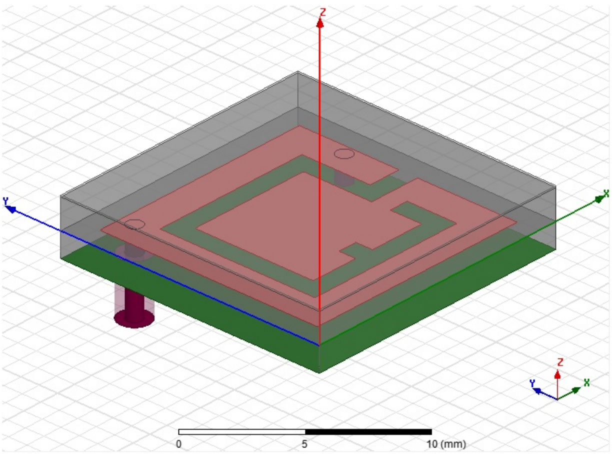

Fig. 3. 3D model of the proposed antenna.

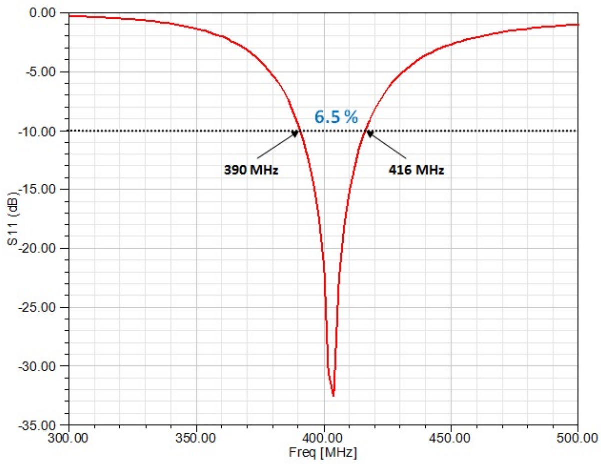

Fig. 4. Simulated return loss S11 of the proposed antenna.

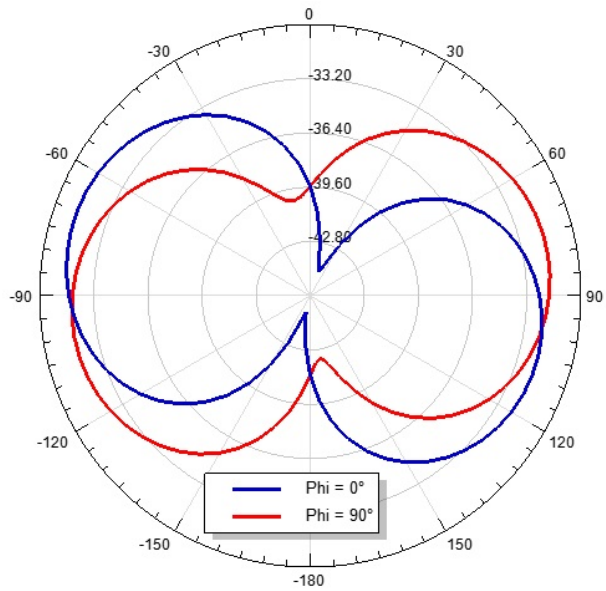

Fig. 5. 2D radiation patterns measured at 404 MHz.

4. Simulation results and discussion

The variation of the return loss amplitude as a function of frequency of the proposed antenna is shown in Fig. 4. It is observed that antenna resonates at 404 MHz with a return loss of -32.58dB. We see that the antenna operates from 390 to 416 MHz which provides a bandwidth of 26 MHz. Proposed antenna is simulated on HFSS (High Frequency Structure Simulation).

The 2D and 3D far-field radiation pattern at $\varphi = 0^\circ$ and $\varphi = 90^\circ$ of the proposed patch antenna are respectively shown in Fig. 5 and Fig. 6. The polarization is linear with bidirectional radiation at the frequency of 404 MHz where the adaptation is maximum. The antenna has a directivity of 5.27 dB.

4.1. Effect of variation of feed point position

The feed position (F) plays an important role in antennas designing. It can change the antenna's radiation characteristics as well as the antenna adaptation. The effect of variation of the feed position is shown in Fig. 7. As shown in the figure, the feed point position affects the adaptation of antenna without changing in the resonant frequency value. It is clear that the variation of the feed position makes no change to the value of the resonant frequency; but it has an important and remarkable influence on return loss S11 value.

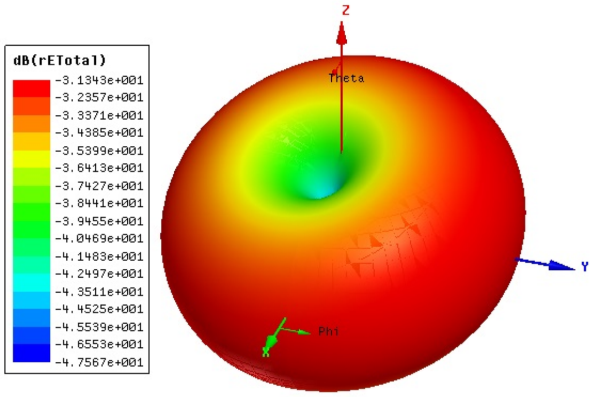

Fig. 6. 3D radiation patterns measured at 404 MHz.

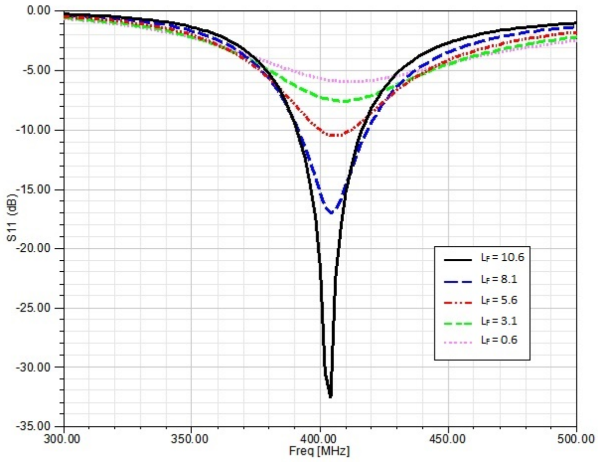

Fig. 7. Simulated return loss S11 for different feed point positions.

4.2. Effect of variation of shorting pin position

The choice of a shorting pin position (S) can reduce the antenna size for a desired frequency [3]. It permits to double the electrical size of the antenna. The effect of variation of shorting pin position is shown in Fig. 8. We see clearly that the shorting pin location affects not only the resonant frequency value but also affects the antenna adaptation.

4.3. Effect of variation of metal pad position

To demonstrate the effect of variation of the pad metal position that acts as a connector between the inner and the outer element on the antenna performance, we simulate now the return loss S11 of the proposed antenna for different metal pad positions as shown in Fig. 9.

The effect of variation of the metal pad position is shown in Fig. 10. As shown in the figure; the position of the metal pad affects not only the operating frequency value but also affects the S11 level.

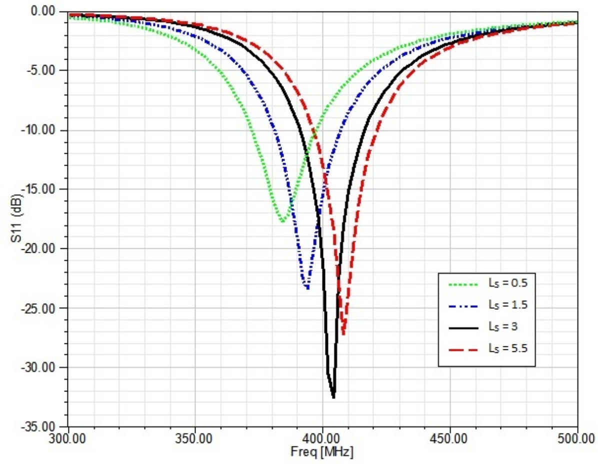

Fig. 8. Simulated return loss S11 for different shorting pin positions.

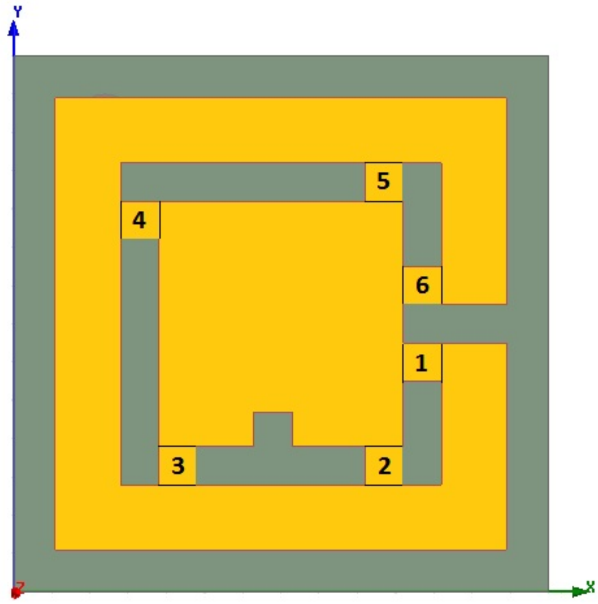

Fig. 9. Different metal pad positions.

4.4. Effect of variation of antenna geometry

In this section, we study the effect on performance characteristics of the proposed microstrip patch antenna with varying design parameters. All of the design parameters such as length and width of the patch, height of the dielectric substrate can control the properties of the antenna and radiation pattern.

4.4.1. Effect of variation of the substrate thickness

The choice of proper substrate thickness is another important point in microstrip patch antenna design; it can completely change the antenna performance. To see the effect of variation of the substrate thickness on the performance

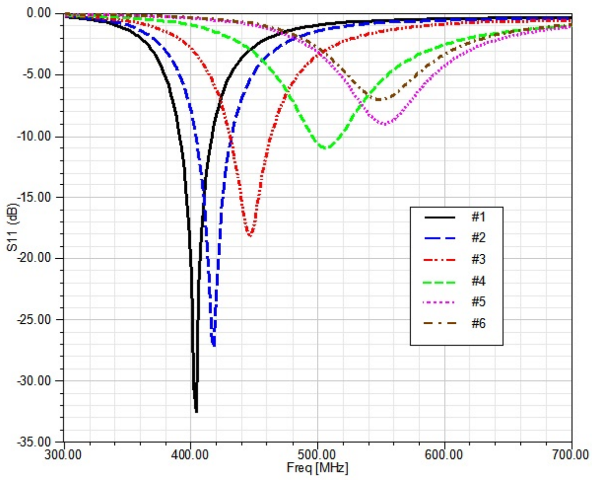

Fig. 10. Simulated return loss S11 for different metal pad positions.

of antenna, we simulate now the return loss S11 of the proposed antenna by varying substrate thickness (h_1) from 0.8 mm to 2.05 mm, the superstrate thickness is kept fixed at 1.83 mm. Different simulation results were observed as shown in Fig. 11.

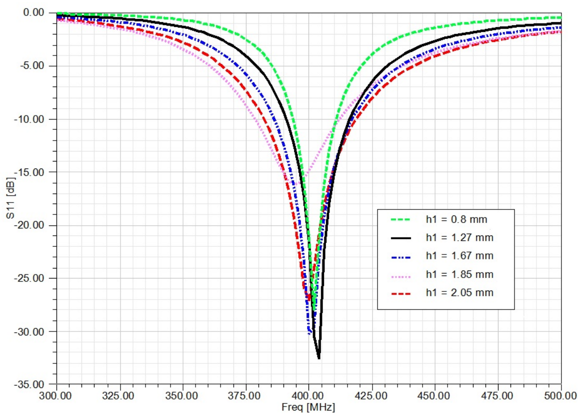

Fig. 11. Simulated return loss S11 for different substrate thickness.

From the data Table 3, We can clearly see that with increasing substrate thickness (h_1), the bandwidth increases but there is a slight decrease in the resonant frequency value. As the height of the substrate increases it adds more volume to fringing effect, thereby an increase in the bandwidth is observed.

4.4.2. *Effect of variation of the patch dimensions*

Dimensions of the patch are its main parameter and it naturally affects most of the antenna characteristics. In this case, a comparative discussion is presented on the effect of

Table 3. Variation of antenna parameters with different substrate thickness.

Substrate thickness h_1 (mm)	Resonant frequency (MHz)	Bandwidth (MHz)
0.8	401	16
1.27	404	26
1.67	400	31
1.85	395	33
2.05	400	37

changing the dimensions of the on the resonant frequency of the proposed antenna. More specifically, the length and width of the outer ring ($L_1 \times L_1$) and the inner square ($L_2 \times L_2$)) elements of the patch are considered is this study.

It has been observed from simulation results of S11 shown in Fig. 12, that with varying L_1 (11 mm, 12 mm,12.5 mm and 13 mm), the antenna response point shifts around 372 MHz, 388 MHz, 404 MHz and 410 MHz respectively. So it is evident that resonating frequency will be decreased with increase of dimensions of the outer ring L_1. Length and width of the patch affects not only the operating frequency value but also affects the S11 level.

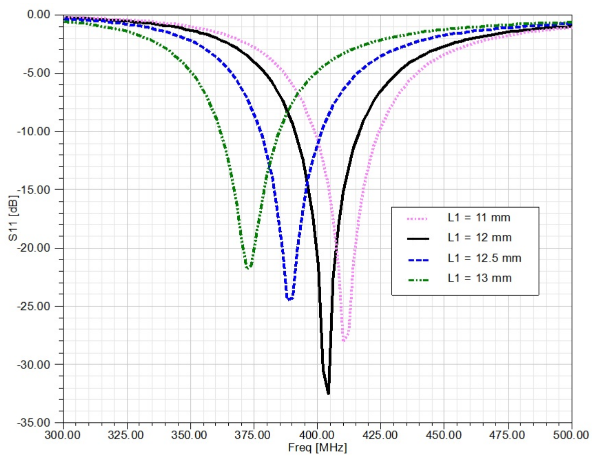

Fig. 12. Simulated return loss S11 for different outer ring sizes.

The inner square element length L_2 was also sequentially varied from 5.4 mm to 7.4 mm. As can be seen in Fig. 13, the resonant frequency value of antenna is inversely proportional to the inner square size.

In our analysis, the results of variation of the patch elements dimensions (the inner ring and the square element) raise the same observation. That is, an antenna operating at higher frequency is smaller in size than compared to an antenna operating at low frequency.

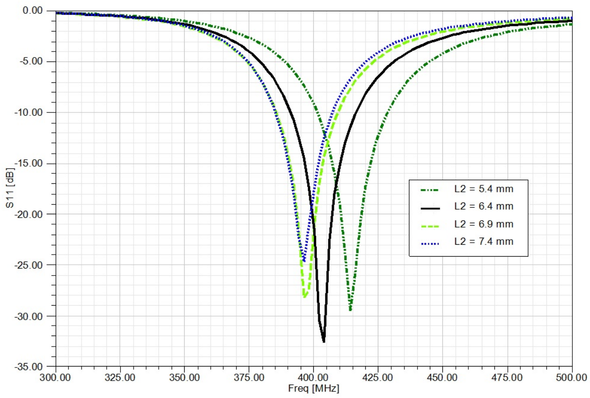

Fig. 13. Simulated return loss S11 for different inner square sizes.

The dimensions of the patch have a major effect on the resonant frequency. Similarly, the bandwidth is also affected by the height of the substrate. So we have to opt for choosing the optimum dimensions of patch to perform our desired requirements.

The electric field distribution at 404 MHz of proposed implanted microstrip antenna as shown in Fig. 14 is concentrated in the outer ring and the metal pad position. So it clearly see that the metal pad play critical role on the antenna designing to operating in MICS band.

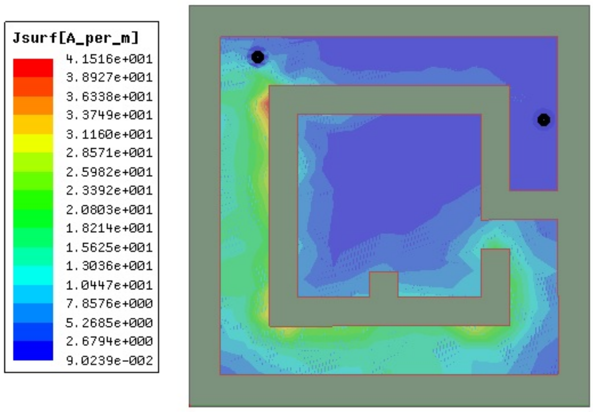

Fig. 14. The electric field distribution at 404 MHz.

5. Conclusion

In this paper, an implantable microstrip antenna design was presented to resonate at a frequency in the MICS band (402-405 MHz) for medical telemetry applications. The proposed design contains two concentric square elements and a metal pad placed between them with a coaxial feeder cable. Also shorting pin which connects the outer annular element to the ground plane plays critical role on miniaturization of the antenna. We have examined the effects of some important parameters on the proposed antenna performance.

Such design results in noticeable reduction in antenna size. In comparison with the previously available designs operating in the MICS band. The obtained bandwidth is 6.5%, and the return loss at resonant frequency is down to -32.58 dB. Eventually it was shown that the antenna's design can be used in wireless communication link for medical implantable systems according to the application wished to attain.

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