A Compact Size Implantable Antenna for Bio-medical Applications

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***Abstract*—Implantable antennas play a vital role in implantable sensors and medical devices. In this paper, we present the design of a compact size implantable antenna for biomedical applications. The antenna is designed to operate in ISM band at 915 MHz and the overall size of the antenna is 4×4×0.3 mm^3. A shorting pin is used to lower the operating frequency of the antenna. For excitation purpose a 50-ohm coaxial cable is used in the design. A superstrate layer is placed on the patch to prevent the direct contact between the radiating patch and body tissues. The antenna is simulated in skin layer model. The designed antenna demonstrates a gain of 3.22 dBi while having a -10 dB bandwidth of 240 MHz with good radiation characteristics at 915 MHz. The simulated results show that this antenna is an excellent candidate for implantable applications.**

***Index Terms*—Implantable Medical devices, Implantable Sensors, Bio-medical telemetry, Patch Antenna.**

I. Introduction

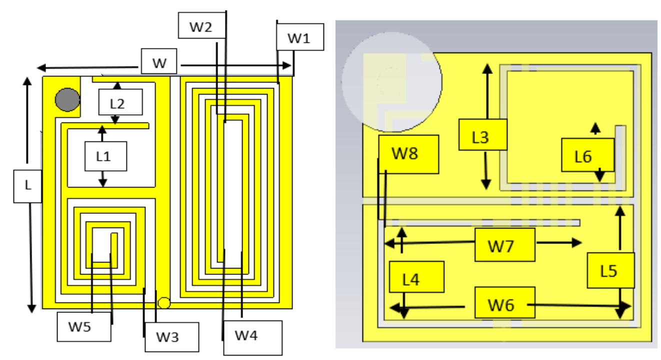
Implantable medical devices play a critical role in everyday life. They are capable of monitoring patient's psychological data and transmit to the external medium [1], [2]. Examples include cardiac pacemaker, defibrillators, capsule endoscopy, blood glucose monitoring, blood sugar level monitoring, cochlear and retinal implants etc. [3]–[9]. In all such devices the antenna is a major building block. If the performance of the antenna is compromised it will affect the performance of whole device and system attached to it [10], [11]. If the antenna is operating at higher frequency it will interfere with other devices causing the signal destruction. On the other hand, if antenna is made to resonate on lower frequency then it will be difficult to achieve the compact size. Human body tissue safety considerations also need to be taken into account when designing such an antenna. So, the selection and design of antenna for implantable applications is a challenging and multifaceted task.

Various implantable antennas are presented in open literature. Ketavath *et al*. proposed a patch antenna in [12]. The antenna is operating at 2.4 GHz with a volume of 24× 22×0.07 mm^3. At 2.4 GHz the antenna exhibits a gain of -19.7 dBi with a bandwidth of 24%. Though the antenna has quite wider bandwidth with considerable gain but the antenna has quite large volume which can be reduced further. Another flexible wideband antenna is given in [13]. The dimensions of the antenna are 10×10×0.4 mm^3. The gain of the antenna at operating frequency of 2.45 GHz is -9 dBi with a bandwidth of 57%. The antenna has a low efficiency of 2.3%. Fu *et al.* [14] proposed a flexible antenna using PMDS (polydimethylsiloxane) as substrate. The size of the antenna is 11×11×2 mm^3. The antenna operates in ISM band at frequency of 2.42 GHz. The realized gain of the antenna is -28 dBi with a bandwidth of 10.4 %. The antenna was optimized using an RLC circuit which makes it a complex design. A probe fed implantable antenna was given in [15]. The antenna has a volume of 12×7.5×0.25 mm^3. The antenna operates on five frequencies. The radiation efficiency of the antenna is 80% with a bandwidth of 168% while the gain of the antenna is not reported.

Xu *et al.* proposed an annular ring antenna for implantable applications in [16]. The volume of the antenna is $\pi\times 5^2\times1.25$ mm^3. The antenna bandwidth is 12.4% with a gain of 22.7 dBi. The size of the antenna can be reduced further to achieve a miniaturized design. An implantable antenna with slotted ground plane was presented in [17]. The antenna operates at two frequencies of 402 MHz and 2.45 GHz. At 402 MHz the gain of the antenna is -41 dBi and bandwidth is 41% while at 2.45 GHz the bandwidth of the antenna is 27.8% with a gain -21.3 dBi. The antenna has a large volume of $\pi\times5.35^2\times1.34$ mm^3. A multiband spiral shaped implantable antenna was given in [18]. The volume of the antenna is 7×6.5×0.377 mm^3. The operating frequencies of the antenna are 402 MHz, 1.6 GHz and 2.45 GHz. The gain of the antenna is -30.5 dBi, -22.6 dBi and -18.2 dBi. The bandwidth of the antenna is 36%, 10% and 3.4%. The efficiency of the antenna is not mentioned. A compact broadband antenna was proposed in [19]. The volume of the antenna is 23×16.4×1.27 mm^3. The bandwidth of the antenna is 49 MHz with a gain of 34.9 dBi. With that large volume of the antenna the gain is quite low and the bandwidth is quite narrow. To address all these issues, we propose a small size antenna which has high gain, low sprcific absorption rate (SAR), good radiation pattern and wider bandwidth. This paper is organized as follows. In section I a brief introduction on implantable medical devices and implantable antennas is given. Section II details the proposed antenna design methodology. Antenna simulation results are summarized in section III. A conclusion is drawn in the last section.

II. IMPLANTABLE ANTENNA DESIGN

The antenna patch view is shown in Fig. 1(a) and the antenna ground plane is shown in Fig. 1(b). This antenna design includes 0.25 mm substrate layer of Rogers RT3010 (ϵ_r = 10.2; tanδ = 0.0023). The superstrate layer is useful to protect the human body tissues from harmful radiation and to lower the operating frequency. The superstrate layer has a thickness of 0.05mm and its material is polyimide (ϵ_r = 4.3; tanδ = 0.004). A 50-ohm coaxial probe is used to excite the antenna. The position of feed is p (x= -1.6; y= 1.6). Shorting pin is also used to further lower the frequency of the antenna p (x= -0.05; y= -1.9).



(a) (b)

Fig. 1: (a)Antenna patch (b) Antenna ground plane

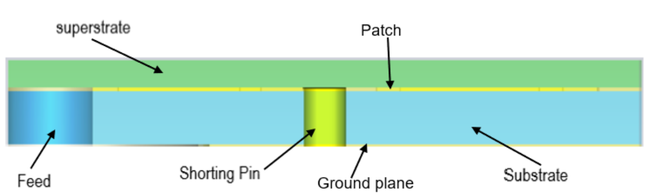


Fig. 2: Antenna side view

The shorting pin also decreases the patch resistance. The copper cladding is used for patch and ground plane. The size of the antenna is (4×4×0.3) 4.8 mm^3. The CST Microwave Studio software is used to design the antenna. The side view of the antenna is shown in Fig. 2. The antenna was simulated in skin box with dimensions of (60×60×60) mm^3 as shown in Fig. 3. The dimensions of antenna are given in Table I.

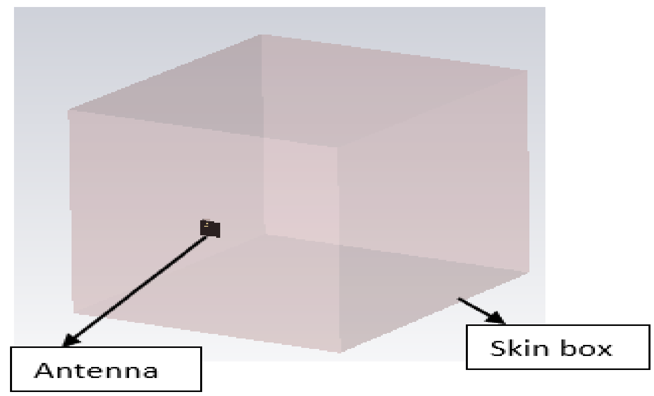


Fig. 3: Antenna in skin box

TABLE I: Antenna Dimensions

Parameter	Unit(mm)	Parameter	Unit(mm)
L	4	W1	0.2
L1	1	W2	0.1
L2	0.7	W3	0.15
L3	1.5	W4	0.45
L4	1.5	W5	0.4
L5	1.6	W6	3.45
L6	0.8	W7	2.7
W	4	W8	0.1

III. RESULTS AND DISCUSSION

The simulated antenna design results are given as follows.

A. *Return loss (S1,1)*

The antenna return loss(S1,1) plot is a measure of the antenna power to be transmitted and reflected back. The lower the value of S1,1 the transmitted power will be high. The standard for an antenna to resonate on a specific frequency is that the value of S1,1$\leq$10. The return loss of the proposed antenna is shown in Fig. 4. It can be seen in the figure that the return loss of the antenna at a resonant frequency of 915 MHz is -21 dB which dictates that much of the antenna power is transmitted to the medium and the reflected back power is very small. The return loss of antenna is also shown in Fig. 4 when antenna was simulated in 1mm, 2mm and 4mm skin layer. The frequency has a minor shift due to loss nature of the medium but still covers the band of operation. The -10 dB bandwidth of antenna is 240 MHz. The bandwidth of the antenna in free space is narrower than the bandwidth of antenna when implanted inside skin layer because of the lossy nature of the skin tissue.

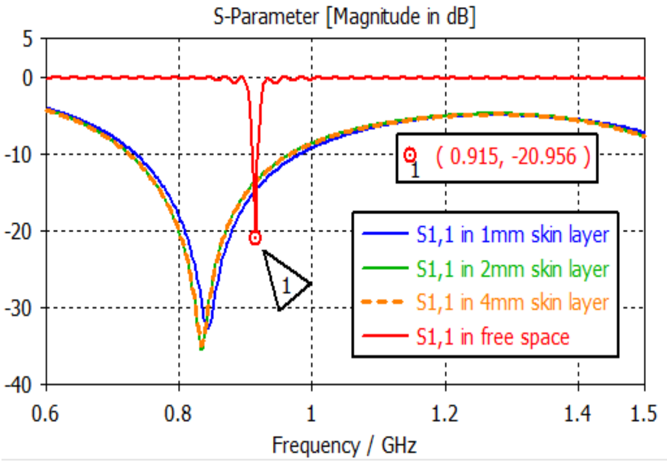
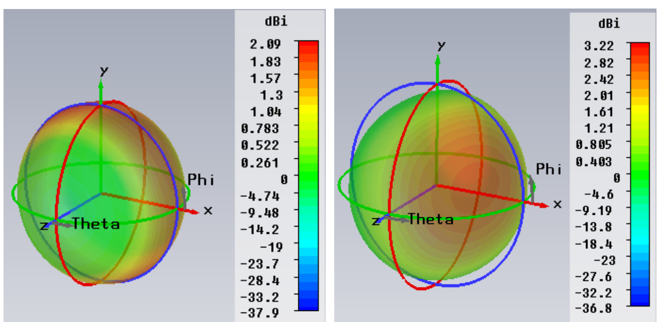


Fig. 4: Antenna return loss plot

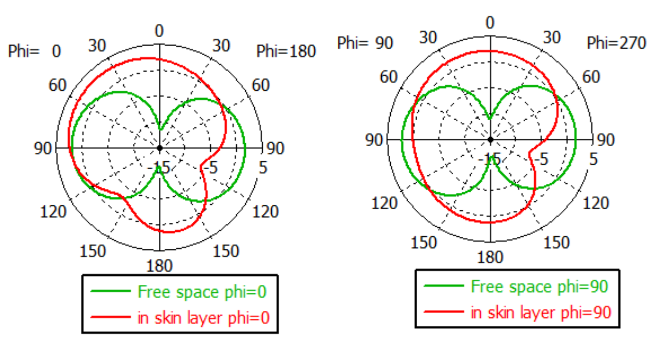
B. Antenna Radiation Pattern and Gain

The radiation pattern of the implantable antenna is changed when implanted inside the human body tissues due to power absorption, reflection, refraction and antenna positioning.



(a) (b)

Fig. 5: 3D radiation pattern of the antenna at 915 MHz (a) Free space (b) skin layer



(a) (b)

Fig. 6: Radiation pattern of the antenna in free space and skin layer at 915 MHz (a) E-plane (b) H-palne

The radiation pattern of proposed antenna is shown in Fig. 5 and Fig. 6. Figure. 5 (a) and (b) shows the 3D radiation pattern of the antenna in free space and in skin layer while Fig. 6 (a) and (b) shows the E- plane and H-plane radiation pattern of the antenna in free space and in skin layer. It can be seen in Fig. 6 that the main lobe magnitude of the radiation pattern has changed when antenna is placed inside skin layer and the angular width has also increased. The antenna has quite omnidirectional radiation pattern which is important in case of implantable medical devices. The antenna has a gain of 2.07 dBi in free space and 3.22 dBi in skin layer. The gain of the antenna has increased inside the skin layer because of power absorption which has also increased the antenna bandwidth.

C. Antenna Current Distribution

The current distribution of the antenna is shown in Fig. 7. It is evident from the Fig. 7 that the current is more on the right side of the patch. So, if the slots size or position is changed it would affect the resonant frequency.

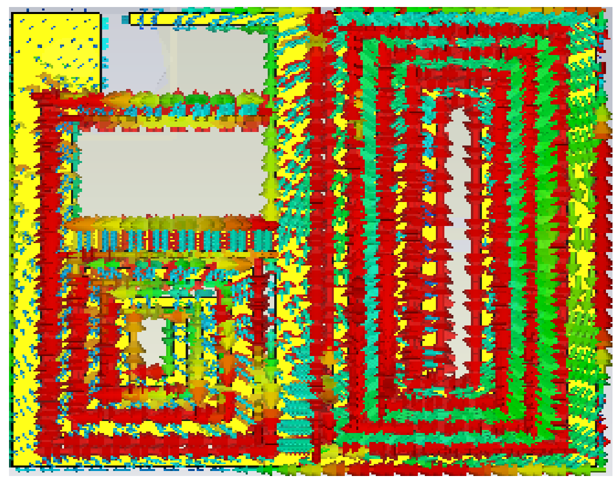
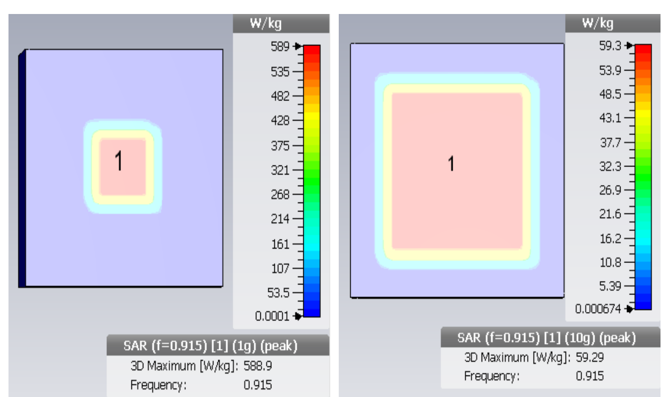


Fig. 7: Antenna current distribution

D. Specific Absorption Rate (SAR)

Specific absorption rate should be within the standard limit to ensure patient safety. SAR should be less than 1.6 w/kg



(a) (b)

Fig. 8: Antenna SAR at 915 MHz (a) 1g (b) 10g

TABLE II: Proposed Antenna Comparison with Previous Work

Reference	Size(mm^3)	Frequency(GHz)	Gain(dBi)	Bandwidth (MHz)	Shorting pin used	SAR 1g avg. (W/Kg)
[13]	10×10×0.4	2.45	-9	1390	NO	124
[14]	11×11×2	2.42	-20	242	NO	356.4
[18]	7×6.5×0.377	0.402; 1.6; 2.45	-30.5; -30; -22.6	148; 171; 219	NO	588; 441; 305
[19]	23×16.4×1.27	0.402	-34.9	49	YES	284
[20]	22×23×1.27	0.402; 2.4	-36.7; -27.1	30; 168	YES	832; 690
Proposed work	4×4×0.3	0.915	3.22	240	YES	589

averaged over 1g cubic volume of tissue according to IEEE C95.1-1999 standard and 2 w/kg averaged over 10g cubic volume of the tissue according to IEEE C95.1-2005 standard [18]. The 1g and 10g SAR of the antenna is shown in Fig. 8. The 1g SAR is 589 w/kg and 10g SAR is 59.3 w/kg at 915 MHz when the antenna input power is 0.5w. These values seems higher than the standard because the human body tissues absorb power. To meet SAR requirements the maximum allowed input power of the antenna should be 2.7 mW for 1g averaging and 34 mW for 10g averaging at 915 MHz [20]. So, the SAR is within the allowable limits. Table II summarizes the characteristics of the designed antenna and compares with other similar work.

IV. Conclusion

In this paper we have presented an implantable antenna operating in ISM band at 915 MHz. The antenna is excited by a 50-ohm coaxial probe feed. Slots are created in the patch to elongate the current path. Shorting pin is used to lower the antenna frequency and the superstrate layer is also used for human body tissue safety purposes. All the simulation results are discussed and analyzed. The antenna overall size is 4.8 mm^3. The antenna is simulated in skin layer. It is evident from the Table II that the antenna has a peak gain of 3.22 dBi with good radiation characteristics which makes it suitable for implantable applications.

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