Design, Simulation and Fabrication of an Implanted Antenna at ISM Band in Body Tissue

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Abstract
A rectangular meandering-microstrip patch antenna (RM-MPA) with short pin for implant antenna and biomedical applications at industrial, scientific, and medical (ISM) band is proposed. The rectangular patch has a length of \( l = 14 \) mm and a width of \( w = 9.4 \) mm. The substrate and superstrate are made of Rogers 3210 with dielectric constant equals to 10.2. The RM-MPA is placed between the substrate and superstrate dielectric layers whose same thickness equals \( 0.635 \) mm. The proposed antenna is fed by a 50-\( \Omega \) coaxial probe, at the centre of the length and edge of the width of the patch. The input impedance of the patch antenna varies with the patch geometry. Thus, the geometry of the patch changed to achieve impedance matching at the ISM band. The rectangular patch divided into three sections along width for meandering. The resonance frequency is tuned by meandering each section. The proposed antenna is simulated in free space and skin phantom. The proposed antenna has an efficiency of 90\%, bandwidth of 1.02\%. Both radiation pattern and SAR have evaluated which SAR level is below the safety and satisfies SAR standards. Finally, the antenna is tested in minced meat and tissue liquid.

Keywords Implanted antenna · ISM band · Meandering · Microstrip antenna · SAR · Shorting pin

1 Introduction

The antenna is an essential component of all wireless devices [1]. With the development of wireless technology, many systems and devices can be proposed and design for medical applications. Implant antennas can be used inside and outside of a human body. Nowadays medical implant devices are widely used for diagnosis, treatment and monitoring [2]. These antennas should be low profile and compact, affordable and safe for the patient therefore, there are challenges to design antenna such as miniaturization, patient safety, improve radiation performance, increase the bandwidth and Specific Absorption Rate (SAR) [3–8]. Some research groups utilized loop [9], circular antenna [2, 3, 6, 7], meanders and spiral [10–14], folded dipole [15], Implantable coplanar waveguide (CPW) -fed rectangular
patch [16–19] triangular slot antenna [18] tapered Multi Input Multi Output [19], Pseudo-normal-mode helical [20] Ultra high frequency (UHF) Radio-frequency identification (RFID) tag antenna for implanted denture [21]. There are several common frequency bands for the operating frequency of the implanted antenna. Medical Implant Communication Service (MICS, 402–405 MHz) is the most commonly used band for these devices [11, 12]. Also, Industrial, scientific, and medical band (ISM, 433–434.8 MHz, 902–928 MHz, 2.4–2.48 GHz) is adopted in various studies [11, 14, 16–19]. Other frequency bands have been suggested for operating frequency like MedRadio (401–406 MHz) [18] and UHF [5, 21]. Considering the advantage of dual [6–8, 11] and triple [12, 13] bands, a set of papers have designed such antennas.

In this paper, we have proposed a rectangular meandering-microstrip patch antenna (RM-MPA) with shorting pin for the ISM band. Section 2 describes the details of the design and configuration of the antenna. Simulation results of free space and tissue liquid including $S_{11}$, radiation pattern, gain, efficiency, SAR diagram are given in Sect. 3 part A and measurement result are discussed in part B of this section, part C presents a comparison between our results and previous works, followed by concluding remarks in Sect. 4.

## 2 Design and Configuration of Antenna

We have presented an RM-MPA with shorting pin for biomedical application at the ISM band. In the proposed antenna, as it seen in Fig. 1, the patch is located on a layer named substrate of Rogers 3210 with dielectric constant ($\varepsilon_r$) equals 10.2 and loss tangent ($\tan\delta$) equals 0.003 and a superstrate with the same material covers the patch. Substrate and superstrate have an equal thickness of 25 mils (0.635 mm).

Since in this type of antenna traditional half-wavelength ($\lambda/2$) and quarter-wavelength ($\lambda/4$) dimensions are useless in implantable applications [4], for antenna radiation some methods should be applied to make the antenna smaller such as making patch spiral and meandered or using a shorting pin, etc. As miniaturization techniques, we have to utilize meandered shape and short pin as well. The proposed antenna is fed by a coaxial probe with a characteristic impedance of 50 ohms. The input impedance of the patch antenna varies with the patch geometry. Thus, the geometry of the patch changed to achieve impedance matching at the ISM band. As illustrated in Fig. 1a the rectangular patch is divided into three sections along width for meandering. Meandering (or this) is applied on four cases as is seen in Fig 2.

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**Fig. 1** Rectangular patch a- top view b- side view
Considering the real part and imaginary part of the input impedance and the reflection coefficient diagrams, meandering is applied on the patch in order to tune resonance frequency. Therefore, if the load at the desired frequency is capacitive or inductive respectively meanders or slots will be created till input impedance equals 50 ohms and the antenna has acceptable radiation. Simulation results for the real and imaginary part of input impedance and reflection coefficient $S_{11}$ are presented in Figs. 3 and 4 respectively.

As it is seen, in the curves of the main design at 2.45 GHz real part of the antenna is very close to 50-ohm, the imaginary part is zero and the antenna has efficient radiation. The geometry of the proposed antenna is given in Fig 5. The detailed values of geometrical dimension are summarized in Table 1.

If the origin of the coordinate system is on the centre of length and edge of width, feeding location is at (0 mm, 0.5 mm) and short pin position is at (0.6 mm, 2.2 mm).
The total size of the antenna is $9.4 \times 14 \times 1.27 \text{ mm}^3$ (167 mm$^3$). For antenna performance analysis HFSS software is used.

### 3 Results and Discussion

As Merli et al mentioned in [13] to overcome all constraints and meet all requirement, at first, the antenna is designed in free space.

#### 3.1 Simulation Results

In Fig. 4 reflection coefficient $S_{11}$ is illustrated. In range 2.331–2.456 GHz antenna has a bandwidth of 1.02%. Radiation pattern and gain are shown in Fig. 6, respectively. The efficiency of the proposed antenna is 90% and the maximum gain is – 17dB.

To evaluate the performance of the antenna in the human body phantom, the electromagnetic characteristics extracted from [19] is used. Table 2 shows the value of these parameters at the operating frequency for skin, fat and muscle tissues in one-layer and three-layered phantoms shown in Fig. 7.

$S_{11}$ schematics is shown in Fig. 8 for one-layer phantom and several implanting depths in three-layered phantom. According to this result by implanting the antenna...
Fig. 6 The simulated radiation pattern of the proposed antenna, (a) Hplan and Eplan and (b) the simulated gain of the proposed antenna.

Table 2 The electromagnetic characteristics extracted from [22]

| Tissue   | $\varepsilon_r$ | $\sigma$    | $\tan\delta$ |
|----------|-----------------|-------------|---------------|
| Skin     | 38.011          | 1.4621      | 0.2827        |
| Fat      | 5.2784          | 0.1052      | 0.1453        |
| Muscle   | 52.71           | 1.7497      | 0.242         |

Fig. 7 1-layer and 3-layered phantoms

Fig. 8 Comparison of the reflection coefficient of 1-layer and 3-layers phantoms
at the edge between fat and skin we will have a better outcome. Observed shifts in the
$S_{11}$ diagram could be due to tissue high $\sigma$ in desired frequency band or phantom for a
given frequency is not much accurate and the depth of implant will affect the resonant
frequency.

As the figure shows one-layer and three-layered phantom results are not much dif-
ferent and as described in [23], a simple phantom can be used to design in order to
reduce the simulation time and complexity of the design. Current distribution can be
shown the performance of the different parts [24], in Fig. 9 the current density dis-
tribuions are illustrated for one and three-layers phantom. Figure 10 shows the local
and average Specific Absorption Rate (SAR) curve along the defined line. As it can be
seen this antenna satisfies the SAR standard.

### 3.2 Measurement Result

The fabricated antenna is shown in Fig. 11 is tested in the laboratory by Network Ana-
lyzer Hp8510c in free space, minced meat and tissue liquid with composition men-
tioned in [14]. Figure 12 shows the fabricated antenna measurement setup.

Reflection coefficients $S_{11}$ for free space, minced meat and tissue liquid are illus-
trated in Fig. 13. Compared to simulation results in Fig. 14, here some losses or shifts
can be seen in the $S_{11}$ diagram due to measurement and fabrication faults or combina-
tion of liquid tissue is not properly prepared. The radiation pattern is shown in Fig. 15.
3.3 Comparison Results

The performance across free space was evaluated (or selected) to achieve a comparison. As it can be seen from Table 3, in many features the presented antenna is similar to other antenna characteristics in the previous articles, the advantage of our antenna is compactness, appropriate bandwidth, high efficiency, good gain and satisfaction of the SAR standard.
4 Conclusion

As miniaturization techniques we have utilize meandered shape (RM-MPA) and short pin for implant antenna and biomedical applications for ISM band at the operation frequency of 2.45 GHz with a volume of 167 mm³ was proposed. Firstly, using miniaturization techniques, the antenna was simulated by HFSS software in free space. Antenna performance was evaluated by studying reflection coefficient $S_{11}$, gain, radiation pattern and SAR, afterwards. To simulate body tissue in the software one-layer and three-layered phantoms were used. Due to the small difference between the results of these two phantoms, simple skin phantom results can be used to reduce complexity and simulation time. Then the antenna is tested at the laboratory in free space, minced meat and tissue liquid. Results show that there is a good agreement between simulation and measurement results and we have achieved our design goal of antenna which was designing a compact antenna with appropriate performance.
Authors’ Contributions MS did the design and simulation and MSB did the fabricated, measured and wrote the article.

Availability of Data and Material All data such as simulations and measurement are given in the text.

Code Availability Simulation using HFSS.

Declarations

Conflicts of interest There is no conflicts of interest.

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Table 3 Comparison between our paper results and previous works

|               | [13] | [12] | [14] | [11] | [7] | Proposed antenna |
|---------------|------|------|------|------|-----|------------------|
| ε_r           | 9.2  | 10.2 | 10.2 | 10.2 | 10.2| 10.2             |
| Short pin     | ✔    | ✔    | ✔    | ✔    | ✔   | ✔                |
| Frequency bands | MedRadio MICS ISM MICS MICS ISM |
|               | ISM  | ISM  | ISM  | ISM  | ISM |
| BW %          | 2.3  | 28.6 | 7.7  | 23   | 38.1| 1.02             |
| Volume mm³    | 6 2  | 28.6 | 7.7  | 23   | 38.1| 1.02             |
| Gain dB       | – 28.8 | – 7 | – 22 | –    | – 34.08| – 17 |
|               | 118.5 | – 11 | dBi  | dBi  | – 15 | dBi              |
| Efficiency %  | 43.65| 39   | –    | –    | 90  |                  |
| SAR           | –    | 341  | 213  | 85.2 | 241.5| 0.4             |
|               | 320  | 149.5| 382  |      | 382 |                  |

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