# Low Profile Wideband Dual-Ring Slot Antenna for Biomedical Applications

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Received 26 May 2021; received in revised form 22 June 2021; accepted 23 June 2021

DOI: https://doi.org/10.46604/peti.2021.7790

## Abstract

In this study, a low-profile, co-planar waveguide (CPW) fed, wideband, and dual-ring slot antenna design for biomedical applications is proposed. The proposed antenna has a total area of 10 mm × 10 mm and a height of 0.4 mm, and is designed by using a thin and biocompatible FR4 epoxy ($\varepsilon_r$ = 4.4) substrate to accomplish human body isolation and great flexibility obtained by implantation. This wideband antenna covers a large bandwidth of industrial scientific and medical (ISM) frequency band, including 902.8 MHz to 928 MHz, 1.395 GHz to 1.4 GHz, 1.427 GHz to 1.432 GHz, 2.4 GHz to 2.485 GHz, and above. The simulation results of return loss, voltage standing wave ratio (VSWR), impedance matching, gain, and radiation pattern of the proposed antenna are obtained through High Frequency Structure Simulator (HFSS) 14 software.

**Keywords:** biomedical application, dual-ring slot, ISM band, implantable antenna

## 1. Introduction

The application of antenna is as much as a vast antenna topic itself. Some of the applications include automobiles, flush-mounted applications, satellites, cars, aircrafts for biomedical purposes, etc. For biomedical purposes, the antenna is not only used as a device to take and pass body information, but is also used for monitoring, tracking, and for many other purposes. However, for the implantation of an antenna, the size of the antenna is one of the main issues introduced for antenna design. As for introducing an antenna inside the human body, the overall dimensions of the antenna must be tiny and flexible, showing a large bandwidth and a low specific absorption rate (SAR) value. Many of the research articles depict various issues in the field of antenna design technology to implement a small antenna for biomedical application.

In previous years, several multiband slot antennas have been proposed [1-5]. Das and Mitra [6] present a small, wideband, flexible, and implantable slot antenna design that provides high gain. To improve the antenna gain, their proposed metamaterial (MTM) array has a very high value of epsilon on the superstrate material of an antenna. The gain of that antenna has been enhanced by about 3dB using MTM. Bashir et al. [7] present a miniaturized wideband implantable antenna for biomedical application. This reported antenna contains the radiating element with rectangular and circular slots and a ground plane with a rectangular slot on it. The maximum gain achieved by this antenna is -12 dBi at 2.45 GHz. The study shows how the parameters such as bandwidth and gain of antenna are varied by positioning the designed antenna in different human body phantoms, e.g., skin, muscles, stomach, small intestine, large intestine, etc. Xu et al. [8] present an antenna with an open-end slot on the ground plane, which is dual band in nature and has resonance at 2.45 GHz in the Industrial Scientific and Medical

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(ISM) band and at 402 MHz in the medical implant communication system (MICS) band. The result shows a measured bandwidth of 52.6% at the lower band. For the upper band, the observed resonant frequency shifts to 2.47 GHz and a measured bandwidth of 4.4% is obtained for S11 < -10 dB. Nesasudha and Fairy [9] present a low-profile antenna design for biomedical applications in the frequency range of 2.65 to 3 GHz. This antenna is evident with three distinct layers of substrate materials, i.e., FR4 substrate, Bakelite substrate, and Roger substrate (RO3010). Among the three substrates, the FR4 possesses a return loss of -32.6 dB which is the best result for the radiation of the antenna.

Guo and Liu [10] present a single-fed miniaturized circularly polarized microstrip patch antenna. The influence of different body phantoms is presented to calculate the sensitivity of the designed antenna. The simulated value of impedance bandwidth of the reported antenna covering from 2.36 to 2.55 GHz is 7.74%. Xiao and Li [11] propose an antenna design for an implantable medical device. A miniature semi-circular implantable planar inverted-F antenna (PIFA) is designed and proposed in this work. There are three arc-shaped slots that are embedded in a semi-circular patch due to which the proposed antenna achieves reduction in size. Chauhan et al. [12] present radio frequency (RF)-linked implantable medical devices. The antenna presented in [13] is implemented to work in the ISM band (2.4-2.4835 GHz). The antenna is inserted within a silicon layer and fed by a whole strip line. The result shows the thin dimension of the antenna, which allows the antenna to flex along the curvature of the body without high performance loss, having a higher bandwidth and a good return loss. Yang and Xiao [14] present a wideband single-fed implantable antenna for the application of ISM biomedical at 2.4 GHz. The simulated result of the S11 bandwidth is below -10 dB ranging from 2.24 to 2.59 GHz (35%). For the low mode, the maximum of the realized gain -20.8 dBi at boresight is obtained. Yang et al. [15] present a design to develop an implantable circularly polarized microstrip patch antenna embedded in a lossy material by addressing its total quality factor. Liu et al. [16] design and verify a single-fed miniaturized wide-beamwidth circularly polarized implantable antenna operating in the ISM band, for subcutaneous real-time glucose monitoring applications. Xia et al. [17] and Gani et al. [18] present two antenna systems that operate on multi bands, including the MICS band and the ISM band.

In this study, two triangular rings with equal spacing are designed with the co-planar waveguide (CPW) feeding technique. At the operating frequency of 2.45 GHz, S11 is less than -10 dB that shows its proper nature for implantation. The proposed design is a low-profile antenna, which shows a wideband from 0.78 GHz to 5 GHz including 902.8 MHz to 928 MHz, 1.395 GHz to 1.4 GHz, 1.427 GHz to 1.432 GHz, and 2.4 GHz to 2.485 GHz. It covers the ISM band and demonstrates a wide range of applications.

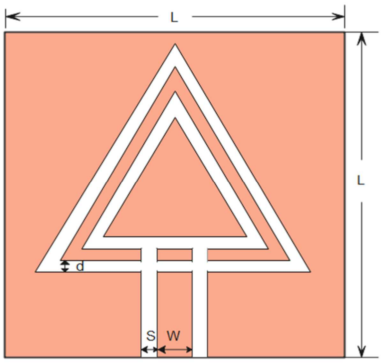
## 2. Design Configuration

The proposed antenna design consists of two concentric triangular ring slots of the equal width d with CPW fed. The design is fabricated on 10 mm × 10 mm FR4 epoxy substrate with a dielectric constant 4.4 and a height of 0.4 mm. Therefore, the overall dimension of the antenna is $10 \times 10 \times 0.4$ mm$^3$. Although a different type of feeding technique is available, in the proposed antenna, the CPW fed with 50 Ω matching is used by using appropriate ground plane spacing (S) and trace width (W). Fig. 1(a) shows the top view of the designed antenna, where d is the spacing between the triangular rings, S is ground plane spacing, and W is tracing width. Their values are presented in Table 1.

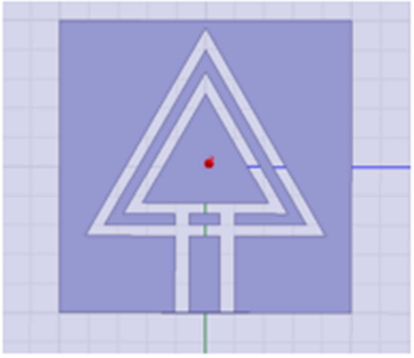
For the design and simulation of the proposed antenna, High Frequency Structure Simulator (HFSS) software [19] is used in this study. HFSS is a three-dimensional electromagnetic software for designing and simulating high frequency antennas, and is commonly used for antenna design and for the design of complex RF electronic circuits.

Table 1 Design parameter of implantable slot antenna

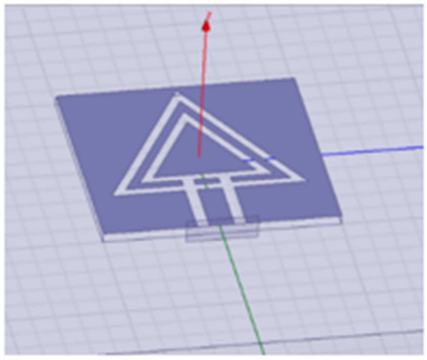
| Parameter | S | L | d | h | W | a | b |
|---|---|---|---|---|---|---|---|
| Value (mm) | 0.5 | 10 | 0.75 | 0.4 | 1.05 | 60 | 40 |




(a) Top view of antenna



(b) Antenna design in HFSS software



(c) Antenna design in HFSS software (continued)

Fig. 1 Antenna configuration

## 3. Antenna Performance

In biomedical applications, the designed implantable antenna should be situated in a body-like model. For this purpose, skin, fat, muscle, etc., have been used. The proposed antenna is simulated inside the muscle box having a relative permittivity of 52.79 and bulk conductivity of 1.705 as shown in Fig. 2. To achieve the radiation characteristics of the proposed antenna, the total height of the muscle box is taken 10 mm whereas the radiation box is taken 20 mm. The value of a and b is given in Table 1.

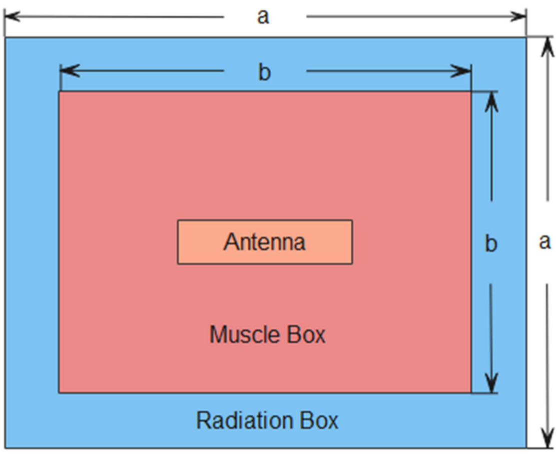



Fig. 2 Antenna placement in muscle box and radiation box

### *3.1. Return loss and input impedance*

The proposed dual concentric triangular slot antenna is simulated inside the muscle model. The simulated result for return loss characteristics is illustrated in Fig. 3.

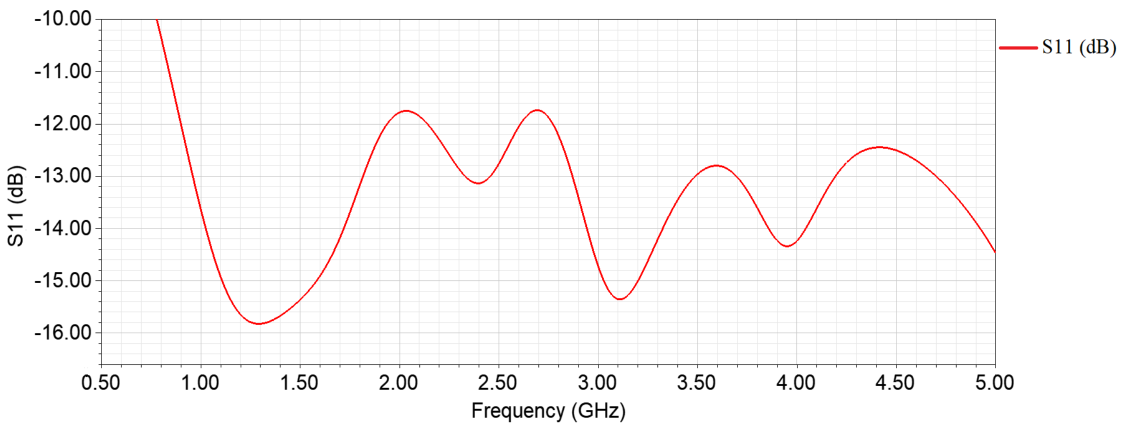



Fig. 3 S11 parameter of antenna

The S11 characteristics of the proposed antenna represent the amount of power reflected from the antenna, so the S11 parameter is known as the reflection coefficient or return loss of the antenna. Therefore, according to power radiation, if S11 is 0 dB, it means 100% reflection. In other words, if no power is into the antenna, all power gets reflected. On the other hand, if S11 is less than -10 dB, it means 90% of available power is already delivered to the antenna and 10% gets reflected back which is the best result for an antenna. Fig. 3 shows the values from 0.78 GHz to 5 GHz under -10 dB, representing that at least 90% input power is delivered to the device and the reflected power is less than 10%, which is sufficient for many applications. The simulated S11 results show that the proposed antenna covers many ISM band frequencies which include 902.8 MHz to 928 MHz, 1.395 GHz to 1.4 GHz, 1.427 GHz to 1.432 GHz, 2.4 GHz to 2.485 GHz, and above. It is useful for many wireless applications. Due to the radiating triangular slot patch at the top of the antenna, the ground is assumed like an effective magnetic current. The image current with respect to the ground assumed as a perfect electric conductor has the same magnitude and phase. Fig. 4 illustrates the input impedance characteristics for the proposed antenna at the desired band.

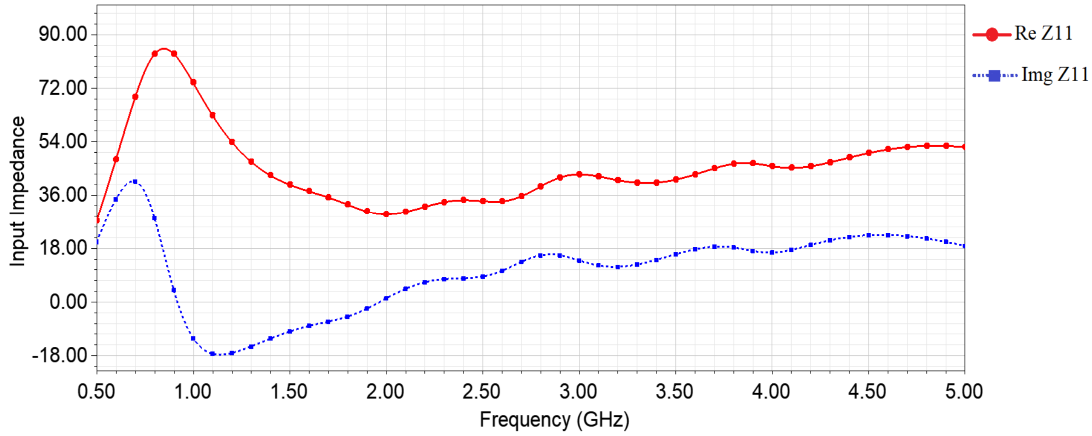



Fig. 4 Input impedance characteristics of antenna

### *3.2. Voltage standing wave ratio*

The voltage standing wave ratio (VSWR) describes the amount of mismatch between the proposed antenna and its feed line connected to it. The value of VSWR is in the range of 1 to infinity. VSWR is 1 when return loss is infinity. Fig. 5 illustrates the value of VSWR between 2.5 dB to 5 dB of the proposed antenna.

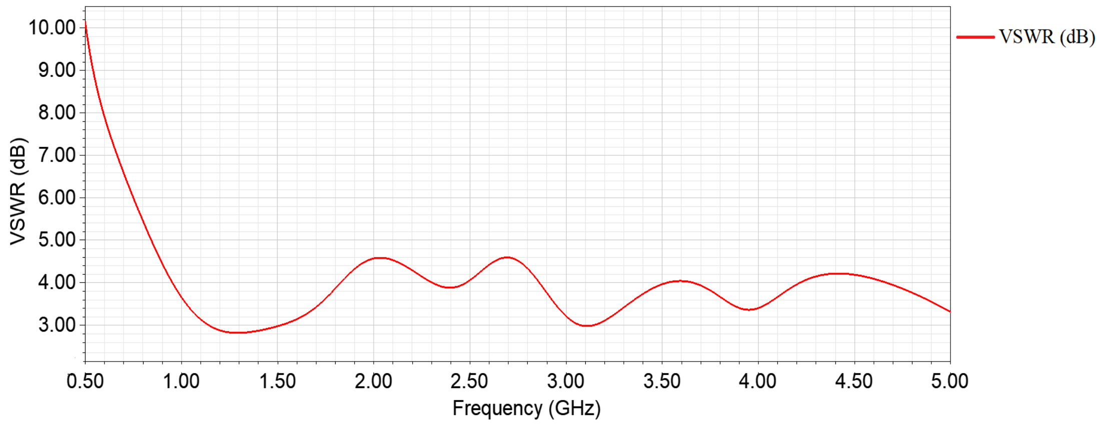



Fig. 5 Voltage standing wave ratio

### *3.3. Radiation pattern*

The three-dimensional radiation pattern describes the strength of radiation emitted in a particular direction as well as the gain of an antenna in terms of electric and magnetic fields. The distance of radiations from the origin represents the strength of radiation emitted in that direction. Fig. 6 shows that the power transmitted along the z axis is maximum.

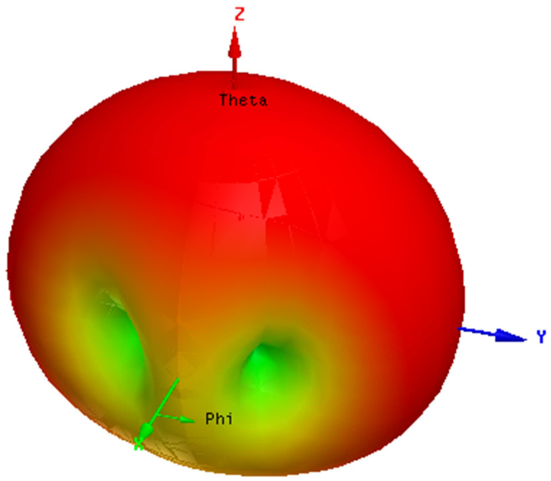
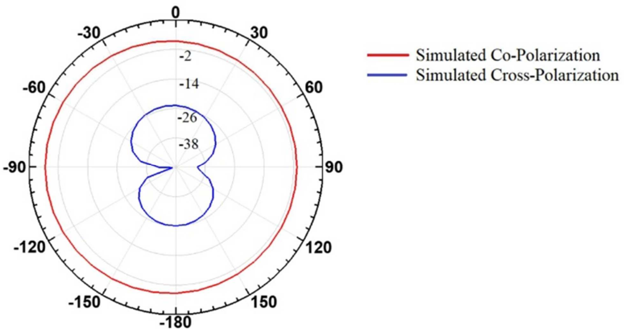
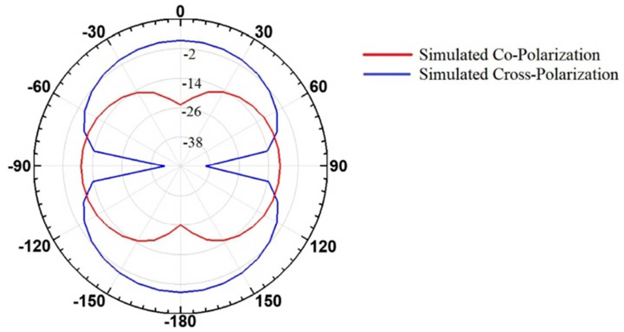



Fig. 6 3D radiation pattern of the proposed antenna

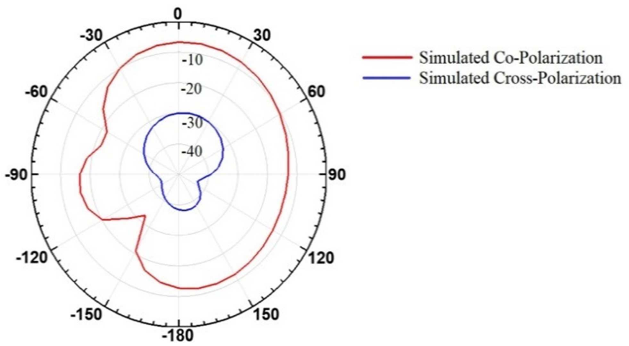
E-plane and H-plane are basically the principal planes for the propagation of waves or radiation fields, where the E-plane shows the plane containing the electric field and H-plane shows the plane containing a magnetic field. Co-polarization means that the polarization of the transmitting and receiving antenna is the same, and cross polarization means that the polarization of the transmitting and receiving antenna is different. The proposed antenna has been simulated at 0.915 GHz and 2.45 GHz. Fig. 7(a) represents the x-z plane graph and Fig. 7(b) represents the y-z plane graph at 0.915 GHz. Similarly, Fig. 7(c) represents the x-z plane graph and Fig. 7(d) represents the y-z plane graph at 2.45 GHz.



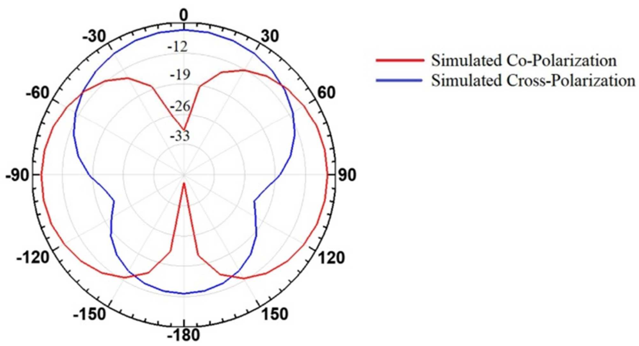

(a) The x-z plane at 0.915 GHz




(b) The y-z plane at 0.915 GHz




(c) The x-z plane at 2.45GHz

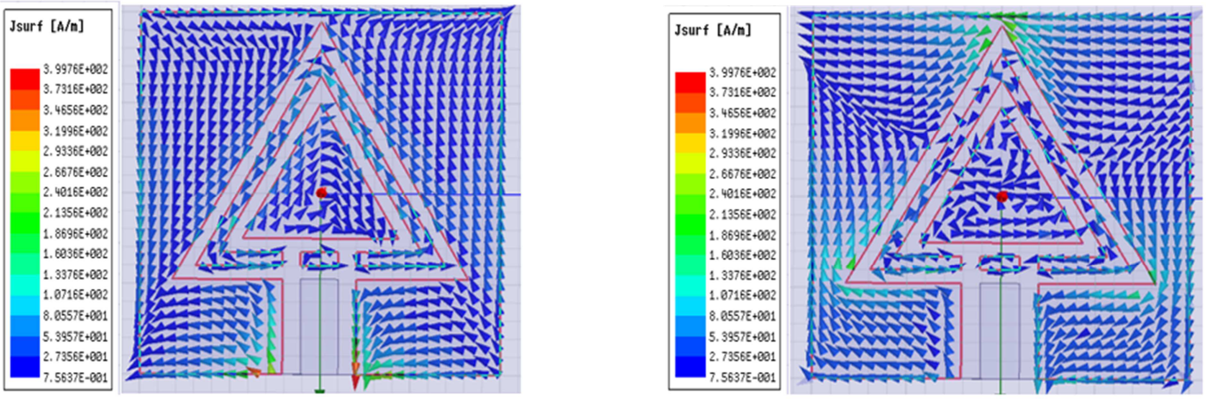



(d) The y-z plane at 2.45GHz

Fig. 7 Radiation pattern of the antenna

### *3.4. The simulated surface current distribution*

To accomplish an effective operation of the proposed antenna, it is required to cover most of the impedance bandwidth by axial ratio bandwidth of the antenna. To introduce the current distribution perturbation on the surface of the proposed antenna, dual triangular shaped slots are cut into the ground with CPW feed line. Fig. 8 illustrates the simulated surface current distribution at 2.45 GHz for time phase 0˚ and 90˚. As a result, an improved current distribution is obtained within the operating band.




(a) Phase angle 0˚ (b) Phase angle 90˚

Fig. 8 The simulated surface current distribution at 2.45 GHz

*3.5. Antenna gain*

The simulated value of gain for the proposed antenna with respect to its desired frequency is plotted in Fig. 9. The frequency is in the range of 0.78 GHz to 5GHz. The maximum simulated gain is observed -17.0411 dB at 0.92 GHz and -14.572 dB at 4.02 GHz. The noticeable radiation characteristics with acceptable gains for desired bands and a wideband including ISM band are achieved with a small size compared to other implantable antennas. This proposed antenna is compared with different designs of the implantable antennas in Table 2.

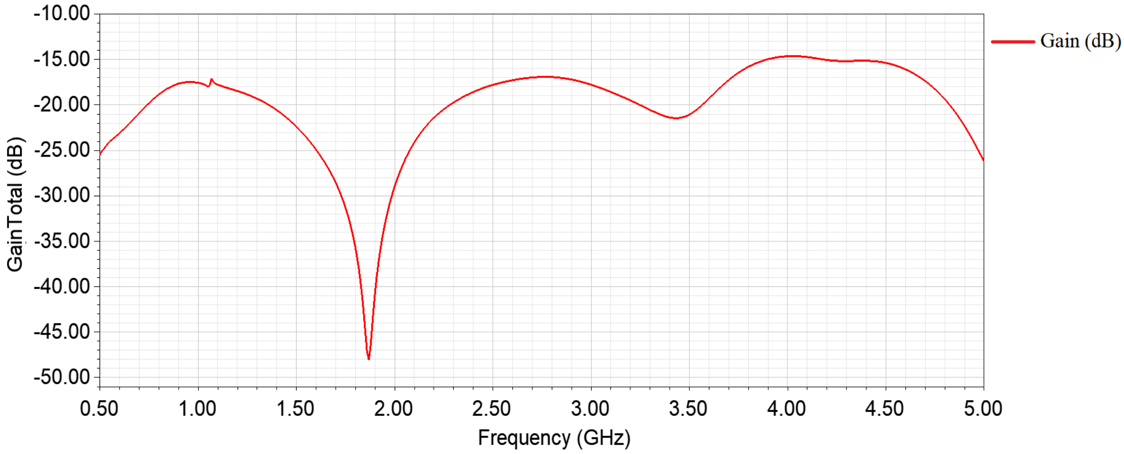



Fig. 9 Gain vs. frequency

Table 2 Performance comparison with different implantable antennas

| Ref. | Frequency (GHz) | Bandwidth (MHz) | Gain (dBi) | Dielectric material | Antenna shape | Volume ($mm^3$) |
|---|---|---|---|---|---|---|
| [7] | 2.45 | 483 | -12 | Rogers Ultralam | Circular | 9.8 |
| [15] | 2.45 | 73 | -20.47 | Rogers RT/duroid 6010 | Zig zag | 21 |
| [16] | 2.45 | 300 | -17 | Rogers 3210 | Circular | 91.75 |
| [17] | 2.45 | 246 | -21.2 | Rogers RT/duroid 6010 | Spiral | 31.5 |
| [18] | 2.45 | 105 | -22.3 | Rogers RT/duroid 6010 | Zig zag | 52.5 |
| The proposed work | 2.45 | 4220 | -14.6 | FR4 epoxy | Triangular | 40 |

## 4. Conclusions

The proposed work presents a CPW fed slot antenna and its design procedure, which is suitable for biomedical applications at a very low cost. This antenna is characterized by its small size, wideband, and single feeding property. The proposed antenna has appreciable gain and good radiation pattern characteristics over a large impedance bandwidth which covers a wide range from 0.8 GHz to 5 GHz and above. This antenna is for biomedical purpose as it covers the ISM band range, including 902.8 MHz to 928 MHz, 1.395 GHz to 1.4 GHz, 1.427 GHz to 1.432 GHz, and 2.4 GHz to 2.485 GHz. The maximum gain of the antenna is -17.0411dB at 0.92 GHz and -14.572dB at 4.02 GHz.

## Conflicts of Interest

The authors declare no conflict of interest.

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