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Design of Miniaturized Printed Spiral Monopole Antenna

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ABSTRACT

This paper introduces the design, simulation and implementation of miniaturized printed monopole antenna for medical application. FR-4 substrate with dielectric constant 4.3, and thickness 0.8 mm has been used. The proposed antenna operates in Medical Implant Communication System (MICS) band. It has a spiral shape with an overall dimension of (9x9x0.8) mm3. The proposed antenna was simulated and evaluated using CST microwave studio package. The simulation results show that the designed antenna operates at a frequency of 401.3MHz with return loss of (-10.904dB) and band width (3.9 MHz). The proposed antenna structure was fabricated and experimentally tested. Results of simulation and implementation show that the proposed antenna possesses a miniaturized dimensions and acceptable performances, enabling their use in medical applications.

1. Introduction

The development of health care is due to the prosperity of Wireless Body Area Networks (WBAN), and this development in turn provides ubiquitous health monitoring by virtue of wearable or implantable sensor nodes that commonly monitor biological signals. Medical applications are of great importance today as they provide continuous monitoring of the patient with the help of sensor nodes that can be warbled or implanted [1].

Many frequencies have been developed for the purpose of exploring and marketing communication systems(WBAN) such as Scientific and Medical (ISM) band(433MHz,915MHz,2.4GHz,…etc) Ultra-wideband (UWB) 3.1-10.76GHz, the Medical Implant Communication Services (MICS) band (402-405)MHz, and others [2-4].

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The antennas are the most important part of these systems that must have special characteristics in order to capture the electromagnetic waves, these characteristics or features involve Omni-directional radiation, moderate gain, high radiation efficiency, and ultra-wide bandwidth.

Omni-directional radiation lets the antenna to accept electromagnetic waves from all directions, which is active parameter in the monitoring system. Moderate gain and high radiation efficiency are necessary for the receiving of high-quality signals that help the accurate detections of the electromagnetic waves. Ultra wide bandwidth antennas help the system to monitor a large range of the spectrum with minimum equipment by using fewer antennas leading to less complex portable stations that are capable of monitoring the usage of a large range of the spectrum.

Antennas in medical devices (wearable and implantable) Characterized by its small size, therefore designer must be focus on how to miniaturize it with maintaining its good performance.

There are several methods used to reduce the antenna size, and each method has advantages and disadvantages, which we will obtain at later chapter. However, the antenna design is very challenging due to several constraints; the antenna should be small enough to be inserted into the human body and have broadband characteristics to operate in the various tissue layers. Occasionally, the antenna may be required for multiband operation. One of the most space-taking antennas in the design of the implantable antenna is the, planar patch where it took great care due to the ease of design, conformity, and flat shape that makes it suitable for most implanted and wearable devices [5-7].

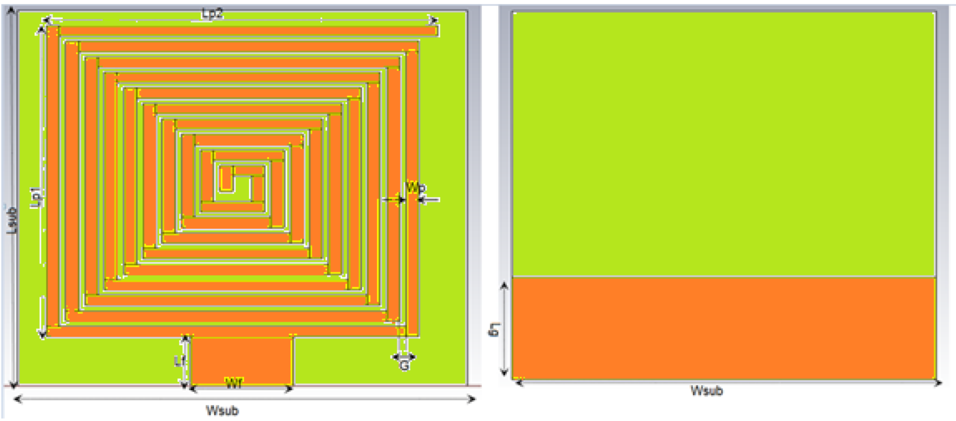
In 2008, Karacolak et al. [8] proposed small size implantable meander line antenna for continuous glucose-monitoring needs, antenna dimension are (22.5×22.5× 2.5 mm^3) operating in dual band frequency MICS (402–405 MHz) and ISM (2.4–2.48 GHz) bands. In 2011, Huang et al. [9] proposed an antenna design operating on three bands (MICS) band at 402 MHz, and (ISM) band at 433 MHz and 2.45 GHz) antenna has a small size of (10 mm × 10 mm × 2.54 mm^3). In 2013, Alrawashdeh, et al. [10] introduced a flexible meandered loop antenna covered the (MedRadio) and (ISM 433–434 MHz), with dimensions of (180 × 100 × 50) mm^3. In 2013 SONDAS et al. [11] introduce an implantable microstrip antenna operating in MICS (402−405 MHz) band for biomedical telemetry applications. In 2015, Muhammad, et al. [12] proposed the Design of Miniaturized Implantable Antenna operating in dual band (MICS,403MHz) and (ISM,2,45GHz) Bands with overall dimension of the purpose antenna are (15 × 18 × 1.97) mm^3. In 2018 Kumar, et al. [13] introduce the design of CPW-fed monopole antenna for diagnosis applications covers almost all bands used in (WBAN) applications ,such as (ISM, 2.4–2.485 GHz) ,(MICS,402_405MHz) and (WMTS, 420–1430MHz) with dimensions of (24 × 18 × 1.6 mm^3). In 2019 KETAVATH, et al. [14] introduced monopole rectangular implanted antenna with three (SSR) and a rectangular slot with CPW feeding operating at ISM band (2.45GHz) with dimensions of (24 × 22 × 0.07)mm^3. In 2019 Li , et al. [15] introduce the design of Miniature patch implanted antenna operates on frequency (MedRadio) band (401–406 MHz) with dimensions of (23 × 16.4 × 1.27) mm^3. In 2020 SMIDA, et al. [16] introduced a Wideband Wearable Antenna of rectangular shape with modified patch and ground. The antenna operates at frequency 2.4 GHz with dimensions of (17× 25×0.787 mm^3).

Most of the antennas proposed in literature have large dimension and complex shape. Therefore, the main purpose of this study is to reduce the size of antenna as much as possible at suitable operating frequency band.

2. ANTENNA DESIGN

2.1. Primary Antenna Structure

The Printed Spiral Monopole Antenna (PSMA) was used as primary antenna structure consists of spiral patch with space between each slot (0.11mm), while the ground is rectangular shape with dimensions (W_{sub} × L_g), and feed line dimension is (L_f × W_f) printed on FR-4 substrate with a dielectric constant of (ε_r=4.3), and a thickness of (0.8 mm). The dimensions of the radiator were chosen using the parametric study to achieve lower resonance frequency around (MICS, 405MHz). The geometry of the antenna is illustrated in Figure -1and the dimensions in Table1.



front view

Back view

Figure -1: primary design of printed spiral monopole antenna.

Table -1: Dimensions of primary design of PSMA.

Dimension	Description	Value (mm)
Lsub	The length of the substrate	7
Wsub	The width of the substrate	7.25
h	Thickness of substrate	0.8
t	Thickness of patch	0.035
Lg	Length of ground plane	2
Lf	Length of the feed line	0.95
Wf	The width of the feed line	1.6
Lp1	Length of patch slot	6
G	Width of gap between slot	0.2
Lp2	Length of patch slot	6.1

The return loss response of primary design shown in Figure -2 illustrate that the antenna operate on single band (576 MHz) with return loss around -10 dB. The operating frequency of this structure is far from the required, so that some changes were applied in order to obtain the required results.

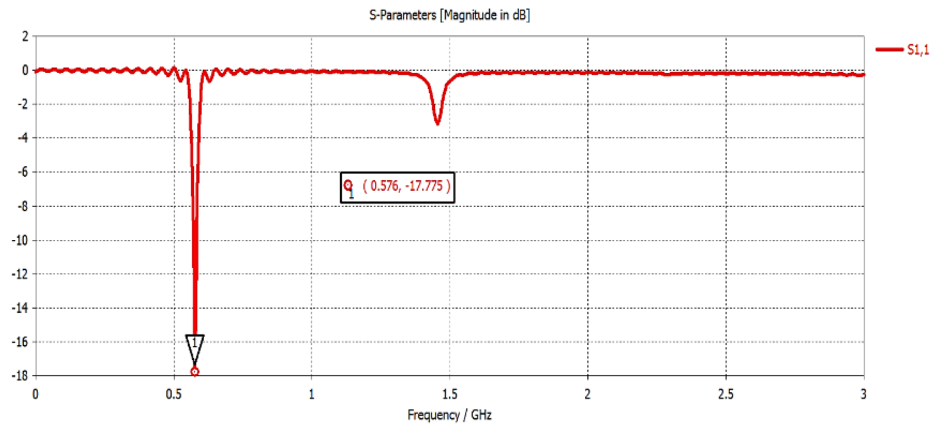


Figure -2: primary antennas return loss.

2.2. Proposed Antenna Structure.

There are several modifications that are made to the antenna, such as ground plane, overall dimension, and radioactive patch in order to obtain the required results and the required performance.

The final geometry of the proposed antenna geometry and dimensions are shown in Figure 3 and Table -2 respectively.

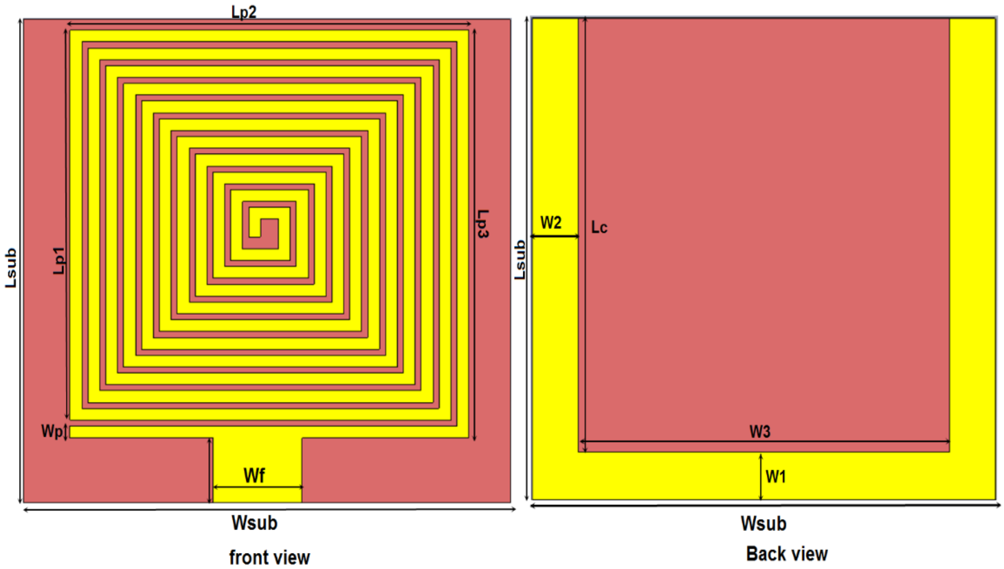


Figure -3: Final geometry of the proposed PSMA.

Table -2: Dimensions of the proposed PSMA.

Dimension	Description	Value (mm)
Lsub	The length of the substrate	9
Wsub	The width of the substrate	9
H	Thickness of substrate	0.8
T	Thickness of patch	0.035
Lf	Length of the feed line	1.21
Wf	The width of the feed line	1.65
S	Width of gap between slot	0.11

WP	Width of patch slot	0.22
Lp1	Length of left outer patch slot	7.26
Lp2	Length of top outer patch slot	7.37
Lp3	Length of right outer patch slot	7.59
W1	Width of lower ground slot	0.9
W2	Width of left ground slot	0.9
W3	Width of cutting ground	7.2
Lc	Length of cutting ground	8.1

Table -2 shows the optimum dimension of proposed antenna. This antenna operates on (MICS) band. The overall dimensions of the antenna are (9×9×0.8) mm^3.

2.3. Simulation Result

Figure -4, shows the return loss of the optimum dimension of proposed antenna. The proposed antenna operating in MICS band (405MHz) with return loss less than -10dB (-10.904) with band width of 3.9MHz which is an acceptable result.

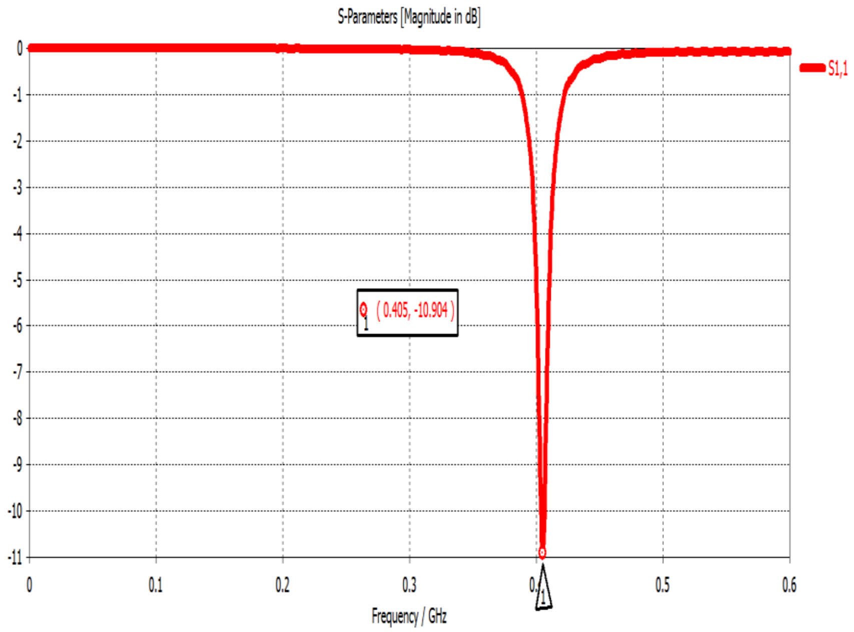
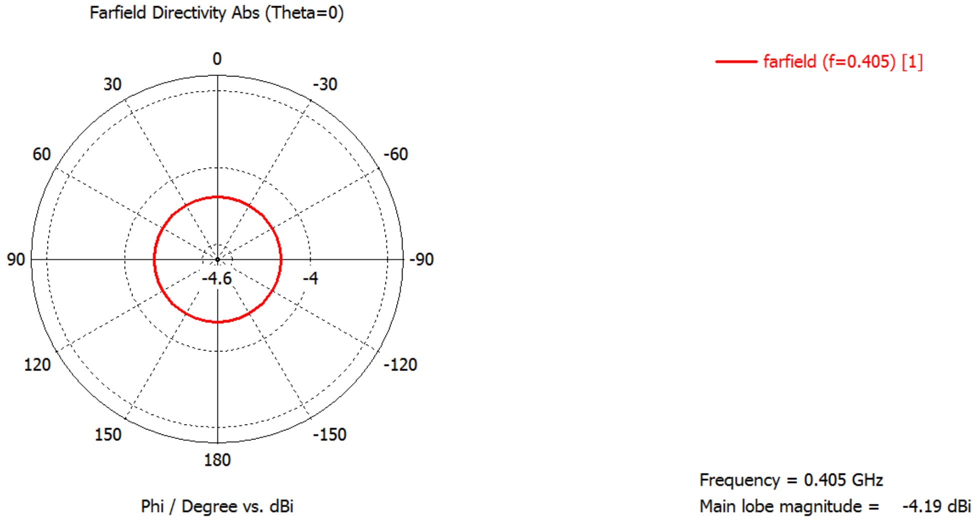


Figure -4: return losses after modifies radiator patch and ground.



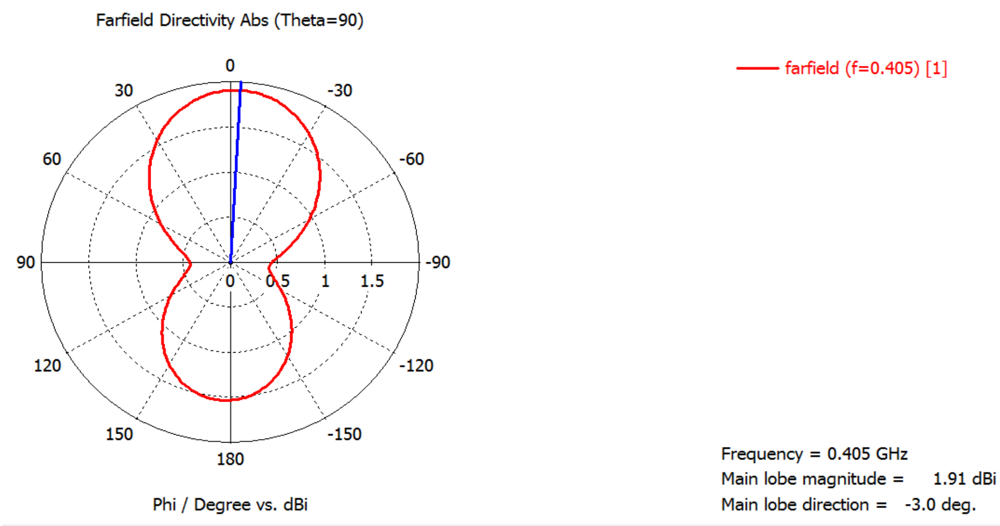


Figure -5: 2-D radiation pattern of the far field directivity for the proposed PSMA (Phi, theta = 90).

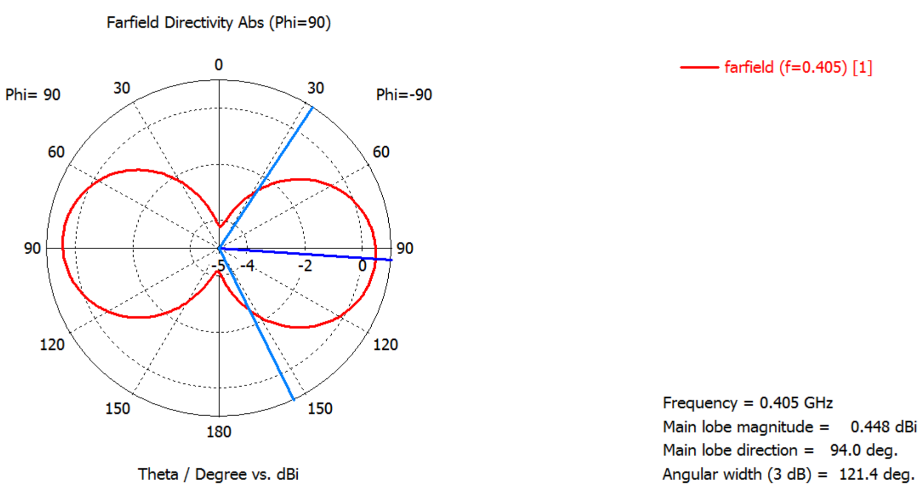


Figure -6: 2-Dradiation pattern of the far field directivity for the proposed PSMA (Phi, theta = 0).

The 3-D radiation pattern of the far field directivity and the surface current distribution for the suggested PSMA are illustrated in Figures 7 and 8 respectively.

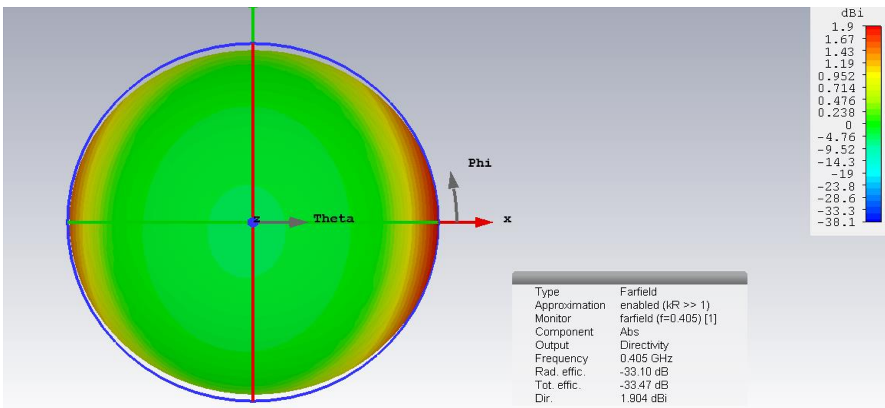


Figure -7: 3-D pattern of the far field directivity for the proposed PSMA.

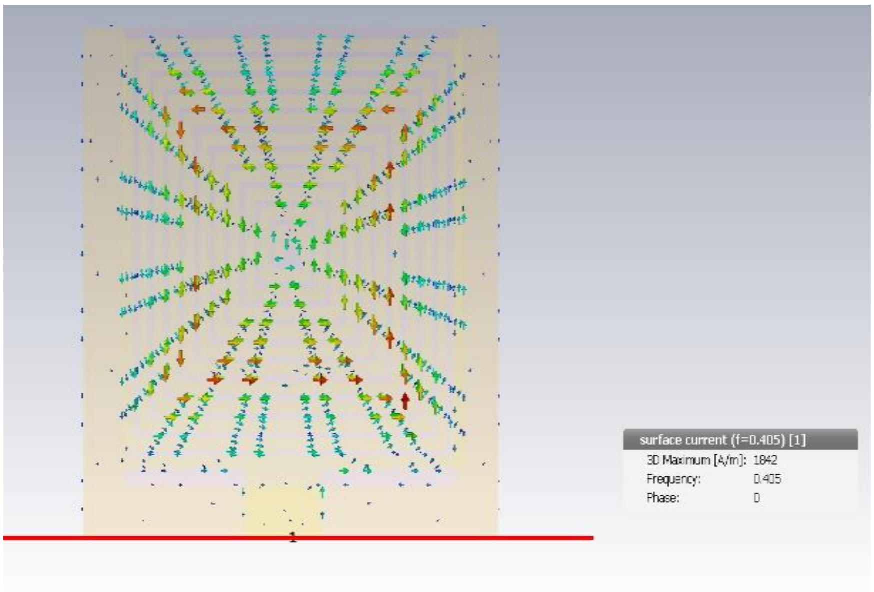


Figure -8: The surface currents for the fundamental frequency and the higher order harmonics of the proposed PSMA.

3.MEASUREMENT RESULT

The PSMA design shown in Figure -3 with the dimensions in Table -2 was fabricated using FR4 substrate of 0.8 mm thickness as shown in Figure -9.

The measurement results of the tested prototype show that the antennas resonate at (401.3MHz) with return loss of (-11.838dB) as shown in Figure -10. There is an acceptable slight difference between the simulation and practical results due to the manufacturing process.

Figure -9: Fabricated PSMA.

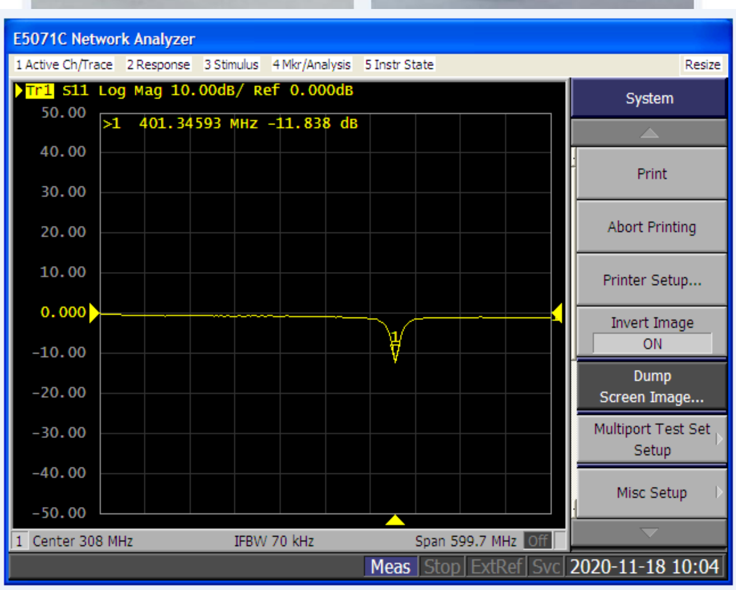
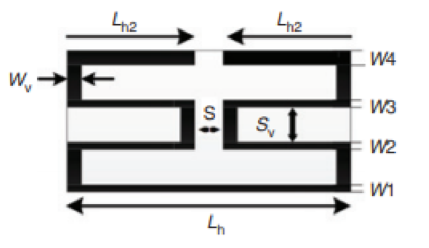
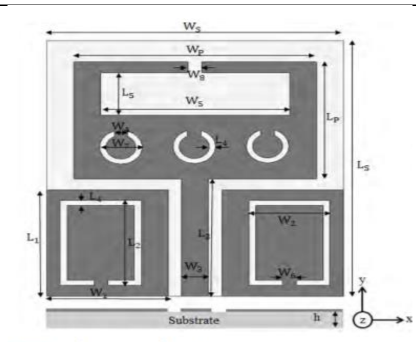


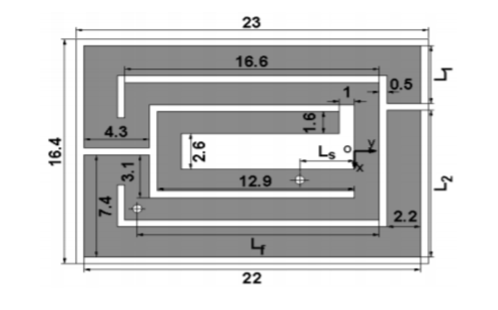
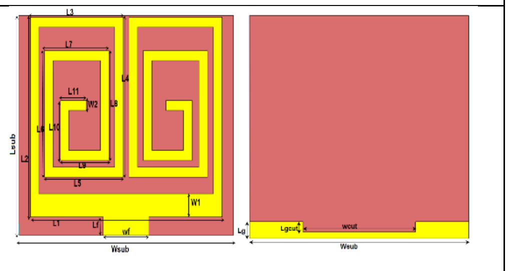
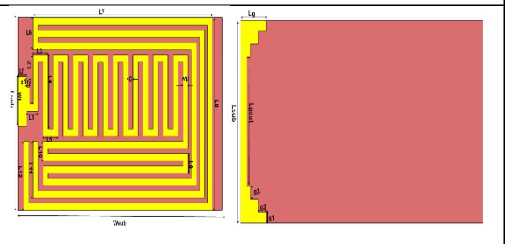
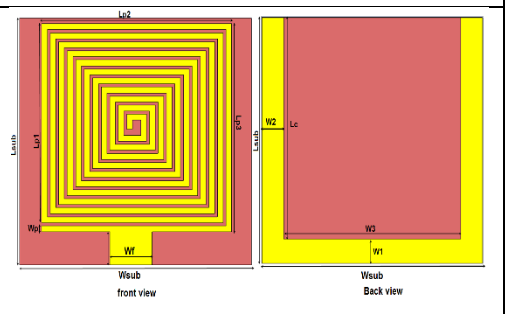
Figure -10: results of the fabricated PSMA.

4. COMPARISON WITH OTHER WORKS

Many antennas have been designed for medical applications. These antennas differ from each other in terms of size, shape, and frequency band and bandwidth. Table - 3 will provide a comparison between these antennas and the antennas designed in this work.

Table - 3 Comparison between the designed antenna and other works

Ref.	Freq. & BW	size	S11	gain	Figure
[10]	433–434 MHz	(180 × 100 × 50) mm^3	-28 dB	-28.4 dB	
[14]	2.4GHz BW = 400 MHz	24 x 22 mm^2	-27.5 dB	-19.6	

[15]	401–406 MHz BW = 52 MHz	(23 × 16.4 × 1.27) mm^3	-25 dB	−34.9 dB	
[17]	2.406GHz BW = 44.021 MHz	7.5×6.6× 0.8 mm^3	-14.7 dB	-13.92 dB	
[18]	915MHz BW = 20.377 MHz	12.25×7.81× 0.8 mm^3	-11.71 dB	-18.1dB	
In this work	405 MHz BW = 3.9 MHz	9×9×0.8 mm^3	-10.9 dB	-31.21 dB	

The comparison shows that the proposed antenna has the minimum size compared with others in the lower band (405 MHz), where the size is an important parameter.

5. **Conclusions**

A miniaturized printed monopole antenna has been proposed in this paper. This antenna operates at the Medical Implant Communication System (MICS) band (401.3MHz) and bandwidth (3.9 MHz) with dimensions (9×9×0.8) mm^3. Due to the small size, light weight, simple configuration and acceptable performance of the proposed antenna can be used for medical applications in either in wearable or implantable medical applications.

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