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Study and Design of C-Shaped Slotted Patch Antenna

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***Abstract**: This work presents the performance of a Dual-band patch antenna with C-shaped slot for biomedical applications. The antenna works at 2.1 GHz and 2.4 GHz. A substrate material which is "FR-4(lossy) with a relative dielectric constant, Ɛr of 4.3, loss tangent, tan δ of 0.025 and thickness, hs of 1.524 mm has been proposed. The size of the antenna is 130 x 80 mm². The slots in the rectangular radiating patch were introduced to produce the resonant frequencies of 2.1GHz and 2.4GHz. The simulations of the microstrip patch antenna shows the reflection coefficient, S11 of -12.2dB and -41.22 dB at 2.1 GHz and 2.4 GHz respectively. The proposed antenna shows a peak gain of 0.62 dB at 2.4 GHz. The results were obtained using CST studio.*
***Keywords**: Microstrip patch Antenna, slotted patch, Wide band.*

I. Introduction

Over the last few decades, wireless communication has really taken off and become a vital part of our everyday lives. As the demand for faster data rates and more efficient communication systems continues to grow, developing antennas that can work across multiple frequency bands while remaining compact has become increasingly crucial. Generally, patch antennas are simple and compact, making them popular in a variety of applications, including wireless communication systems. A patch antenna designed to operate at 2.4 GHz finds extensive utility owing to its placement within the globally allocated Industrial, Scientific, and Medical (ISM) band, which supports a wide range of unlicensed wireless communication systems. It is predominantly employed in wireless local area networks (WLANs) such as Wi-Fi (IEEE 802.11b/g/n), Bluetooth-enabled devices, and ZigBee-based Internet of Things (IoT) applications, thereby facilitating seamless connectivity across consumer electronics, smart homes, and industrial automation. In addition, the antenna is utilized in radio-frequency identification (RFID) systems operating around 2.45 GHz, enabling efficient asset tracking and logistics management. Owing to its low profile, ease of fabrication, and planar geometry, the 2.4 GHz patch antenna is also incorporated in portable medical telemetry systems, unmanned aerial vehicles (UAVs), and wireless sensor networks, where compactness and reliability are critical. Consequently, the 2.4 GHz patch antenna has emerged as a key component in advancing modern wireless communication and IoT infrastructures.

In this study we are trying to achieve an increment in gain value of the antenna by following different petameter study on patch of the antenna. In one case the we change the value of W3 that can be observed in parameter analysis and also we try to achieve that by also using partial ground mothed that are also given in parameter analysis.

II. Antenna design

2.1. Calculation method

The first design of our microstrip patch antenna is accomplished by following equations:

Width of patch (W)

$$w_p = \frac{C}{2f_r}\sqrt{\frac{2}{\varepsilon_r - 1}} \qquad (1)$$

Where,

- C is the Free space velocity of light.
- fr is the Resonant frequency for the current design.
- Ɛr is Dielectric constant of the substrate.

Effective dielectric constant(Ɛeff) is

$$\varepsilon_r = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+\frac{12h}{w}\right]^{-\frac{1}{2}} \quad (2)$$

Where, h is Thickness of the substrate

Length extension

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{\omega}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h}+0.8\right)} \quad (3)$$

Length of patch (Lp)

$$Lp = L_{eff} - 2\Delta L \quad (4)$$

Where,

$$L_{eff} = \frac{c}{2fr\sqrt{\varepsilon_{reff}}} \quad (5)$$

2.1 Design of the Microstrip Patch Antenna

The antenna is designed to operate at 2.4 GHz. The size of the antenna is 130 x 80mm². The substrate used is "FR4-(lossy)" with a relative dielectric constant, Ɛr of 4.3. with the thickness of hs with 1.524. The feed line technique is introduced to connect the patch to the 50Ω feeding line. W1 as middle feeder and W2 as end feeder and Lf are respectively the length and width of the feed line. The ground has been modified and the antenna was introduced partially grounded instead of full ground. The dimensions of partial ground plane are Lg=80 mm and Wg =87.1 mm.

A c-shaped and rectangular slots are inserted in the Patch plane. The slots embedded are illustrated in Fig. 1.

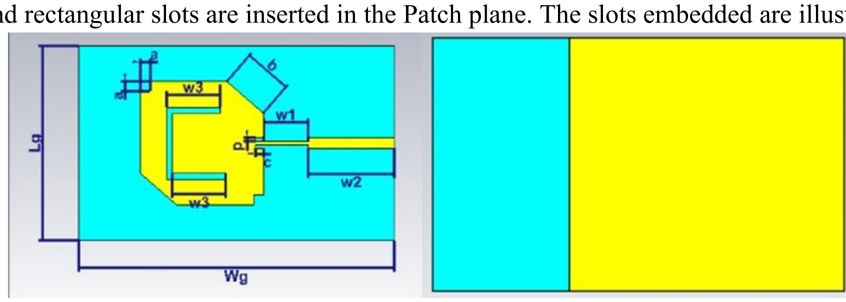


Figure. 1. Geometry of proposed Antenna Front view, Back view

The design dimensions of proposed antenna are listed in Table 1.

Parameters	Wg	Lg	Wp	Lp	W1	W2
Values (mm)	130	80	50.65	50.65	18.45	35.42
Parameters	W3	W4	a	b	c	d
Values (mm)	22	27	4.01	19.5	3	1.5

Table 1: Dimensions of the optimized antenna parameters

2.2 Development of the Design

After the dimensions of the initial rectangular patch were finalized, the patch and the ground plane modification was per-formed to achieve an operating band with enhanced gain, good efficiency.

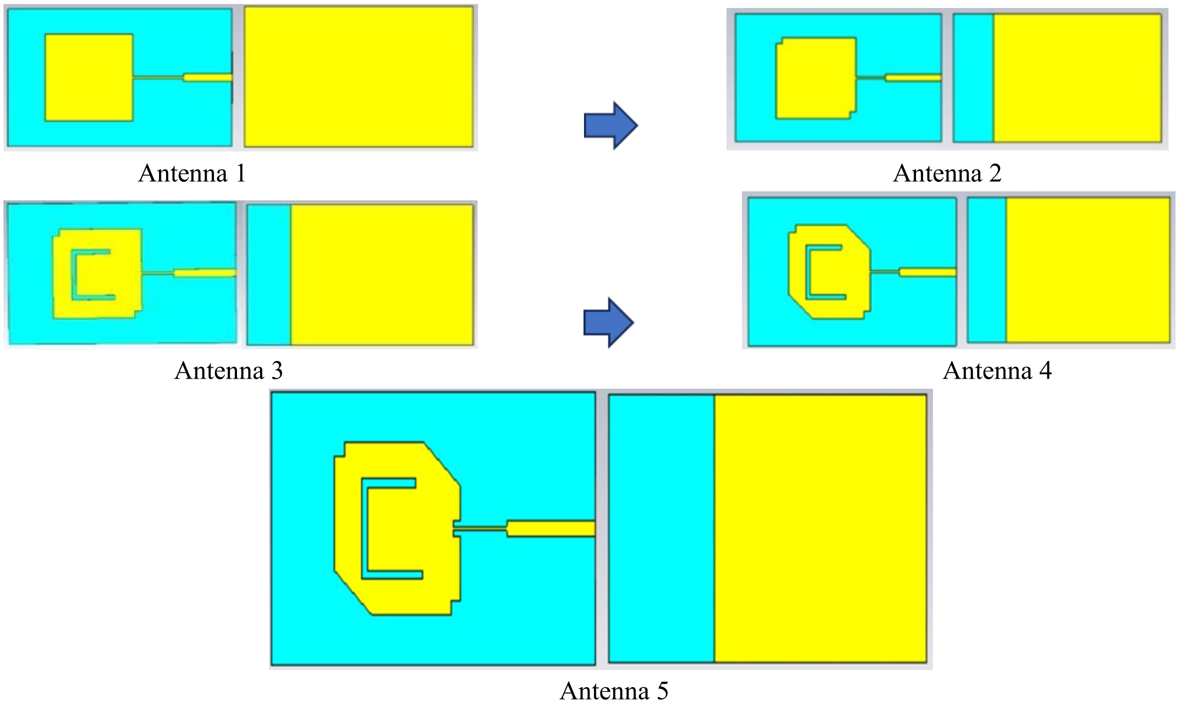


Figure. 2. Evolution process of patch antenna design

2.3 Parametric study

The simulated reflection coefficient (S11) for the different stages is shown in Fig. In the first stage the design of antenna we see the s11 resonates at near to 2.4Ghz but the gain value does not meet the requirement. As for the second stage the s11 value resonates at two frequencies.as for the second stage the gain value changes bit.

At third stage a c-shaped strip is added to the patch, to which the s11 value improver and the change in gain value, and at fourth stage the triangle shaped are modified at the corners of the patch as shown in figure. This results in the positive gain value at the resonant frequency.

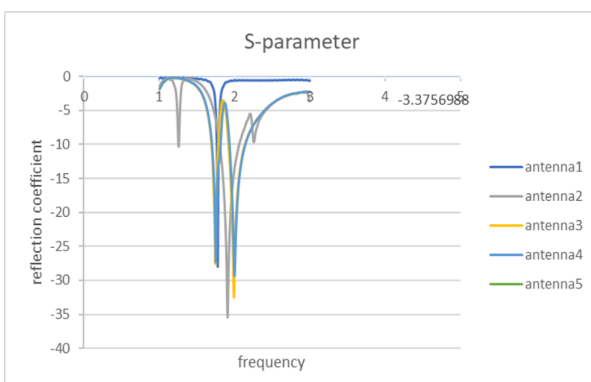


Figure. 3. Analyzed reflection coefficient at different stages

An improvement in S11 was observed at 2.4 GHz, duo to impedance matching technique by inserting two slots between the feed line and the patch, in addition to reducing the ground plane length. A new working band is observed at 2.1GHz and the antenna turned from a single-band patch antenna into a dual-band patch antenna at final stage.

a. Analysis of Parameter W3

A parametric analysis of various parameter W3 values was conducted to obtain appropriate impedance matching.

The simulated S11 is presented in Fig. 4, the parameter value was varied between 24 mm and 22 mm in decrements of 1 mm. The study revealed that the parameter W3 had an important influence on the antenna's performances, we obtained the best results with W3=22 mm.

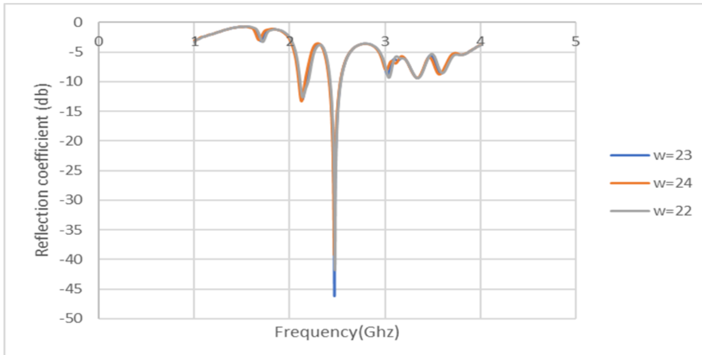


Figure. 4. Reflection coefficient with various W3 values

b. Analysis of Parameter G

The impact of the parameter G on antenna input impedance matching is shown in Fig. 5. The analysis was conducted with varying parameter G. The increase in the parameter G, ranging from full ground as G1 to partial which Wg-25 as G2 and G at 87 asG3 lead to a good impedance matching and this explains the preference of partial ground instead of full ground. The partial ground plane reduces the back radiation of the antenna and help to suppress surface waves that propagate on the ground plane. The best impedance matching is observed with G = 87.1 mm.

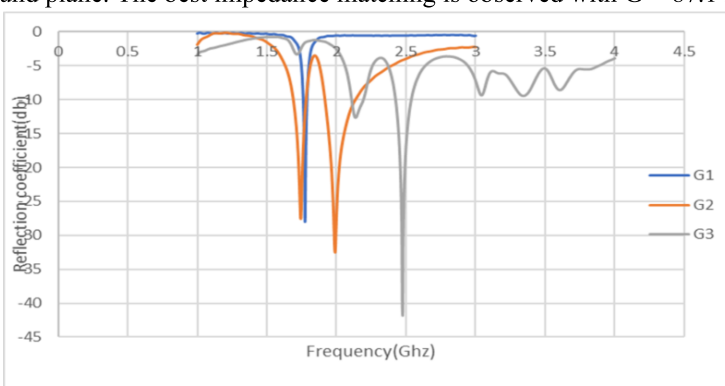


Figure.5: Reflection coefficient with various G values

III. Results

3.1. Return loss of proposed antenna

The Return loss of the proposed antenna is represented in the figure

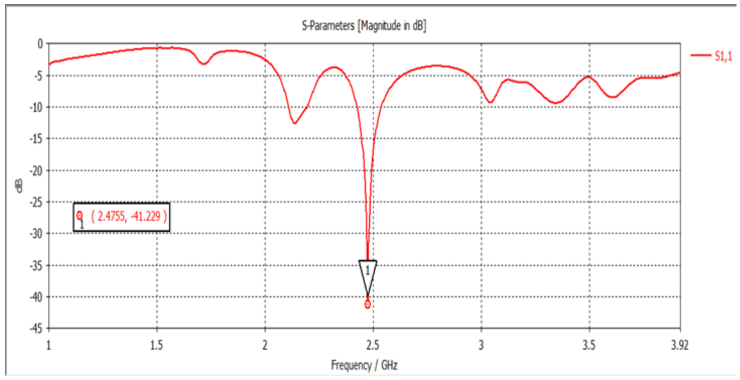


Figure.6: Analyzed reflection coefficient of proposed structure

The simulated reflection coefficient (S11) for the proposed antenna is shown in Fig.6, The first band appears with a return loss of -41.22 dB.

3.2. VSWR

The proposed antenna voltage standing wave ratio (VSWR) simulated curve is illustrated in Fig.7. The standard values of VSWR are less than 2 for the microstrip patch antenna operating bands. The achieved values of VSWR are 1.017 at 2.47 GHz.

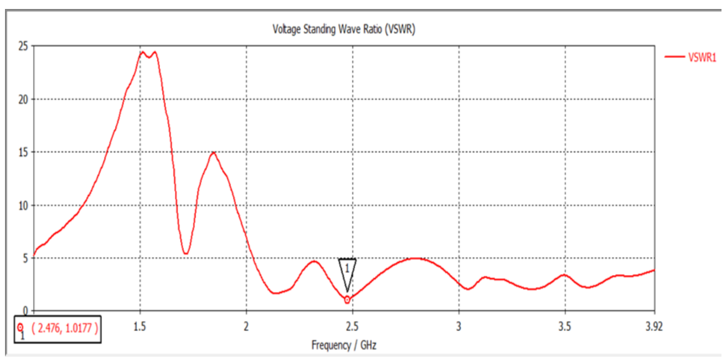
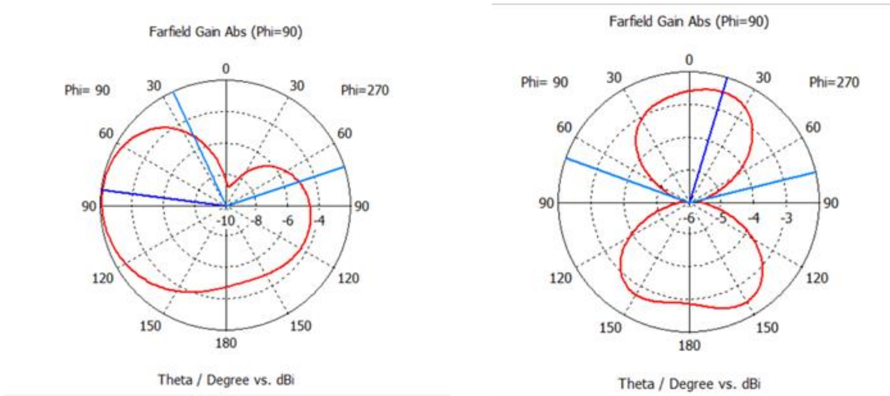


Figure.7. VSWR of proposed structure.

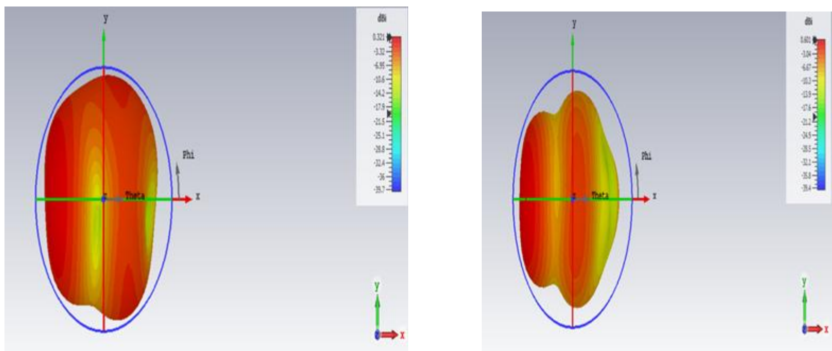
3.3. Radiation Pattern

The radiation patterns are revealed in Fig.8. The gains of proposed work are 0.321dB and 0.62 dB at 2.1 GHz and 2.4 GHz respectively. The 3D radiation patterns are shown in Fig. 9. Antenna gain relates the intensity of an antenna in a given direction to the intensity that would be produced by a hypothetical ideal antenna that radiates equally in all directions and has no losses.



(a) (b)

s



(a) (b)

Figure. 9. 3D Radiation Pattern of proposed structure (a) at 2.1 GHz, (b) at 2.4 GHz.

Table 2. gives the comparison of the proposed antenna with other antennas reported in the literature.

Ref.	Freq (GHz)	S11 (dB)	VSWR	Gain (dB)
[5]	2.41 / 5.8	-14.10 / -27.51	1.49 / 1.08	-
[9]	2.4 / 3.3	-31.67 / -20.25	1.16 / 1.08	5.01 / 4.87
[7]	1.875 / 2.4	- 31.6 / - 25.2	<2	5.8 / 4.08
[8]	3.9 / 5.7	-21.55 / -14.73	-	1.27 /1.35
This work	2.1/2.4	-12/-41.22	1.62/1.01	0.321/0.631

Table 2. Comparison of proposed antenna with the reported work in literature.

IV. Conclusion

This work proposes a patch antenna with a C-Shaped slot and partial ground, operate at 2.4GHz, dedicated for biomedical applications. The proposed antenna is a rectangular patch with a C-Shaped and rectangular slots on the patch. The substrate used is "FR-4(lossy)" with antenna dimension of 130 × 80 mm2. With a partial ground plane and slotted patch, the antenna showed a good reflection coefficient of -12.22dB and -41.22 dB at 2.1 GHz and 2.4GHz respectively. The C-shaped slot added on the patch produce two resonant modes with different resonant frequencies and it has been demonstrated that the partial ground improves clearly the antenna performances specifically the return loss.

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