JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. **17** No 3, 03021(4pp) (2025)

ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том **17** № 3, 03021(4cc) (2025)

OPEN ACCESS

REGULAR ARTICLE

A Circular CPW Fed Patch Antenna with an *L*-Shape and Two Semi-Circular Shaped Slots for L, Ku and K-Bands

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(Received 07 April 2025; revised manuscript received 20 June 2025; published online 27 June 2025)

This suggested circular patch antenna was developed with the help of CST studio, a numerical calculation performed based on the FDTD approach. Here, the proposed antenna contains three layers like copper material, which is used as a ground layer, FR-4 substrate is used as a substrate material and finally copper is used a patch layer, and the total size of the antenna is 21 × 21 mm^2.The proposed tri–band antenna is operating at three different frequency bands like 1-2.1 GHz (L-band), 13 – 13.4 (Ku–band), and 22.6 – 24.2 (5G mm–wave). The prescribed design possesses an L-shape and two semi-circular shaped slots on a polyimide substrate for L, Ku and K-bands. The suggested antenna has a peak gain of 8.6 dBi at 1.8 GHz, 7.2 dBi at 13.2 GHz, and 9.4 dBi at 23.3 GHz, the obtained radiation efficiencies are 84 %,76 % and 92 % at 1.8 GHz, 13.2 GHz and 23.3 GHz respectively. The proposed antenna possesses various advantages including triple bands, high gain and high radiation efficiency. This makes it an attractive option for devices that operate in the Sub-6 GHz, Ku-band, and millimeter-wave frequencies. Both E and H field distributions are validated to show the performance of the suggested antenna. Additionally, parametric analysis is also done to check the proposed antenna performance.

Keywords: Antenna, Dual-band, Gain, mm-wave, 5G.

DOI: 10.21272/jnep.17(3).03021 PACS number: 84.40.Ba

1. INTRODUCTION

The advancement of communication technology has consisted in the need for wireless communication networks to provide data rates that have never been higher. The lower frequency range is now experiencing problems with limited bandwidth and reduced transmission speeds. This problem can be solved by using higher frequencies and improving wireless communication networks. This is why a lot of researchers are trying to figure out how to improve communication systems so that they can provide more bandwidth and faster data rates. The 5G standard stands out because to its remarkable data throughput. The 5G standard uses frequencies between 3 and 300 GHz. The millimetre (mm) wave spectrum offers a lot of bandwidth compared to lesser frequency bands, which allows it to transmit faster data speeds. Considerations like size, impedance bandwidth, gain, and radiation efficiency are of utmost importance when dealing with antennas in any frequency band, especially in the millimeter band. In addition, the antenna design must incorporate multiband properties to accommodate wireless devices that operate on multiple frequency bands. Patch antennas are sometimes called low-profile antennas [1-2] because they have many benefits, such as being able to work in a variety of frequency bands and difficult environments, being flexible, and having a small size [3-4]. There are several feeding techniques that work together to activate the radiating patch of a patch antenna. Some of these approaches are microstrip, aperture, and proximity coupling. According to [5], the probe and microstrip transmission methods are the most frequently employed techniques. A triple-band antenna is an essential component of modern portable wireless communication devices, as it allows for the operation of multiple services on distinct

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Cite this article as: S. Kalli et al., *J. Nano- Electron. Phys.* 17 No 3, 03021 (2025) https://doi.org/10.21272/jnep.17(3).03021

frequency bands. [6-8]. According to [6], portable communication devices are required to comply with specific specifications regarding their size, efficacy, and power consumption. To accomplish this, planar and low-profile patch antennas are placed on the transmitter and receiver extremities to transmit and receive electromagnetic radiations [9].

2. ANTENNA DESIGN DESCRIPTION

The suggested circular patch antenna was developed with the help of CST studio, a numerical calculation performed based on the FDTD approach. As shown in Figure 1, the proposed circular patch antenna contains two semicircular shaped slots and a L-shaped slot with coplanar structure as shown in the Figure 1 and their dimensions are shown in Table 1. The proposed antenna contains three layers like copper material, which is used as a ground layer, FR-4 substrate is used as a substrate material and finally copper is used a patch layer and the total size of the antenna is 21×21 mm^2.

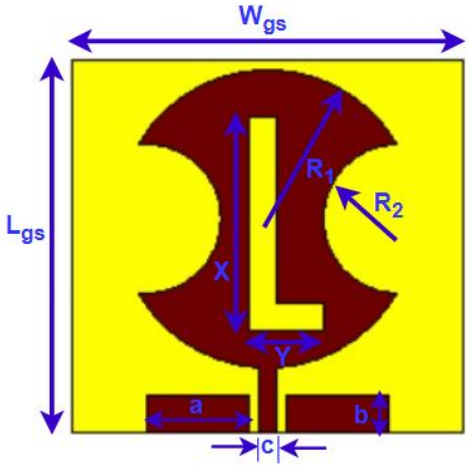
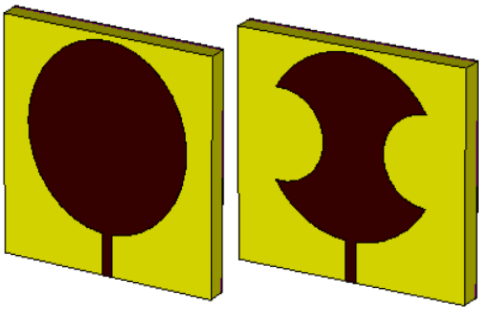


Fig. 1 – The Proposed circular patch antenna with circular and L-shaped slots

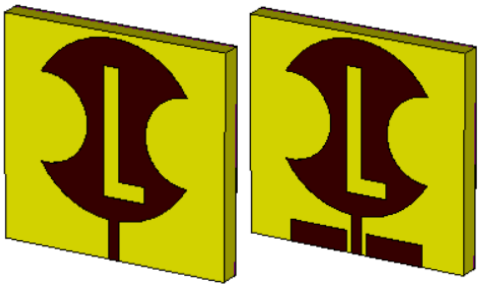
Table 1 – Proposed antenna dimensions (mm)

Parameter	L_{gs}	W_{gs}	R_1	R_2	a	b	X	Y	c
Dimensions	21	21	8	4	5.5	2	12	4	2

Initially, we have taken a basic circular patch as a radiating element. In second step, the semicircular cuts are applied to the circular patch. Step (iii) involves placing an L-shaped slot in the middle of the circular patch, and then applying CPW feed to the suggested antenna to improve performance, as seen in the Fig. 3.



(i) (ii)



(iii) (iv)

Fig. 2 – Different steps (i to iv) applied to achieve the final proposed antenna

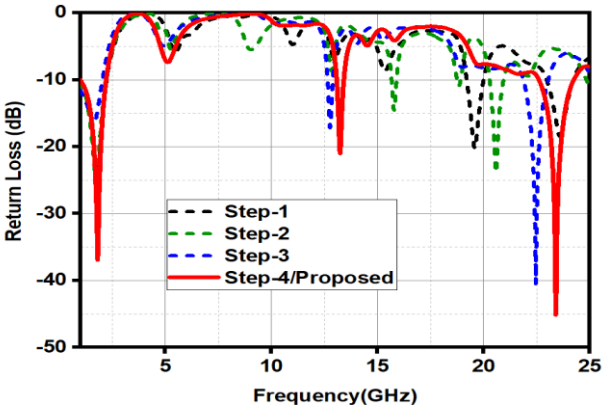


Fig. 3 – Obtained S_{11}(dB) response for the proposed antenna

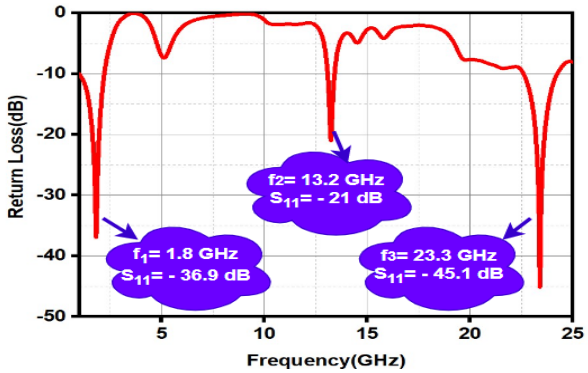


Fig. 4 – Obtained S_{11}(dB) response with operating frequencies and S_{11} values

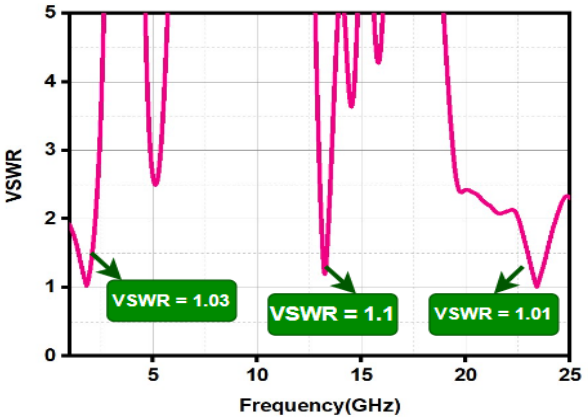


Fig. 5 – Obtained VSWR response at three operating frequencies

Using this proposed design, triple bands (shown with red color in Fig. 3) are achieved for L, Ku and K bands. As can be seen from Fig. 4, the suggested tri-band antenna operates in the following frequency bands: 1–2.1 GHz (L-band), 13–13.4 (Ku–band), and 22.6–24.2 (5G mm–wave). The whole performance of the suggested antenna with different parameters is displayed in Table 2.

Table 2 – The suggested antenna's performance metrics

Parameter	First band	Second band	Third band
Resonant Frequency (GHz)	1.8	13.2	23.3
S_{11}(dB)	– 36.9	– 21	– 45.1
Band range (GHz)	1 – 2.1	13 – 13.4	22.6 – 24.2
Bandwidth (GHz)	1.1	0.4	1.6
Gain (dBi)	8.6	7.2	9.4
VSWR	1.03	1.1	1.01
Radiation efficiency (%)	84	76	91

3. RESULT ANALYSIS

As shown in Fig. 6(i), a parametric analysis is performed for various parameters like R_1, R_2, X and Y. Compared to the remaining parameter values, a better performance can be achieved for the parameters $R_1 = 8$ mm, $R_2 = 4$ mm, $X = 12$ mm and finally $Y = 4$ mm values, which are shown with red color in Fig. 6.

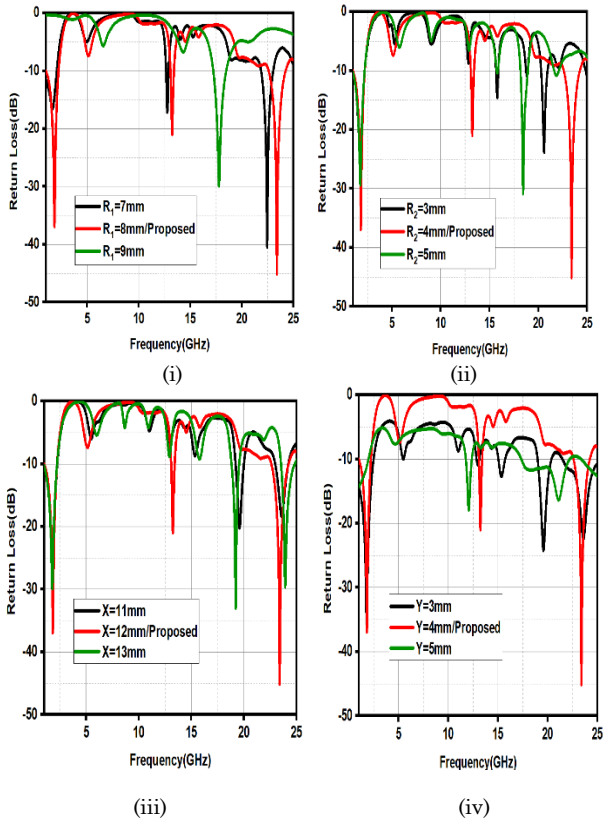


Fig. 6 – Obtained S_{11}(dB) response for various parameters present in the proposed antenna

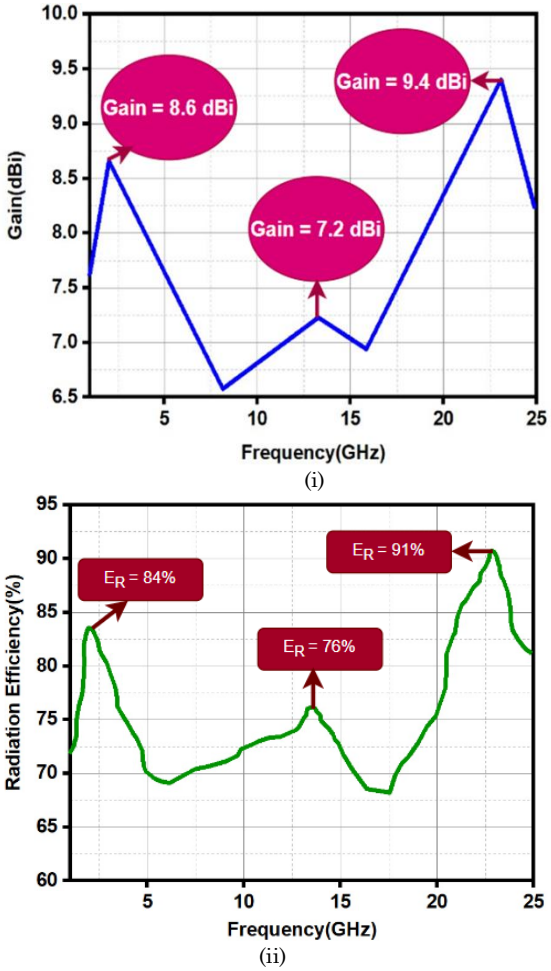


Fig. 7 – Obtained (i) gain and (ii) radiation efficiencies plots of the prescribed design

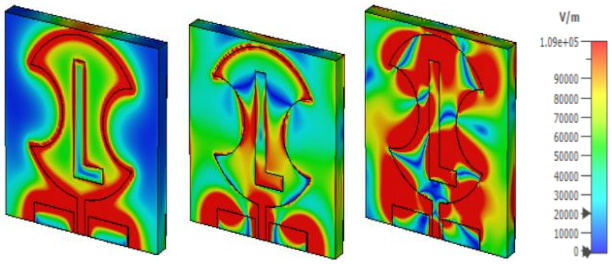


Fig. 8 – Obtained *E*-Fields at (a) 1.8 GHz, (b) 13.2 GHz and (c) 23.3 GHz

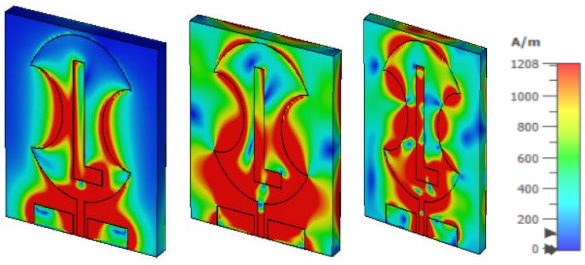


Fig. 9 – Obtained *H*-Fields at (a) 1.8 GHz, (b) 13.2 GHz and (c) 23.3 GHz

The suggested antenna's peak gain at 1.8 GHz, 13.2 GHz, and 23.3 GHz is 8.6 dBi, 7.2 dBi, and 9.4 dBi, respectively, as shown in Fig. 7(a). The radiation efficiencies are achieved at 1.8 GHz, 13.2 GHz, and 23.3 GHz are 84 %, 76 %, and 92 %, respectively, as shown in Fig. 7(b). A maximum *E*-field can be seen in the vertical direction and a maximum *H*-field can be seen along the horizontal directions, as shown in Fig. 8. and 9. This indicates that the antenna performs better.

4. CONCLUSION

This research presents the design and simulation of a Tri-band microstrip radiating patch with circular and L-shaped slot of a CPW feed line. The antenna's size has been significantly decreased in comparison to the conventional microstrip antenna. The prescribed structure possesses of an L-shape and two semi-circular shaped slots on a polyimide substrate for L, Ku and K-bands. The proposed antenna's radiation efficiencies at 1.8 GHz, 13.2 GHz, and 23.3 GHz are 84 %, 76 %, and 92 %, respectively, and its peak gain is 8.6 dBi, 7.2 dBi, and 9.4 dBi at those frequencies. Additionally, antenna's performance is verified by E and H-fields. The Suggested Tri-band novel shape radiating antenna can be used for L-, Ku- and K-band Applications.

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Кругла патч-антена CPW FED з L-подібною формою та двома напівкруглими прорізами для L-, Ku- та K-діапазонів

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Запропонована кругла патч-антена була розроблена за допомогою CST studio, числовий розрахунок, виконаний на основі підходу FDTD. Антена містить три шари, такі як мідний матеріал, який використовується як заземлювальний шар, підкладка FR-4 використовується як матеріал підкладки, і, нарешті, мідь використовується як патч-шар, а загальний розмір антени становить 21 × 21 мм². Запропонована тридіапазонна антена працює в трьох різних частотних діапазонах, таких як 1-2,1 ГГц (L-діапазон), 13 – 13,4 (Ku-діапазон) та 22,6 – 24,2 (5G мм-хвиля). Конструкція має L-подібну форму та два напівкруглі пази на поліімідній підкладці для L-, Ku та K-діапазонів. Піковий коефіцієнт підсилення становить 8,6 дБі на частоті 1,8 ГГц, 7,2 дБі на частоті 13,2 ГГц та 9,4 дБі на частоті 23,3 ГГц, отримані коефіцієнти випромінювання становлять 84 %, 76 % та 92 % на частотах 1,8 ГГц, 13,2 ГГц та 23,3 ГГц відповідно. Запропонована антена має різні переваги, включаючи три діапазони, високий коефіцієнт підсилення та високу ефективність випромінювання. Це робить її привабливим варіантом для пристроїв, що працюють у діапазонах менше 6 ГГц, Ku-діапазоні та міліметровому діапазоні. Розподіл полів E та H перевірено, щоб показати продуктивність запропонованої антени. Крім того, для перевірки продуктивності запропонованої антени також проведено параметричний аналіз.

Ключові слова: Антена, Дводіапазонна, Коефіцієнт посилення, Мілімтровий хвильовий діапазон, 5G.