SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V10I12P107

Volume 10 Issue 12, 65-71, November 2023

Original Article

Design of Rectangular Microstrip Patch Antenna with Dual-Band for 5G Millimeter-Wave Applications

Ruaa Shallal Abbas Anooz[1], Kareem Ali Al-Sharhanee[2], Istabraq M. Al-Joboury[3],
Ali Hamzah Najim[4]

[1]*Department of Avionics Techniques Engineering, Al-Furat Al-Awsat Technical University (ATU), Kufa, Iraq.*
[2]*Department of Communication Techniques Engineering, Al-Farahidi University, Baghdad, Iraq.*
[3]*Department of Medical Instruments Technical Engineering, Al-Bayan University, Baghdad, Iraq.*
[4]*Department of Computer Technical Engineering, Imam Al-Kadhum College (IKC) , Baghdad, Iraq.*

[1]*Corresponding Author : coj.rua@atu.edu.iq*

Received: 07 October 2023 Revised: 10 November 2023 Accepted: 08 December 2023 Published: 23 December 2023

Abstract *- Wireless communication systems reached the mm-wave frequencies because of the high bandwidth and data transmission demand. In this paper, a Microstrip Patch Antenna (MPA) with dual-band for mm-wave communications is designed and analyzed. A small antenna with dimensions 9.086X6.65X0.1575mm*^{3} *was proposed with an inset feed line technique that matches the 50 Ω microstrip feedline and the radiating patch. The first band resonates at 23.8GHz with -27.5dB return loss, 0.7GHz bandwidth, and 2.84dB gain. In contrast, the second band resonates at 37.5GHz with -28.87dB return loss, 1GHz bandwidth, and 3.33dB gain. The design of the antenna and the simulation are done utilizing HFSS software, and based on the results, the antenna is suitable for 5G applications.*

Keywords *- Microstrip Patch Antenna, Patch antenna, Rectangular microstrip patch antenna, mm-wave applications, 5G applications.*

1. Introduction

The Ka-band frequency of the millimeter-wave (mm-wave) spectrum is well-suited and attractive for innovative applications in wireless communications systems. The antenna must be designed with specific characteristics to get appropriate results for these systems, such as larger bandwidth and better gain [1]. The potential mm-wave frequency range, unpacked by the International Telecommunications Union (ITU) at a World Radio communication Conference in 2015, is between (24 and 84) GHz [2].

Microstrip Patch Antenna (MPA) is a planar antenna that has recently received more attention, and it consists of a metal patch pressed on a grounded plane. MPA offers many advantages, involving multiple existing designs, simpleness in manufacture, miniature size, little cost, and lightweight and static form, which meets the requirements of wireless communications systems. Without antennas, nothing in the field of wireless communication could have progressed to this point in technological advancement [3, 4].

The majority of earlier research on this subject indicates that depending on the application, an antenna's performance and usability are determined by the shape of the MPA and the characteristics of the substrate. A single band with high bandwidth is required for many applications to transport data while keeping the size as small as feasible [5].

Numerous studies on optimizing MPA performance have been published. Wireless application developers are interested in broadband antenna technologies because of their small physical size, high gain, omnidirectional radiation, and simplicity of production using traditional manufacturing processes. This is because of its benefits, which include low power consumption, substantial capacity, affordability, high data rate, dependability, and ease of use [6, 7].

Under the International Mobile Telecommunications 2020 (IMT2020) agreement, the mm-wave frequency bands from 24 to 71GHz, with a spectrum bandwidth of 17.25GHz, are set aside for 5G design. When propagating, mm-wave frequencies are attenuated by trees, building materials, rainfall, water vapour, and atmospheric gases [8].

Attenuation has led to lower wavelengths, which have generated diffraction and absorption of materials at these frequencies. The best operating frequencies for 5G wireless communication networks have been determined to be 28GHz and 38GHz since attenuation from the atmosphere is comparatively lower at these frequencies. Therefore, more studies were proposed at 28GHz frequency. For instance, an MPA was studied and designed to operate in 5G applications at a frequency of 28 kHz in [3, 8-12] with feeding using an inset line. Also, studies are proposed at 28 GHz with microstrip feed lines like [13, 14]. Some studies proposed dual-band frequencies in [2, 6, 15]. A triband frequencies antenna was presented in [16]. Reducing the size and enhancing the communication network's performance is essential as electronic technology advances. For this reason, The small size and thin profile of microstrip patch antennas appeal to many researchers.

The study in [17] proposed a compact microstrip patch antenna with dimensions 10x10x1.6 mm^3 for mm-wave applications at 24.5GHz with a broader bandwidth of 2.05GHz and 6.32dB maximum gain. A U-shaped slot rectangular MPA with a single band is introduced in [18] for mm-wave applications that use frequencies above 60GHz. The results showed a wide bandwidth of about 26.76GHz at the operating frequency of 71.03GHz and a peak gain of 4.04dB.

In [19], a rectangular MPA is proposed for 5G applications with an operating frequency of 39GHz. The results showed a wide bandwidth of about 3.5GHz and a maximum gain of 4dB. Using 5G mm-wave bands with an operating frequency of 26GHz, an MPA is proposed in [20] for high-quality online education and other 5G applications.

The results displayed a bandwidth of about 3.56GHz and a gain of 10dB. In this paper, we proposed a dual-band rectangular MPA for 5G applications. The presented antenna has a low-profile size of 9.086X6.65X0.1575 mm^3.

The paper arrangement is as follows: Section 2 discusses the antenna design and its dimensions. The results of the simulation are displayed in section 3. Finally, the conclusion is finished in section 4.

2. Antenna Design

The MPA main components are the substrate, ground, patch, and feed line. The substrate plane is designed from a dielectric material, while the others are created from a conductive material. It has various shapes like rectangular, circular, square, ellipse, and ring; it is used in cellular communications, microwave applications, and millimeter-wave applications.

This section argues the proposed antenna design and development for mm-wave applications. Figure 1 shows the antenna structure, including the front and side views. The substrate is made from FR4 epoxy with ϵ_r of 4.4 dielectric constant and thickness H_S of 0.1575mm. The equations utilized to calculate the parameters in this work are as follows [8]:

1. Patch Width (W_P)

$$W_P = \frac{c}{2f\sqrt{\frac{\epsilon_r + 1}{2}}}$$

2. Patch Length (L_P)

$$L_P = L_{eff} - 2\Delta L$$

$$L_{eff} = \frac{c}{2f\sqrt{\epsilon_{eff}}}$$

$$\Delta L = 0.412\frac{(\frac{W_P}{H_S} + 0.246)(\epsilon_{eff} + 0.3)}{(\epsilon_{eff} + 0.258)(\frac{W_P}{H_S} + 0.813)}$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}(1 + 12\frac{H_S}{W_P})^{\frac{-1}{2}}$$

3. Feed Line Width (W_F)

The suggested antenna was linked to a 50Ω inset feed transmission feedline because this method doesn't need more matching components. The following equation is used to compute the transmission feedline's width.

$$W_F = \frac{7.48H_S}{e^{(50\frac{\sqrt{\epsilon_r + 1.41}}{87})}}$$

4. The ground plane width and length

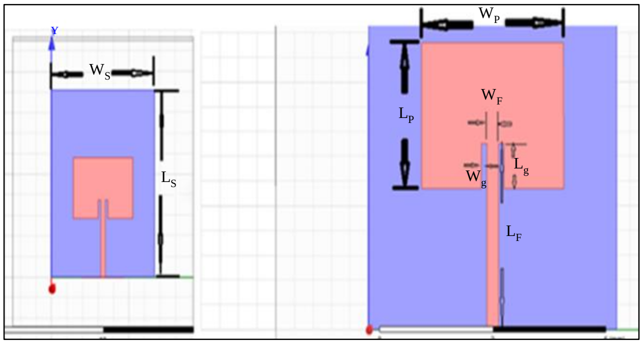
$$W_G = 6H_S + W_P$$

$$L_G = 6H_S + L_P$$

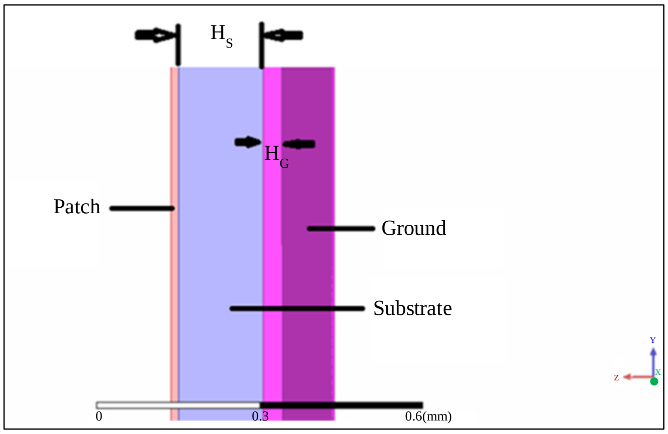
We denote the ground plane width and length by W_G and L_G, respectively, and its values are the same as the substrate width and length.

Table 1. The proposed antenna parameter's dimensions

Parameter	Dimension (mm)
Substrate and Ground Width (W_S)	6.65
Substrate and Ground Length (L_S)	9.086
Substrate Thickness (H_S)	0.1575
Ground Plane Thickness (H_G)	0.035
Width of Patch (W_P)	3.804
Length of Patch (L_P)	2.945
Feed Line Width (W_F)	0.3011
Feed Line Length (L_F)	2.8541
Gap Width (W_g)	0.1506
Gap Length (L_g)	0.9



(a) Front view



(b) Side view

Fig. 1 The structure of the presented antenna

3. Simulation Results and Discussion

3.1. Return Loss and Bandwidth Results

For wireless or mobile communication, the antenna accepts 90% of power, and only 10% of the power is reflected; therefore, the value -10dB of return loss is taken as the base value. Figure 2 illustrates the proposed antenna return loss in dB against the frequency in GHz. It represents two bands generated by this antenna, one at frequency 23.8GHz with -27.5dB return loss and the other at frequency 37.5GHz with -28.87dB return loss. From the Figure, the return loss values of both bands at -10dB are high, and therefore, this antenna is perfect in mm-wave communications, especially 5G communications. We can calculate the bandwidth from the Figure of return loss, where the return loss is less than -10dB for the antenna bandwidth range of frequencies. Therefore, the bandwidth for the frequency 23.8GHz is 700MHz, and the frequency 37.5GHz is 1GHz. So, the proposed antenna's overall bandwidth is 1.7GHz.

3.2. Voltage Standing Wave Ratio (VSWR) Results

The VSWR for any patch antenna must be not more than two along the efficiency bandwidth and ideally should be 1. Figure 3 demonstrates the VSWR values in dB against the frequency in GHz. We can observe that the VSWR values of the frequencies 23.8GHz and 37.5GHz are 1.01dB and 0.97dB, respectively.

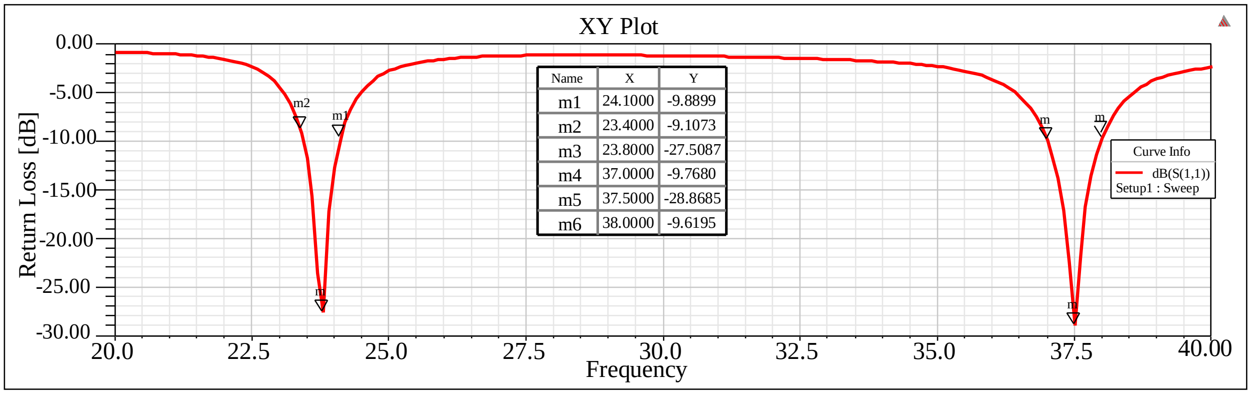
3.3. The Gain and Radiation Pattern Results

The gain for the MPA could be better because substrate thickness and relative dielectric constant affect the antenna gain, where the gain is in direct proportion to the antenna's thickness and in inverse proportion to the relative dielectric constant. Figure 4 illustrates the 3D plot of the presented antenna gain. The figure shows that the gain for the frequency 23.8GHz is 2.84dB, and the frequency 37.5GHz is 3.33dB.

The radiation pattern feature illustrates the overall antenna performance, which is very important. Figure 5 demonstrates the proposed antenna radiation pattern for both bands, 23.8GHz and 37.5GHz. The H plane is directed in Figure 5a, but the E plane is roughly omnidirectional. Figure 5b shows the omnidirectional radiation pattern in the E and H planes.

3.4. Current Distribution Results

We studied the current surface distributions for the proposed antenna at frequencies to better comprehend the electromagnetic radiation pattern for bands. As illustrated in Figure 6, the patch's edges and the end of the feed line displayed a large surface current density at both bands, 23.8GHz and 37.5GHz, respectively. Table 2 reviews the simulation results for the proposed antenna with the previous studies.



Name	X	Y
m1	24.1000	-9.8899
m2	23.4000	-9.1073
m3	23.8000	-27.5087
m4	37.0000	-9.7680
m5	37.5000	-28.8685
m6	38.0000	-9.6195

Fig. 2 The proposed antenna return loss

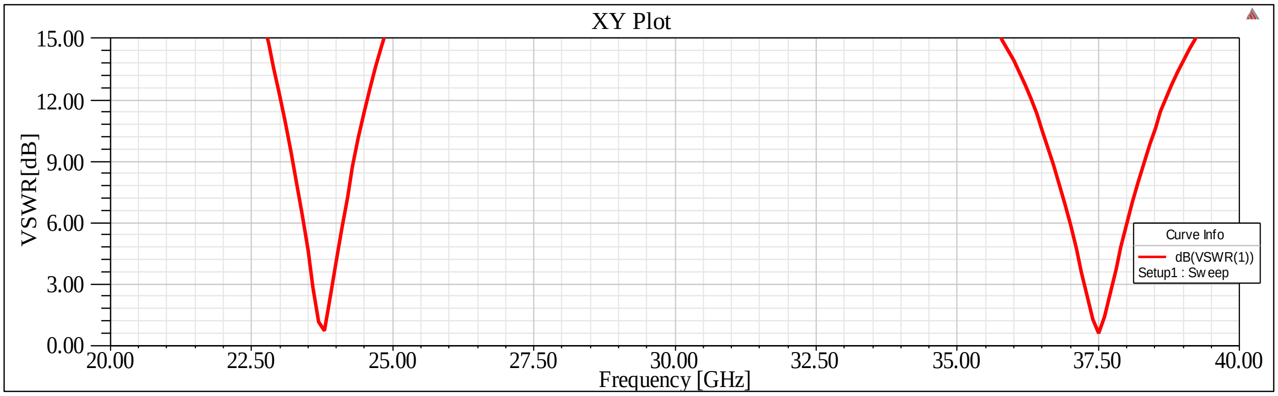
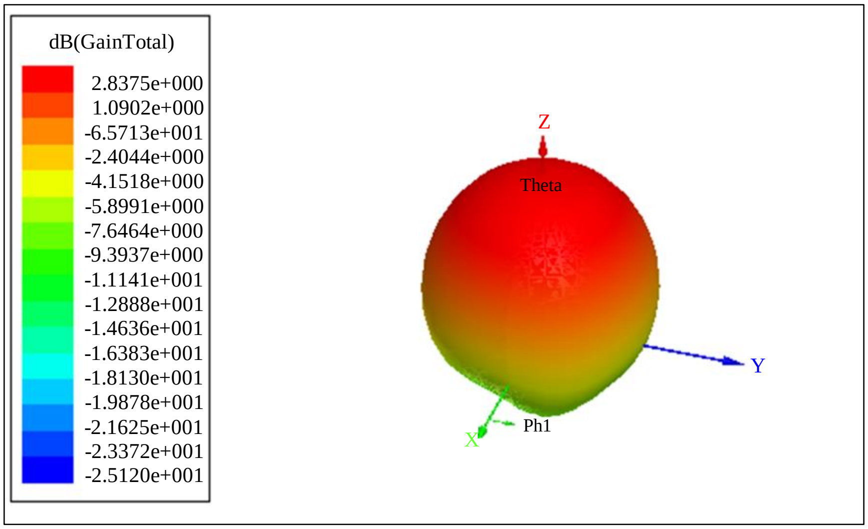
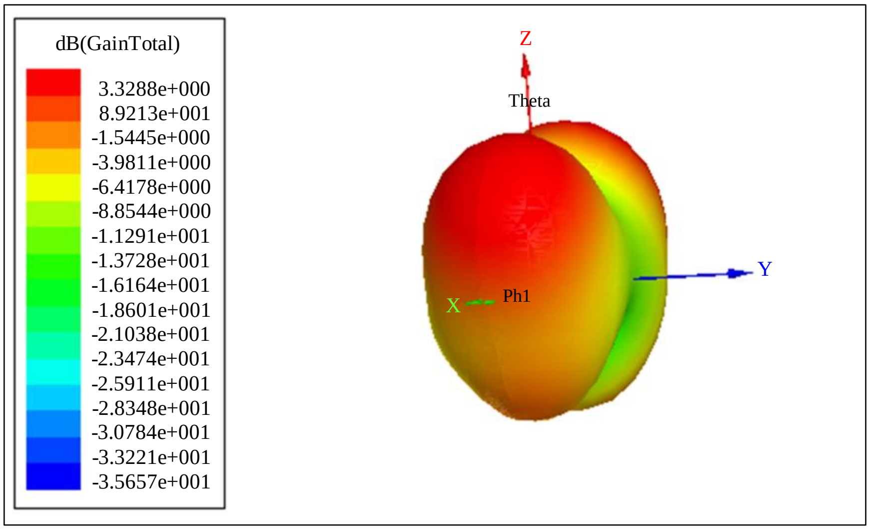


Fig. 3 Frequency vs VSWR of the proposed antenna

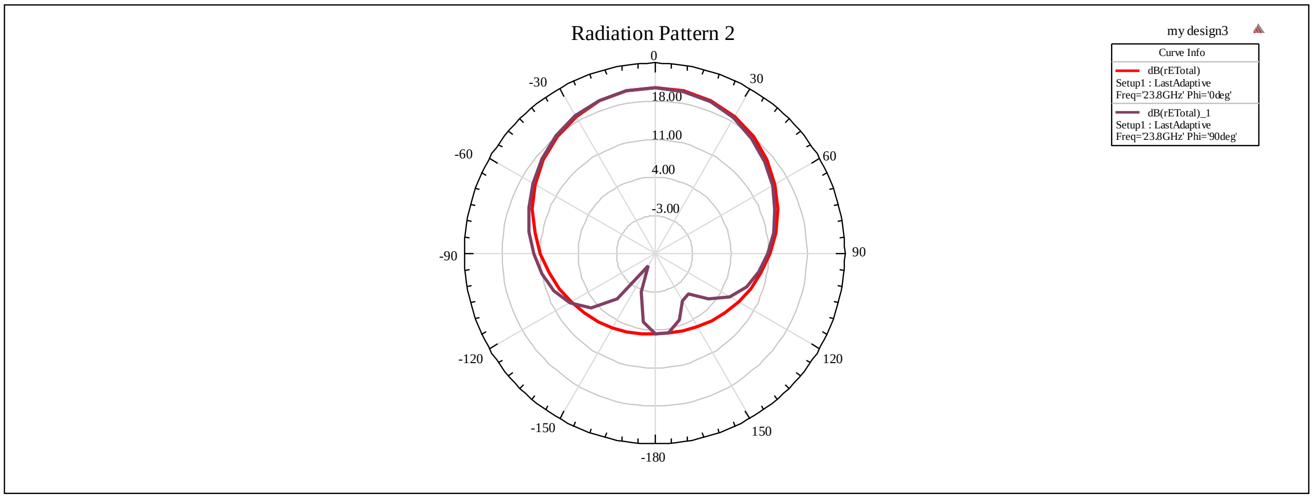


(a) 23.8GHz frequency

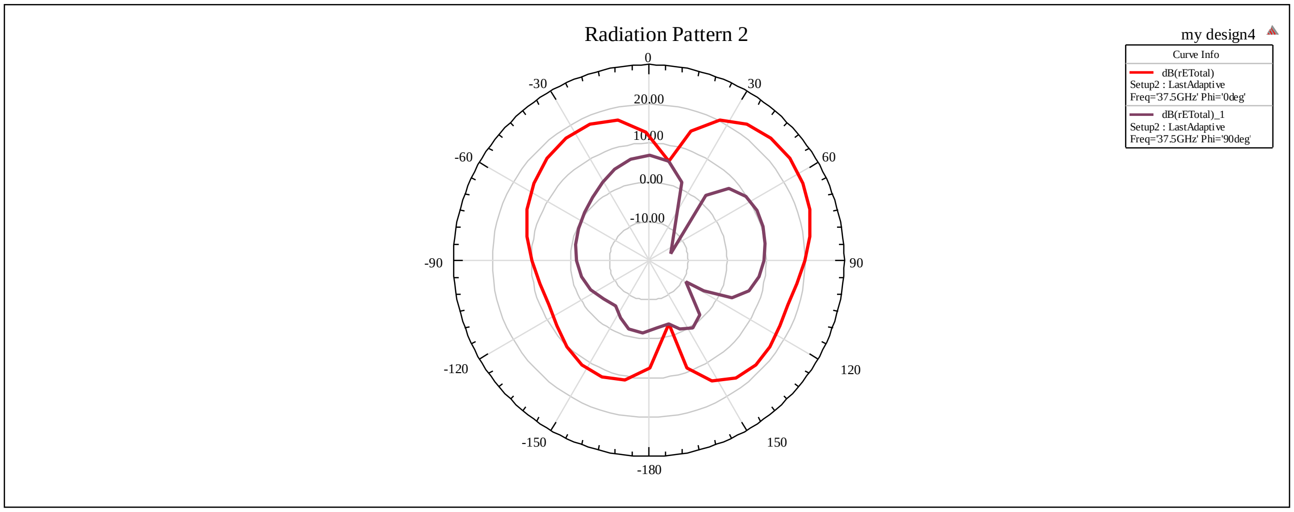


(b) 37.5GHz frequency

Fig. 4 The 3D plot for the proposed antenna gain

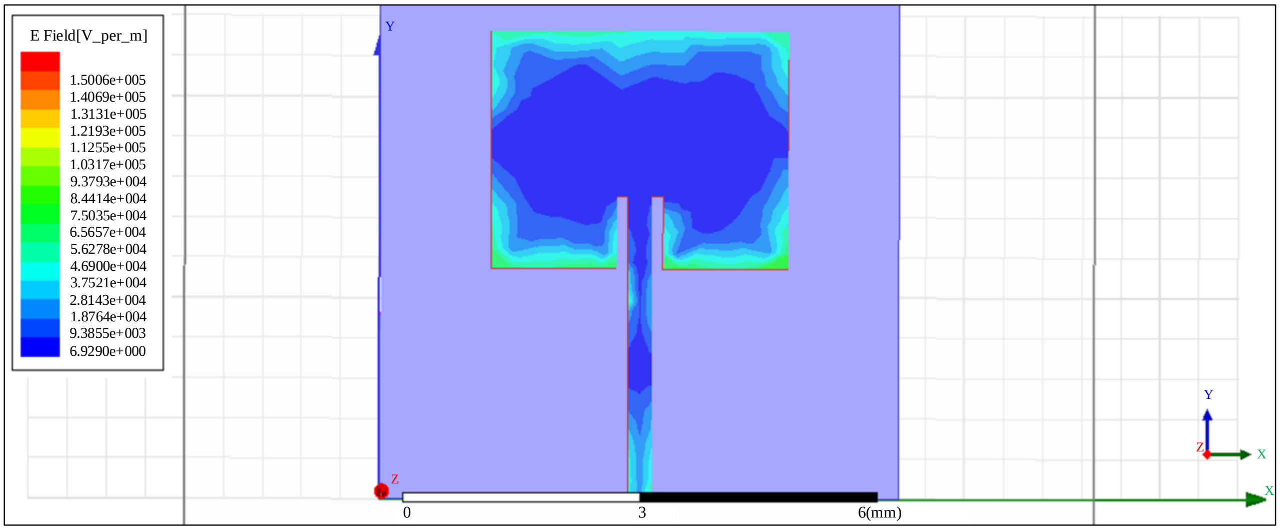


(a) Frequency 23.8GHz

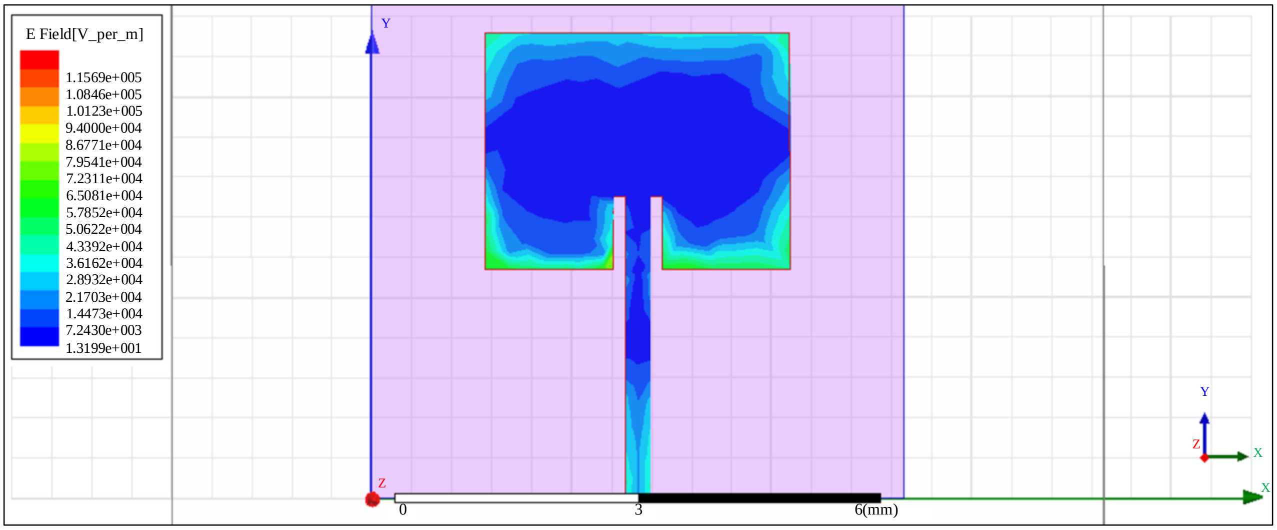


(b) Frequency 37.5GHz

Fig. 5 The proposed antenna radiation pattern



(a) Frequency 23.8GHz



(b) Frequency 37.5GHz

Fig. 6 The current distribution of the proposed antenna

Table 2. Comparison of the presented antenna with antennas of the prior studies

Ref.	**Size (mm^3)**	**S_{11}(dB)**	**Resonant Frequency (GHz)**	**Gain (dB)**	**Bandwidth (GHz)**
[8]	6.285 X 7.235 X 0.5	-13.48	28	6.63	0.847
[9]	3.9 X 2.955 X 0.1	-30.5	28	7	0.46
[10]	4.7245 X 3.942177 X 0.244	-38.87	28	7.587	1.046
[11]	4.2 X 3.3 X 0.5	-20.95	28	7.5	1.06
[12]	6 X 6 X 0.2	-45.23	28	6.68	0.770
[13]	3.942177 X 4.7245 X 0.244	-20.5949	28	7.587	1.046
[14]	14.71 X 7.9 X 0.254	–12.59	28	6.69	0. 582
[16]	8 X 8 X 0.5	-12.4 -18.86 -24.3	41.08 47.4 54.4	6.16 9.89 5.54	0.150 0.222 0.219
This Study	9.086 X 6.65 X 0.1575	-27.5 -28.87	23.8 37.5	2.84 3.33	0.7 1

4. Conclusion

A dual-band rectangular MPA for 5G mm-wave applications has been proposed in this work. The antenna has a small structure with dimensions 9.086X6.65X0.1575 mm^3; therefore, it can integrate into a device with limited space. The simulated results show a return loss, bandwidth, and gain of about -27.5dB and -28.87dB, 0.7GHz and 1GHz, 2.84dB, and 3.33dB for 23.8GHz and 37.5GHz, respectively. The suggested antenna is a candidate for 5G wireless communications.

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