Plasmonics (2021) 16:1417–1425
https://doi.org/10.1007/s11468-021-01412-x

Design of Efficient 37 GHz Millimeter Wave Microstrip Patch Antenna for 5G Mobile Application

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Received: 2 October 2020 / Accepted: 17 February 2021 / Published online: 4 March 2021

Abstract
Millimeter wave (mmWave) wireless technology has become a part of human life for high-speed and secure data transmission. This paper presents a square-slotted microstrip patch antenna at 37 GHz resonant frequency for mmWave wireless communication. The antenna consists of one H-slot and one inverted T-slot loaded over the radiating patch. The proposed antenna has been designed and investigated on Rogers RT5880 substrate with relative permittivity 2.2 and loss tangent 0.0009 using Electromagnetic Simulation Software CST Microwave Studio. The result of this paper shows minimal return loss −43.05 dB, gain 8.18 dB, and impedance bandwidth 16.22% at 37 GHz resonant frequency. The voltage standing wave ratio (VSWR), E-plane, and H-plane radiation pattern has also presented for the proposed antenna which can be strong candidate for 5G mmWave cellular communication.

Keywords Fifth generation (5G) · Millimeter wave (mmWave) · Microstrip patch antenna · Wireless communication

Introduction

Fifth Generation (5G) networks beyond the 4G networks will play important role in wireless communication by operating at millimeter wave (mmWave) frequency band. The mobile communication revolution is rated from 1 to 4G where each generation is being improved from their previous generation [1, 2]. The common application of 4G technology is machine to machine communication, remote host monitoring, video call data flow etc. There are some limitations of 4G technology which are high energy consumption, connection loss, and poor quality and coverage area which degrade system performances [3, 4]. Each day, a large number of new devices are connecting to the wireless networks [5]. 4G wireless technology will not meet the future demand due to rapid growth of connected device in mobile communication [6]. Mobile communication system must be upgraded to ensure high data rates, better connectivity, high-quality network, and larger bandwidth [7]. 5G wireless technology is a promising solution for multi-Gbps data rates in future mobile communications.

In addition, the antenna design is one of the most challenging tasks for supporting future 5G cellular communication. An efficient and high-performance–based antenna is needed to increase the performance of mobile communication. One of the most common types of antenna is microstrip patch antenna which is widely used for their low cost, small size, and light weight [8]. The Federal Communication Commission (FCC) announced three licensed mmWave frequency bands in 2016 for fifth generation mobile communication that are 27 GHz (27.5 to 28.35 GHz), 37 Hz (37 to 38.6 GHz), and 39 GHz (38.6 to 40 GHz) [9]. Afterward, different mmWave frequency bands have been proposed for fifth-generation cellular communication, which are 15 GHz, 28 GHz, 37 GHz, 60 GHz, 64 GHz, 71 GHz, and 73 GHz [10–13]. MmWave spectrum 37 GHz has been proposed by FCC for 5G wireless network, Internet of Things, and others advanced spectrum basis services [14, 15].

Different researchers have been working at 37 GHz operating frequency for 5G technology [9, 16–21] separately. Their main objective is to design an optimal

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antenna having high gain, larger bandwidth, and better radiation pattern at operating frequency of 37 GHz. A novel mmWave multiband Microstrip patch antenna has been proposed by Lodro et al. [16] at operating 37 GHz and 54 GHz. The authors describe their proposed antenna result in terms of reflection coefficient, efficiency, and E–H field pattern. Goudos et al. [17] proposed an E-shaped dual-band antenna at center frequency 25 GHz and 37 GHz for 5G mobile communication. They used teaching learning optimization algorithm to design E-shaped patch antenna. A millimeter wave phased dipole array antenna with two opening holes has been presented by Peng et al. [9] from 37 to 40 GHz operating frequency. A compact substrate-integrated waveguide (SIW) slotted antenna at 37 GHz has been presented by Shehab et al. [18] for polarimetric radiometer system (PMR) in soil moisture measurement. Their designed antenna achieved high Q-factor and high gain which makes suitable for radiometer application. A magneto electric dual-band dipole antenna was proposed by Dadgarpour et al. [19] for wireless communication operating frequency from 26.5 to 38.3 GHz. Higher gain and radiation efficiency was achieved in their proposed antenna. A multiple input-multiple output rectangle Microstrip patch antenna at 28 GHz, 37 GHz, 41 GHz, and 74 GHz frequency was reported by Sunthari et al. [20] for 5G cellular communication. Simulation output has been described in terms of return loss, VSWR, and radiation efficiency. A dual polarized antenna subarray at center frequency 37 GHz has been proposed by Chu et al. [21]. A printed patch antenna array was reported by Oktafiani et al. [22] for 37 GHz operation with five elements in an array structure using Microstrip methods. From 29.5 to 37 GHz frequency range, a circular polarized dipole antenna has been described by Dadgarpour et al. [23] for multiple input-multiple output 5G wireless communications.

Moreover, different studies have been performed and have proposed different antennas for 5G cellular communication. Their proposed antenna has either a larger size or lower impedance bandwidth or lower gain which degrades antenna performance in wireless communication. Further studies are required to support high-speed data transmission. The main goal of this research is to design an antenna with minimal return loss, higher gain, and larger impedance bandwidth for cellular wireless communication. The novelty of the proposed antenna lies on its slot and observed features. This paper proposed a high-performance microstrip patch antenna with impedance bandwidth 16.22%, gain 8.25, and return loss −43.4 dB at 37 GHz resonant frequency for 5G cellular communication.

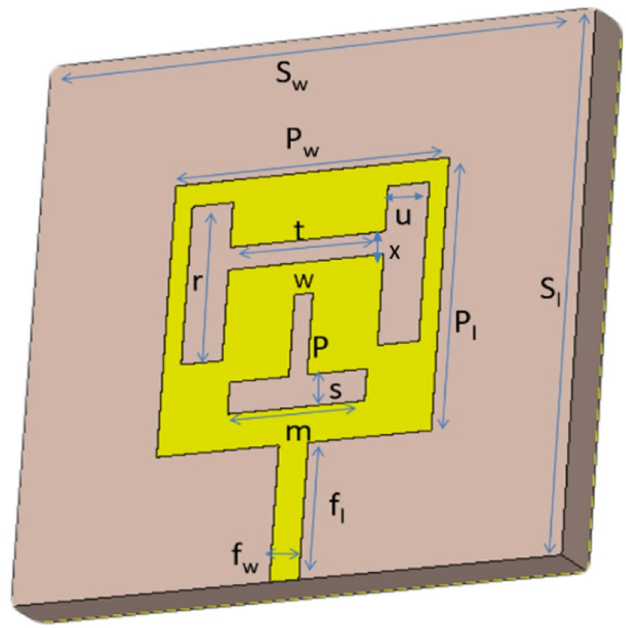

Fig. 1 Structure of proposed antenna

Antenna Design and Configuration

The geometrical configuration of the proposed single-band square microstrip patch antenna at operating frequency 37 GHz is shown in Fig. 1. It comprises three plane: radiating plane, substrate plane, and ground plane. The proposed antenna was designed on a Rogers RT5880 substrate with a dielectric constant of 2.2, thickness of 1.2 mm, and loss tangent of 0.0009. The top surface of the radiating patch consists of two slots. The H-shape slot has been etched at the upper side of the patch and the inverted T-shape slot was introduced at the bottom side of the square radiating patch. Rogers Corporation RT5880 has been used as substrate material due to its sustainability in high frequency and minimal dispersion loss [24]. Two slots over the radiating patch have been adapted to resonate with the antenna at center frequency 37 GHz. It also achieves wide impedance bandwidth, higher gain, and perfect impedance matching [25].

A copper plate with the dimension $12\times12\times.0035\text{mm}^3$ has been used as a ground plane. Ground plane location from the feed line determines impedance matching for microstrip patch antenna. The length and width of the radiating patch occupies $p_l=6$ mm and $p_w=6$ mm, respectively. The length and width of the H-slot occupy $r=3.5$ mm and $t=3.4$ mm, respectively. The values of w and p for the inverted T-slot which belong to the y-axis are $w=0.4$ mm and $p=1.8$ mm. The values of m and s which belong to the x-axis are 3 mm and 0.7 mm, respectively. All of the aforesaid dimensions over the radiating patch have notable effect on the antenna performance. The proposed antenna has been excited by the microstrip feed line to achieve 50Ω impedance characteristics which provides good frequency response over the entire frequency ranges. The width and length of the microstrip feed line are $fw = 0.64$ mm and $fl = 3$ mm. The dimension of antenna is optimized after many simulations using EM software CST Microwave Studio.

Numerical Analysis

A slotted square microstrip patch antenna has been designed at 37 GHz operating frequency for 5G cellular communication. The entire schematic dimension for proposed design was selected according to transmission line model [26, 27]. The values of effective dielectric constant ϵ_{reff} and length extension have been calculated using Eqs. 1 and 2. The dimension of the proposed antenna is tabulated in Table 1:

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}[1 + \frac{12h}{w}]^{-1/2} \quad (1)$$

$$\Delta L = h \times 0.421 \frac{(\epsilon_{reff} + 0.3)(\frac{w}{h} + 0.264)}{(\epsilon_{reff} - 0.258)(\frac{w}{h} + 0.8)} \quad (2)$$

where ϵ_r is the dielectric constant, w is the width of the radiating patch, and h is the height of the substrate. The actual length of microstrip patch is expressed as [26]

$$L = L_{eff} - 2\Delta L \quad (3)$$

Table 1 The geometrical parameters of the proposed antenna

Parameters	Value (mm)
G_w	12
G_l	12
p_w	6
p_l	6
s_w	12
s_l	12
f_w	0.64
f_l	3
t	3.4
r	3.5
w	0.4
p	1.8
m	3
s	0.7
u	0.5
x	0.3

Finally, the effective length and width of the patch are calculated as [26]

$$L_{eff} = \frac{v_0}{2f_r\sqrt{\epsilon_{reff}}} \quad (4)$$

$$W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}} \quad (5)$$

Result and Analysis

The proposed antenna in Fig. 1 is simulated using EM software CST microwave studio, which is based on the finite element method as a numerical analysis. The result of this proposed antenna has been investigated in terms of return loss, voltage standing wave ratio (VSWR), and gain and radiation pattern at 37 GHz resonant frequency for 5G cellular communication. The best performance of an antenna depends on these parameters. An extensive parametric analysis has been performed for investigating the effects of antenna parameters on the antenna performance. Firstly, the length and width of the inverted T slot has been varied over the antenna. The reflection co-efficient (S11) is one of the vital parameters for investigating antenna performances whose value should be less than −10 dB. Figure 2 depicts the simulated reflection coefficient for w1 = 0.4 mm, w2 = 0.3 mm, and w3 = 0.2 mm for the proposed antenna. The simulation result shows that return losses are about −43.05 dB, −39.57 dB, and −37.64 dB, respectively, for the different values of w1, w2, and w3 at 37 GHz center frequency.

Figure 3 shows the effect of reflection co-efficient (S11) of the proposed antenna for various values of s1, s2, and s3. The corresponding reflection coefficients (S11) about −43.05 dB, −44.03, and −30.37 dB have been achieved for the values of $s1 = 0.7$ mm, $s2 = 0.8$ mm, and $s3 = 0.6$ mm, respectively. It is observed that minimal return loss −44.03 dB has been obtained for the value of s2 = 0.8 mm at 37.20 GHz center frequency.

In addition, the dimension of H slot width also affects the antenna performance. The values of reflection coefficient (S11) for different values of $u1$, $u2$, and $u3$ are about 34.90 dB, −43.05 dB, and −32.10 dB respectively which is depicted in Fig 4. The minimal values of S11 have been obtained as −43.05 dB for u2 = 0.5 mm at 37 GHz center frequency.

The optimal values of $w = 0.4$ mm, $s = 0.7$ mm, and $u = 0.5$ mm have been achieved after analyzing various dimensions of the H slot and inverted T slot which are etched over the radiating patch. After considering the optimal values, the return loss vs frequency plot of the proposed antenna has been depicted in Fig 5. The minimal return loss (S11)

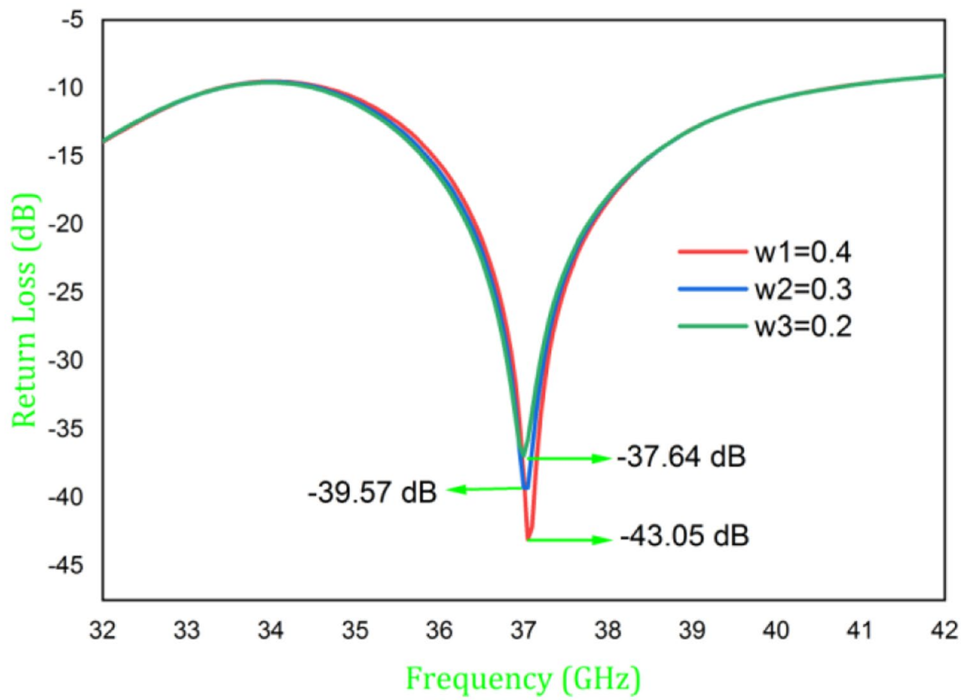

Fig. 2 The return loss characteristics for various values of *w* (*w*1 = 0.4 mm, *w*2 = 0.3 mm, and *w*3 = 0.2 mm)

−43.05 dB has been obtained with impedance bandwidth 6 GHz ranging from 34.50 to 40.50 GHz.

Gain is another important parameter for analyzing antenna performance. The variation of gain with respect frequency is shown in Fig 6. The proposed antenna gain is found up to 8.24533 dB at 37 GHz resonant frequency.

The voltage standing wave ratio versus frequency plot has been shown in Fig 7. The VSWR is used to measure the mismatch between feeding line and antenna. The ideal value of VSWR is 1 for perfectly impedance matching, which means a hundred percent power is accepted with zero reflection. In practical application, VSWR is always

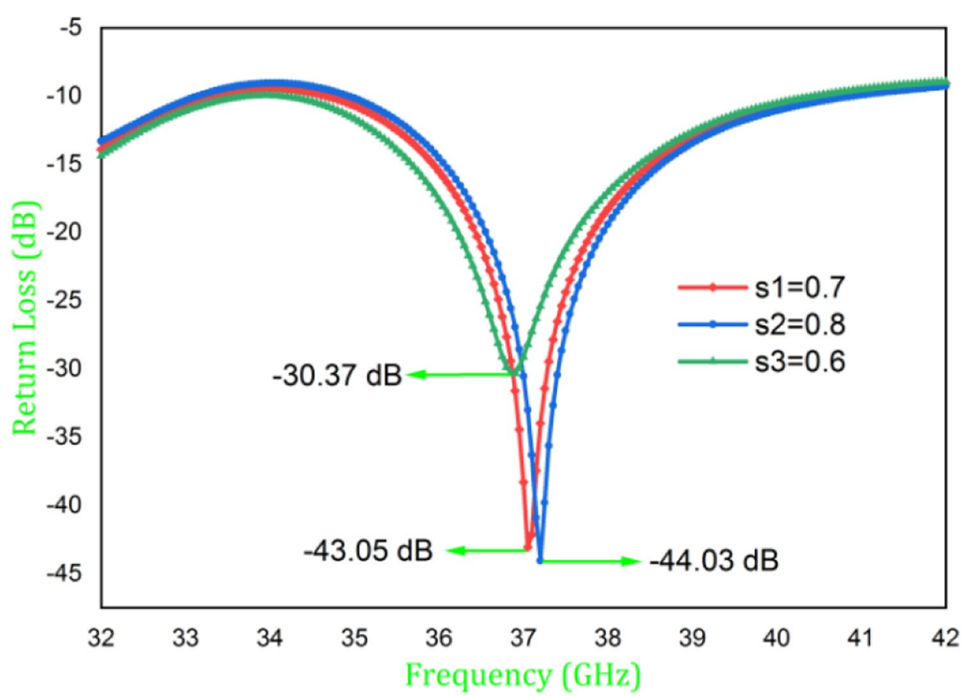

Fig. 3 The return loss characteristics for various values of *s* (*s*1 = 0.7 mm, *s*2 = 0.8 mm, and *s*3 = 0.6 mm)

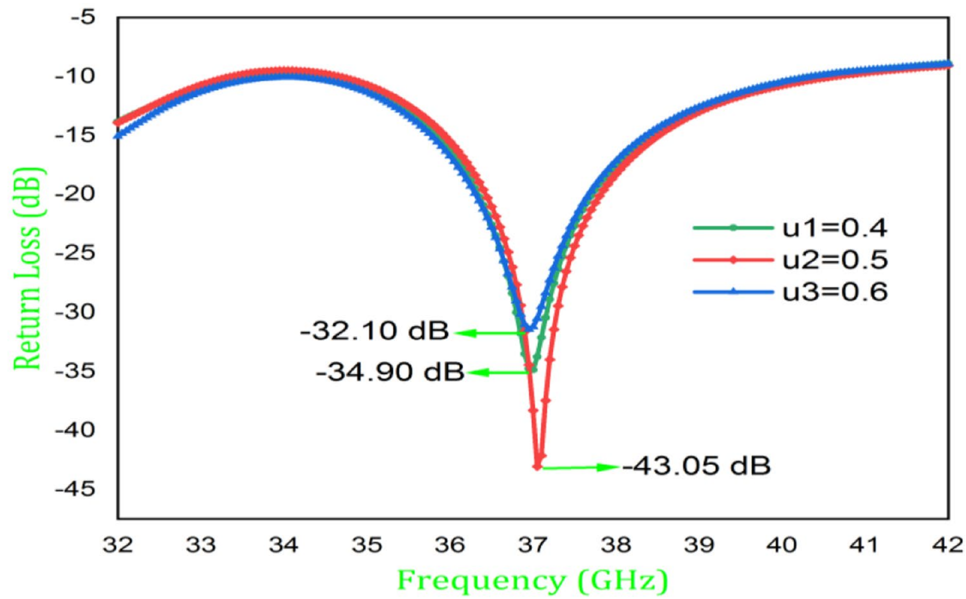

Fig. 4 Return loss characteristics for various values of u ($u1=0.4$ mm, $u2=0.5$ mm, and $u3=0.6$ mm)

preferred less than 2 for good impedance matching. The voltage standing wave ratio of the proposed antenna is 1.017 which represents that a good impedance matching is obtained at 37 GHz resonant frequency.

The simulated total efficiency and radiation efficiency has been shown in Fig. 8 with respect to frequency from 32 to 42 GHz. At 37 GHz center frequency, the total and radiation efficiency is 0.1016 dB and 0.1023 dB, respectively.

The radiation patterns of E-plane and H-plane of the proposed antenna have been depicted in Fig. 9. It is observed that maximum power is broadly radiated with wide beam width at 37 GHz center frequency. The values of the main lobe magnitude, main lobe direction, and 3 dB angular width are about 2.58dBi, 74.0 degree, and 92.9 degrees, respectively, which have been achieved for the H-plane. Furthermore, main lobe magnitude, main lobe direction, and 3 dB angular width

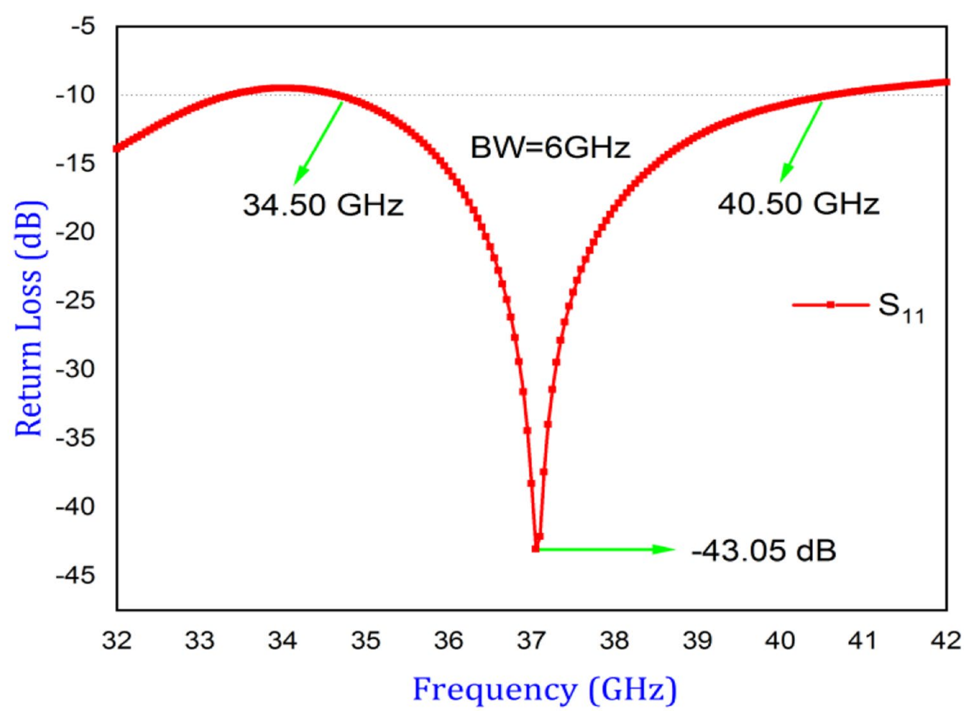

Fig. 5 The S11 characteristics of the proposed antenna

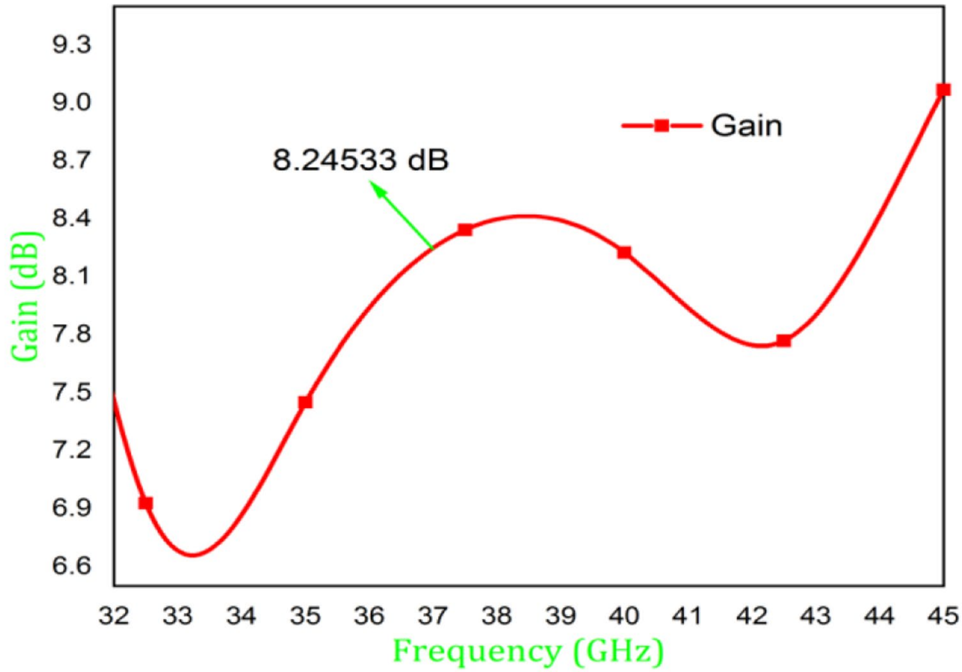

Fig. 6 The gain vs frequency characteristics of the proposed antenna

are about 6.67dBi, 24.0 degree, and 21.8 degree obtained for the E-plane at 37 GHz resonant frequency.

The performance comparison between the proposed antenna and some of the presented antennas in terms of size, frequency, return loss, gain, and impedance bandwidth is shown in Table 2. The proposed antenna has higher gain 8.245dBi, larger impedance bandwidth 16.22%, and minimal reflection coefficient −43.05 dB compared with existing reported antennas. It is observed that the proposed antenna has higher performance in terms of return loss, gain, and impedance bandwidth compared with the reported ones. The wider impedance bandwidth and adequate gain of the proposed antenna make it an excellent candidate for future 5G cellular communication.

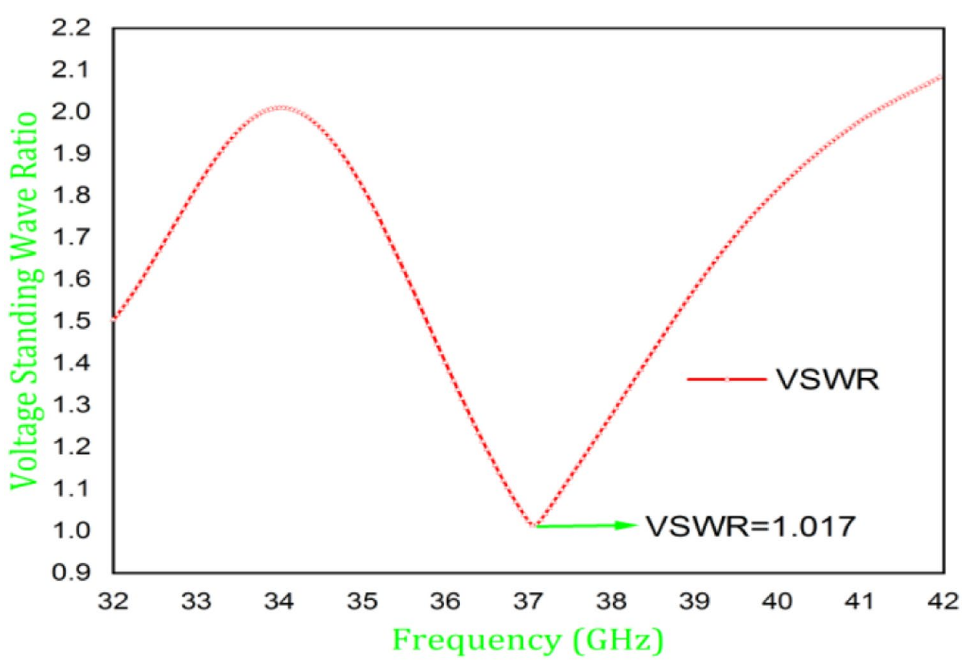

Fig. 7 The VSWR vs frequency characteristics of the proposed antenna

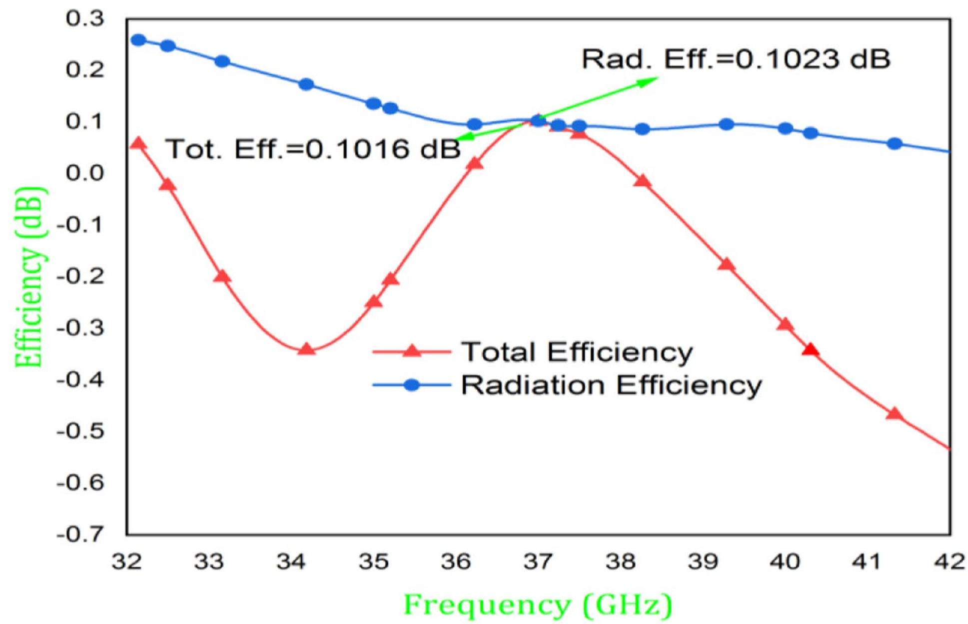

Fig. 8 The radiation efficiency vs frequency characteristics of the proposed antenna

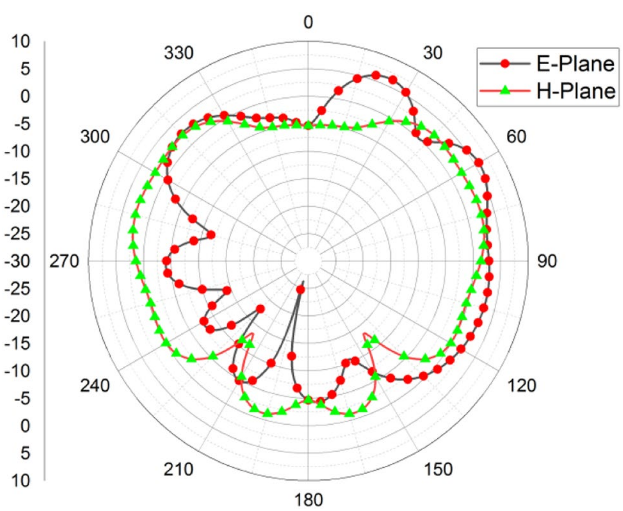

Fig. 9 The E-plane and H-plane characteristics of the proposed antenna

Table 2 Comparative analysis with previous works

Reference	Size (mm^2)	Frequency (GHz)	Return loss (dB)	Gain (dB)	Bandwidth (%)
[16]	7.2×5	37/54	−25.8/−27.8	5.5/6	14.86/16.05
[17]	4.96×6.86	25/37	−25.73/−25.77	6.71/1.72	8/16.22
[19]	9.8×7	37	−36	6.7	3.78
[23]	30.25×9.5	37	−45.5	5.75	2.70
[25]	–	38	−28	6.5	7.14
[26]	10×10	60	−31.45	6.03	5.48
Proposed work		37	−43.5	8.25	16.22

Conclusion

A single-band–slotted microstrip patch antenna for 5G cellular communication has been proposed and analyzed at 37 GHz resonant frequency. The antenna performance has been investigated in terms of return loss, gain, impedance bandwidth, VSWR, and radiation pattern for both E-plane and H-plane. Two slots (one H slot and one inverted T slot) have been used to enhance the impedance bandwidth and gain of the antenna. These two slot's length and width also have been analyzed and investigated. The result simulation shows return loss of −43.05 dB, gain of 8.245 dB, and impedance bandwidth of 16.22% at 37 GHz resonant frequency. The proposed microstrip patch antenna is very much suitable for the next-generation 5G cellular communication.

Author Contribution S. M. Shamim designed and performed the experiments, derived the models, and analyzed the data. Umme Salma Dina, and Nahid Arafin worked out almost all of the technical details and performed the numerical calculations for the suggested experiment. S. M. Shamim wrote the manuscript in consultation with Umme Salma Dina, Nahid Arafin, and Mst. Sumia Sultana. All the authors discussed the results and commented on the manuscript.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

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