A new design of 5G multilayers planar antenna with the enhancement of bandwidth and gain

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Article Info

Article history:

Received Oct 31, 2021
Revised Oct 20, 2022
Accepted Nov 3, 2022

Keywords:

5G
Microstrip technology
Multilayers
Patch antenna
Substrate

ABSTRACT

In this work, we design a microstrip patch antenna having a dimension of 3.279×4.232 mm^2 and consisting of a Foam-like substrate, of a relative dielectric permittivity of 1 and with a width of 0.5 mm, placed between two identical Rogers RT5880 substrates, having a value of 2.2 as relative dielectric permittivity, a loss tangent of 0.0009 and a height of 0.508 mm. The designed antenna resonates at 28 GHz, featuring a maximum gain of 9.77 dBi and a wide frequency bandwidth of 2.9 GHz. Compared to the conventional antenna, this proposed structure achieved an important enhancement of the directivity, with a value around 38.8°. The CST Microwave Studio software was used for all designs and analysis.

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1. INTRODUCTION

The 5G technology is able to connect millions of devices to each other. Fifth generation manages applications such as smart. This future 5G technology can be used in smart cities, intelligent transport, surgical robots, and the "Internet of Things", while maintaining very high speeds, energy efficiency, traffic capacity per zone, spectral efficiency, mobility, connection density, data rate per user, and ultra-short latency. This has prompted the development of microstrip patch antenna. 5G antennas have the best performance in terms of gain, frequency bands, and radiation patterns.

The implementation of the microribbon antennas in the 5G application requires the proper selection of the substrate used in their design to ensure good performance in terms of antenna gain and directivity. A substrat with a low relative permittivity, a low tangential loss (δ), and a large thickness should be used to increase gain and reduce power loss [1].

The fundamental drawback of microstrip patch antennas is their limited bandwidth characteristics. This disadvantage can be mitigated by employing several approaches such as etching slots on the radiating patch or a defected ground structure on the ground plane (DGS), the partial ground plane technique [2], [3], and the feeding technique of the coplanar waveguide line (CPW) [4], [5]. Li *et al*. [6], the loaded slots in the ground plane have produced multiple resonant frequencies, and the return loss characteristics were enhanced by using a partial ground plane, generating a frequency band of 12, 4 GHz. An improvement in the frequency band from 1.77 GHz to 2.14 GHz has also been reported by using the DGS [7]. Li *et al*. [8] by adding two slots in the radiation element of the proposed antenna two frequency bands are generated around 6 GHz and 8 GHz.

After the introduction of slots in the patch antenna, the S11 and the frequency band were improved by 17.808 dB (-53.147 dB) and 0.040 GHz (1.08 GHz), and by inserting a slot in the shape of a diamond on the ground plane, the return loss is further improved to -62.957 dB [9]. The partial ground plane is also used to improve the frequency band [6]–[11]. There is also a planar inverted-F antenna (PIFA) technique to achieve an antenna communicating for multi frequency bands [12]. The antenna array is a technique widely used by researchers to improve the gain and efficiency of the fift generation (5G) antenna. For instance, in the studies [13]–[21], the use of antenna arrays increased the gain and made the antenna radiation patterns more directional, in addition to some improvement in bandwidth.

The aim of this work is to design a microstrip antenna printed on multilayer substrates in order to have a final proposed structure that functions at 28 GHz, and offers a high gain throughout the frequency bandwidth. This antenna is suitable for 5G mobile applications due to its dimensions, performance in terms of radiation, gain, directivity, and bandwidth. The optimized 5G planar antenna is suitable for many countries, as depicted in Table 1 [22] and communication standards.

Table 1. The frequency bands of some countries for 5G applications around 28 GHz

Countris	The 28 GHz frequency band
United States	27.5-28.35
Canada	27.5-28.35
South Korea	26.5-28.9
India	27.5-29.5
Australia	24.25-29.5
Hong Kong	24.25-28.35
Japan	28.3-29.1
Malaysia	26.5-28.1
Singapore	26/28
Uruguay	27.5-28.35

2. DESIGN PROCEDURES OF THE PROPOSED ANTENNA

2.1. Conventional antenna design

We startarted this study by designing a conventional patch antenna based on microstrip technology. This design is based on (1) to (4), the aim is to validate a resonant antenna at 28GHz mounted on RT 5880 substrate [23].

$$L=\frac{1}{2f_r\sqrt{\varepsilon_{reff}\sqrt{\mu_0\varepsilon_0}}}-2\Delta L \tag{1}$$

$$W=\frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{2}$$

L, W: The length and the width of the rectangular patch antenna,
fr: The resonant frequency of the antenna,
μ_0 et ε_0: Permeability and permittivity in free space,
εr: The dielectric relative permittivity,
ΔL: The extension of the patch length around the slots.

The dielectric effective permittivity (ε_{reff}) can be calculated by (3):

$$\varepsilon_{reff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-\frac{1}{2}} \tag{3}$$

here, ‘h’ denotes the substrate’s height, and ΔL can be calculated by (4):

$$\frac{\Delta L}{h}=0.412\frac{(\varepsilon_r+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{4}$$

the conventional antenna consists of a patch having dimensions of 4.232×3.279 mm^2, printed on a Rogers RT 5880 substrate of 0.508 mm height, a relative dielectric permittivity of 2.2, and a tangent loss of 0.0009. The patch antenna is fed by a quarter microstrip line having a width of 0.32 mm, and a length of 2.07 mm. The final optimized parameters of the rectangular antenna are illustrated in Table 2. The geometry of the microstrip patch antenna is presented in Figure 1.

Table 2. The optimized parameters of the conventional patch antenna

Parameter	Value(mm)
Ws	6.22
Ls	6.22
Wp	3.029
Lp	4.232
Wf	0.32
Lf	2.07
h	0.508

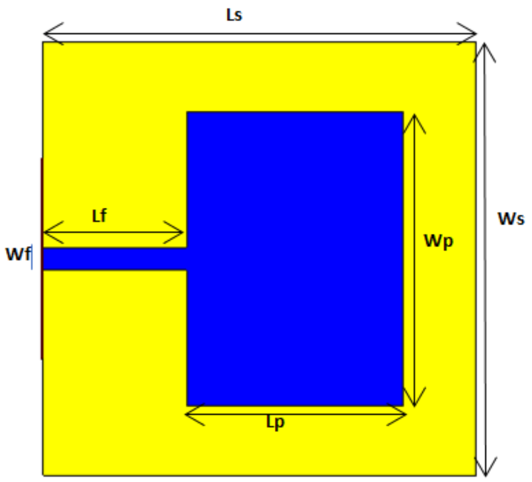


Figure 1. The geometry of the conventional patch antenna

The patch antenna is simulated by using an electromagnetic solver based on the finite integration technique (FIT) and using a high meshing density. As can be depicted from Figure 2, the antenna presents a good matching of input impedance at 28 GHz with a reflection coefficient of -47 dB. For the radiation performances, the simulated antenna has a gain of 7.38 dBi (cf. Figure 3) and a stable radiation pattern with an aperture having an angle of 78° (cf. Figure 4).

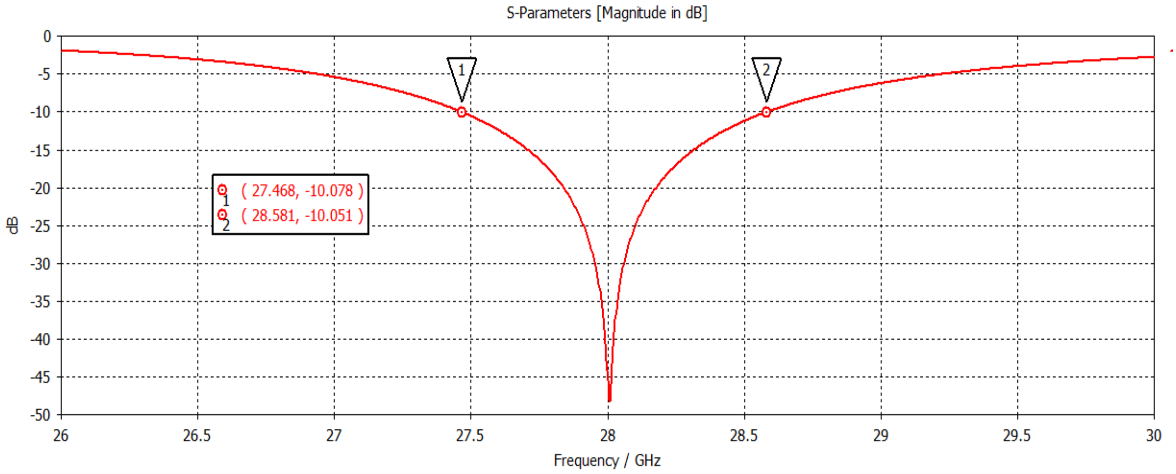


Figure 2. The reflection coefficient versus frequency of the conventional antenna

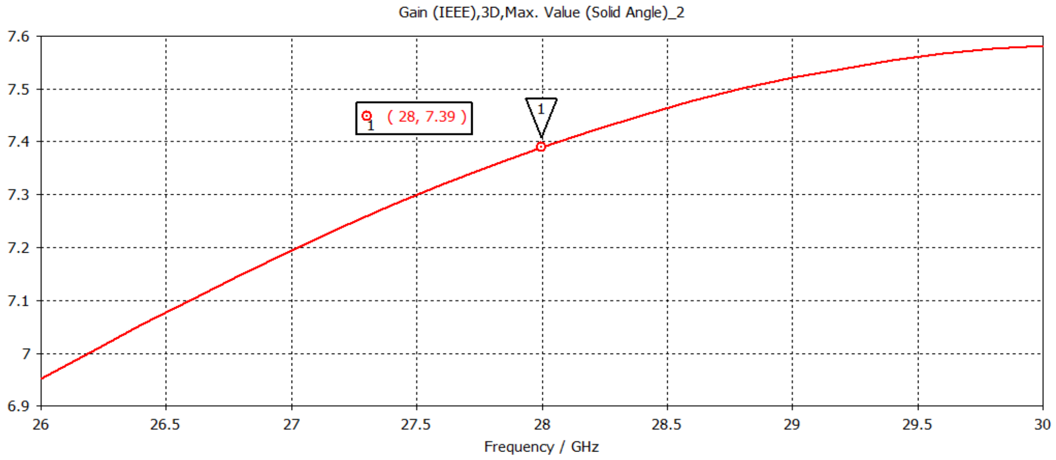


Figure 3. Gain versus frequency of the conventional antenna

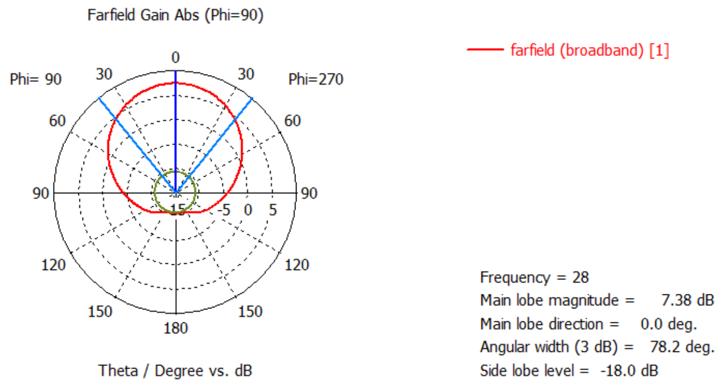


Figure 4. Radiation pattern of the conventional antenna

2.2. Design of the multilayers patch antenna

After the validation of the conventional patch antenna, we have conducted another study in order to enhance the performances of the antenna in terms of matching input impedance, gain and directivity. In this section, we will describe the design procedures of the multilayers antenna using three substrates. As shown in Figure 5, the proposed antenna is printed on a Foam substrate placed between two identical Rogers RT 5880 substrates, with the Foam thickness layer of Ha=0.5 mm. In order to study the influence of some antenna parameters, we have conducted a parametric study on the length of the fed line Lf. Figure 6 shows that the value Lf=1 mm offers a good matching input impedance at 28 GHz.

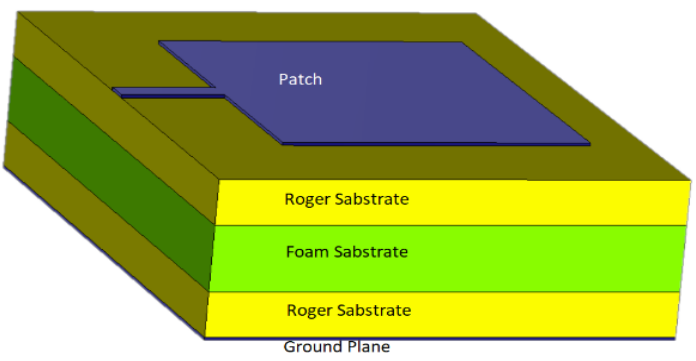


Figure 5. The geometry of the proposed multilayer antenna

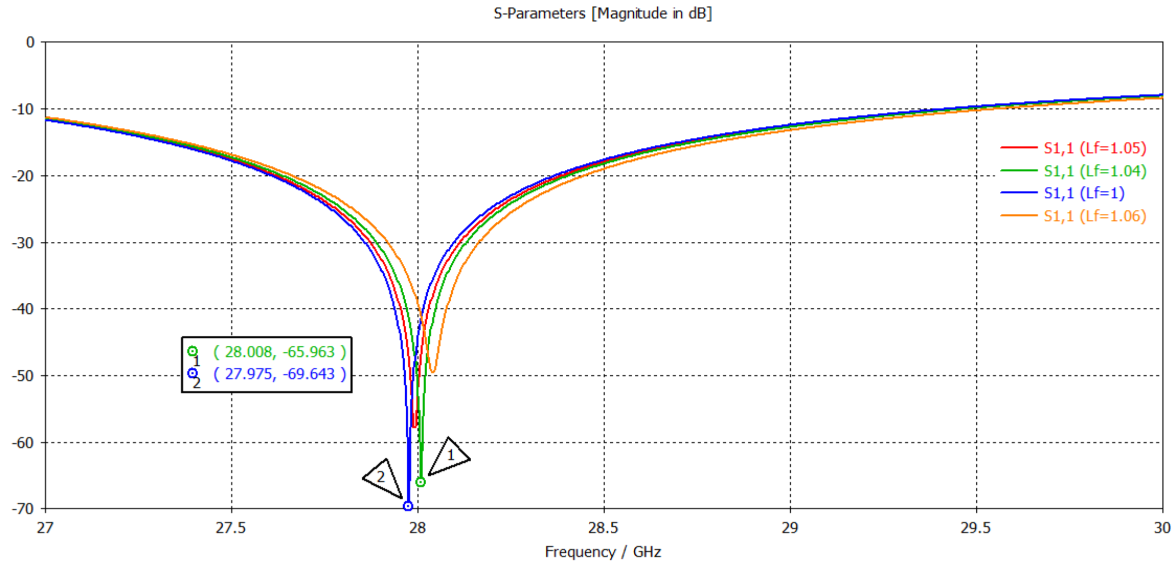


Figure 6. The reflection coefficient as a function of the length L_f of the fed line

In order to choose the adequate substrate which will give us good performances in terms of gain and matching input impedance, we have conducted a study on different versions of Rogers substrates. Figure 7 shows that the Rogers RT5880 substrate presents a good matching of input impedance around 28 GHz, and offers a high gain as illustrated in Figure 8. RT5880 substrate has a permittivity of 2.2, loss tangent of 0.0009, and a thickness of 0.508 mm.

After a series of optimizations in the electromagnetic solver by using various methods, we observed an enhancement of the bandwidth, of the multilayer antenna compared to the conventional antenna, which passed from 1.1 GHz to 2.9 GHz. In addition, we noted an improvement in the reflection coefficient from -47 dB to -65 dB (cf. Figure 9). As presented in Figure 10, there is also an important improvement in the directivity of the radiation pattern; indeed, the standard antenna's aperture angle at 3 dB equals 78.1° (cf. Figure 10(a)), whereas the suggested multilayer structure has an aperture angle of 38.8° (cf. Figure 10(b)). The gain of the proposed antenna and that of the conventional one are plotted versus frequency in Figure 11. We can see that the proposed antenna has better values of gain practically over the entire spectral range with a maximum gap of 2.38 dBi between the two plots at the resonant frequency of 28 GHz.

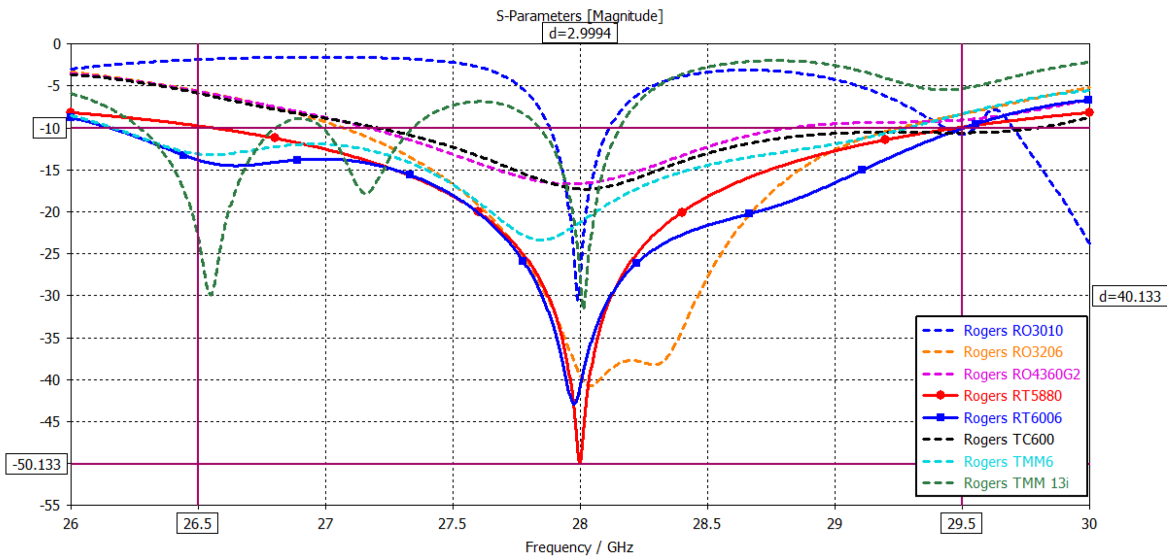


Figure 7. The reflection coefficient of the proposed antenna with different ROGERS substrates

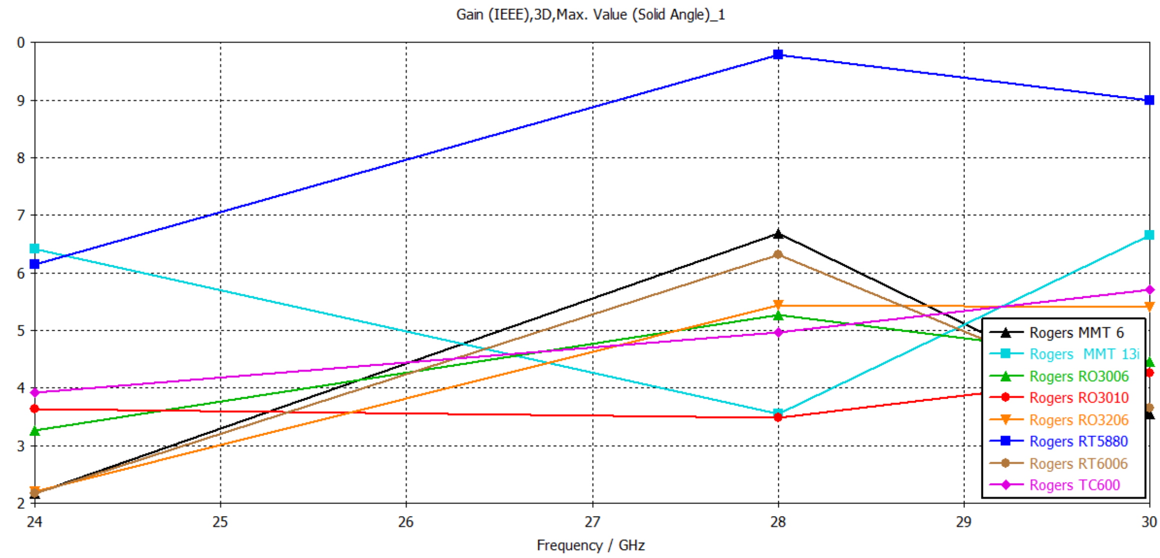


Figure 8. The gain of the proposed antenna with different ROGERS substrate materials

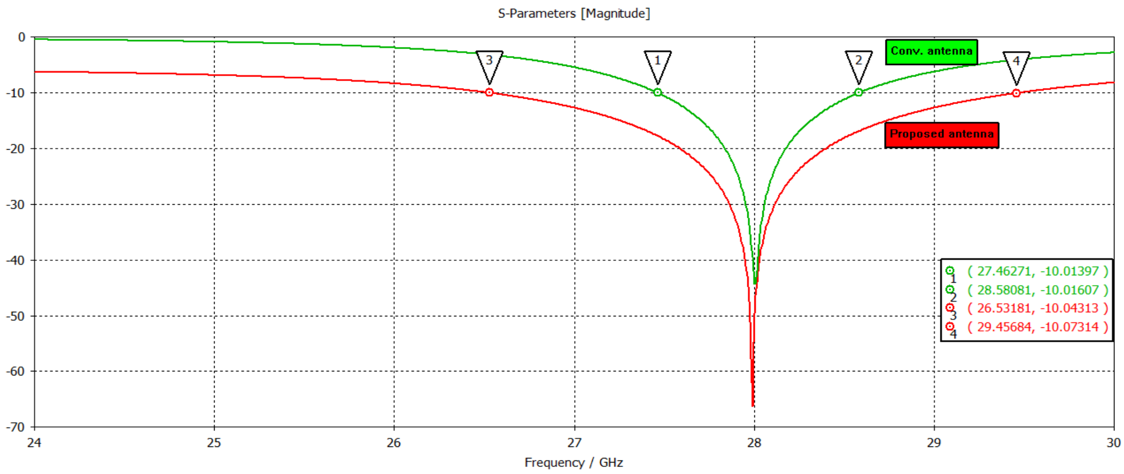
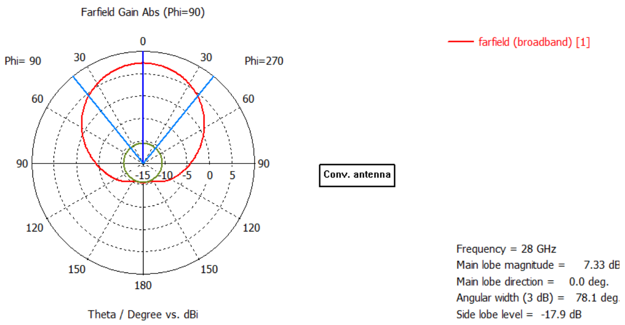
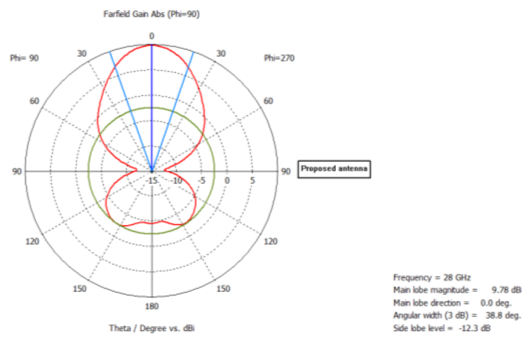


Figure 9. Reflection coefficient of the multilayer antenna and conventional antenna as a function of frequency



(a)



(b)

Figure 10. Two-dimensional simulated radiation pattern of the proposed antenna and the conventional antenna at 3.5 GHz (a) the conventional antenna and (b) the suggested multilayer antenna

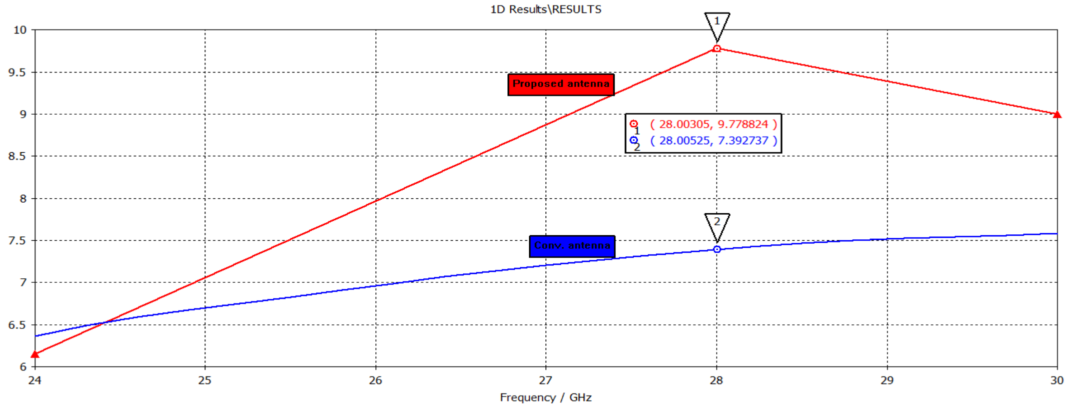


Figure 11. The gain of the proposed antenna in comparison with the conventional one

Finally, Table 3 compares the proposed antenna to various antennas previously proposed in the literature. The comparison took into account various performance parameters, including bandwidth, gain, return loss, and size. Overall, we can say that our antenna has good performance and a fairly small size.

Table 3. Comparison between the proposed antenna and some published antennas

Antenna structure	Operating freqency (GHz)	Gain (dB)	Return loss (dB)	Bandwidth (GHz)	Antenna size dimensions (mm^2)
El-Sayed and Gad [24]	17.07; 26.82	7.65; 5.64	-31; -29.7	0.81; 0.845	5.439×6.975
Saini and Agarwal [25]	28	5.54	-35.7	3.94	3.258×1.664
Jaafar and Ali [26]	28; 38	5.8; 5.5	-45; -20	0.7; 0.38	1.3×1.83
Waleed and Khan [27]	28; 38	3.75; 5.06	-43; -18	3.34; 1.39	1.3×1.2
Hashem and Haraz [28]	28; 45	7.6; 7.21	−40; −14	1.3; 1	6×6
Awan and Zaidi [29]	28	7.6	-56.9	1.38	2.77×4.68
Ghazaoui and El Alami [30]	28.02	5.61	-42.2	4.07	1.8×2.5
Goyal and Modani [31]	28	6.83	-18.2	1.1	4.74×3.45
Mamdouh and Sebak [32]	28	6.6	-40	----	5×5
Al-Khaffaf and Alshimaysawe [33]	60	3.49	-42.4	20.5	1.5357×1.5357
Proposed work	28	9.77	-65	2.9	4.232×3.029

3. CONCLUSION

In this work, we have validated a novel antenna structure suitable for 5G applications that resonates at 28 GHz. This antenna has a stable radiation pattern, a high gain of 9.77 dBi, a wide bandwidth of 2.9 GHz, and a reflection coefficient of -65 dB. We think that associating metamaterials to such antennas, we can obtain enhanced performances and at the end, we can design an antenna array having a high gain and directivity, which is demanded for 5G applications.

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