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

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Abstract. This work presents and describes the design of a novel multilayer antenna structure based on metasurfaces for 5G mobile applications. The suggested antenna has good matching input impedance around 28 GHz, a bandwidth of 2.2 GHz, and an enhancement of gain in comparison with standard patch antenna. This antenna is mounted on two substrates; the first one is the foam, and the second is Roger's substrate suitable for 5G mobile applications. The whole dimensions of the final circuit are 3.28x4.23mm^2. The proposed antenna structure has a high gain, good matching of input impedance and an aperture angle of 57 ° which is more directive compared to the rectangular antenna element.

1 Introduction

Microstrip antennas present interesting candidates for Fifth generation wireless communications, due to their small size, light weight, cheap cost, ease of manufacture, and integration with passive and active microwave circuits, and the possibility to have a multiband behavior. The main requirements of such antenna design are the improvement of the antenna characteristics as a high gain, wide band matching input impedance, and stable radiation characteristics.

For these reasons, researchers have proposed different techniques and methods for meeting the requirements of 5G mobile communication such as the use of Defected Ground Structure (DGS), the partial ground plane permitting to improve the matching input impedance frequency band [1-6]. For gain and radiation efficiency, antenna array configurations can be used to improve them [7-9], among the technique which can enhance and improve the performances of the designed antenna we can use meta-surface [10-12].

In this work a microstrip multilayer, Meta-surface loaded antenna is proposed, operating at 28GHz for millimetric band suitable for 5G mobile applications. The final designed circuit presents an increasing of the gain, and a wide bandwidth. The findings reveal that the suggested antenna is giving good performances in comparison with a standard rectangular patch. The optimized 5G planar antenna is suitable for many countries as depicted in Table.1 [12].

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

Country	28 GHz Band	Country	28 GHz Band
United States	27.5–28.35	Japan	28.3–29.1
Canada	27.5–28.35	Malaysia	26.5–28.1
South Korea	26.5–28.9	Singapore	26/28
India	27.5–29.5	Uruguay	27.5–28.35
Hong Kong	24.25–28.35		

2 Design procedures

2.1 Design of a conventional rectangular patch antenna

Firstly, we have started this study by validating a radiating patch antenna in order to have an idea about the different performances of the rectangular patch comprising the bandwidth of the matching input impedance, the gain, and the radiation pattern. Because, the goal of this work is to develop a novel approach for improving the antenna's radiating performances. The first step was the calculation of the patch dimensions by using the following equations [13]:

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

$$W=\frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (2)$$

- f_r: the antenna's resonance frequency
- μ_0 et ε_0: Permeability and permittivity in free space.
- ε_r: The dielectric material's relative permittivity.
- ΔL: The extension of the patch length around the slots.

The dielectric effective permittivity (ε_{reff}) can be determined using the equation (3).

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

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The height of the substrate is referred to as 'h,' and ΔL may be computed using the following equation (4):

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

After the validation of the patch element dimensions permitting to have a resonant frequency of 28GHz, we have associated the quarter wavelength in order to match the input impedance to 50 Ohm. This antenna is mounted on a Rogers substrate which is adequate for 5G mobile applications having a loss tangent of 0.0009, a relative dielectric permittivity of 2.2, a thickness of 0.508 mm, and a relative dielectric permittivity of 2.2. Metallization thickness is t=0.035mm (see Fig. 1). The rectangular antenna's optimized parameters are shown in Table.2:

Table 2. The frequency bands of some countries for 5G applications around 28GHz.

Parameter	Value(mm)	Parameter	Value(mm)
Wp	4.232	Wf	0.32
Lp	3.279	Lf	2.07
Ws	6.22	h	0.508
Ls	6.22	t	0.035

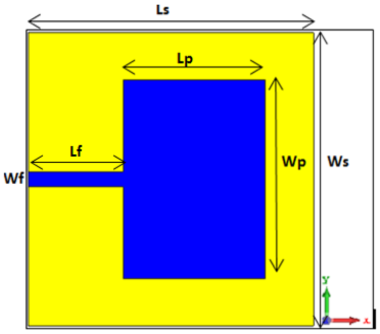
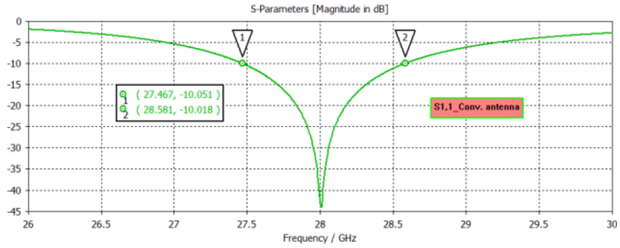
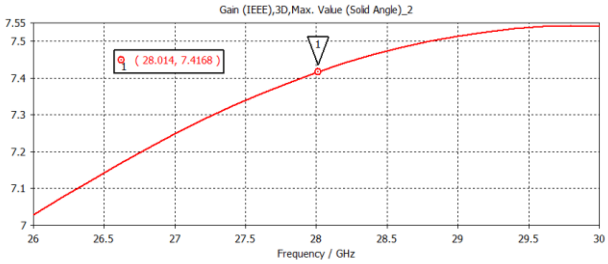


Fig. 1. The patch antenna's geometry

Following the patch antenna simulation, we obtain a good matching input impedance around 28 GHz. With -44dB as reflection coefficient and 1.1 GHz as bandwidth (see Fig. 2 (a)). The obtained gain is around 7.4dBi for 28 GHz (see Fig. 2 (b)). For the radiation pattern, the antenna has an angular width equal to 78.1° (see Fig. 3).



(a)



(b)

Figure 2: (a) Reflection coefficient vs. frequency; (b) Gain vs. frequency

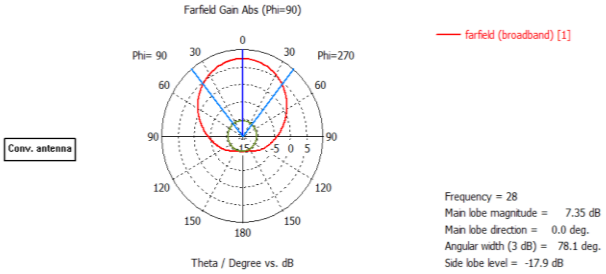


Fig. 2. The polar radiation pattern of the patch antenna

2.2 Design of the multilayer antenna using two Rogers substrates

It is critical to select a substrate with a low loss tangent, low relative dielectric permittivity (ϵr), and high thickness to improve the performance of the planned antenna in terms of gain, directivity, and bandwidth [14]. In the literature, the most commonly used substrates for the design of 5G antennas for millimeter waves is ROGERS type substrate, because of reduced dielectric loss and dispersion [15].

In this section, to increase the suggested antenna's bandwidth, we have used two Roger's substrates. The goal of using two layers is to increase the bandwidth and to increase the gain, and the directivity we have integrated metasurface technique (see Fig. 4). Table 3 shows the metasurface parameters that have been optimized:

Table 3. The metasurface's optimal parameters.

Parameter	Value(mm)
Wm	1.12
Lm	1.12
Lfn	1

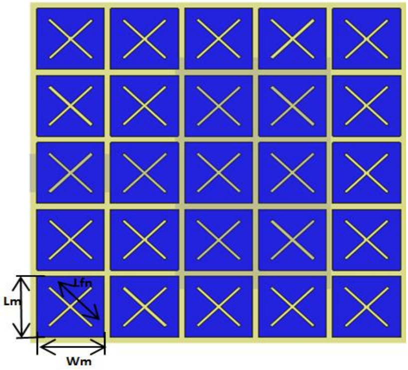
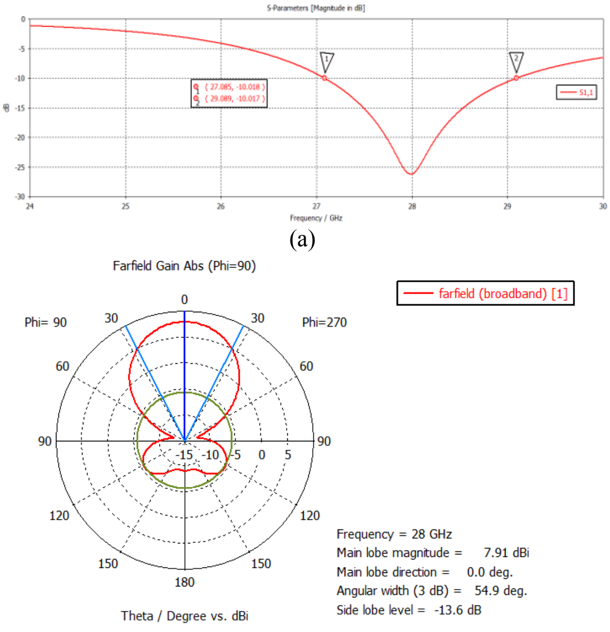


Fig. 4. The proposed multilayer antenna integrating metasurface.

By using the multilayer antenna loaded with metasurface, the bandwidth is improved from 1GHz to 2GHz compared to the standard patch antenna (see Fig. 5 (a)).

The final antenna structure's radiation pattern is steady, with an angular width of roughly 54.9° (see Fig. 5 (b)).



Frequency = 28 GHz
Main lobe magnitude = 7.91 dBi
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 54.9 deg.
Side lobe level = -13.6 dB

(a)

(b)

Fig. 5. (a) The suggested antenna multilayer's reflection coefficient vs frequency, (b) Radiation pattern at 28GHz.

The multilayer antenna loaded with metasurfaces, offers a gain of 7.93dBi at 28GHz (see Fig. 6).

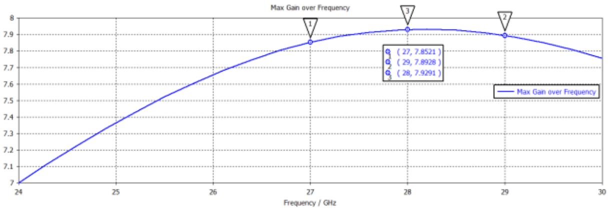
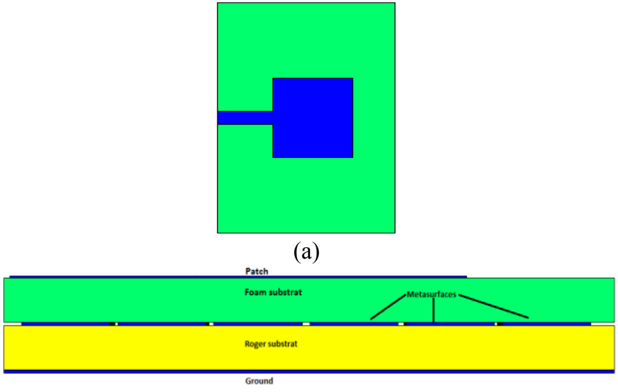


Fig. 6. Gain versus frequency

2.3 Design of the multilayer antenna using the Foam and Roger substrates

The upper substrate of the previous ROGERS-type multilayer antenna is replaced by another FOAM-type substrate with dielectric relative permittivity of 1, a thickness of 0.508 mm, and a loss tangent of 0.0006 (see Fig. 7).



(a)

(b)

Fig. 7. The final antenna structure mounted on the Foam and Roger substrates. (a) From the top, (b) from the side.

Parametric analysis of simulated results shows that the number of resonators influences the performance of the antenna. The figure shows that loading resonators provide a high gain of 9.2dB (see Fig. 8).

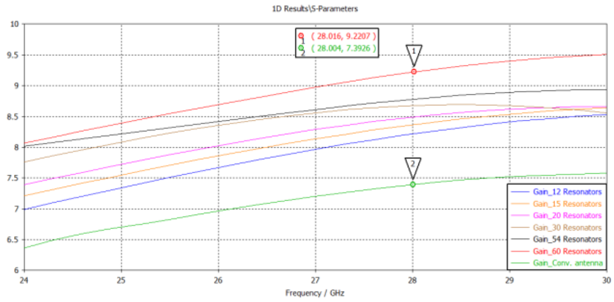
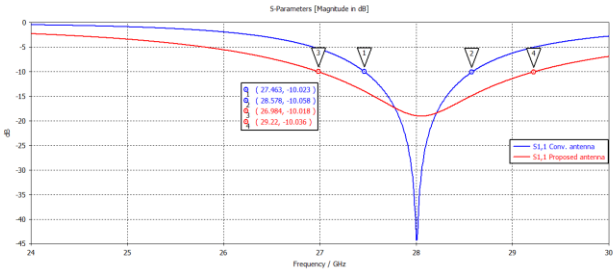
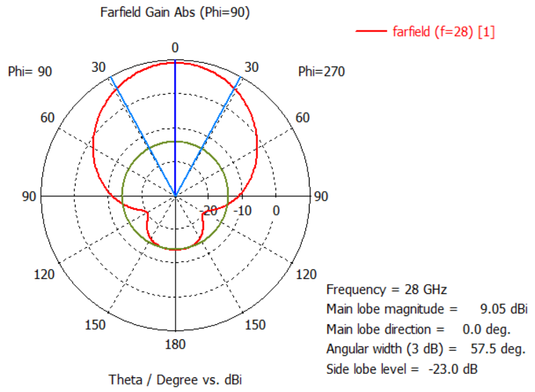


Fig. 8. The reflection coefficient versus number of resonators

Using the suggested antenna, the frequency band is improved from 1.1GHz to 2.2GHz (see Fig. 9 (a)). The radiation diagram is more directional than of the base antenna. An improvement in the opening angle to 3dB is observed for this antenna from 78.1° for the conventional antenna to 57.5 ° for the antenna using metasurfaces (see Fig. 9 (b)).



(a)

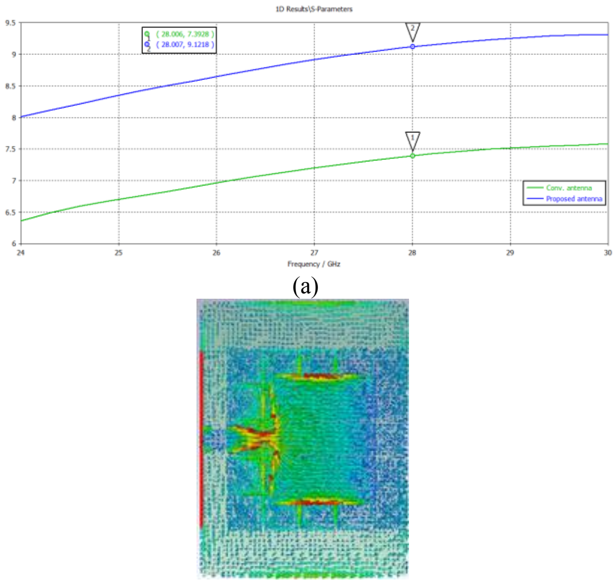


(b)

Fig. 9. (a) Reflection coefficient comparison for the both multilayer antennas versus frequency, (b) Polar radiation pattern for the proposed antenna at 28 GHz

The gain of the proposed antenna is constant throughout the bandwidth, with an improvement to 9.12dB compared to the conventional antenna (see Fig. 10 (a)).

The suggested antenna's current distributions at the 28GHz reasoning frequency are shown in figure 10. The current density reaches its peak towards the patch's margins, as can be seen. (see Fig. 10 (b)).



(a)

(b)

Fig. 10. (a) Comparison of the gain for conventional antenna and multilayer optimized antenna, (b) Current distribution at 28GHz

After the suggested multilayers antenna has been validated in terms of radiation pattern and matching input impedance, Table 4 compares the proposed antenna to several antennas that have been validated in the literature. As we conclude from Table 4, the proposed antenna presents good performances and a compact seize.

Table 4. The proposed antenna is compared to other published antennas.

Ref no.	Antenna size (mm^3)	Operat. Freqency (GHz)	Band. (GHz)	Gain (dB)
16	7×7×1.28	28	0.63	4.55
17	10×10×0.25	28	0.68	6.8
18	19×19×0.708	28.1	1.02	8.03
19	6.28×7.23×0.5	27.95	0.84	6.62
20	5× 5× 0.76	28	1.38	7.6
Pro.	6.22×6.22×0.508	28	2.2	9.12

3 Conclusion and perspectives

This work has described a new study using multilayer antenna associated to metasurface permitting to enhance the radiation performances of a rectangular conventional rectangular patch. The obtained results into simulation have permitted to validate the final antenna structure with an increasing in the bandwidth, the gain and directivity. This structure was validated after many series of optimization by using Random method integrated in the electromagnetic solver. The antenna structure is validated for 5G mobile applications around 28 GHz, the obtained bandwidth permits to use this antenna for many standards of wireless communication. As perspectives to this work and in order to increase more the gain and the directivity we can increase the number of radiating elements by using antennas array. In the same time, the association of varactor diodes will permit to control the frequency band.

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