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A 28 GHz Rectangular Microstrip Patch Antenna for 5G Applications

Omar Darboe[1], Dominic Bernard Onyango Konditi[2] and Franklin Manene[3]

[1]*Department of Electrical Engineering, Pan African University Institute of Basic Sciences Technology and Innovation, Kenya.*

[2]*School of Electrical and Electronics Engineering, The Technical University of Kenya, Kenya.*

[3]*Department of Electrical and Control Engineering, Egerton University, Kenya.*

Abstract

Communication systems have been driven towards the fifth generation (5G) due to the demands of compact, high-speed, and large bandwidth systems. In this research, a 28 GHz rectangular microstrip patch antenna is designed and simulated. The patch has a compact structure of 6.285 mm × 7.235 mm × 0.5 mm. The proposed antenna resonates at 27.954 GHz with a return loss of -13.48 dB, bandwidth of 847 MHz, gain of 6.63 dB and efficiency of 70.18%. An inset feed transmission line technique is used for matching the radiating patch and the 50 Ω microstrip feedline. In the design, a Roger RT Duroid 5880 substrate which has a dielectric constant of 2.2 and loss tangent of 0.0009 with a height of 0.5 mm was used. The geometry of the antenna was calculated and simulated results have been displayed and analysed using Computer Simulation Technology Microwave Studio.

Keywords: 28 GHz, millimeter wave, Microstrip patch antenna, 5G, Return Loss**.**

I. INTRODUCTION

The fifth-generation network is expected to greatly enhance communication capacity by exploiting the vast amount of spectrum in the millimetre wave. It is also expected to be able to provide and support very high data rates as much as 100times of fourth generation capacity [1], [2].This leads to new challenging network requirements as well as in the antenna design for 5G communication systems in order to meet the expected data rate and capacity.

Due to the stupendous increase in mobile data in 5G, several fields such as realistic Ultra High Definition, Artificial Intelligence, Blockchain, and services of Internet of Things such as Smart Cities, Smart Transportation and Smart grids will be significantly enhanced. As the mobile industry gears towards utilizing the millimetre-wave spectrum, carriers are likely to use the 28, 38, and 73 GHz bands that will become available for future technologies [3].

Base on the requirements for 5G, antennas with light weight, low profile (compact size), low cost mass production, ease of installation, conformable to planar surface and also non-planar surface, mechanically robust when mounted on rigid surface and compatible with monolithic microwave integrated circuit are quite important [4]. Despite its narrow bandwidth, Microstrip patch antenna can be a perfect candidate to meet all the above requirements.

In this research, a single microstrip patch antenna is proposed for 5G communication. The proposed antenna is designed to resonate at 28 GHz and has a low-profile structure with dimensions of 6.285 mm × 7.235 mm × 0.5 mm.

II. MATERIALS AND METHODS

For performance predictions and simplified analysis, a rectangular shaped microstrip patch antenna operating at 28 GHz for 5G application is proposed as shown in the figure below:

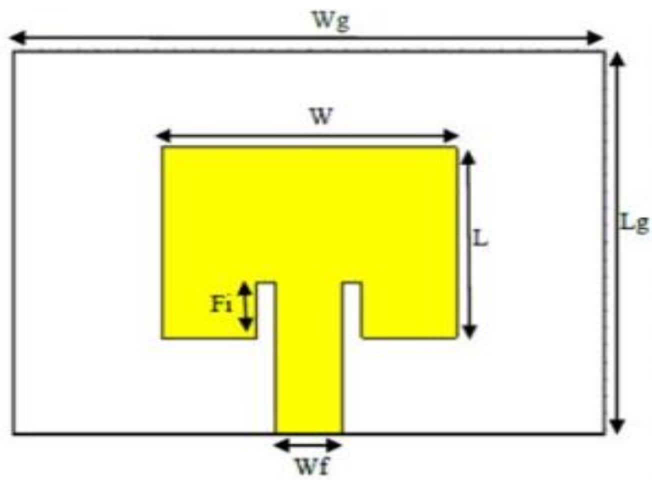


Fig. 1: Geometry of the proposed Mcrostrip patch antenna

After choosing the operating frequency (28 GHz) and dielectric constant of the substrate (RT Duroid 5880), the main parameters are the Length L, the width W, and the thickness h, of the substrate as shown in fig 1. The dimensions of the microstrip patch antenna were designed using the approximation equation [5],[6],[7] below.

1. The Patch Width, W.

$$W = \frac{c_o}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (1)$$

Where c_o is velocity of electromagnetic wave in free space, f_r is operating frequency, ε_r is dielectric constant of the substrate.

2. Effective Dielectric Constant, ε_{reff}.

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{w}\right)^{-0.5} \quad (2)$$

Where h is thickness of the substrate in mm, w is width of the patch in mm.

3. Effective Length, L_{eff}

$$L_{eff} = \frac{c_o}{2f_r\sqrt{\varepsilon_{reff}}} \quad (3)$$

The patch of the antenna is electrically longer than the physical dimension due to fringing factor. This factor is subtracted from the effective length to give the actual length of the patch which is given by:

$$\Delta L = 0.412\frac{\left(\frac{w}{h}+0.264\right)(\varepsilon_{reff}+0.3)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h}+0.813\right)} \quad (4)$$

$$L = L_{eff} - 2\Delta L \quad (5)$$

where ΔL is the length extension and L is the actual length of the antenna.

The proposed antenna was connected with 50 Ω inset feed transmission feedline. This technique was used because it requires no further additional matching element. The transmission feedline length and width are calculated using equation. To match the input impedance, the feed position was moved to 1.44 mm away from the edge whilst the gap between the patch and the feedline is 0.12mm.

$$F_i = 10^{-4}\{0.001699\varepsilon_r^7 + 0.13761\varepsilon_r^6 - 6.1783\varepsilon_r^5 + 93.187\varepsilon_r^4 - 682.69\varepsilon_r^3 + 2561.9\varepsilon_r^2 - 4043\varepsilon_r + 6697\}\frac{L}{2} \quad (6)$$

$$W_f = \frac{7.48\times h}{e^{\left(z_0\frac{\sqrt{\varepsilon_r+1.41}}{87}\right)}} - 1.25\times t \quad (7)$$

Where z_0 is the input impedance, t is the ground thickness in mm.

4. Ground Plane dimensions

$$W_g = 6h + W \quad (8)$$

$$L_g = 6h + L \quad (9)$$

Where W_g is the width of the ground plane in mm, L_g is the length of the ground plane in mm.

Figure 1 and figure 2 shows the geometry and simulation environment of the rectangular patch antenna respectively. The overall dimension of the antenna is with a ground length and width of 6.285 mm and 7.235 mm respectively. The dimension of the physical parameters was optimized as tabulated in table 1.

Table 1. Optimised Dimension of the Proposed Antenna

Parameter	**Dimension (mm)**
Ground Plane Length, L_g.	6.285
Ground Plane width, W_g.	7.235
Length of patch, L.	3.4
Length of width, W.	4.1
Height of substrate, h.	0.5
Width of feedline, W_f.	1.25
Feedline insertion, F_i.	1.25
Ground Thickness, t.	0.035

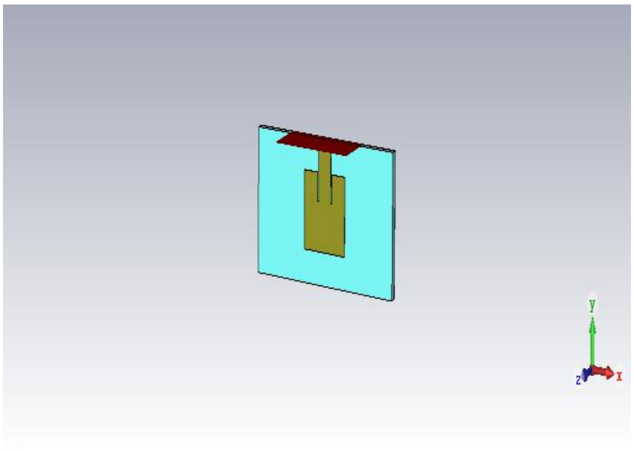


Fig. 2: Simulation environment of the proposed rectangular microstrip patch antenna

III. SIMULATED RESULTS AND DISCUSSION

The design, modelling and simulation of the antenna was done in Computer Simulation Technology Microwave Studio.

III.I Return Loss

A Return loss value of -10 dB is taken as the base value which signifies that 10% of incident power is reflected i.e. 90% of the power is accepted by the antenna which is considered excellent for mobile communication. The patch antenna resonates at 27.954 GHz with a return loss of -13.48 dB as shown in figure 3 below. The S_{11} parameter were obtained using waveguide port configuration. The antenna is having an impedance bandwidth of 847 MHz.

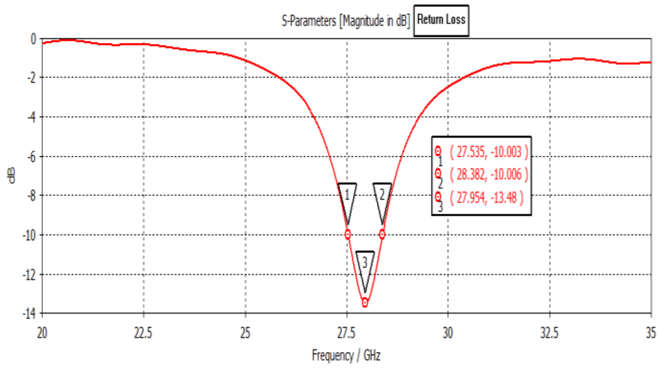


Fig. 3: Return Loss versus frequency of proposed antenna

III.II VSWR

For a patch antenna, the VSWR should not be more than 2 and less than 1 along the bandwidth of efficiency. Ideally it should be 1. Figure 4 shows the voltage standing wave ratio against the frequency. As can be observed from figure 4, the VSWR value achieved at resonant frequency of 27.954 GHz is 1.5376.

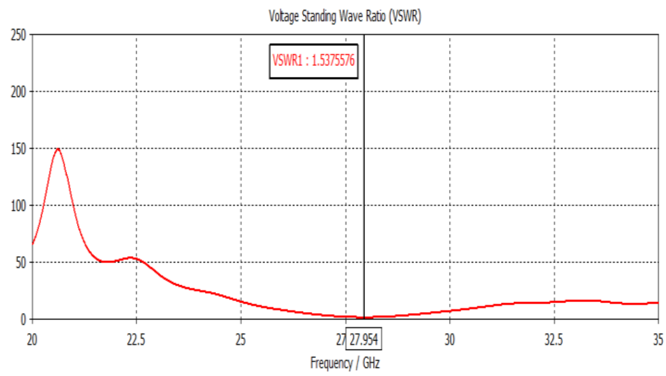
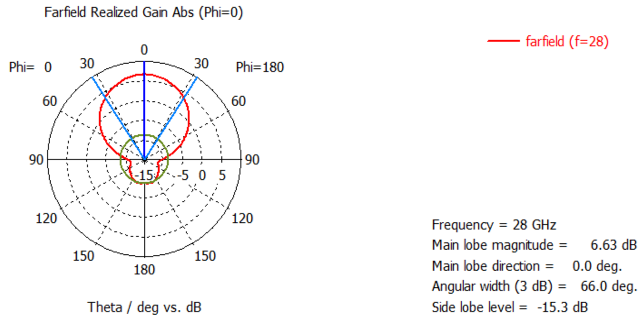


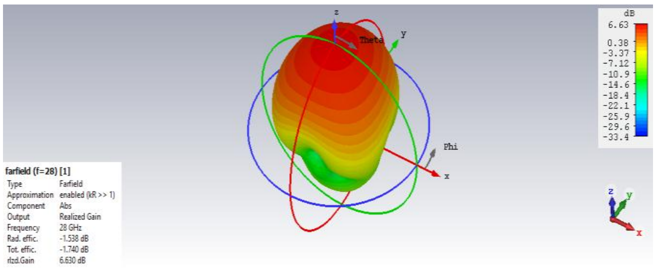
Fig. 4: VSWR of the proposed antenna.

III.III Gain

The antenna has a relative high gain of 6.63 dB which is considered very good for compact microstrip antenna and a half power beam width of 66.0° with side lobe level of -15.3 dB as shown in figure 5.



(a)

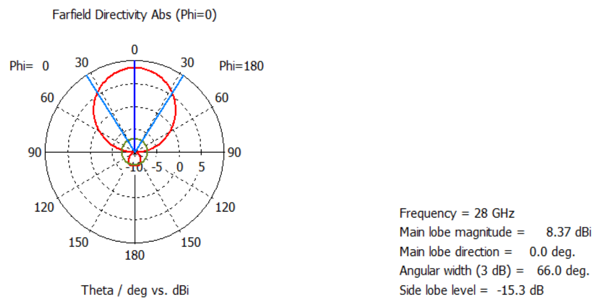


(b)

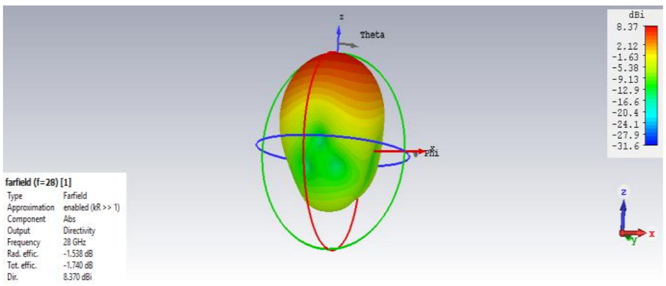
Fig. 5: (a) 2-D polar plot **(b)**3-D Plot of the gain of the proposed antenna.

III.IV Radiation Pattern

Figure 6 (a) and (b) shows the 2-D and 3-D radiation pattern of the proposed antenna respectively. It shows that the antenna has a directivity of 8.37 dBi.



(a)



(b)

Fig. 6: (a) 2-D polar plot Radiation Patterns of the proposed prantenna at phi=0 **(b)** 3-D radiation pattern

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III.V Surface Current

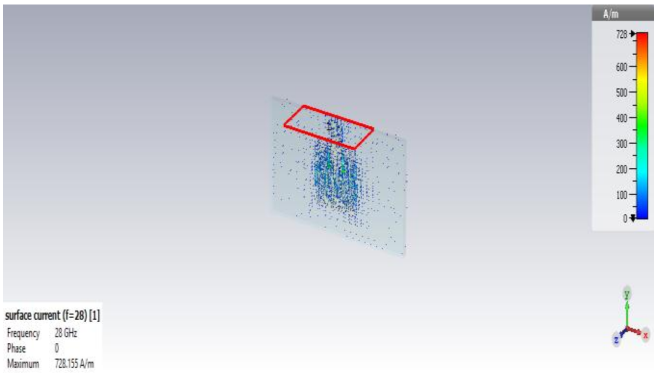

Fig. 7: Surface current distribution of the proposed antenna

III.VI Smith Chart

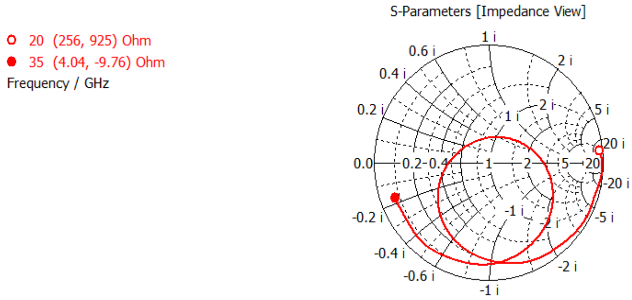

Fig. 8: Smith Chart of the proposed antenna

Table 2. Summary of Simulated Results

Antenna Parameter	Values
S_{11}	-13.48 dB
Bandwidth	847 MHz
Gain	6.63 dB
VSWR	1.5376
Efficiency	70.18%
HPBW	66.0^0

IV. CONCLUSION

Due to the increase in demand of mobile data and portable devices, a rectangular microstrip patch antenna has been proposed for 5G application. The antenna resonates at 27.954 GHz with a return loss of -13.48 dB. The proposed antenna shows a radiation efficiency of 70.18% and a gain of 6.63 dB. The results also shows that a bandwidth of 847 MHz can be achieved as compared to previous work: 400 MHz in [8] and 582 MHz in [9].This proposed antenna can serve as good option for 5G mobile communication which requires high bandwidth. The size of the antenna is very compact and thus is suited devices where the space is a major constrain.

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