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A Compact High-Gain Microstrip Patch Antenna with Improved Bandwidth for 5G Applications

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ABSTRACT- This paper presents a High Gain, enhanced Bandwidth Patch antenna for 5G operations. The dual-band is achieved using an inset-fed feeding technique for the microstrip patch antenna, which operates at the 28/38GHz millimeter-wave band. The high gain of the patch is achieved by inserting two rectangular slots on the radiating element of the patch. The designed antenna Bandwidth is improved by incorporating three steps at the edge of the rectangular patch. The substrate used for the format is Rogers RT Duroid 5880, with a thickness of 0.508mm, loss tangent of 0.0009, and a relative permittivity constant of 2.2. Ansys HFSS software is used for the simulation. The design attained a maximum gain of 8.2dB and 7.8dB at 27.84GHz and 39.32GHz. The impedance bandwidth response of 1.46 and 4.27GHz at the respective resonating frequencies below the -10dB line of the parameters are achieved. A compact antenna is proposed with a size of 3.2x4.9x0.508 and has a high Gain with a wide Bandwidth at both bands. The proposed antenna has achieved a good performance within the operating bands, making it suitable for 5G applications.

Keywords: 28/38GHz band, 27.84GHz and 39.32GHz resonances, Microstrip-Patch, Dual-Band, High Gain, 5G-Application, slots, and Bandwidth.

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1. INTRODUCTION

The rapid growth of wireless communication brought in a lot of challenges for the service providers to offer better services to their customers. Wireless technology has grown from one generation to another, with services as demanded. Some of the services, such as the INTERNET and other IOTs, require greater Bandwidth, fast connectivity, and additional security for efficient communication. The wireless industry has progressed from analog to digital systems such as 2G (second generation). The evolution of 3G (third-generation) brought in applications such as television/video and global roaming with broad Bandwidth. The industry's growth brought in 4G (late technology evolution), which gave us better video calls, mobile TV, and video broadcasting service [1]. The need for better performance in the wireless industry brought in 5G, which can power technology better than the earlier generations could handle. The 5G technology can provide robotization, remote healthcare, and IoT (internet of things) devices [2].

The microstrip patch antenna element provides good candidacy for the 5G antenna requirements due to its compactness, conformability, lightweight, and low cost. However, the microstrip patch antennas have disadvantages in their primary forms, such as low gain, narrow Bandwidth, and low efficiency [3]. Literature shows that so many experimenters have used different approaches to improve the performance of the patch antenna [4-5]. So many researchers have used arrays in various works [6-9], while others use single elements with different configurations for different applications [10-12]. In [13]. In the same year, A. Pon Bharathi et al. proposed a compact microstrip patch antenna using DGS for 5G applications [14]. The researcher achieved broadband of 6GHz, but the gain was minimal at the resonating frequency. In [15], H-slotted DGS was used to develop a dual microstrip patch for 5G. Recently, a comparison of FR4 and Rogers substrates in multiband two-slot rectangular patch antenna for 5G applicate has been investigated[16]. A coplanar waveguide is presented in[17] for 5G applications. The proposed antenna used an elliptical shape for its advantage of wide Bandwidth. They achieved a wide bandwidth of 4.78GHz at the lower and 4.16GHz in the band. In [18], A novel design was used for a compact patch antenna operating at 38/60GHz; matching impedance of 2GHz and 3.2GHz at each band was achieved.

Recent works have made much progress in designing antennas for the millimeter-wave band. Nonetheless, for the 5G systems applications, directional antennas with wideband and high gains are needed for high data rate transmission[19]. This paper proposed a compact microstrip patch antenna operating in dual-band. The design focuses on the Bandwidth and gain of the patch antenna. The rectangular shape is chosen because of its fabrication simplicity compared with other forms proposed by Darboe et al. [20]. A microstrip feedline method is selected for our design because it can give a larger Bandwidth than the other feeding Techniques [21]. Our paper is arranged in sections as follows: *Section-1*, the introduction introduces the topic and a brief discussion of the works done by other researchers. *Section-2*, Design of the Antenna, gives detailed Mathematical modeling and analysis of the proposed patch antenna. *Section-3* discusses results and other related works. *Sections-4* gives the conclusion of the design.

2. DESIGN OF THE PROPOSED ANTENNA

2.1 Design Configuration and the Antenna Model ling

In the initial stage, the standard formulae of a rectangular microstrip patch are used to calculate the parameters of the proposed antenna as indicated in *equations (1) to (7)*. This formula can be used to calculate the width of our designed patch

$$w = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

Where c is the velocity of light, f_r is the resonant frequency, and ε_r is the relative permittivity.

Since the field is not only limited to the inside of the substrate material, we must consider the effective dielectric material of the substrate, which is determined by *equation (2).*

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

h = Height of the patch, w = width, and ε_r = dielectric constant of the substrate

The actual length of the patch is determined by

$$L = L_{eff} - 2\Delta L \tag{3}$$

The effects of the fringing fields are a result of the effective length, which is determined by

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \tag{4}$$

Where ΔL is the extension of the length because of fringing effects. The microstrip antenna patch is electrically longer than the physical scope[22]. The formula represents this

$$\Delta L = 0.412h\frac{\left(\frac{w}{h} + 0.268\right)(\varepsilon_{eff} + 0.3)}{(\varepsilon_{eff} - 0.3)\left(\frac{w}{h} + 0.8\right)} \tag{5}$$

The dimensions of the ground plan are given by

$$L_g = 6h + L \tag{6}$$

$$w_g = 6h + w \tag{7}$$

The L_g and w_g are the ground plane's length and the ground plane's width, respectively.

The microstrip feeding technique adopted in this paper is determined by

$$z_{in} = \sqrt{z_o \times z_1} \tag{8}$$

$Z_o = 50\Omega$ is to the transmission line impedance.

Z_1 is the characteristic impedance.

The two parameters in the inset feed are fed width (wf) and length (Lf). The formula of the given parameters is given in equations 9 and 10, respectively.

$$w_f = \frac{2H}{\pi}\{B - 1 - \ln(2B - 1) + \frac{\varepsilon_o - 1}{2\varepsilon_r}[\ln(B - 1) + 0.39 - (\frac{0.61}{\varepsilon_r})]\} \tag{9}$$

$$L_f = 3.96 \times w_f \tag{10}$$

Where $$B = \frac{377\pi}{2z_o\sqrt{\varepsilon_r}} \tag{11}$$

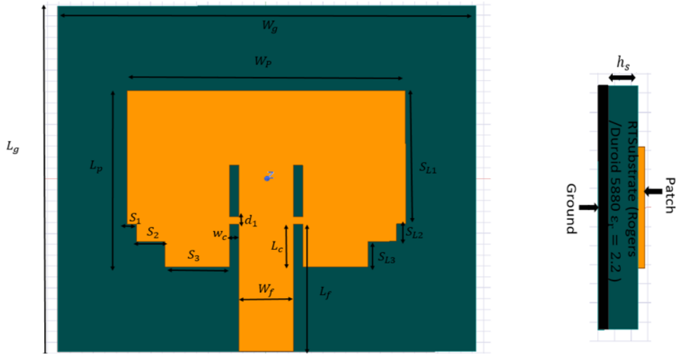
The proposed design is a high gain, enhanced bandwidth microstrip patch antenna. These parameters are achieved in three different stages. Initially, a dual-band microstrip patch antenna was designed, and the dual-band property was acquired by inserting a feedline into the radiating element of the patch antenna. The inset feed is radiating at 38GHz, whiles the patch element radiates at 28GHz. Two rectangular slots are used to improve the antenna's properties (Gain) by inserting them into the radiating part of the antenna. Which gave the antenna better properties than the first design (*Figure 1a*). A simple novel approach is used to improve the antenna's Bandwidth, which is done by cutting the bottom edges of the patch in three steps. The proposed antenna operates in the millimeter band for 5G application. The initial design of the rectangular patch made the antenna radiate at 26.8GHz and 37.02GHz with a return loss below $-10dB$. The patch optimization by using slots and steps as mentioned is stated in *table 1* below.

(a) First step (b) Second step (c) Third step

Figure 1: Design steps of the Proposed Patch Antenna

Table1. Dimensions of the Design Parameters

Variable	L_g	W_g	L_P	W_P	L	W	h_s
Values (mm)	8	8	4.9	3.2	8	8	0.508
Variable	W_f	L_C	W_C	$S_1, S_2 and\ S_3$	$S_{L1}, S_{L2} and\ S_{L3}$		
Values (mm)	1	0.8	0.15	0.164,0.475,and 2.561	4.24,0.3169, and 0.4751		



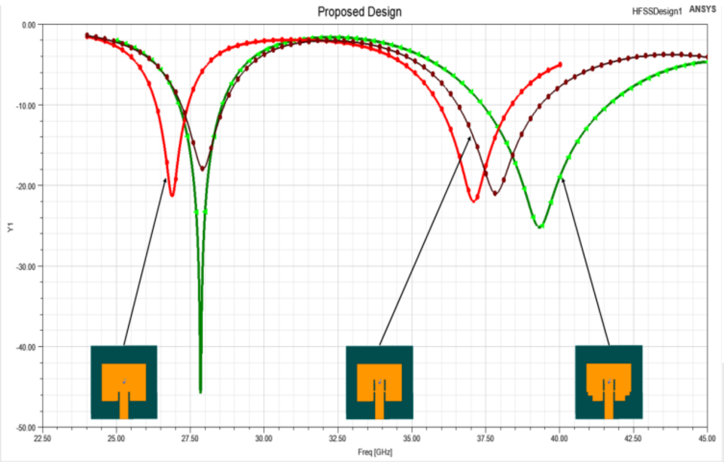
(a) Top view (b) side view

Figure 2: The Geometrical layout of the proposed antenna

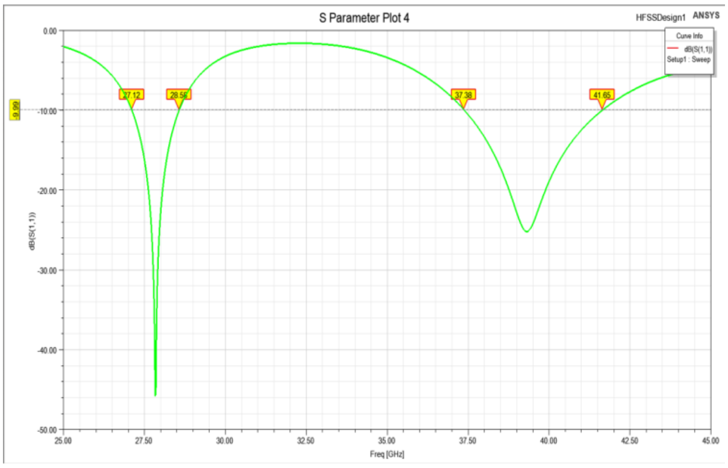
3. DISCUSSIONS OF RESULTS

3.1 Resonating frequency and bandwidth of the antennas

In this section, the results of this paper are discussed. The reflection coefficient of the proposed design shows that the patch antenna is resonating at 27.84GHz and 39.32GHz. It can be observed that the patch antenna achieved a bandwidth of 1.46GHz and 4.27GHz at the respective bands with a return loss of -45.85 and -25.21, as shown in *figure 3* below. The approach used is to improve the Bandwidth to achieve a 60% increment for the proposed antenna. The results of each design approach are shown in *figure 3*.



(a) Return loss of the different designs



(b) The Bandwidth of the proposed design

Figure 3: The return loss of the Designs

The proposed designs are in step one and step two in *figure 1a*. The first design achieved the dual-band characteristic with a resonating frequency of 26.89 and 37.41. However, the gain was low, which was improved in *step 2* in *figure 1b* to 6.8 and 7.4 at the respective bands of operation. As shown in *figure 1c*, the third step enhanced the Bandwidth to 1.5GHz and 4.3GHz at the individual bands.

3.2 Gain of the designed antenna

In *figure 4*, the system gain of the proposed antenna is and at the respecting bands of operations which is sufficient for 5G application systems. The inserted slots on the radiating patch are effective for improving the gain. This is a more straightforward method than other designs, and it proved to be effective, as demonstrated by the simulation results.

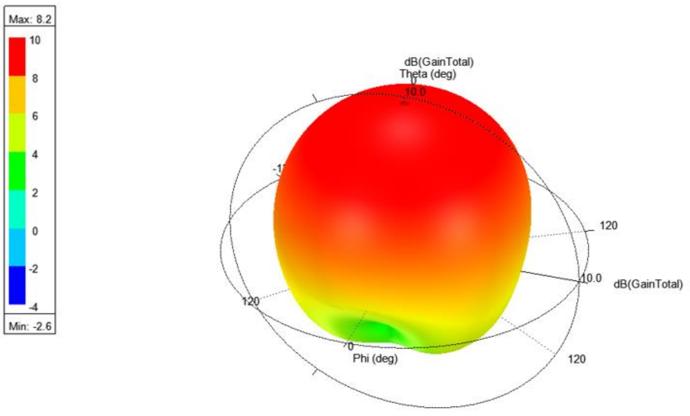


Figure 4. antenna radiation at 27.84GHz

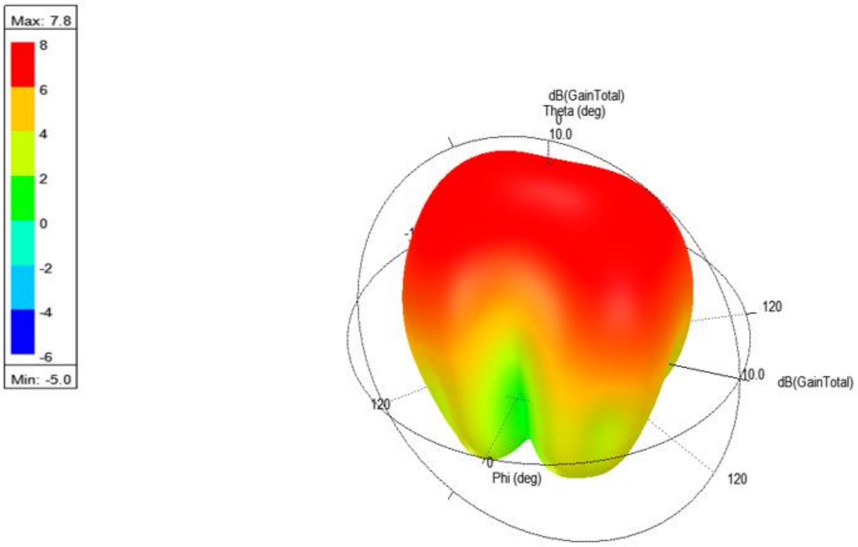
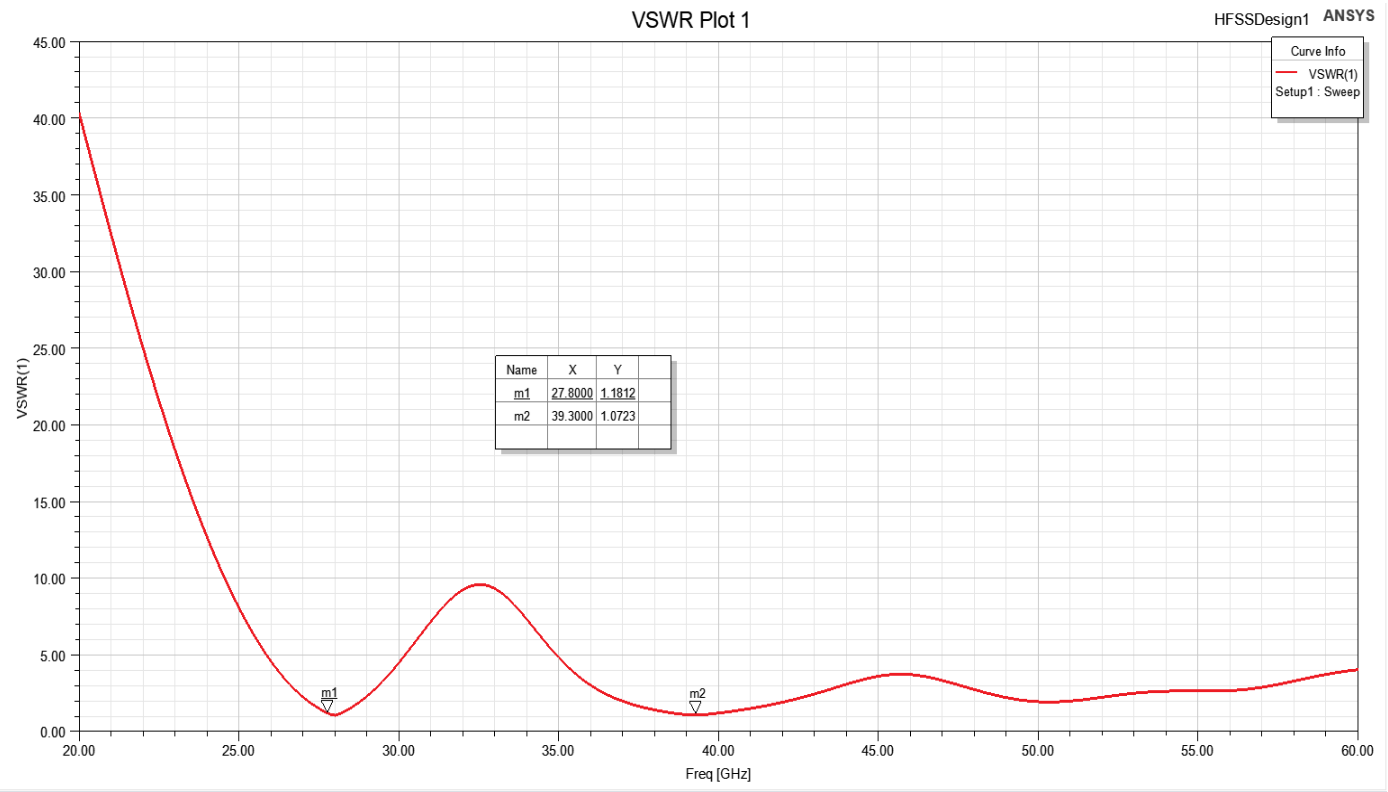


Figure 5. antenna radiation at 39.32GHz

3.3 Voltage standing wave ratio (VSWR)

The VSWR should be between 1 and 2, which shows that the antenna performs efficiently and matches. It is observed that the VSWR values of 1.18 and 1.07 are achieved at resonant frequencies of 27.84GHz and 29.32GHz, as depicted in *figure 6* below.



Name	X	Y
m1	27.8000	1.1812
m2	39.3000	1.0723

Figure 6. Voltage standing wave ratio (VSWR)

3.4 Results and discussions

The Proposed design gives good results suitable for 5G applications. It can be seen that inserting slots on certain portions of the radiating element of a microstrip improves the antenna properties. This approach gives the design a high gain of 8.2/7.8dB at respective bands of operations suitable for 5G applications. The method used for the bandwidth enhancement is a simple approach but effective in improving the Bandwidth to a maximum value of 4.44GHz at the upper band. This is achieved by cutting the edges of the patch. This also improves the return loss, as shown in *table 2*. Some researchers have used other methods like incorporating contours on the radiating patch element [23], but our approach adopted in this paper has better results in improving the gain and the Bandwidth of the microstrip patch antenna.

3.5 Summary of designed antenna

Although the slots and the steps incorporated in the design of the antenna alter the resonating frequency, it was able to improve the performance of the proposed antenna, and the antenna is resonating within the desired bands frequency.

Table 2: Summary of the Design Process

Design	**Resonating Frequency (GHz)**	**Return Loss (GHz)**	**Gain(dB)**	**Bandwidth (GHz)**	**VSWR**
First Design	26.89/37.41	-21.5/-22	5.3/6.2	1.42/2.6	1.56/1.38
Second Design	27.91/37.68	-18/-21	6.8/7.4	1.5/3.8	1.61/1.23
Proposed Design	28.12/39.34	-45.85/-25.21	8.2/7.8	1.46/4.44	1.18/1.07

3.6 Comparison with other works

Table 3 compares our data with other works in the open literature. Our data compare favorably with most of the data, which implies that cutting edges in the microstrip patch makes the proposed antenna compact and enhances its Bandwidth and corresponding high gain.

Table 3. Comparison with other published Works

Ref	**Resonating Frequency GHz**	**Bandwidth GHz**	**Gain (dB)**
[12]	23.52/28.39	1.16/0.634	4.55
[24]	28/38.5	5.13/11.63	8.31/6.38
[25]	56.32	5.5/8.67	5.5/6.87
[17]	38/60	2.0/3.2	6.5/5.5
[9]	28	0.847	6.63
[26]	1.738/6.01	4.272	2.75
This work	28/38	1.5/4.3	8.2/7.8

4. CONCLUSION

The proposed antenna is composed of a single element but by cutting it at the edges, it is demonstrated that it offers relatively good gain and return loss. Based on its attributes the proposed antenna is suitable for 5G applications. Furthermore, the Beam width has also been enhanced. The future works of this design will be the use of the single element to design an array and fabricate it.

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