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Gain enhanced 5.8 GHz patch antenna with defected ground structure: design and measurement

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ABSTRACT

A rectangular microstrip patch antenna including a rectangular defective ground structure (DGS) is introduced to simultaneously enhance gain, bandwidth, and return loss while reducing antenna dimensions. This small antenna is engineered for 5.8 GHz applications, functioning throughout the frequency spectrum of 5.62 to 5.94 GHz. The design was executed on a 1.6 mm thick FR-4 substrate with a relative permittivity of 4.3, utilizing a microstrip line feed. The dimensions of the antenna are 31.75×28 ×1.6 mm³. The design approach utilized computer simulation technology (CST) Microwave Studio simulation software. The antenna attains resonance at 5.8 GHz, providing an initial bandwidth of 270 MHz and a return loss of -26 dB. A rectangular DGS was implemented to boost performance, yielding a 21.89% increase in bandwidth to 323 MHz and substantially enhancing the return loss from -23 dB to -47 dB. The gain increased from 3.95 dBi to 5.10 dBi, indicating a 30% enhancement, while sustaining an efficiency of around 83% at the resonant frequency. The antenna was constructed, and experimental measurements of parameters including gain and return loss closely matched the computer results.

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1. INTRODUCTION

Due to their low profile, light weight, and ease of manufacture, planar patch antennas are widely used in wireless uses [1], [2]. Traditional patch antennas often have narrow bandwidths because the ground plane and the patch are coupled in a way that sounds like a resonance. Also, as the working frequency drops, the antenna measurements get much bigger because they are inversely related to frequency [3]-[5]. The electromagnetic field distribution between the patch and the ground plane can be changed by adding a defected ground structure (DGS) to patch antenna designs. This can help reduce the size of the antenna, increase bandwidth, and improve gain. Reddy and Vakula [6] a DGS in the form of a circular dumbbell was used to increase the bandwidth across all three frequency bands, but it did so at the cost of a small drop in gain. This kind of DGS was first made to be used in filter design. Ahn *et al*. [7] subsequently various other DGS shapes were investigated to facilitate the development of different microwave circuits, including filters [8]-[15] amplifiers. Dash *et al*. [16] two independent yet complementary DGS configurations rectangular and H-shaped slots were employed, resulting in enhanced bandwidth and reduced return loss. Bhadouria and Kumar [17] DGS structures were implemented to achieve improved antenna characteristics. Both configurations demonstrated enhanced bandwidth and gain across all three frequency bands; however, a reduction in efficiency was observed. Gupta *et al*. [18] demonstrated successful patch antenna miniaturization by employing a shorting post along with a U-shaped DGS; however, this approach led to decreased gain and efficiency in the lower frequency range. Salih and Sharawi [19] it was shown that a three-band antenna could be made smaller by using an E-type unit cell and an F-shaped slot in the DGS. However, this method limited the bandwidth. Different design techniques can make multiband operation possible, but they often have problems with how well they work with bandwidth. Ali and Biradar [20], a dual-band antenna was designed by reducing its size through the inclusion of a central square slot etched into the patch. To achieve dual-band operation, two symmetrical L-shaped slots with additional slits were added to the radiating element. Nevertheless, the design exhibited a narrow bandwidth. Ali *et al*. [21], a U-shaped feeding approach was employed to improve gain; however, the bandwidth enhancement was not particularly significant. Mobashsher *et al*. [22] a rounded-corner rectangular radiating patch was used to achieve dual-band functionality and high gain; however, the bandwidth was restricted. Additionally, DGS can be employed to introduce band-notch characteristics. Tiang *et al*. [23], two DGS resonators were used to cut down on interference in the X-band downlink for satellite transmission (7.0-7.40 GHz). If you change the gap width of the resonators, you can control the amount of signal loss. The integration of an open-ring DGS [24] into the meta surface unit results in a significant reduction in stopband suppression, achieving a level of 20 dB, while maintaining in-band antenna performance. However, the larger antenna size may not be ideal for 5G IoT applications. On the other hand, DGS has proven to be crucial in reducing mutual coupling between array antennas, offering a solution to enhance performance in compact designs [25]. This work introduces a rectangular-shaped DGS that simultaneously improves bandwidth, gain, and return loss, with enhancements in one parameter not affecting the others.

2. ANTENNA DESIGN

Computer simulation technology (CST), a finite element electromagnetic solver tool, was used to test and simulate the antenna design. The design process had two steps, and the next few sections will go into more depth about how they were done. At first, a standard rectangle patch antenna was made on a FR4 substrate that had a thickness of 1.6 mm, a relative permittivity of 4.3, and a loss tangent of 0.002. There was a large ground plane on the substrate's base, as shown in Figures 1(a) to (c). Here's how to describe the resonant frequency (f_r) [26].

$$f_r = \frac{c}{\sqrt{\varepsilon_{eff}}\,\lambda} \tag{1}$$

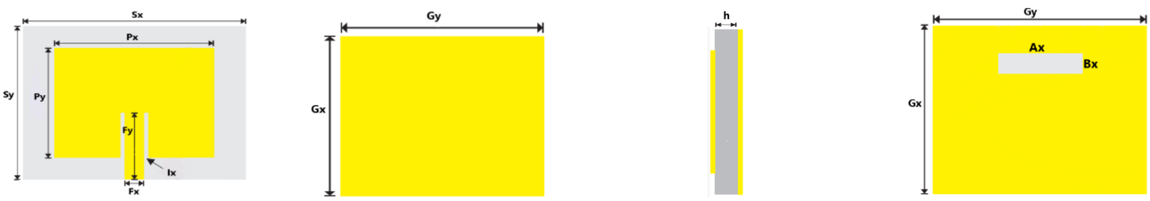
where λ is the directed wavelength at the chosen frequency $\mathcal{E}_{eff}$ is the effective dielectric constant, which is:

$$\varepsilon_{eff} \approx \frac{\mathcal{E}_r+1}{2} + \frac{\mathcal{E}_r-2}{2}\left(1 + 12\frac{w_p}{h}\right)^{-0.5} \tag{2}$$

In this instance W_p signifies the radiator's width, whereas h specifies the substrate's thickness. The length L_p of the radiator can be estimated using:

$$L_p = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \tag{3}$$

This antenna potentially resonates at half its wavelength with a full ground plane. Figure 1(d) depicts the antenna ground plane using the proposed rectangular DGS. The optimized parameters for the standard patch are shown as follows: S_x= 28 mm, S_y= 31.5 mm, h= 1.6 mm, P_x= 15.88 mm, P_y= 11.88 mm, F_x= 2.86 mm, F_y= 4.44 mm, I_x= 0.16 mm, G_x= 28 mm, and G_y= 31.5mm.



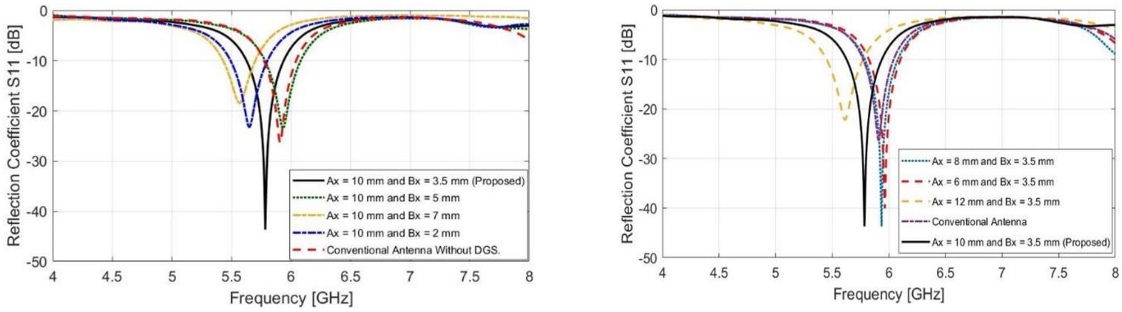
(a) (b) (c) (d)

Figure 1. Conventional antenna and with antenna ground with DGS; (a) front view of conventional antenna, (b) back view of conventional antenna, (c) side view, and (d) ground after incorporating DGS

3. RESULTS AND DISCUSSION

3.1. Bandwidth and return loss enhancement

Adding a rectangular faulty ground structure shown in Figure 1(d), changes the way current flows through the ground plane, which greatly improves return loss and bandwidth. The DGS raises the inductance and capacitance, which makes the antenna's impedance matching better over a wider frequency range. The increase from -23 dB to -47 dB shows that this makes a big difference in lowering return loss. As shown in Figure 2(a) and (b), the resonance frequency changes from 5.95 GHz to 5.8 GHz, which means that signals are sent more efficiently and there are fewer echoes. The DGS also reduces higher order harmonics, which lets the antenna work well over a wider frequency range. The frequency goes from 270 MHz to 323 MHz, which is a 21.89% increase. The data gives a detailed look at how the DGS measurements (length Axe and width Bx) affect return loss and bandwidth, with a focus on the best setting for these factors. In addition, the DGS ensures that the resonance frequency is set correctly to 5.8 GHz, as shown in Figure 2(a) and (b).

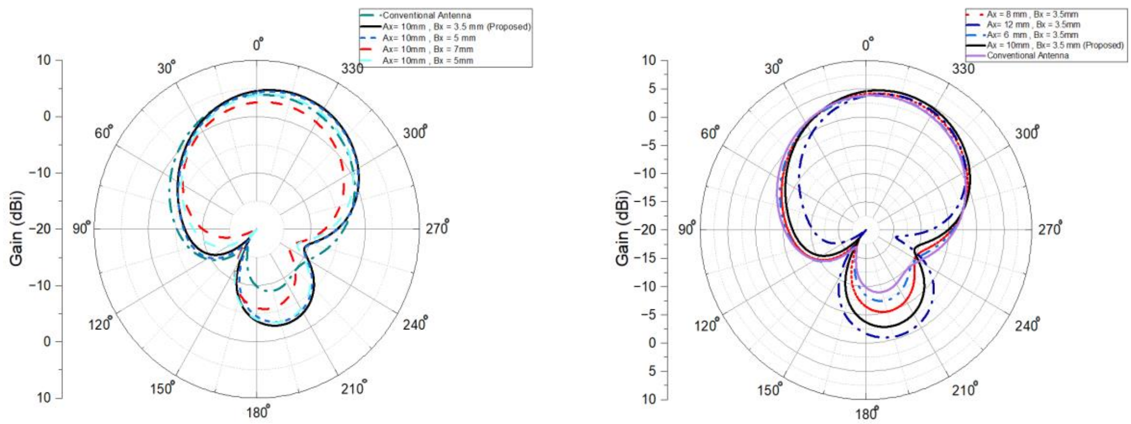


(a) (b)

Figure 2. Parametric analysis of reflection coefficient; (a) corresponding to Bx when Ax is constant and (b) corresponding to Ax when Bx is constant

3.2. Enhancement on gain

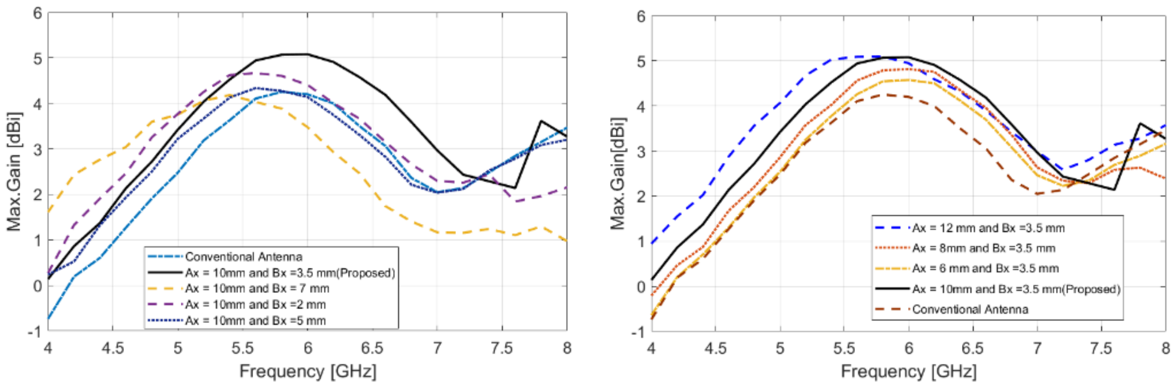
The DGS enhances the antenna's gain by more efficiently directing emitted energy into the desired direction. By reducing surface wave losses and improving radiation efficiency, the DGS channels a greater amount of power into the primary lobe of the radiation pattern, thereby increasing gain. The design demonstrates an increase in gain from 3.95 dBi at θ=340° to 5.10 dBi at θ=310°, reflecting a 30% improvement, as shown in Figures 3(a) and (b). The data highlight the variation in gain across different DGS dimensions, emphasizing the optimal combinations for maximizing performance in gain while maintaining improvements in bandwidth and return loss.



(a) (b)

Figure 3. Parametric analysis of radiation gain; (a) corresponding to Bx when Ax is constant and (b) corresponding to Ax when Bx is constant

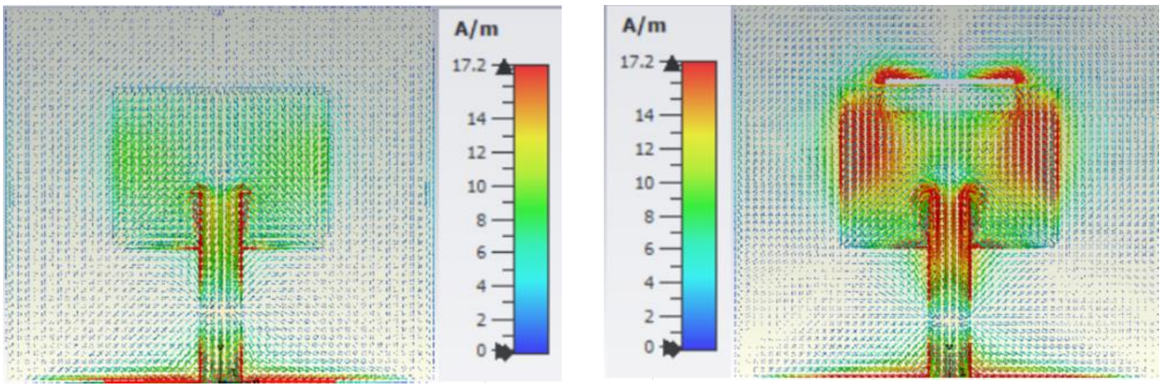
Figures 4(a) and (b) illustrate the effects of varying lengths and widths of DGS. The antenna gain varies with varied values of length and width. The highest attainable benefit can be determined by modifying the dimensions.



(a) (b)

Figure 4. Parametric analysis of antenna gain; (a) corresponding to Bx when Ax is constant and (b) corresponding to Ax when Bx is constant

In Figure 5(a), the antenna without the DGS exhibits a relatively uniform current distribution, primarily concentrated near the feedline and patch region. This results in moderate radiation efficiency but with limited gain. The antenna resonates at 5.95 GHz, and the current distribution indicates that energy is not efficiently radiated into the far field, thereby limiting overall performance. Upon incorporating the rectangular DGS, as shown in Figure 5(b), the current density near the edges of the ground plane becomes more pronounced. This indicates that the DGS interacts with the surface currents of the ground plane, enhancing coupling between the patch and ground. Consequently, this modification alters the electromagnetic field distribution, improving impedance matching at the reduced resonance frequency of 5.8 GHz, thereby enhancing radiation efficiency.



(a) (b)

Figure 5. Surface current distribution; (a) surface current distribution without DGS and (b) surface current distribution with DGS

The DGS enhances energy distribution across the antenna, especially at the ground plane, resulting increased radiation and an elevation in gain from 3.95 dBi to 5.10 dBi. This improvement is further corroborated by the transition in the resonance frequency from 5.95 GHz to 5.8 GHz, resulting in enhanced operational efficiency of the antenna.

4. PERFORMANCE ANALYSIS

We fabricated the designed antenna to analyze its real-life performance, showed in Figures 6(a) and 6(b). Figure 6(a) shows the front side of the fabricated antenna and backside in Figure 6(b). The suggested antenna is meant to work within a 5.8 GHz bandwidth. The Center frequency can change depending on how accurately the PCB is manufactured. The rectangular DGS has final measurements of Ax=10.2 mm (length) and Bx=3.6 mm (wide), which can be seen in Figure 6(b). With the suggested rectangular DGS, the 5.8 GHz antenna's patch area shrinks by 4%, from 884 mm² to 849 mm². The proposed 5.8 GHz antenna's measurement data are shown in Figure 7. The center frequency shift that was seen is accurate, and the calculated frequency of 5.8 GHz is within the -10 dB bandwidth. Figure 7 shows that the suggested antenna has a reflection coefficient of -21 dB at 5.8 GHz.

(a) (b)

Figure 6. Proposed antenna with rectangular DGS patterns constructed on a FR4 PCB; (a) front side and (b) back side

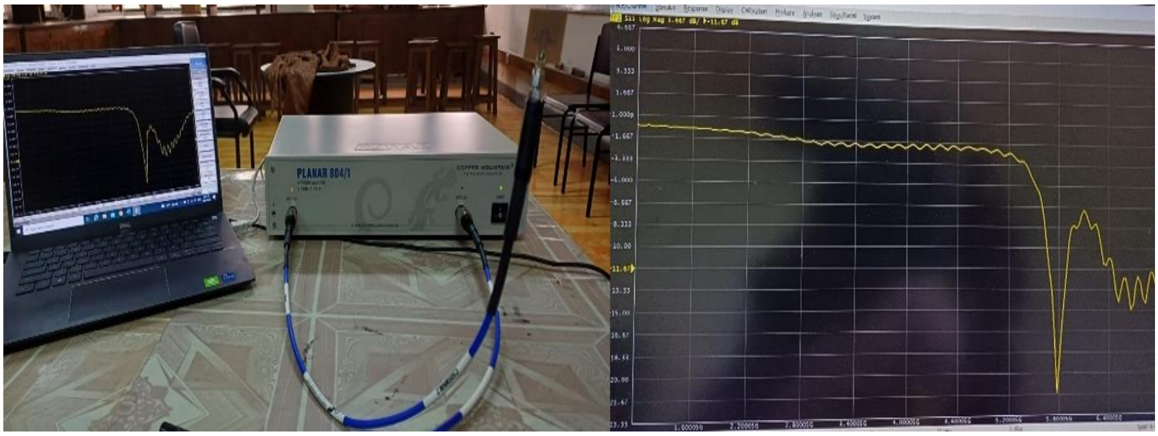


Figure 7. Measurement setup of proposed antenna

The frequency of resonance is very close to what was found in the experiment. The suggested antenna has a frequency bandwidth of 323 MHz, which is 21.89% better than the antenna that doesn't have the DGS. The gain went up from 3.9 dBi to 5.1 dBi, which is a 30% improvement. As we can see from Figures 8(a) and (b), the antenna gain that was measured is 4.85 dBi. The difference in radiation patterns between the simulation and measurement data is because of the dielectric jig. It was placed vertically to keep the antenna stable during the measurement setup. Table 1 shows a comparison of how well the proposed antenna works compared to earlier tests that used DGS and were aimed at 5.8 GHz. The suggested antenna's bandwidth has grown by 21.89%, and its radiation gain has gone up by 30%.

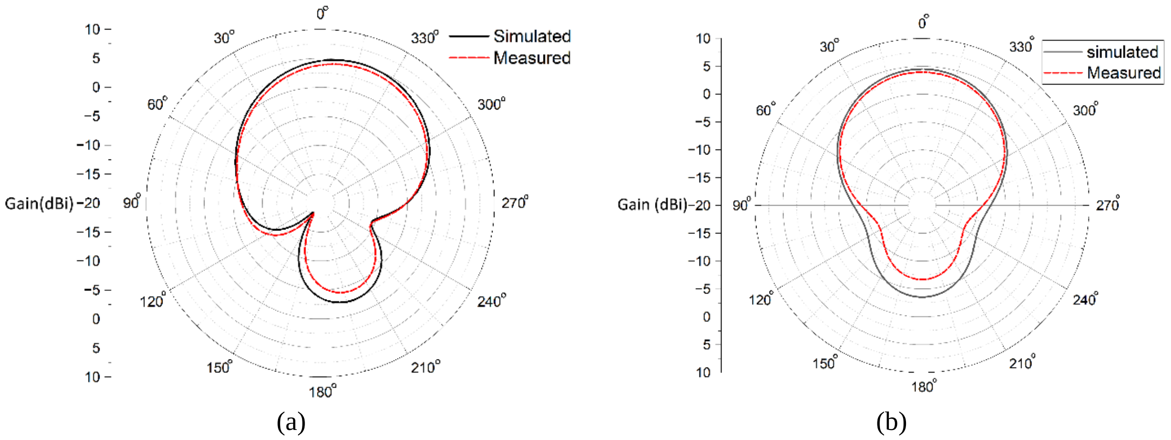


Figure 8. Simulation and measurement outcomes of the suggested patch antenna's radiated gain; (a) H-plane radiation patterns and (b) E-plane radiation patterns

Table 1. Comparative performance analysis of the patch antenna with DGS at approximately 5.8 GHz

Study	[27]	[28]	[29]	This work	
				Without DGS	With DGS
Frequency (GHz)	5.2	5.8	5.8	5.95	5.8
Bandwidth (GHz)	0.12	0.16	0.15	0.273	0.323
Fractional bandwidth (%)	2.3%	2.4%	2.37%	4.5%	5.6%
Gain (dBi)	4.14	1.59	1.84	3.95	5.10
Substrate, thickness (mm)	RT duroid (0.76)	FR4(3.2)	FR4(0.8)	FR4(1.6)	FR4(1.6)
Address event representation (AER)	3.57	2.16	4.4	4.3	4.3

5. CONCLUSION

To improve both bandwidth and gain at the same time, a 5.8-GHz patch antenna with a rectangle DGS is suggested. The rectangular DGS successfully reduces patch sizes. By lowering the resonant frequency, the suggested geometry takes advantage of the benefits of DGS to achieve downsizing while also ensuring wideband performance and uniform radiation features. The antenna had a -10 dB S11 spread of about 323 MHz and a 5.10 dBi peak gain. Because it is small and has a wide bandwidth, the antenna can be used in communication devices.

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AUTHOR CONTRIBUTIONS STATEMENT

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Md. Sohel Rana		✓		✓	✓	✓	✓			✓	✓	✓	✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [M.N.H], upon reasonable request.

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