

# A Miniature Rectangular Patch Antenna Using Defected Ground Structure for WLAN Applications

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**Abstract**—The purpose of this work is to miniaturize a rectangular patch antenna which resonates at 2.4 GHz. To achieve this, we present a new geometry of a pi-shaped slot with three annular rings as a Defected Ground Structure (DGS). DGS is a periodic etched structure or aperiodic sequence of configurations, and it has been used to switch the resonance frequency from starting value 13 GHz to an ending value at 2.4 GHz without any changes in the areas of the actual rectangular microstrip patch antenna (RMPA). The proposed antenna is structured on an FR-4 substrate with thickness 1.6 mm and permittivity 4.4. The general size of the ground plane is  $34 \times 34 \text{ mm}^2$ . Using the optimal position and dimension of the pi-shaped slot on the ground, the resonant frequency is reduced to 2.4 GHz, which signifies an 81.53% decrease. Proposed antennas with and without DGS are simulated by using High-Frequency Structure Simulator (HFSS) and Advanced Digital System (ADS) Agilent technology, fabricated, and measured for Wireless Local Area Network (WLAN) application.

## 1. INTRODUCTION

Ku-band is broadly utilized for satellite communications [1]. Fundamentally wireless communication plays an important role in everyday life. It has created a huge need in the design of Microstrip Patch Antennas (MPA) for different applications. The main attributes of MPA are low profile, light weight, achievability in expense, and simple fabrication [2], but MPA also has some disadvantages, such as low efficiency, low return loss, low gain, and narrow bandwidth. These drawbacks can be overcome by using various techniques like array configuration [3], different feeding [4], and double L and U-slots in a patch with proper placement [5, 6]. We use notches and slits on the microstrip patch antenna with distinct shapes [7, 8], fractal geometry [9], and metamaterial [10]. A combination of different methods can also be used for acquiring miniaturized antenna, such as Earlier Photonic Band Gap (PBG) [11], Defected Microstrip Structure (DMS) [12], Defected Ground Structures (DGS) [13], and Electromagnetic Band Gap (EBG) [14]. When a defect is introduced in the metallic ground plane of planar transmission lines (e.g., Coplanar, microstrip, and conductor-backed coplanar waveguide), it disturbs the current shield distribution [15, 16], and due to this, there is an adjustment in attributes of a transmission line such as inductance and capacitance [17]. The patch antenna equivalent circuit is a parallel resonant RLC circuit, and the values of capacitance and inductance parameters are calculated by electromagnetic fields of the antenna [18].

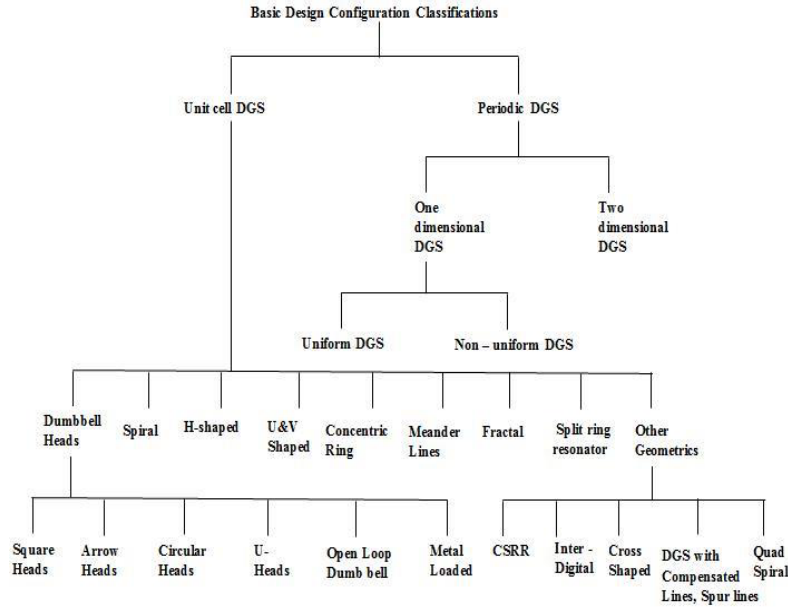
DGS is primarily utilized in microstrip antenna design for several applications, for example, harmonic suppression, cross-polarization reduction, and antenna size reduction. It is an easy method which has been introduced to miniaturize the patch antennas, and DGS consists of simple and difficult shapes etched off in the ground plane for gaining better performances. Fig. 1 presents different configurations of DGS etched off in the ground plane [19, 20]. The DGS is implemented by an equivalent

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**Figure 1.** Some basic configurations of DGS [19, 20].

circuit of a parallel L-C resonator. The values of the capacitance and inductance rely on the dimension of the defect and the area of the defect. By changing several dimensions of the defect, the necessary resonance frequency can be accomplished.

In this article, we propose a new pi shaped with three annular rings as a defected ground structure (DGS) which is etched off in the ground plane. The intention is to miniaturize the proposed rectangular patch antenna, which resonates at 13 GHz, and later with the utilization of DGS technique the patch antenna resonates at 2.4 GHz for WLAN applications. In this paper, we include three sections. In Section 2, firstly a rectangular microstrip patch antenna design is described, then a pi-shaped slot with three annular rings DGS is resolved. Section 3 describes the measurement and simulation results of current distribution, radiation patterns, return loss, and VSWR of the MPA antenna with and without DGS. Section 4 discusses the fabrication. Finally, we will conclude the application in the conclusion part.

## 2. DESIGN AND SPECIFICATIONS OF ANTENNA

### 2.1. Rectangular Microstrip Patch Antenna

Initially, a Rectangular Microstrip Patch Antenna (RMPA) without DGS which resonates at 13 GHz in Ku-band range is considered, and to change the position of the resonant frequency of quarter wavelength transformer microstrip antenna we are employ a Defected Ground Structure (DGS) to analyze its working. Here two kinds of antennas have been planned firstly. Fig. 2 shows a rectangular microstrip patch antenna without DGS which resonates at 13 GHz. The mathematical description and requirements of the specific proposed RMPA are given as follows. The length ( $L$ ) and width ( $W$ ) of the microstrip patch antenna can be composed by using theoretical equations which are presented in [29–31].

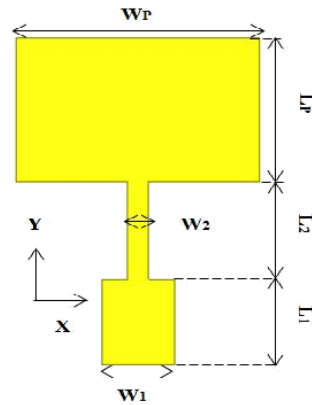
$$L = \frac{1}{2f_r \sqrt{\epsilon_{r\text{eff}}} \sqrt{\epsilon_0 \mu_0}} - 2\Delta L \quad (1)$$

$$W = \frac{1}{2f_r \sqrt{\epsilon_0 \mu_0}} \sqrt{2/(\epsilon_r + 1)} \quad (2)$$

In this design, the proposed rectangular microstrip patch antenna is structured on an inexpensive FR-4 substrate, which has dielectric constant 4.4, loss tangent ( $\tan \delta$ ) 0.025, and substrate thickness

Antenna parameter	Value
$L_P$	4.57 mm
$W_P$	6.99 mm
$W_1$	2.1 mm
$W_2$	0.6 mm
$L_1$	2.7 mm
$L_2$	3.1 mm

**Table 1.** The dimension of the proposed antenna.



**Figure 2.** Proposed antenna geometry — Top view.

1.6 mm. It covers the whole area of  $34 \times 34 \text{ mm}^2$ , and the proposed antenna dimensions are optimized by using two different solvers, HFSS and ADS. Its optimized parameters are shown in Table 1.

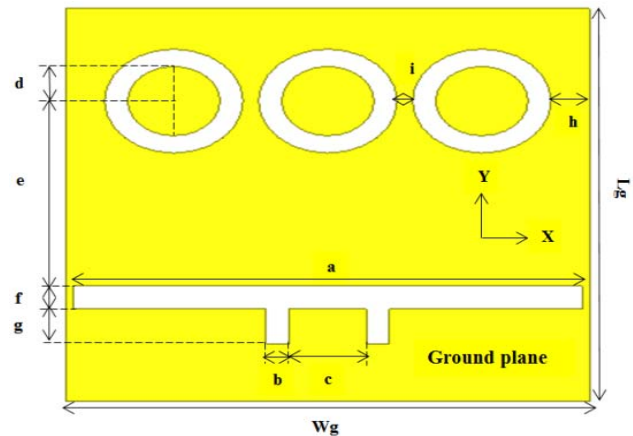
**2.2. Defected Ground Structures (DGS) Configuration**

Secondly, Fig. 3 shows the geometry of a pi-shaped DGS with three annular rings resonating at 2.4 GHz, which is placed on the ground plane. The resonant frequency can be switched from one place to another, by varying the dimensions of the pi-shaped slot. After many optimizations by HFSS and ADS electromagnetic solver, the DGS dimensions are shown in Table 2.

DGS is implemented by etching off different shapes in the ground plane, which disturbs the shield current distribution depending on the configuration of the defect. This disturbance will influence the components of a transmission line, for example, line capacitance and inductance. It can also manage the electromagnetic wave propagating into the the substrate layer and excitation. Energy is focused around the DGS, and as a result, the resonance frequency can shift from 13 GHz to 2.4 GHz. In other words, any defect etched off in the metallic ground plane of the microstrip leads to increasing effective inductance and capacitance.

Antenna parameter	Value
$a$	33 mm
$b$	1.5 mm
$c$	5 mm
$d$	3 mm
$e$	16 mm
$f$	2 mm
$g$	3 mm
$h$	2.5 mm
$i$	1 mm

**Table 2.** The dimension of the proposed antenna without DGS.



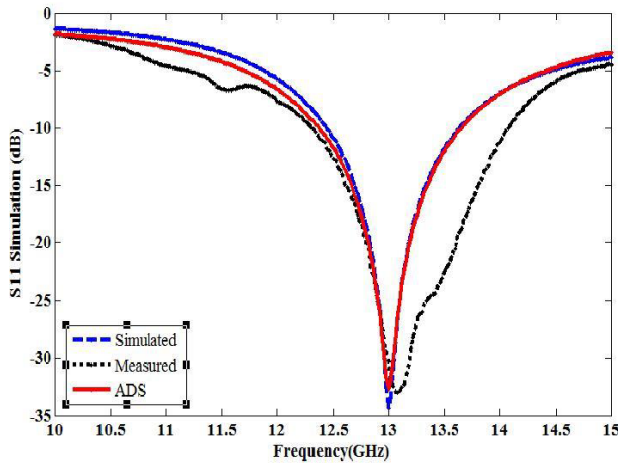
**Figure 3.** The proposed antenna design model — view from the bottom.

### 3. SIMULATED, MEASURED AND DISCUSSIONS

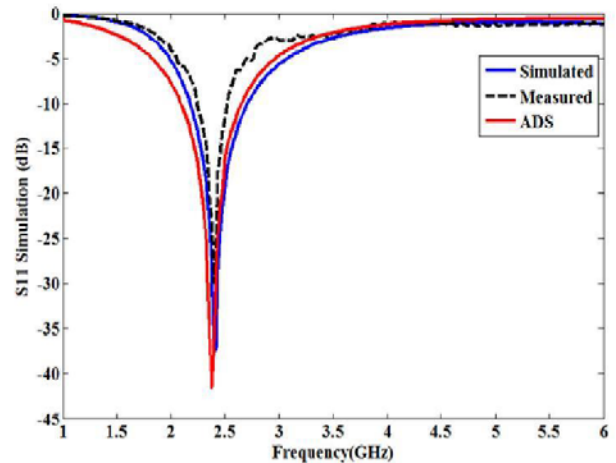
The proposed Rectangular Microstrip Patch Antenna (RMSP) is simulated with Electromagnetic (EM) simulation software such as HFSS and ADS. In results, the return loss, VSWR, current distribution, and Radiation patterns are explained.

#### 3.1. Return Loss

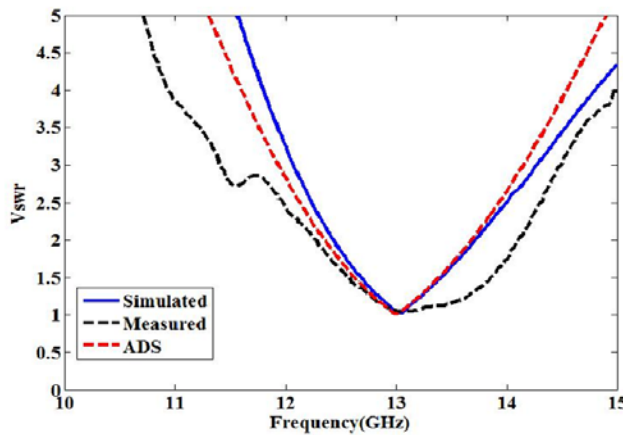
The simulated and measured return losses are obtained from this microstrip patch antenna by using HFSS and ADS, shown in Fig. 4. It gives good impedance matching at 13 GHz, with a little acceptable change in the comparison between two solvers. The simulated and measured reflection coefficients of the proposed antenna with DGS yield good matching at 2.4 GHz with a bandwidth equal to 520 MHz (2.18 GHz to 2.70 GHz) and return losses of  $-37.5$  dB and  $-29.9$  dB, respectively. The result obtained for the return loss is shown in Fig. 5, and we can see that the effect of pi-shaped DGS permits to change the position of resonant frequency from 13 GHz to 2.4 GHz.



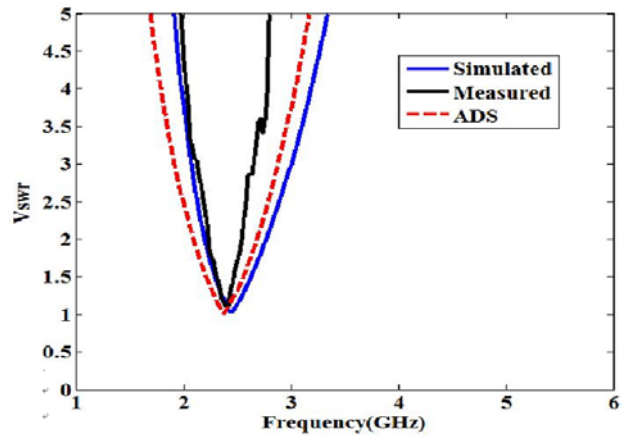
**Figure 4.** Simulation and measurement return loss of RMPA without DGS using HFSS and ADS.



**Figure 5.** Simulation and measurement return loss of RMPA with DGS using HFSS and ADS.



**Figure 6.** Measurement and simulation VSWR for without DGS using HFSS and ADS.



**Figure 7.** Simulation and measurement VSWR for with DGS using HFSS and ADS.

### 3.2. VSWR

A significant parameter of a rectangular microstrip patch (RMSP) antenna is voltage standing wave ratio (VSWR). The range of VSWR for basic RMPA is less than or equal to 2. This range is satisfied by all resonant frequencies. The acceptable value of VSWR must be situated from 1 to 2. VSWR is relevant to the reflection coefficient, and it is characterized as the division of voltage peak point to the voltage valley point of standing wave stored in the dielectric. Figs. 6 and 7 show the plot of VSWR for the portrayed model with values of 1.02 and 1.04 for the corresponding resonant frequencies of 13 GHz and 2.4 GHz, respectively. The variations in resonant frequencies, return loss, bandwidth, and VSWR of RMPA antenna with and without DGS are listed in Tables 3 and 4.

**Table 3.** Comparison of simulated and measured results of proposed antenna with and without DGS using HFSS.

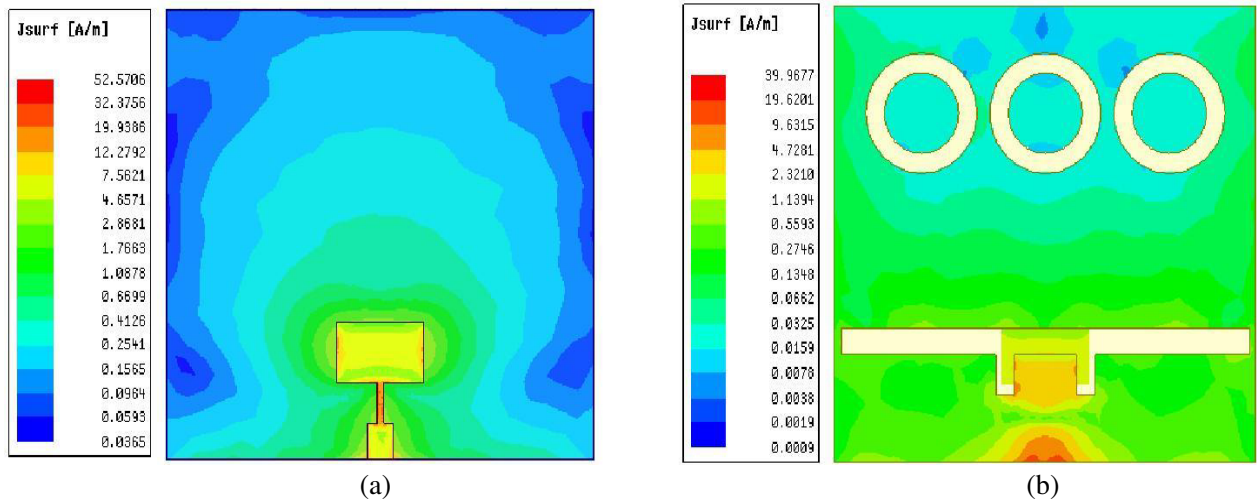
Type of Antenna	Resonant frequency (GHz)	Return loss (dB)	VSWR	Band Width (MHZ)
Simulated RMPA without DGS	13	-34.2	1.02	1180
Measured RMPA without DGS	13	-33.2	1.06	1750
Simulated RMPA with Annular Rings DGS	2.4	-37.5	1.04	520
Measured RMPA with Annular Rings DGS	2.4	-29.9	1.11	300

**Table 4.** Comparison in gain, directivity and bandwidth of proposed antenna with and without DGS.

Type of Antenna	Resonant frequency (GHz)	Gain (dB)	Directivity (dB)	Bandwidth (GHz)
Simulated RMPA antenna without DGS	13	5.64	6.54	1.18
Simulated RMPA antenna with Annular Rings DGS	2.4	1.68	3.85	0.52

### 3.3. Current Distribution

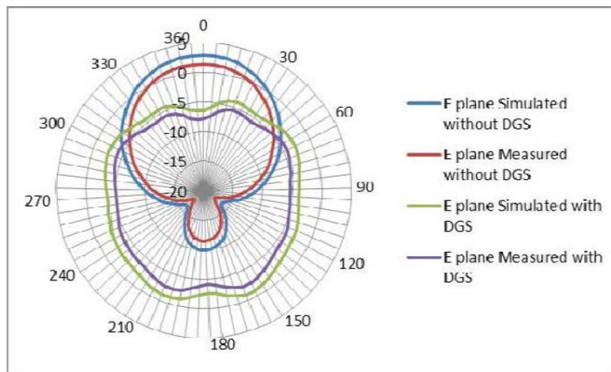
Fig. 8 demonstrates the patch antenna with and without DGS surface current distributions respectively at 13 GHz and 2.4 GHz in which the current density is most focused around DGS. Anyway, a huge surface current density is seen over the structure of the microstrip line without DGS.



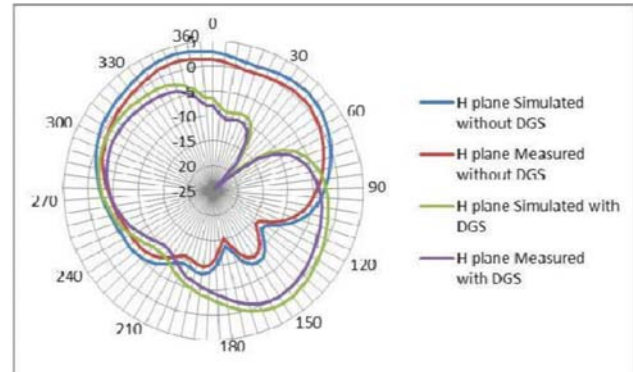
**Figure 8.** The Surface current distributions at (a) 13 GHz without DGS and (b) 2.4 GHz with DGS in HFSS.

### 3.4. Radiation Pattern

The radiation patterns shown in Fig. 9 and Fig. 10 are obtained for the patch antenna with and without DGS. The gain obtained is 5.64 dB at 13 GHz, and for our DGS antenna at 2.4 GHz the simulated gain is about 1.68 dB. This reduction in gain is described by the increase of lateral and longitudinal radiations due to the surface wave propagation. Specifically, these radiations adversely influence the main lobe power, and therefore a decrease of the gain is produced.



**Figure 9.** Measurement and simulation radiation patterns for with and without DGS ( $E$ -plane).



**Figure 10.** Measurement and simulation radiation patterns for with and without DGS ( $H$ -plane).

The proposed design models are structured and verified at different slot lengths. Fig. 11 shows the top and bottom views of the proposed models with and without DGS structures.

The return loss for the pi-slot of different lengths ' $a$ ' is depicted in Fig. 12. We can see the effect of DGS, as the length of the slot increasing; it gives the impact of shifting the first resonances (Right to Left) to lower frequencies. The length ' $a$ ' of a pi-shaped slot is 13 mm (dot-dashed black curve), and it has its first resonance at 5.4 GHz, whereas the second resonance is almost fixed at around 4.8 GHz for ' $a$ ' = 16 mm. Furthermore, with an increase of ' $a$ ', i.e., 31 mm and 33 mm, we observe the occurrence of resonance at 2.6 GHz and 2.4 GHz, respectively. Table 5 gives a comparison of the final proposed antenna dimensions with published literature for different applications.

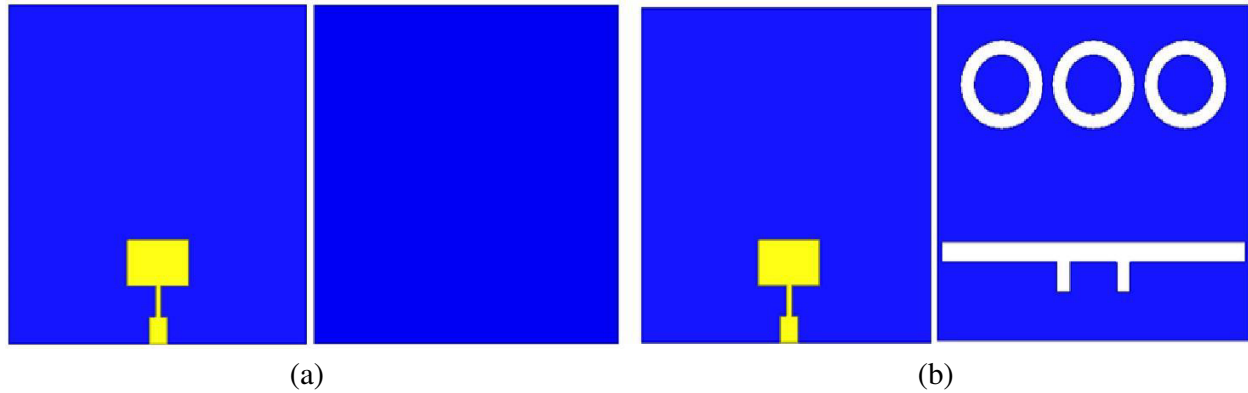


Figure 11. (a) Top and (b) Bottom view of the proposed models.

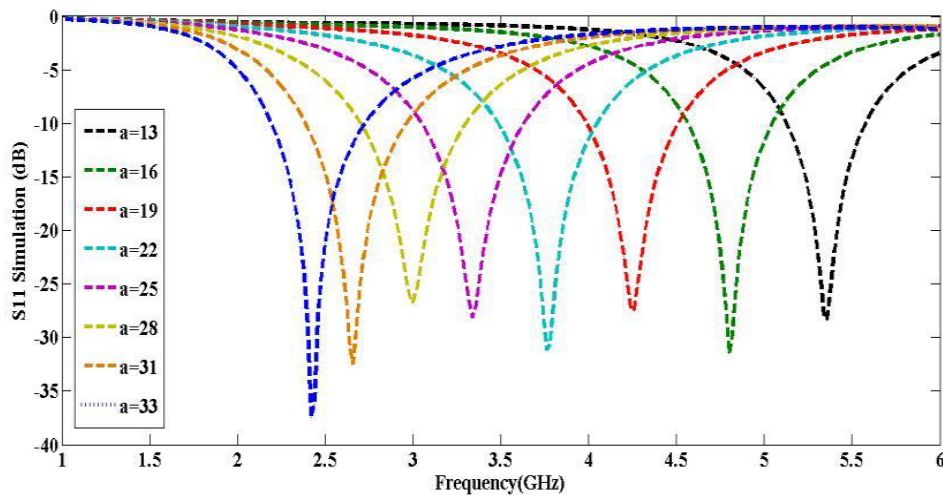


Figure 12. Simulated Return loss for the pi slot of different lengths ‘a’.

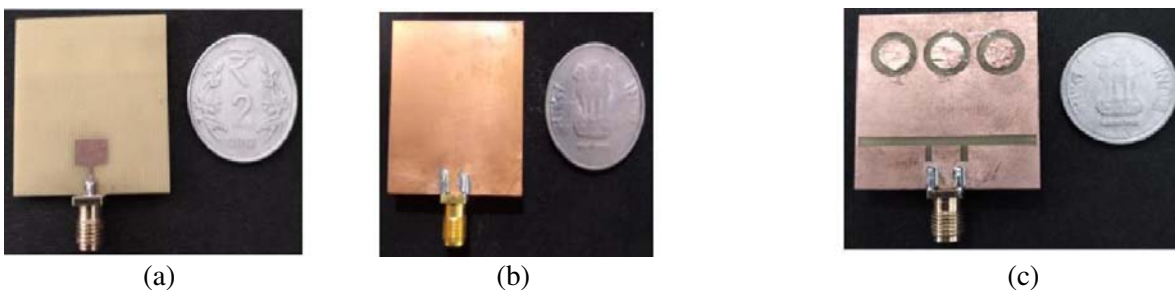


Figure 13. Photograph of fabricated of proposed antennas. (a) Top view, (b) bottom view without DGS (ground view) and (c) bottom view with DGS (ground view).

#### 4. FABRICATION AND MEASUREMENT

After the verification of the simulation results of the proposed patch antenna, we have manufacture. Fig. 13 presents photographs of the fabricated antenna with and without DGS, which has a size of  $34 \times 34 \times 1.6 \text{ mm}^3$ . The proposed antenna with pi-shaped three annular rings as DGS is fabricated by using the MITS prototyping machine and experimented by using the Vector MS2037C Network Analyzer (VNA).

**Table 5.** Comparison between proposed antenna with other published literature.

Ref.	Dimensions	Shifting of Resonant Frequency	Percentage of miniaturized	Application
[21]	34 mm × 34 mm	5.8 GHz to 2.5 GHz	56.89	ISM
[22]	20 mm × 22 mm	5.7 GHz to 3 GHz	47.36	WiMAX
[23]	27.9 mm × 35.75 mm	5.8 GHz to 2.45 GHz	57.77	ISM
[24]	40.48 mm × 50 mm	10 GHz to 7.5 GHz	25.0	Arrays
[25]	27 mm × 30 mm	10 GHz to 3.5 GHz	65.0	WiMAX
[26]	34 mm × 34 mm	5.8 GHz to 2.45 GHz	57.77	ISM
[27]	140.7 mm × 57.1 mm	5.8 GHz to 2.45 GHz	57.77	Arrays
[28]	14 mm × 21.6 mm	5.8 GHz to 2.69 GHz	53.6	Arrays
Proposed system	34 mm × 34 mm	13 GHz to 2.4 GHz	81.53	WLAN

## 5. CONCLUSION

In this paper, we have built an innovative approach of miniaturized rectangular microstrip patch antenna by utilizing DGS strategy. Initially, the proposed antenna without DGS is tested at 13 GHz. The objective of this work is to move the resonance frequency from 13 GHz to 2.4 GHz. By inserting our pi-shaped slot with three annular rings as DGS on the ground plane of the patch antenna, the surface current path is wandered, and hence the antenna electrical length is increased. So by increasing the antenna electrical length, the resonance frequency is shifted. After the accomplishment, we have gained a great understanding between simulated and measured results. A miniature rectangular microstrip patch antenna has been created, examined, and approved for WLAN applications.

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