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# Design and Performance Optimization of Microstrip Patch Antenna for Wireless Communication Applications

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**ABSTRACT:**

The bandwidth and gain are vital parameters that characterize the performance of microstrip patch antenna. In this work, four (4) Rectangular Microstrip Patch Antennas (RMPAs) were designed and simulated: RMPA with inset, RMPA with inset and diagonal slots, RMPA with inset and-corner slotted and, RMPA with inset, all-corner slotted and partial-ground. Flame Retardant-4 Epoxy substrates having equal dielectric constant (4.4) and thickness of 1.6mm was used for this work. Each of the designed antennas was fed with 50Ω input impedance using microstrip feed-line technique at 2.4GHz for wireless communication applications. The designs were carried out with the aid of Computer Simulation Technology (2021) software and the performance parameters such as return loss, bandwidth, Voltage Standing Wave Ratio, impedance and the gain. The proposed antenna has simulation results of -28dB, 118.2MHz, 1.08, 50.16Ω, 3.023dBi for return loss, bandwidth, VSWR, input impedance and gain respectively. The results of proposed antenna suggested that partial ground or deformed ground structure is an effective mechanism for enhancing the bandwidth and other parameters of microstrip patch antenna for wireless communication applications at 2.4GHz frequency.

**Keywords:** RMPA, Configuration, inset, slot, deformed ground structure, return loss, bandwidth, VSWR, gain, FR-4, CST.

## 1. INTRODUCTION

With ever-increasing wireless communication technology in recent time, devices and gadgets operating at 2.4GHz, this license-free band is becoming more congested with multiple users, thereby communication speed becomes slower at center frequency. Microstrip Patch Antenna (MPA) has foremost drawbacks of narrow bandwidth and low gain (Balanis, 2005). Hence, the need to employ optimization mechanisms to enhance the performance such as gain and bandwidth of a microstrip patch antenna by employing inset, slots on the patch and partial ground (DGS).

The return loss of antenna is controlled by proper impedance matching of feed line and patch. Etching through the patch of an antenna along both sides of the microstrip feedline (inset). This mechanism is another method of controlling and improving antenna parameters such as input impedance and return loss (Matin 2018, Singh 2016). Properly calculated inset feed dimensions (x-y) give the point where the input impedance is 50 ohms. The inset feeding is one of the popular techniques for perfect matching, thereby reducing the power loss at the input port and allows adequate power supply to the load. The experimental and numerical results showed that the input impedance of an inset-fed rectangular patch varied as a Cos4 function of the normalized inset depth (Ndujuiba, 2017).

Slot is a method etching metallic part of either the patch or the ground plane of a MPA. Though, it is commonly referred to as etching on the patch antenna. Slot is always expected to be at the x-y edges of the patch before sweeping to the x-y origin to achieve a suitable point on the patch (Neha, 2017). The antenna bandwidth of MPA increases with the addition of slot(s) to a given patch (Anab and Khattak, 2020). These structures are periodic in nature, that forbids the propagation of all electromagnetic surface waves within a particular frequencies band known as the bandgap, and permits additional control of the behavior of electromagnetic waves other than conventional guiding/filtering structure (Kumar et al., 2009). One practical way of cutting slot for a rectangular patch antenna for best performance consideration $1 < \frac{W}{L} > 2$, given mathematically in as $W_{slot} = \frac{W}{27.2}$ and $L_{slot} = \frac{L}{27.2}$(Ndijuiba et al., 2017). The antenna bandwidth increases with the addition of slots to a given patch. These structures are periodic in nature, that forbids the propagation of all electromagnetic surface waves within a particular frequency band known as the bandgap, and permits additional control of the behavior of electromagnetic waves other than conventional guiding/filtering structure (Siju and Mehajabeen 2015), Neha, 2017).

Microwave segment with deformed ground structure (DGS) has been picked up ubiquity among every one of the strategies detailed for improving the parameters because of its basic plan (Viswanathan, (2014), Siju and Mehajabeen, (2015)). Partial ground is etching of certain portion of the ground structure, which results in deformed ground structure (DGS). Scratched openings or deformities on the ground plane of microstrip circuits are alluded to as DGS. Single or various deformities on the ground plane might be considered as DGS. At first, DGS was accounted for channels underneath the microstrip line. Present day correspondence requests the accessibility of productive, smaller, and versatile gadgets that can be worked at high information speed (broadband) and at low flag powers (Sumathi, 2020). Reduction of the ground plane is a popular method of antenna characteristic enhancement. It has been used to increase efficiency, improve impedance matching and also increase bandwidth of rectangular antennas (Viswanathan, 2014).

## 2. RECTANGULAR MICROSTRIP ANTENNA DESIGN GEOMETRY AND M0DEL

The proposed Antennas framework and their point by point dimensional configuration are exhibited in Figure 1 and table 1. The contain a rectangular patch. The patch is in charge of the resonating frequency at 2.4GHz. The waveguide port was excited by 50Ω input impedance through the microstrp line. The ouline and production of these structures were completed on FR-4 substrate of 4.4 dielectric constant, 3.91 effective dielectric constant and height of 1.6mm. The antenna dimensions were kept constant at 50×47.8×1.6mm.

Mathematical equations adopted to calculate the design dimensions of the rectangular microstrip patch antenna are as follows:

**The width of patch Wp antenna:**

$$Wp = \frac{2}{2f_0}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

where; c = $3*10^8$ (m/s) in free space velocity, $f_0 =$ resonant frequency, and $\varepsilon_r$ dielectric constant.

The effective dielectric constant $\varepsilon_{reff}$ was determined through equation

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

where; h= height of dielectric substrate.

**The extension length** is also determined through equation;

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{reff}+0.3)\left(\frac{w}{h}+0.264\right)} \quad (3)$$

$$Lp = L_{eff} - 2\Delta L \quad (4)$$

where $L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}}$

**Width of** microstrip ($W_0$) feedline:

$$Z_c = \frac{120\pi}{\sqrt{\varepsilon_{reff}}\left[\frac{W_0}{h}+1.393+0.667\ln\left(\frac{W_0}{h}+1.444\right)\right]} \quad W_0/h > 1 \quad (5)$$

The point where the input impedance is equal to 50 ohms on the patch.

$$Y_0 = \frac{L}{\pi}\cos^{-1}\left(\sqrt{\frac{Zin}{R_{in}}}\right) \quad (6)$$

**The minimum ground length and width:**

$$W_g = 6h + W \quad (7)$$

$$L_g = 6h + L \quad (8)$$

**The feedline point** was determined.

$$Y_f = \frac{w}{2}, \quad (9)$$

$$X_f = 0 \quad (10)$$

**The feed length ($l_f$)** of the antenna.

$$l_f = \frac{\lambda}{4} \quad (11)$$

where $\lambda = \frac{\lambda_0}{\sqrt{\varepsilon_{reff}}}$ and $\lambda_0 = \frac{c}{f}$

**The width ($Ins_x$) and length ($Ins_y$) of inset**:

$$Ins_x = \frac{c}{\sqrt{2\varepsilon_r eff}} \cdot \frac{4.65 \text{ X } 10^{-9}}{fc} \quad (12)$$

$$Ins_y = \frac{\cos^{-1}\sqrt{2/Rin}}{\pi/L_p} \quad (13)$$

**The length and width dimensions of slots**:

$$L_{slot} = \frac{L}{27.2} \quad (14)$$

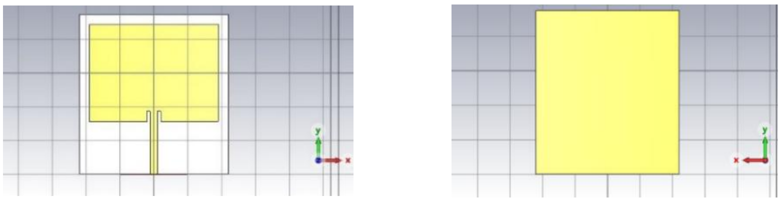
$$W_{slot} = \frac{w}{27.2} \quad (15)$$

where w = width of patch, L = length of patch.

**Table 1: Design geometry of patch antenna**

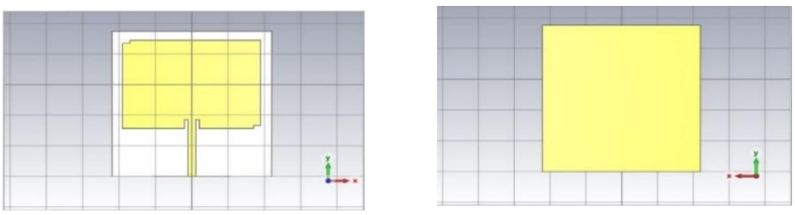
| S/N | Operational dimension | Parameters used (mm) |
|---|---|---|
| 1 | Patch width (W) | 38 |
| 2 | Patch Length ($L_p$) | 28.83 |
| 3 | Patch thickness (t) | 0.02 |
| 4 | Substrate thickness (h) | 1.6 |
| 5 | Substrate/grounding length ($L_s$ / $L_g$) | 50 |
| 6 | Substrate width (Ws) | 47.8 |
| 7 | Grounding width (Wg) | 38 |
| 8 | Feedline length ($L_f$) | 15.6 |
| 9 | Feedline width ($W_f$) | 2.57 |
| 10 | Inset width ($Ins_x$) | 1 |
| 11 | Inset lenght ($Ins_y$) | 3 |
| 12 | Length of slot ($L_{slot}$) | 1 |
| 13 | Width of slot ($W_{slot}$) | 2 |
| 14 | Lenght of partial groung (Lpg) | 50 |
| 15 | Width of partial groung (Wpg) | 4.7 |

***2.2 ANTENNAE MODEL***



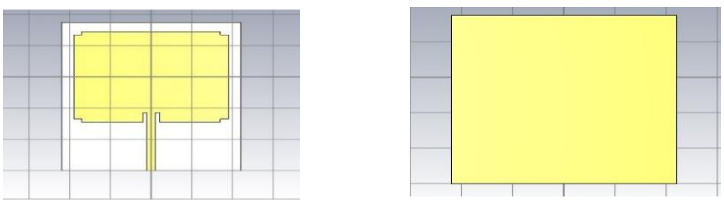
(a) (b)

Figure 1: Front view (a) and Back view (b) of RMPA with inset.



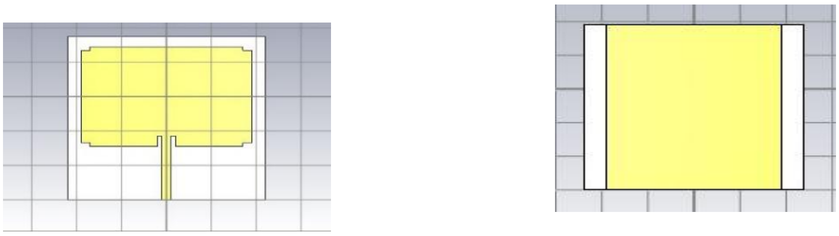
(a) (b)

Figure 2: Front view (a) and Back view (b) of RMPA with inset and diagonal slots.



(a) (b)

Figure 3: Front view (a) and Back view (b) of RMPA with inset and all-edge slotted.



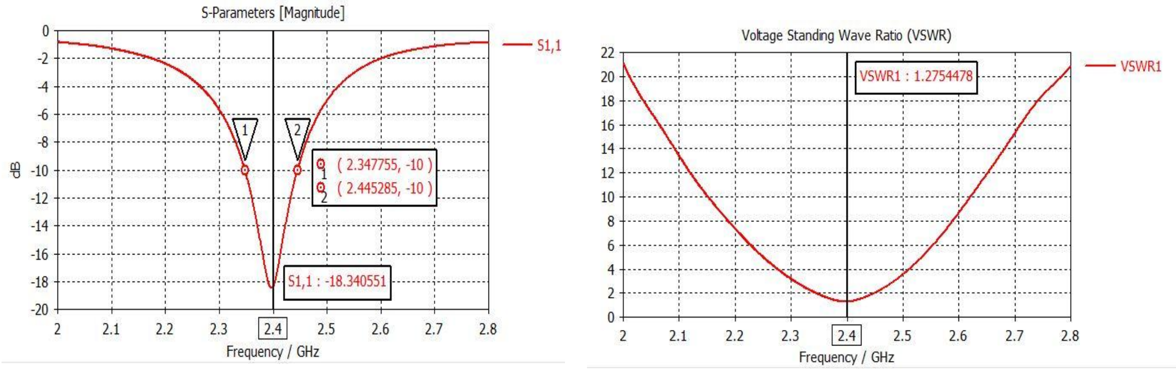
(a) (b)

Figure 4: Front view (a) and Back view (b) of RMPA with inset, all-edge slots and partial ground.

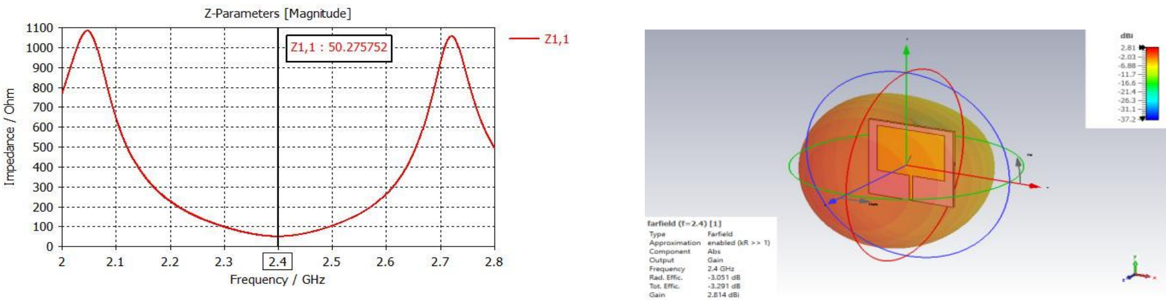
## 3.0 SIMULATION RESULTS AND DISCUSSION

The Antenna simulations were carried out using Computer Simulation Technology (CST@2021) Software. Simulated results of the four antennas using different enhancement mechanisms such as inset, slots and partial grounding are as illustrated below**.**

Figure **5 (a-d)** depicts the simulated results of antenna with inset mechanism. The antenna achieved return loss of -18.340551dB below -10dB, bandwidth of 97.53 MHz ranging from 2.347755GHz to 2.445285GHz, VSWR is 1.2754478, input impedance is 50.275752Ω, and gain of 2.814dB at 2.4GHz.




(a) (b)

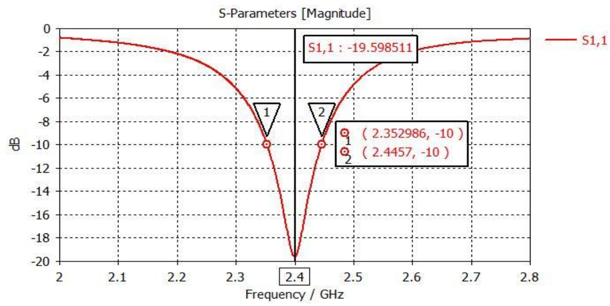


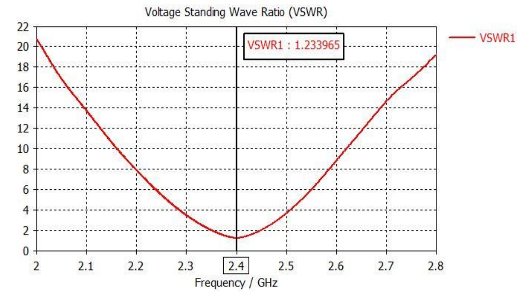

(c)

(d)

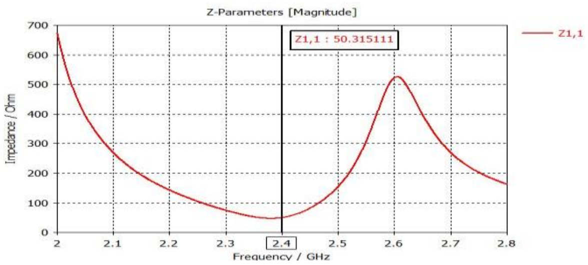
**Figure 5: Simulated results of (a) return loss, (b) VSWR, (c) Input impedance and (d) Gain (IEEE) of inset RMPA.**

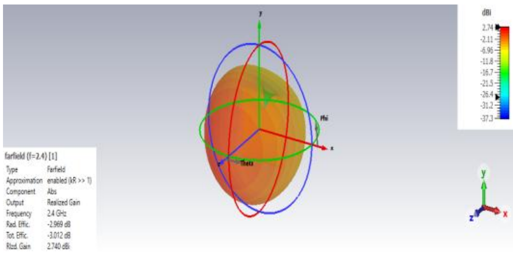
Figure **6 (a-d)** depicts simulation results of antenna with inset and diagonal slots. The antenna achieved return loss of -19.598511dB below -10dB, bandwidth of 92.8MHz ranging from 2.3529GHz to 2.4457GHz, VSWR is 1.233965, input impedance of 50.315111, and gain of 2.783337dBi at 2.4GHz.




(a) (b)

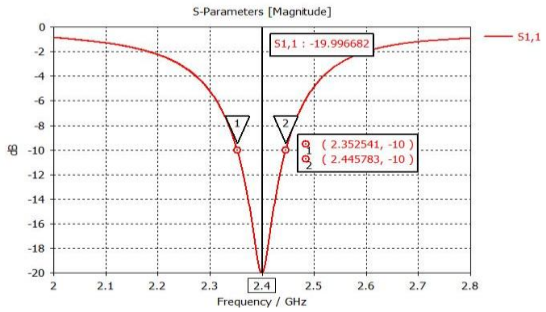


(c) (d).

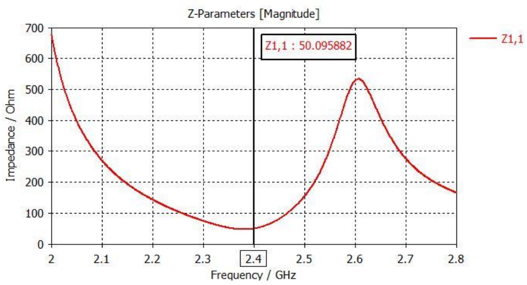
**Figure 6 (a-d): Simulated results of (a) return loss, (b) VSWR, (c) Input impedance and (d) Gain (IEEE) of RMPA with diagonal slots.**

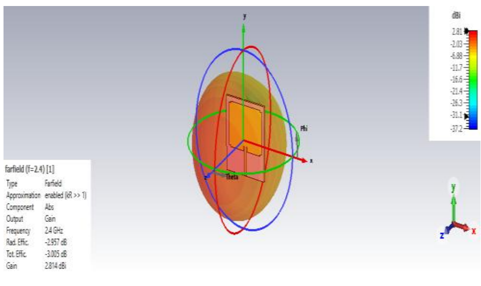
Figure 7 (a-d) depicts the simulated results of with inset and four corner slots. The antenna achieved return loss of -19.996682dB (90.00%) below -10dB, bandwidth of 93.2MHz ranging from 2.3529GHz to 2.4457GHz, VSWR is 1.22, input impedance is 50.09Ω and, gain was 2.814dBi at 2.4GHz.





(a) (b)

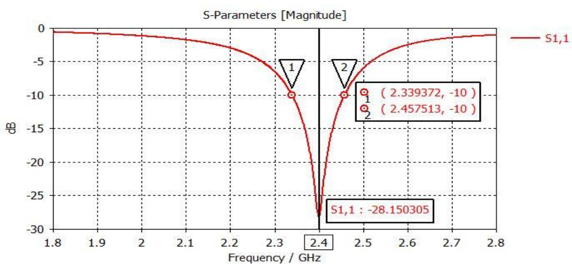


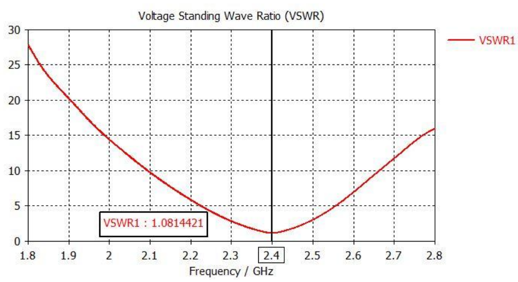



(c) (d)

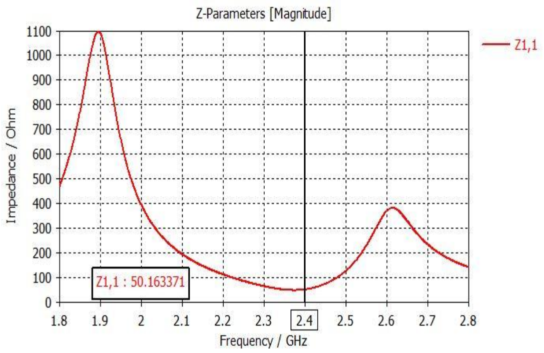
**Figure 7 (a-d): Simulated results of (a) return loss, (b) VSWR, (c) Input impedance and (d) Gain (IEEE) of inset RMPA with four edge slotted.**

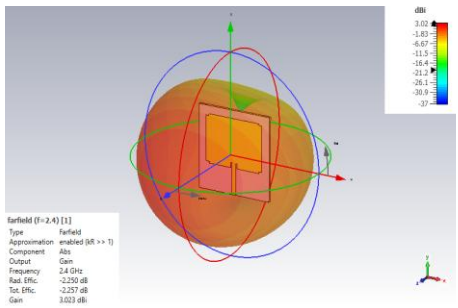
Figure 8 (a-d) shows the simulated results of patch antenna with inset, four corner slots and partial ground. The antenna achieved return loss of -28.150305dB ((96.1%) below -10dB, bandwidth of 118.16MHz ranging from 2.3393GHz to 2.4575GHz, VSWR is 1.014, input impedance is 50.16Ω, and antenna gain of 3.023814dBi at 2.4GHz.



(a) (b)



(c) (d)

**Figure 8 (a-d): Simulated results of (a) return loss, (b) VSWR, (c) Input impedance and (d) Gain (IEEE) of inset RMPA with all-edge slotted and partial ground.**

**Table 2: Comparison of RMPA Simulated Results of antenna with inset, antenna with inset and diagonal Slots, antenna with inset, four edge slots and, antenna with inset, four edge slots and partial ground.**

| Antenna | Antenna with inset only. | Antenna with inset and diagonal slots | Antenna with inset and four edge slots | Antenna with inset, four edge-slots and partial ground |
|---|---|---|---|---|
| Return loss (dB) | -18.34 | -19.599 | -19.997 | -28.150 |
| Bandwidth (MHz) | 97.53 | 92.8 | 93.2 | 118.16 |
| VSWR | 1.28 | 1.23 | 1.22 | 1.08 |
| Impedance (Ω) | 50.27 | 50.31 | 50.09 | 50.16 |
| Gain (dB) | 2.81 | 2.79 | 2.80 | 3.023 |

## 4.0 CONCLUSION

In this work, difference reconfiguration mechanisms such as inset, slots and partial ground were employed to improve antenna performance parameters such as return loss, bandwidth, VSWR, input impedance and gain. From the simulation results, as clearly shown in **Table 2**, the bandwidth and gain of 97.53MHz and 2.81dBi were achieved for antenna with inset, 92.8MHz and 2.79dBi were obtained for antenna with inset and diagonal slots, 93.2MHz and 2.81dBi for antenna with inset and four-edge slotted, while maximum bandwidth and gain of 118.16MHz and 3.023dBi was achieved for antenna with inset, four edge-slotted and partial ground. The general results prove that antenna with four edge-slots and partial ground outperformed the others. Hence, to achieve a broadband microstrip patch antenna, employing partial ground mechanism in the design is a very good technique to enhance MPA performance parameters. The proposed antenna is suitable for wireless communication applications.

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