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Design and Implementation of Bandwidth Enhanced Microstrip Patch Antenna at 2.4 Ghz for Wireless Communication Systems

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ABSTRACT:

Bandwidth and gain are vital metrics that characterize the performance of microstrip patch antenna. In this work, a Rectangular Microstrip Patch Antennas (RMPA) with inset, four edge-slotted and partial-ground was designed on Flame Retardant-4 Epoxy substrates having equal dielectric constant (4.4) and thickness of 1.6mm was used for this work. The antenna was fed with 50Ω input impedance using microstrip feed-line technique at 2.4GHz for wireless communication applications. The design was carried out with the aid of Computer Simulation Technology (2021) software and implemented. The performance metrics such as return loss, bandwidth, Voltage Standing Wave Ratio, input impedance, and the gain were simulated, fabricate and compared with base paper. The simulation results of -28dB, 118.2MHz, 1.08, 50.16Ω, 3.023dBi for return loss, bandwidth, VSWR, input impedance and gain respectively. While the measured results obtained for the return loss, bandwidth, Voltage Standing Wave Ratio, input impedance and the gain are -24.6dB, 106.1MHz, 1.12 and 53.3Ω and 3.021dBi 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 systems at 2.4GHz frequency.

Keywords: RMPA, Configuration, inset, slot, Partial ground (PG), return loss, bandwidth, VSWR, gain, FR-4, sub-miniature A connector, Vector Network Analyzer, 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.

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). 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 (Mojereola et al. 2023).

Slot is a method cutting through the 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. 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 & Mehajabeen, 2015; Neha, 2017).

Microwave segment with partial ground has been picked up ubiquity among every one of the strategies detailed for improving the parameters because of its basic plan (Viswanathan, 2014; Siju & Mehajabeen, (2015). Partial ground is etching of certain portion of the ground structure, which results in partial ground. Scratched openings or deformities on the ground plane of microstrip circuits are alluded to as PG. Single or various deformities on the ground plane might be considered as PG. At first, PG 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 Antenna framework and point by point dimensions presented in Figure 1 and table 1. The antenna is design to operate at 2.4GHz. The waveguide port was excited by 50Ω input impedance SMA through the microstrp line. The construction of these structures were completed on AUTOCAD and transfer to 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. Measurement of fabricated antenna was obtained with the aid of miniVNA (100Hz-3gHz) and comparison was made among Simulated, fabricated and base paper. 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; f_0 = resonant frequency, and ε_r dielectric constant.

The effective dielectric constant ε_{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 $L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}}$

Width of microstrip (W_0) feedline:

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

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:

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

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

The length and width dimensions of slots:

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

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

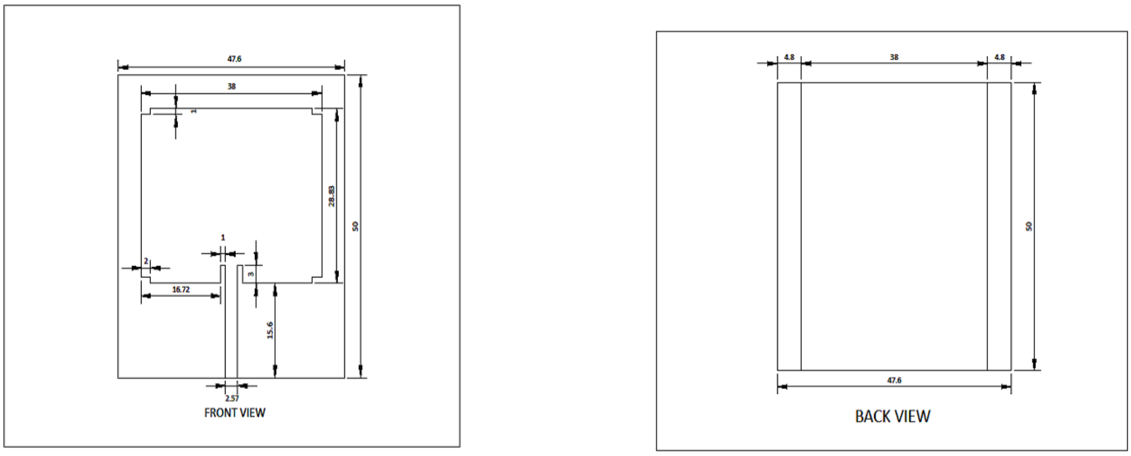
where w = width of patch, L = length of patch.

Table 1: Design geometry of patch antenna

S/N	Operational dimension	Parameters used (mm)
1	Patch width (W_p)	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

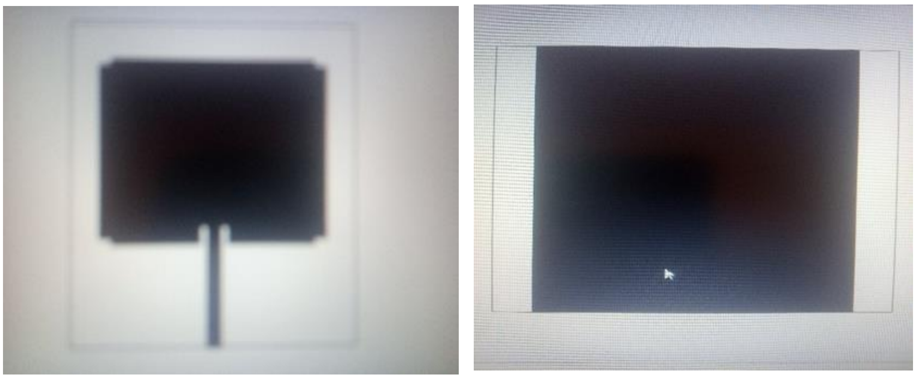
2.2 ANTENNAE MODEL

Figure 1 through 4 below depict the sequential arrangement of fabrication process of the RMPA. While **Figure 6** shows the measurement process of the antenna.



(a) (b)

Figure 1: Front view (a) and Back view (b) AUTO-CAD geometry design of patch of RMPA.



(a) (b)

Figure 2: Front view (a) and Back view (b) imprint geometry of RMPA.

(a) (b)

Figure 3: Fabrication Process (a) Cutting and milling of Substrate and (b) Masking of sized substrate.

(a) (b)

Figure 4: Fabrication Process (a) Etching and (b) Cleaning and drying of RMPA.

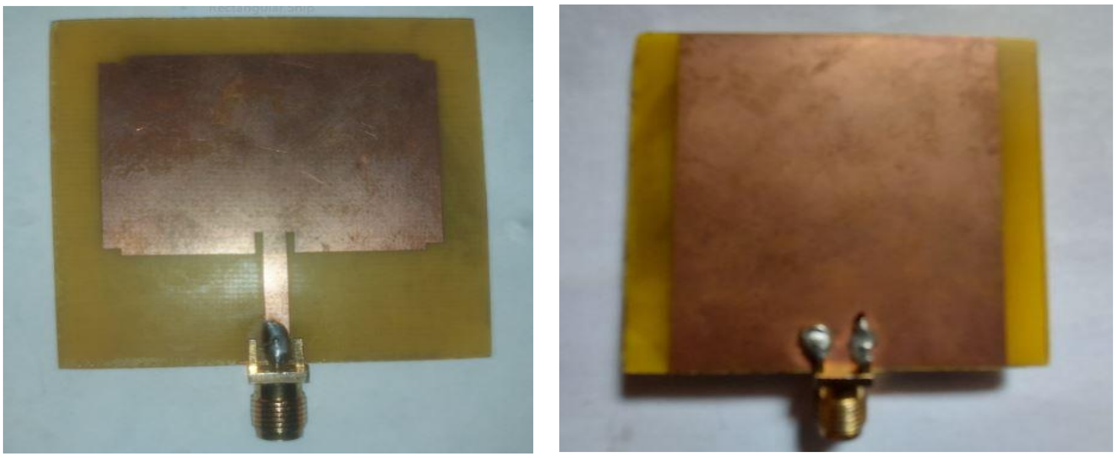


Figure 5: Front view (a) and Rear view (b) of finished fabricated antenna with SMA connector.

Measurement was carried out via a set-up comprising a Laptop computer (Display) connected to the RMPA (device under test) through Vernier Network Analyzer of 100MHz – 3GHz capacity (measuring device) as shown in Figure 6 below. Data of simulation and measured results for each performance metric was exported onto Excel spreadsheet, where comparative graphs were plotted with respective simulation results.

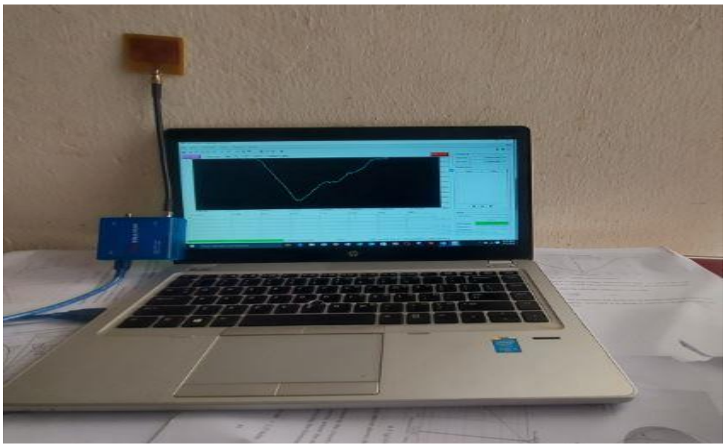


Figure 6: Measurement set-up for proposed MPA

3.0 DISCUSSION OF RESULTS

Simulation and measured data of Antenna were transferred into EXCEL spread sheet and comparision graphs were plotted for respective metric against frequency as shown in **Figure 7 through 10.**

Figure 7 shows the simulation and measured results of the proposed RMPA. The antenna achieved return loss of -28.150305dB ((96.1%) below -10dB, bandwidth of 118.16MHz ranging from 2.3393GHz to 2.4575GHz at 2.4GHz. While the fabricated antenna produced return loss of -24.6 and bandwidth of 106.2MHz at 2.418GH operating frequency below -10dB. The deviation in the value is due to a shift of 0.2GHz on simulation data. However, both result is tightly within the operating frequency of 2.4Ghz and 2.42Ghz.

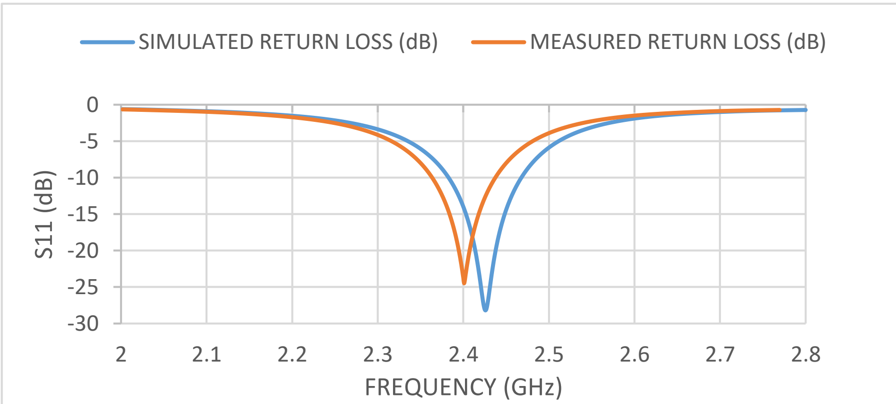


Figure 7: Simulated and Measured results of return loss.

Figure 8 represents the of simulation and measured VSWR. Simulated VSWR is 1.014 while the measured value is 1.12. Both values are tightly within the perfect range for a good antenna.

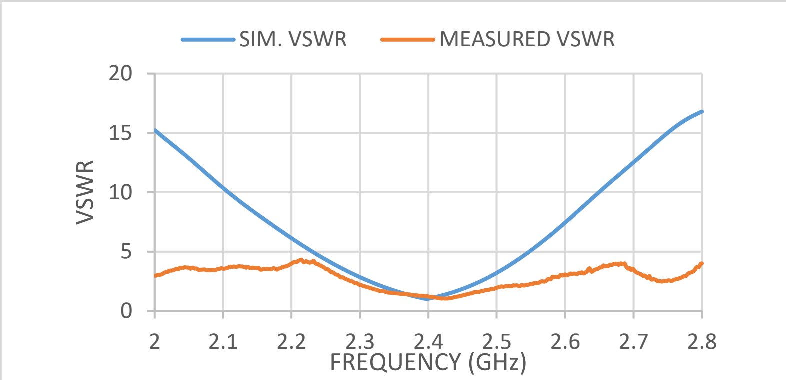


Figure 8: Simulated and Measured results of VSWR

Figure 9 depicts the of simulated and measured input impedance. The Simulated and measured input impedance are 50.16Ω and 53.3Ω respectively.

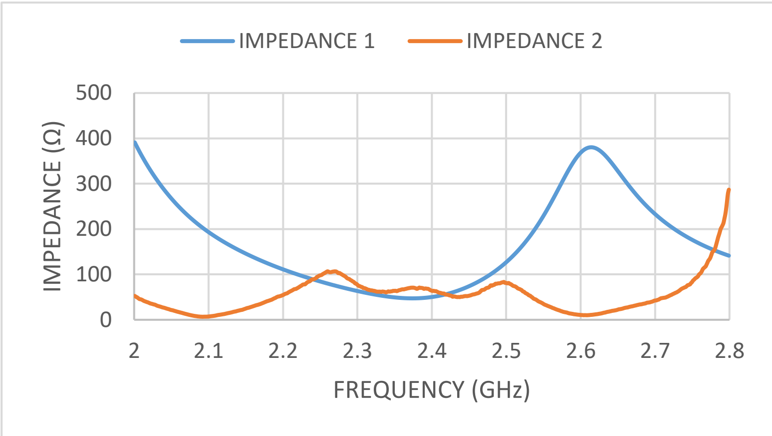
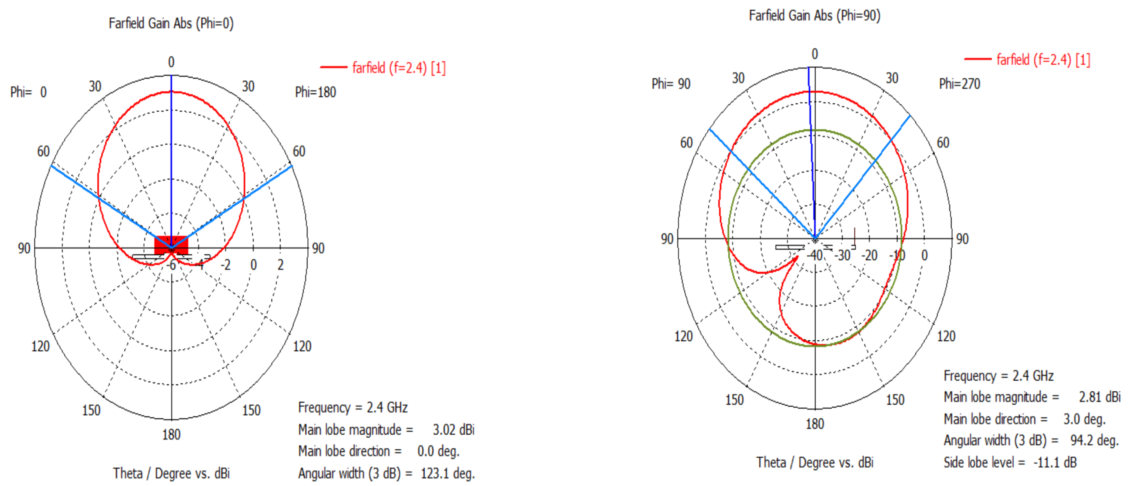


Figure 9: Simulated and Measured results of impedance

Figure 10 a-b present simulated and measured antenna gain. The results give 3.023814dBi and 2.81dBi for simulated and measured value at 2.4GHz respectively.



(a) **(b)**

Figure 10: Simulated gain (a) and Measured gain results of RMPA with all-edge slotted and partial ground.

Table 2: Comparison of Simulated and Measured results of Inset RMPA with four edge slots and partial ground.

Antenna	Simulated antenna	Measured antenna	Base paper (Alaa et al. (2021)
Return loss (dB)	-28.150	-24.6	-38.86
Bandwidth (MHz)	118.16	106.2	58
VSWR	1.08	1.12	1.021
Impedance (Ω)	50.16	53.3	-----
Gain (dBi)	3.023	2.81	-----

4.0 CONCLUSION

In this work, RMPA was reconfigured with metric enhancement 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 **Table 2**, the bandwidth and gain of simulated antenna are 118.16MHz and 3.023dBi respectively, while the fabbricate antenna achieved values of 106.2MHz and 2.81dBi respectively for antenna with inset, all-edge slotted and partial ground. The simulation and measured results prove that four edge-slotted and partial ground RMPA achieves well enhanced bandwidth compare to Base paper (Alaa et al. 2021). Hence, to achieve a broadband microstrip patch antenna, employing four edge-slot and partial ground mechanisms 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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