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Broad-Band Rectangular Patch Antenna With Configurable Patch and Partial Ground Plane

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Abstract:

A rectangular patch microstrip antenna is a tool for wireless communication, suitable due to its advantages such as being low profile, low cost, easy to connect with electronic circuits, and light weight. We introduce a way to increase band width by introducing the technique of reconfigurable patching and tuning of the width of the ground plane. Three steps are done to get the final design, which results in significant effects on return loss and demonstrates bandwidth broadening compared with a traditional rectangular patch antenna. An extensive analysis was conducted to determine the optimal dimensions and parameters of the proposed antenna, including the ground plane width, slot width and length, the gap between the patch edge and ground plane, and the offset of the strip line feed. The optimal dimensions were determined to maximize the performance of the proposed antenna. The optimal dimensions for the width and length of the patch slots are determined to be 2.8 and 7.5 mm, respectively, with a ground plane height of 14.5 mm. The best offset value for strip line feed is -1.5 mm for the y-axis. Finally, the overall bandwidth achieved from the proposed antenna is 10.47 GHz, covering the ultra-wideband range. There are many applications, such as improved Bluetooth, Wi-Fi, Wi-Max, and satellite communication.

Keywords: Monopole, HFSS, Bandwidth Enhancement, Reconfigurable Antenna.

1. Introduction

People are surrounded by a multitude of digital technologies in modern culture, including consumer electronics, mobile devices, and computing equipment [1]. Wireless communication is often the means by which these devices come together; therefore, a common transmitting technology with high data rates is required [2]. The channel capacity in narrowband systems is mainly determined by the ratio of the intended signal intensity to the unwanted (noise) signals due to the bandwidth restriction. However, even when the signal-to-noise ratio (SNR) significantly increases, channel capacity only slightly improves due to the logarithmic proportionality [3]. Furthermore, for the majority of digital equipment, increasing signal strength is frequently unfeasible [4]. In these conditions, broadband technology, encompassing wideband, super-wideband, and broadband, holds potential for achieving a high channel capacity [5, 6]. By extending the channel bandwidth and keeping SNR low, these methods improve channel capacity [7]. As a result, these technologies are used in imaging, positioning systems, networking, wireless communication, and radar systems, among other fields [8]. It is projected that these developments will lead to increased use of smartphones, internet of things accessories, contemporary consumer electronics gadgets, computers, medical equipment, and other devices [9]. Planar microstrip patch antennas are widely used in modern communication systems because of their many benefits, including being lightweight, small in size, and able to handle many resonant frequencies [10]. However, limitations such as low gain and narrow impedance bandwidth prevent it from being widely used in wireless applications [11]. Scholars are investigating many strategies to greatly improve gain, bandwidth, and miniaturization [12]. The utilization of various components, such as dielectric substrates, parasitic patches, metamaterials, and different feeding techniques (including dual and multiple feeding methods), is observed. Additionally, procedures involving air gaps to increase substrate width, the implementation of defective ground structures and shorting pins, the addition of loading slots to radiating patches and ground planes, and modifications to path geometries are also being employed [13]. Techniques such as the open slot method, stub impedance matching, and brick techniques are employed to further enhance bandwidth by accurately matching impedances [14, 15]. In order to get a high bandwidth outcome, one can also reduce the benefit of an antenna's resonant modes by using slot stubs or short-circuited strips to bring them closer together [16]. Various methodologies are utilized to improve antenna performance [17]. One method to enhance signal amplification is by surrounding the antenna with polarization-rotating meta-surfaces, electromagnetic bandgap structures, ladder-like directors, and metamaterial resonance structures. One approach to generating an electric field that is in-phase on surfaces that reflect just a portion of light is to place a layer of highly permeable mesh on top of the surface [18-22]. These antennas, sometimes referred to as 'high-profile' antennas, exhibit increased power gain depending on the size of the base [23]. A second way to boost gain is through shunt inductive loading. This method connects the patch structure to the ground via a shorting pin, which improves the total patch area and gain [24]. The third method, which aims to increase the signal strength, involves using metal reflectors, artificial magnetic conductors (AMC), and frequency-selective surfaces (FSS) positioned at an ideal distance below the patch antenna. These components are used to reflect radiation in phase with the main lobe. To increase gain and decrease dielectric losses and surface waves, the fourth approach includes partially removing the substrate [21]. The greatest gain increase is offered by AMC/PEC and FSS among these techniques. The FSS reflector improves overall compactness by decoupling the antenna from nearby metal components and increasing gain [18]. In this paper, we design, simulate, and fabricate a rectangular patch microstrip antenna RPMS and study the opportunities to investigate the potential for enhancing the bandwidth and its performance compared with the traditional RPMS by utilizing reconfigurable patch and partial ground plane techniques [26,29].

2. Antenna Theory and Design

The analysis of a rectangular patch antenna can be conducted using either cavity or current model methods [25]. This analysis considers the dimensions of the rectangular patch, specifically the width and length, in order to determine the efficiency of the antenna as a radiator. The value should be assigned as one-half of the wavelength that corresponds to the average of the two dielectric mediums, namely the substrate and air. This can be calculated using equation (1) [27,30].

$$W = \frac{c}{2f_0\sqrt{\frac{(\epsilon_r+1)}{2}}} \qquad \text{□□□}$$

where c is the speed of light, f0 resonant frequency and ϵ_r is the relative permeability of the substrate. The resonant frequency is calculated from equation (2):

$$f_0 = \frac{c}{2L_e\sqrt{\epsilon_e}} = \frac{15}{L_e\sqrt{\epsilon_e}}\ (GHz) \qquad \text{□□□}$$

Where ϵ_e is the effective permeability of the medium, is given by equation (3):

$$\epsilon_e = \frac{(\epsilon_r+1)}{2} + \frac{(\epsilon_r-1)}{2}\left[1 + \frac{10h}{W}\right]^{-1/2} \qquad \text{□□□}$$

Where h is the height of the substrate. Due to the fringing fields the electrical length is given by: equation (4)

$$L_e = L + \Delta L \qquad \text{□□□}$$

where ΔL is related to the relative permittivity as in equation (5):

$$\Delta L = \frac{h}{\sqrt{\epsilon_e}} \qquad \text{□□□}$$

For operation frequency 2.4 GHz, the dimensions of the RPMS are 40mm and 36mm for width and length, respectively, simulated and designed on the Epoxy-RF4 substrate of dielectric constant = 4.4 with tangent loss of 0.02 and height h of 1.6mm. The optimum dimensions of the substrate (size of ground plane) are given by equations (6a and 6b) [28].

$$L_{groud} = L + 6h$$

□□□□□

$$W_{groud} = W + 6h$$

□□□□□

□

3. Simulation Results

Using HFSS software to simulate and design the RPMS, Fig. 1 illustrates the return loss via frequency. As shown from the figure, the antenna reflection coefficient presents multi-resonant frequency in the operating range from 2 to 12 GHz due to the general formula of the resonant frequency of the RPMS at any TMnm mode, which can be determined using the equation (7):

$$f_{mn} = \frac{c}{2\sqrt{\epsilon_e}}\left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2\right]^{1/2}$$

□□□

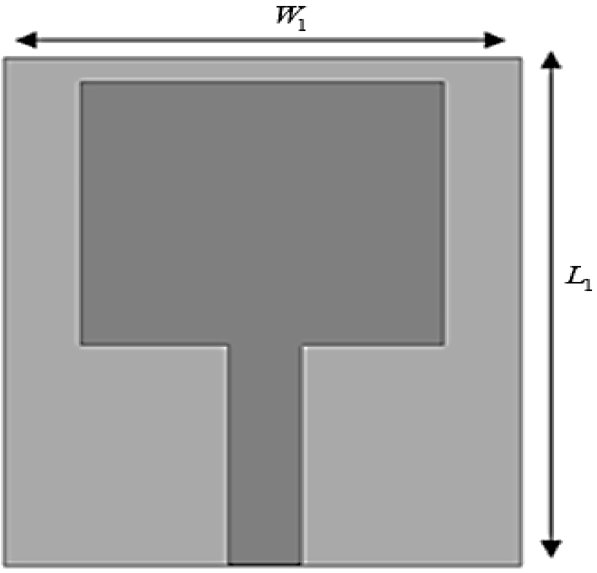

Fig. 1. The front face of the rectangular patch microstrip antenna RPMS.

4. Broadband PRMA Parametric Study

In this section, we examine the dimension of the ground plane GND width and the dimension of the slots on the patch of the RPM, while the offsetting of the center feed location of the strip line.

4.1 Parametric study of the GND width

To investigate the impact of tuning the width of the GND to get the wider bandwidth, the parametric study was done by varying the parameter g for 4.5-1.5 mm by steps of 0.5 mm. The result is depicted in Fig. 2. The best value for broadening return loss is 1.5 mm; this is due to the effect of the fringing field. As depicted in the figure, the change in the GND width primarily impacts the low-frequency band (2-4 GHz) and high-frequency band (9-12 GHz) due to alterations in the path of the edge. The best value I got is g = 1.5mm.

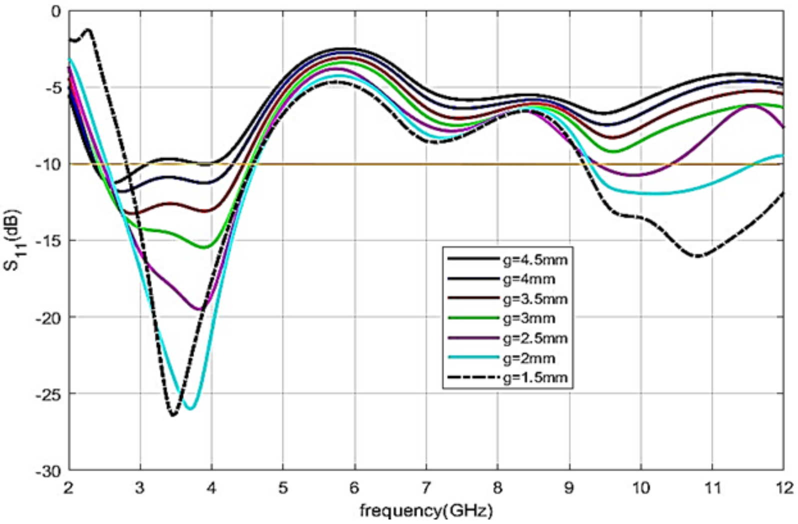

Fig. 2. Reflection coefficient for the RPMS antenna with different values of g.

4.2 Parametric study of the patch slots width and length

To decrease the resonance frequency of the RMSA, an alternative method is to enhance the path length of the surface current by creating slots in the patch. By expanding the width and length of the slot, the trajectory of the surface current extends from one open end to the opposite open end. As a result, a parametric analysis was conducted by altering both the width and length of the slots, as illustrated in Figure 3. The dimensions of the slot, specifically its width and length, have an impact on the course of the surface current. This results in an overall increase in bandwidth. The ideal values for the width and length of the slot are 2.8mm and 7.5mm, respectively.

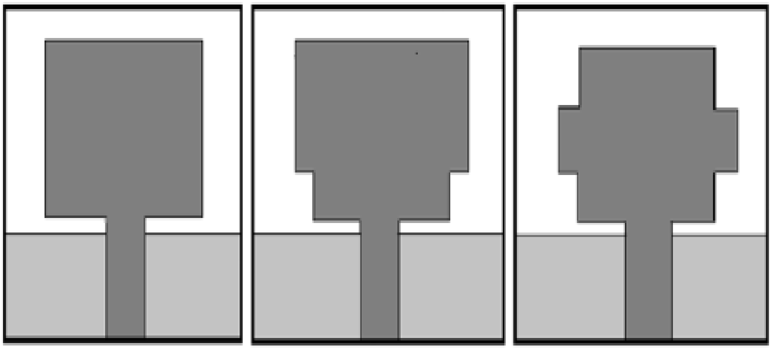

Fig. 3. The geometrical progression of the antenna.

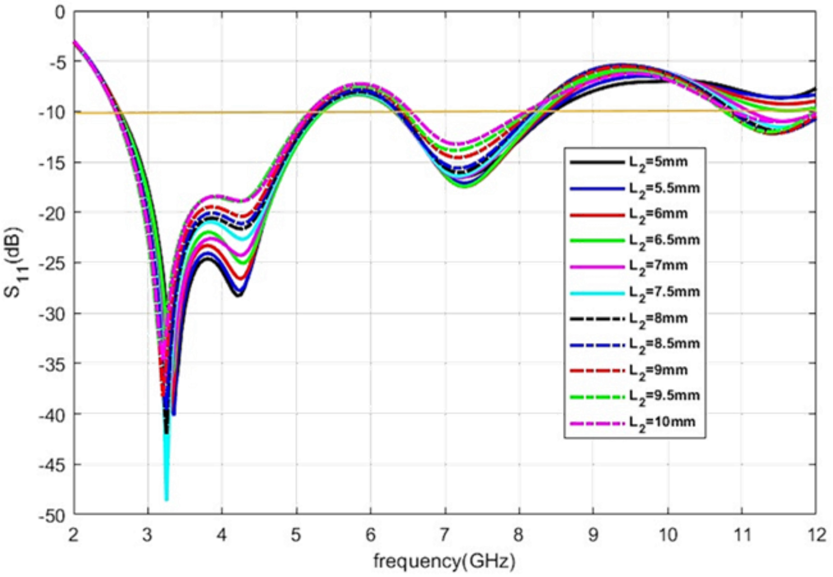

Fig. 4: Antenna reflection coefficient for different values of L_2.

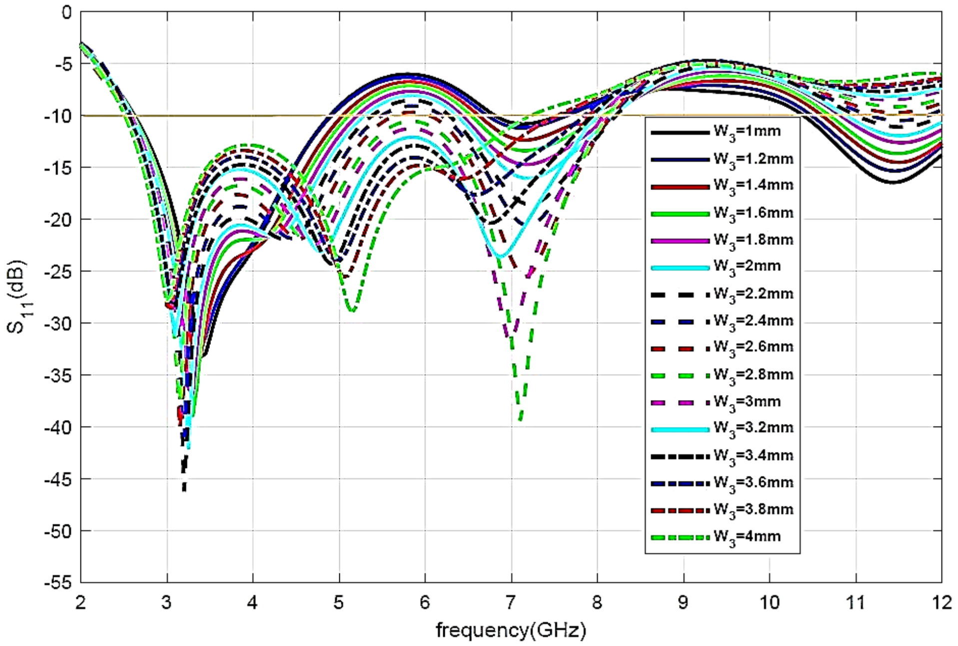

Fig. 5. Antenna reflection coefficient for different values of W_3 .

4.3 Parametric study of offset the strip line feed

A parametric analysis is conducted to evaluate the performance of the created antenna in comparison to a conventional antenna. The software is used to test and experimentally verify factors such as reflection coefficient, gain, and radiation characteristics. Figure 6 illustrates the relationship between the return loss and the offset parameter (pos). This study examines the impact of the feeding offset on the distribution of the reflection signal along the feed line, comparing the case of an offset with the case of no offset. The optimal offset value for the position (pos) is -1.5mm with respect to the y-axis.

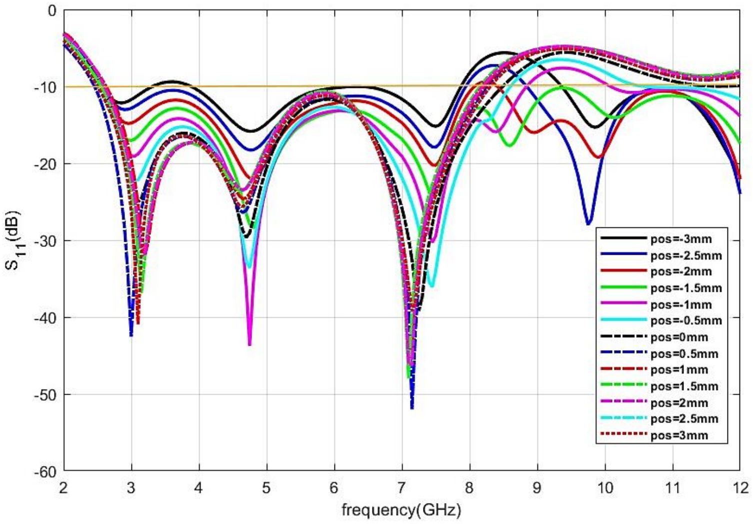

Fig. 6. Antenna reflection coefficient for different offset location.

The simulation results are displayed in Figures 2, 3, 4, 5, and 6. The optimal values for the proposed antenna are presented in Table 1.

Table 1. Dimensions of the designed antenna.

Parameter	Value(mm)	Parameter	Value(mm)	Parameter	Value(mm)
W_1	36	L_1	7.5	W_f	3
L_1	40	L_3	6	Pos	-1.5
W_2	18.4	L_f	16	h	1.6
W_3	2.8	g	1.5	-	-

Fig. 7 depicts the antenna that was developed based on the results of the thorough parametric studies conducted in this paper. Figure 8 illustrates the return loss of the antenna under consideration. The diagram clearly illustrates that the suggested antenna has a broader frequency range, surpassing the Ultra-Wideband (UWB) spectrum, covering frequencies from 2.4 to 13 GHz.

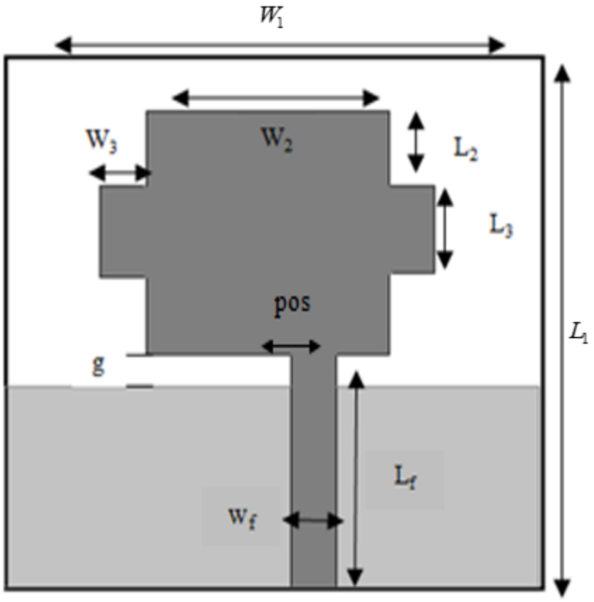

Fig. 7. Schematic diagram of the proposed antenna.

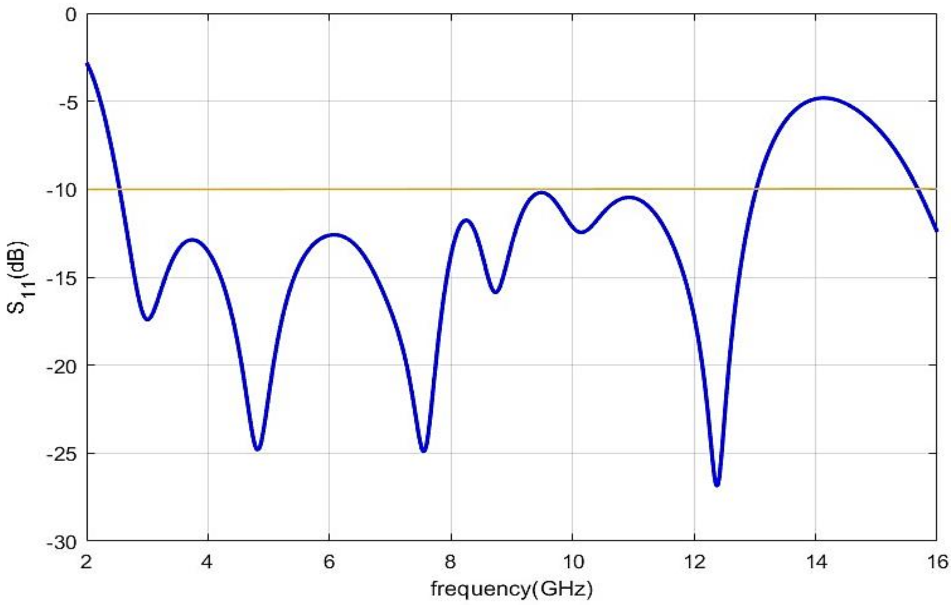

Fig. 8: Simulated reflection coefficients for the proposed antenna.

5. Experimental Result

Following the determination of the optimum of the proposed antenna, the antenna was fabricated, as shown in Fig. 9, and tested experimentally using the vector analyzer of trade mark ROHDE & SCHWARZ ZVZ™ with operating frequency 10 MHz to 24 GHz in four channels, as shown in Fig. 10.

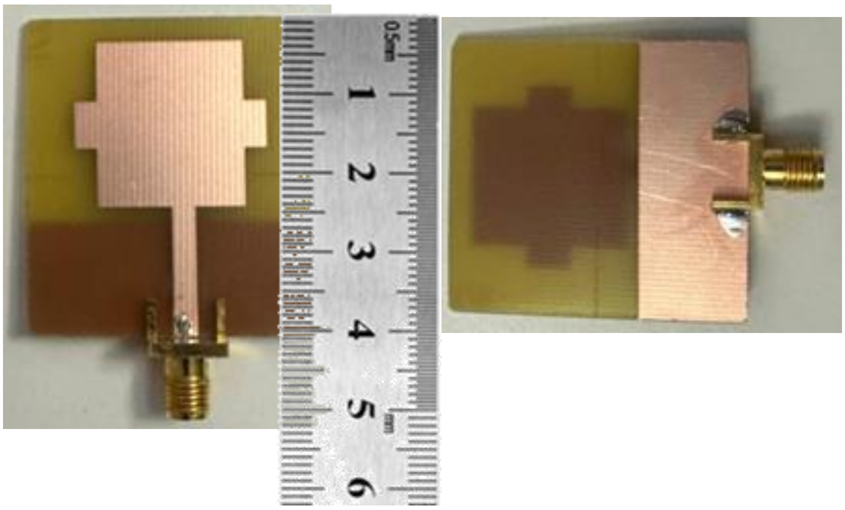

Fig. 9. Prototype proposed antenna.

Fig. 10. Vector analyzer and testing process

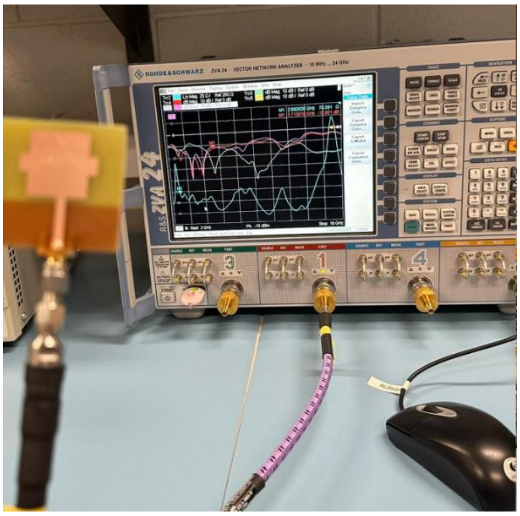

Fig. 11. The comparison result between the simulation and experimental result

Fig. 10: Vector analyzer and testing process (a) vector analyzer and (b) Device under test. The analyzer was calibrated, normalized, and then tested on the single antenna to get the return loss. Fig. 11 shows the comparison result between the simulation and experimental result, from which it is clear to conclude that there is a high correlation between the simulated and experimental result.

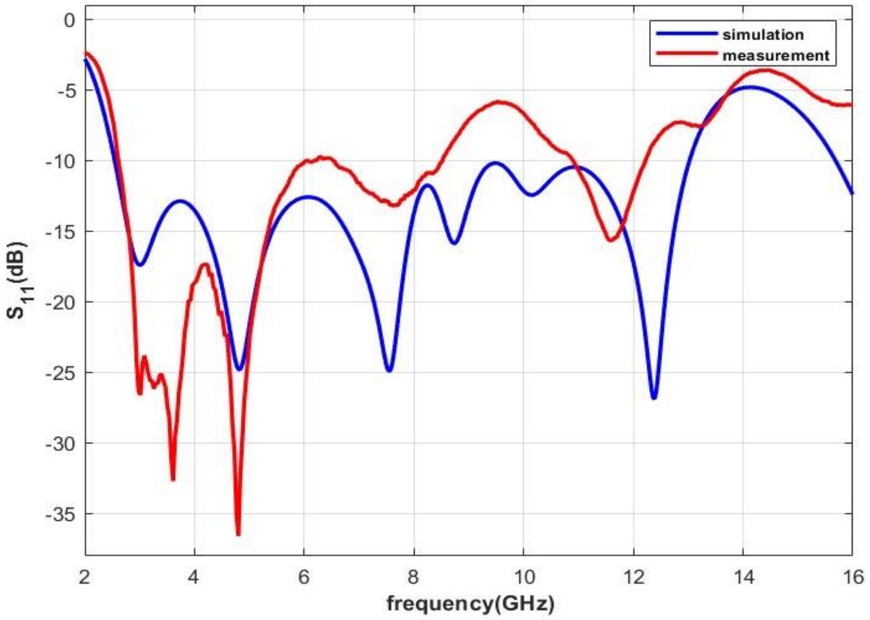

Fig. 11. Simulated and Experimental results

6. Conclusion

While traditional RPMA offers several advantages, it suffers from limitations such as narrow bandwidth, low gain, and a narrow beamwidth. Many techniques are used to enhance the bandwidth, gain, and beam width, for example, by introducing a modified (reconfigurable) radiating patch or ground plane. Based on an extensive parametric study to model and construct the suggested antenna, this study concludes that the radiation slots have a notable impact on the bandwidth, while the width of the ground plane also plays a significant role in expanding the frequency range of the proposed antenna compared to the conventional one. The new antenna is highly valuable in the wide range of wireless applications such as IMS band, Wi-Fi, Wi-Max, and satellite communications, allowing higher bandwidth communications at a comparatively low cost.

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