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Original Article

Design of a Compact Rectangular Microstrip Patch Antenna for 2.45 GHz ISM Band

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Abstract *- Antenna is an indispensable part of wireless communication. In particular, the microstrip patch antenna has gained significant popularity due to its distinctive advantages in terms of compactness, ease of manufacturing, and low energy requirements. On the other hand, microstrip patch antenna suffers from several practical limitations such as small bandwidth, low gain, and less efficiency with decreasing size, etc. With the advent of smartphones and smart IoT devices, the necessity of a compact and robust antenna has reached an unprecedented level. However, designing such an antenna is challenging due to the various physical properties of antenna components, undesirable side effects, and conflicting requirements. This report presents a compact and lightweight Rectangular Microstrip Patch Antenna (RMPA) design to address the aforementioned limitations. The proposed, designed antenna operates at a 2.45 GHz ISM band suitable for WLAN application. The design has been simulated in CST Studio Suite 2015 software. Critical analysis of simulation results reveals superior antenna performance compared to state-of-the-art designs available in the literature. The suggested single element compact designed RMPA antenna shows low return loss (–47.208 dB), VSWR (1.009) and gain (3.18 dB), high directivity (5.18 dBi), and efficiency (61.57%).*

Keywords *- ISM band, WLAN, Microstrip patch antenna, Compact design, Microstrip line feed.*

1. Introduction

Wireless communication has become an increasingly pervasive mode of communication nowadays, replacing traditional wired technology. At the core of wireless communication is the antenna device, which enables the transmission and receipt of wireless signals. Driven by the wide range of wireless communication applications, antenna design has gone through multiple evolutions since its inception as a large metallic device. Microstrip Patch Antennas (MPA), in particular, have gained significant popularity in recent years due to their clear advantages over conventional designs in terms of compact form factor, mechanical robustness, low cost, low power consumption, and ease of fabrication [1]–[5].

Fig. 1 shows the basic structure of a Rectangular Microstrip Patch Antenna (RMPA) with three different layers. It consists of a conducting patch and ground layers above and below the substrate plane. Due to its distinctive features, MPA facilitates many new application domains, including mobile communication, computer network system, radar application, global positioning system, smart IoT devices, etc. [1].

These devices are made for the ISM band and usually communicate through the Wireless Local Area Network (WLAN) band as defined in the IEEE 802.11b standard [6]. As a result, many novel works have been proposed in the literature aiming to provide a compact, robust and efficient antenna design for the ISM band [3]–[5], [7]–[9].

Despite its attractiveness, especially in the engineering field, MPA suffers from several practical limitations, such as small bandwidth, low gain, and less efficiency with decreasing size, etc. [10]. Therefore, a practical antenna needs to be carefully designed to minimize these limitations. It must feature a small form factor and low weight so that it can be integrated into portable devices [11], [12]. It should also have robust performance, less power consumption, and low manufacturing cost.

MPA can be of various types. Among these, rectangular and circular MPA is widely adopted [13]. An RMPA shows superior performance than its circular counterpart for the same design constraints. Besides, RMPA is more practical from a manufacturing perspective. For these reasons designing a compact RMPA has been chosen as the primary objective of this paper.

At the present time, compact, high-performance antenna design has become a much-needed issue. Although many significant research works have been conducted since its very first appearance, it has become the most competitive topic among researchers during the last decade, when many novel designs have been published. An RMPA with a relatively large patch has been presented in [14]. Though it shows high directivity, it suffers from very poor gain, return loss, and Voltage Standing Wave Ratio (VSWR). Lubis et al. [15] have proposed an alternate design with a taller form factor. Though their design shows improved gain compared to [14], it has a poorer directivity and mediocre return loss.

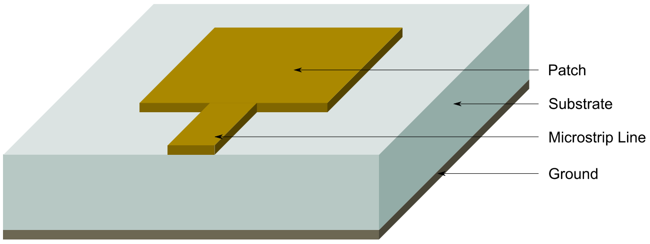

Fig. 1 Rectangular microstrip patch antenna

Shimu and Ahmed proposed another RMPA featuring a large substrate [7], which has significantly high directivity and high gain. However, it also shows poor return loss, and its manufacturing cost would also be higher due to its larger dimension. A compact RMPA design has been proposed in [16] with a smaller patch size than earlier designs. It achieves very high gain and directivity and also shows superior return loss performance. However, its VSWR performance is relatively poor and also has a large discrepancy between simulation and real-world performance.

This paper presents a novel RMPA design that offers improved performance at a compact and lightweight rectangular form factor. The novel design shows superior performance in terms of high directivity, comparatively high efficiency, low return loss, and smaller VSWR with respect to state-of-the-art designs found in the literature [7]–[10], [14]–[17]. The proposed antenna operates at the WLAN band from 2.4 GHz to 2.5 GHz. The design has been simulated in CST Studio Suite 2015 software.

The rest of the paper is organized into several sections. Section II describes the design methodology. Simulation results and discussion are presented in Section III. Finally, Section IV ends the paper with some concluding remarks.

2. Antenna Design Methodology

The design methodology consists of three individual component designs such as the ground plane, the substrate, and the radiating patch. The microstrip line feed technique is used in this design. Copper annealed is used for the ground plane and radiating patch. FR-4 (lossy) substrate with a relative permittivity $\varepsilon_\gamma = 4.3$, the loss tangent of 0.025, and thickness h = 1.6 mm is chosen. The patch antenna parameters are calculated using the standard design equations explained below at the reference resonant frequency. The ISM Band 2.4–2.5 GHz is considered for the present simulation study.

The resonance frequency for ISM Band (2.4–2.5 GHz) is

$$f_r = \frac{2.5 + 2.4}{2} GHz = 2.45\ GHz$$

The width of the patch antenna

$$W_0 = \frac{c}{2f_r} \times \sqrt{\frac{2}{\varepsilon_\gamma + 1}} = 37.61mm$$

The effective dielectric constant is

$$\varepsilon_{eff} = \frac{\varepsilon_\gamma + 1}{2} + \frac{\varepsilon_\gamma - 1}{2\sqrt{\left(1 + 12\frac{h}{W_0}\right)}} = 3.993$$

The length extension ΔL on each side is

$$\Delta L = 0.41h \times \frac{\varepsilon_{eff} + 0.3}{\varepsilon_{eff} - 0.258} \times \frac{\frac{W_0}{h} + 0.264}{\frac{W_0}{h} + 0.8} = 0.737mm$$

The effective length of the patch is

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} = 30.639mm$$

The actual length of the patch is

$$L = L_{eff} - 2\Delta L = 29.165mm$$

The ground plane dimensions would be given as

$$L_g = 6h + L = 38.765mm$$

$$W_g = 6h + W_0 = 47.21mm$$

These all are the calculated values of antenna parameters of the proposed antenna at the resonance frequency of 2.45 GHz. Initially, we designed the RMPA using the calculated values as obtained above and examined its performance. Following that, we used the trial and error method in order to reduce the size of the proposed antenna as well as to improve its radiating performance. We cut three slots (slot 1, 2, and 3) of different dimensions (width × length dimensions of slots 1, 2, and 3 are 7.2 mm × 2 mm, 1 mm × 3 mm, and 1mm × 5.5 mm, respectively) on the radiating patch and also optimized the length and width of the patch to a value of 28 mm and 36 mm, respectively, to meet the design objectives of the proposed antenna. The design of the proposed antenna is finalized with the dimensions listed in Table I. The final design is illustrated in Fig. 2.

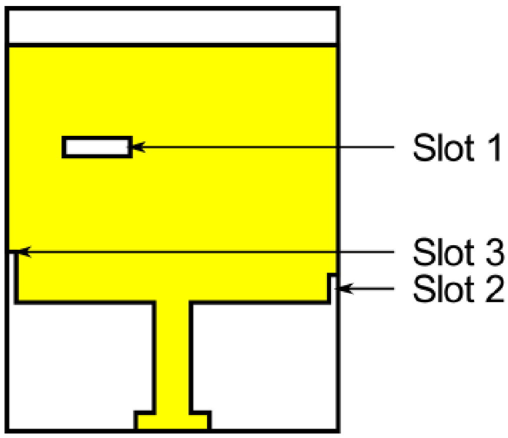

Fig. 2 Illustration of the designed RMPA

Table 1. Design parameters values of the proposed antenna

	Length(mm)	Width (mm)	Height (mm)	Material
Ground	46	36	0.035	Copper annealed
Substrate	46	36	1.600	FR-4(lossy)
Feeding Patch	28	36	0.035	Copper annealed
Transmission Line	12	4	0.035	Copper annealed
Microstrip Line	2	4	0.035	Copper annealed

3. Simulation Results and Discussion

The proposed RMPA is designed using CST STUDIO SUITE 2015 software. The performance of the proposed RMPA has been presented in terms of the following parameters: return loss, VSWR, antenna gain, directivity, efficiency, and radiation pattern.

3.1. Return Loss or S-parameter

The Return Loss of the proposed microstrip antenna is shown in Fig. 3. It shows an impressive return loss figure of–47.20828 dB at the center resonant frequency of 2.45 GHz, which is a significantly larger negative value as compared to the standard value of -10dB. This increased negative return loss value signifies good impedance matching with respect to the reference impedance of 50W.

That most of the power is radiated, and only a minute portion is lost by the proposed antenna. It is also observed that the effective bandwidth of the proposed antenna is 0.1158 GHz which satisfies the requirement of an operating bandwidth from 2.4 GHz to 2.5 GHz.

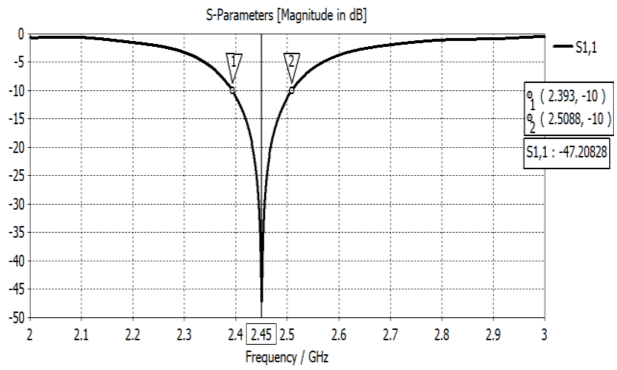

Fig. 3 Return loss Vs. Frequency plot of the proposed RMPA

3.2. VSWR

Fig. 4 presents the VSWR graph of the proposed RMPA antenna. It is seen that the VSWR value of the proposed antenna is 1.0087605 at the center resonant frequency of 2.45 GHz, which indicates that the designed antenna performance is outstandingly close to the ideal VSWR value of 1. It also implies that there is a good impedance matching between the source and the feed line, which is essential for the proper working of the antenna.

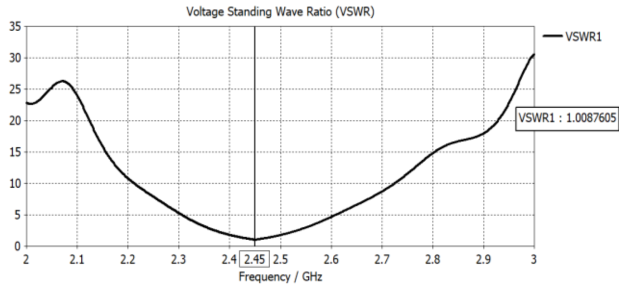

Fig. 4 Voltage Standing Wave Ratio (VSWR) Vs. frequency plot

3.3. Antenna Gain

Antenna gain describes how much of the antenna power is radiated in a given direction. Fig. 5 shows a 3D plot of antenna gain. It is seen that the designed antenna has a gain of 3.074 dB at a center frequency of 2.45 GHz, which implies that the antenna is more efficient at this frequency.

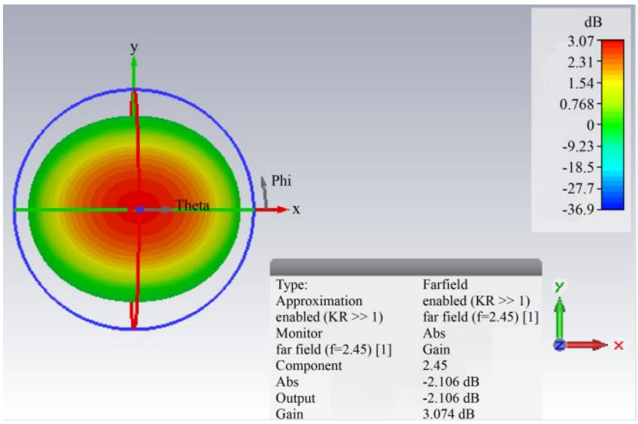

Fig. 5 3D plot of fairfield gain of the proposed antenna at 2.45 GHz

3.4. Directivity

The directivity of an antenna reveals the ability to radiate energy in a specific direction during power radiation or its ability to receive energy from a specific direction during power reception. A good quality antenna requires high directivity. Fig. 6 shows a 3D plot of the directivity of the proposed rectangular antenna. It is seen that the directivity (maximum amount of radiation intensity) equals 5.18 dBi at the center frequency of 2.45 GHz.

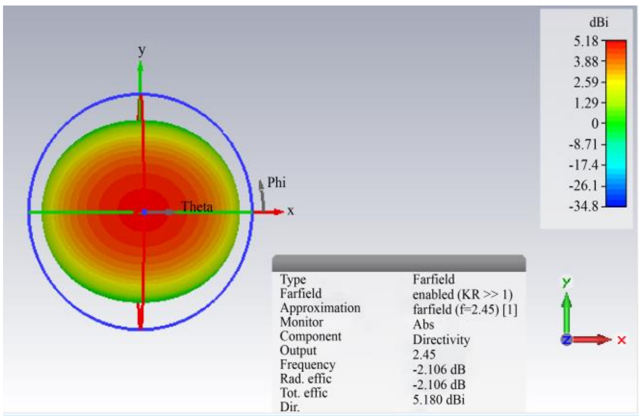

Fig. 6 3D plot of farfield directivity of the proposed antenna at 2.45 GHz

3.5. Antenna Efficiency

Antenna efficiency measures how much energy radiates in the air in all directions. It is defined as the ratio of the radiated power to the incident power at the antenna. For high-performance antennas, antenna efficiency needs to be high. Fig. 7 shows the radiation efficiency of the proposed antenna. It is seen that the radiation efficiency is 61.57 % at the resonant frequency of 2.45 GHz, whereas it is around 62% at the corner frequencies of operation.

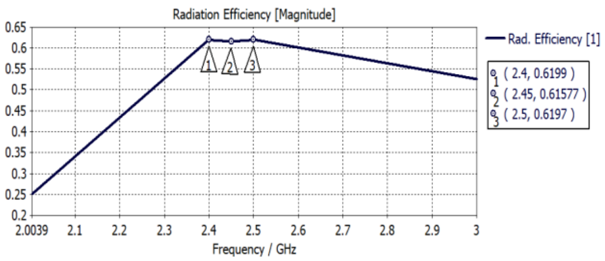

Fig. 7 Radiation efficiency of the proposed antenna

3.6. Radiation Pattern

A radiation pattern describes how the energy is radiated out into space by the antenna or how it is received. It is represented by the far-field radiation properties of the antenna as a function of the spatial coordinates specified by the elevation angle *Theta* and the azimuth angle *Phi*. The 2D far-field radiation patterns of the proposed rectangular microstrip patch antenna are shown in Fig. 8 and Fig. 9.

3.6.1. E-Field Pattern

Fig. 8 demonstrates the polar plot of the E-field pattern of the proposed rectangular microstrip patch antenna. It is seen that at the center frequency of 2.45 GHz, we see main lobe magnitude is 17.8 dBV/m, the main lobe direction is 1.0 degrees, the angular width is 90.2 degrees, and the sidelobe level is –7.5 dB.

3.6.2. H-Field Pattern

Fig. 9 demonstrates the polar plot of the H-field pattern of the proposed rectangular microstrip patch antenna.

It is observed that at the center frequency of 2.45 GHz, we see the main lobe magnitude is –33.7 dBA/m, the main lobe direction is 1.0 degrees, the angular width is 90.2 degrees, and the sidelobe level is –7.5 dB.

The above simulation results of the proposed, designed rectangular patch antenna are presented in Table II. Table III shows a comparison of the present simulated results of the proposed antenna with the previously published research results found in the literature.

From Table III, it is observed that our proposed antenna is more compact in size as compared to the other research works shown in the table for the same substrate material. Return loss and VSWR of a good designed antenna should be approximately equal or smaller than -10dB and 2. In our proposed antenna, both parameters value meets the requirements and are also much smaller as compared to other research works shown in the table. The gain of our proposed antenna is not large enough as compared to other research works, and this is due to the high tangential loss of substrate material and low thickness of our proposed antenna. The reduced size of our antenna also influences the reduction of antenna gain. The directivity of our antenna is comparatively high, as illustrated in Table III.

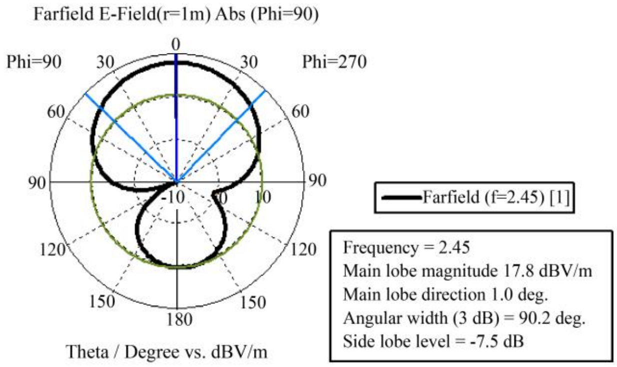

Fig. 8 Far-field E-field pattern of the proposed antenna

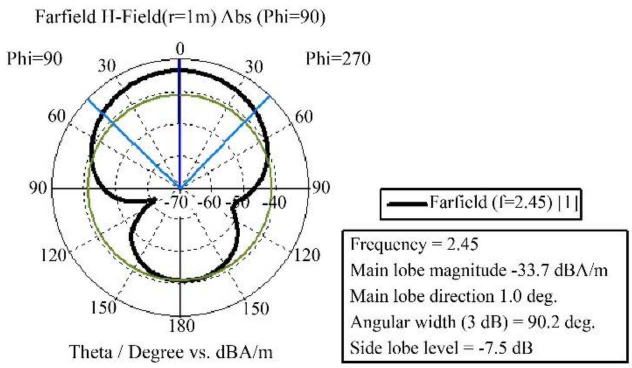

Fig. 9 Far-field H-field pattern of the proposed antenna

Table 1. Performance results of proposed RMPA

Parameters	Value
Resonant Frequency	2.45 GHz
Bandwidth	0.1 GHz (from 2.4 GHz to 2.5 GHz).
Return Loss	-47.20828 dB
VSWR	1.0087605
Directivity	5.18 dBi
Gain	3.08 dB
Efficiency	61.57%

Table 3. Comparison of present and past results

Research work	Antenna dimension (mm)	Substrate Dimension (mm)	Working Frequency (GHz)	Return Loss (dB)	VSWR	Gain (dB)	Directivity (dBi)
Prabhakar et al. [14]	38.03×29.44	47.636×39.043	2.0 – 2.5	-13.15	1.56	1.59	4.88
Lubis et al. [15]	32.00×72.00	--	2.4 – 2.48	-13.57	-	3.81	3.88
Shimu and Ahmed [7]	39.52×31.03	60.00×60.00	2.4 – 2.5	-38.50	1.02	5.49	7.48
Thilagam.J and Babu T.R [16]	36.60×28.17	42.90×46.30	2.4 – 2.5	-42.29	1.52	5.50	5.73
This work	36.00×28.00	36.00×46.00	2.4 – 2.5	-47.21	1.01	3.07	5.18

The analysis presented above reveals the superiority of the designed RMPA antenna in terms of its compactness, directivity, VSWR, and return loss with respect to the state-of-the-art designs available in the literature. The proposed design shows a VSWR of 1.009, which is very close to the ideal. Consequently, its return loss figure of –47.208 dB is much lower than the theoretical bound. The antenna also shows high directivity of 5.18 dBi. More importantly, the proposed design has a dimension of 36mm × 28mm, which is more compact than the state-of-the-art designs. Although the antenna shows superior performance in terms of size, directivity, return loss, and VSWR, it also exposes some limitations. It displays comparatively low gain and antenna efficiency. This is a side effect of reducing antenna size and high tangential loss of the substrate material. However, the benefits of a compact antenna outweigh the disadvantages of the limitations.

4. Conclusion

A compact rectangular microstrip patch antenna (RMPA) has been designed and simulated for a 2.45 GHz ISM band suitable for WLAN application. The proposed antenna is designed using CST Studio Suite 2015 software, and a number of iterations are performed in the design process to get an optimized and viable compact and lightweight antenna structure with superior performance. Three slots of different dimensions and a quarter-wave matched microstrip feedline are used to improve the performance of the antenna. The designed antenna is significantly more compact than the theoretical dimensions; in fact, it has the smallest form factor compared to state-of-the-art antenna designs available in the literature. The proposed antenna framework shows a low return loss. (–47.208 dB), VSWR (1.009) and gain (3.18 dB), high directivity (5.18 dBi), and efficiency (61.57%).

In future works, we will focus on the fabrication and testing of the proposed antenna and performance comparison of the simulated and fabricated antenna. An extension of the present work would be integrating the proposed single elemental design into an array on a single substrate. Such an arrangement can show enhanced gain, directivity, and efficiency compared to its singular counterpart. Another possible approach to improve low gain and efficiency would be to use a different substrate material with lower tangential loss. However, the availability, cost, and ease of manufacturing play important factors in choosing a substrate material.

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