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For S-band WLAN applications, a patch antenna design, simulation, and optimization

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ABSTRACT

A rectangular microstrip patch antenna for 2.45 GHz is designed, tested, and analyzed in this study. It uses two substrate materials (design I and II) with different permittivity levels. RT5880 (design-I) and FR-4 (design-II) substrates have a thickness of 1.57 mm and 1.6 mm, respectively. Design-I and design-II substrates have relative permittivity of 2.2 and 4.3, respectively. Performance and efficiency are considered due to the substrate material's relative permittivity and thickness; return loss (S_{11}), voltage standing wave ratio (VSWR), gain, directivity, surface current, and efficiency. Design II and design I have 3.25 dBi and 8.089 dBi gains, respectively, and 5.92 dBi and 8.64 dBi directivity, respectively. Design I had the best antenna efficiency, 93.64%, compared to design II, 54.96%. In contrast to the design I and design II, which had return losses (S_{11}) of -53.29 dB and -51.38 dB, each of the suggested antennas had a return loss (S_{11}) of more than -50 dB. The VSWR for design I is 1.0043, while the Design II material is 1.0054. This study aims to reduce return loss (S_{11}) and close the VSWR to 1. This proposed design improves antenna gain, directivity, and efficiency for future wireless applications on wireless local area networks (WLANs).

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1. INTRODUCTION

Microstrip patch antennas are widely employed in many communication systems, such as satellite and mobile communications, healthcare applications, radar, the global positioning system (GPS), wireless local area networks (WLANs), and radiofrequency energy harvesting systems. The field of communication has developed tremendously over the past several years, and the technology behind wireless communication is affecting people's lives today. The next generation of wireless terminal communications equipment is being developed to capitalize on the growing demand for low-cost beamforming antennas [1], [2]. Current antenna technologies for wireless networks are being developed to satisfy the growing demands of emerging applications, including wireless applications [3]. Patch antennas are lightweight, compact, low-profile, and more cost-effective than conventional microwave antennas [4]. Nevertheless, the microstrip patch antenna is bound by numerous properties, including diminished amplification, broad frequency range, reduced effectiveness, and limited power tolerance. By constructing many patch antennas with different geometry, such as rectangular and circular ones, it is possible to avoid these limits. To increase the bandwidth, the ordered patch antenna structures, which include circular and rectangular patches, have been transformed into circular and rectangular ring patch antennas after being changed [5]. Today's wireless networks require connectivity for over five billion devices to support voice, data, and many other applications. Microstrip patch antennas are gaining popularity in wireless communication because of their cost-effectiveness, ease of fabrication, lightweight nature, flexible feed lines, and compatibility with solid-state electronics. In the 1950s, the first microstrip antenna was made available to the public. The pace of its development picked up in the early 1980s, and it is still going strong now [6]. The microstrip patch antenna has conducting and insulating materials segmented into three distinct sections. The upper and lower layers employ conductive materials, especially patch and ground. Copper is suitable for constructing the ground structure layer, also known as the bottom structure layer. Conversely, a dielectric substance, sometimes referred to as a substrate, is used as the intermediary layer that divides the two levels [7].

2. LITERATURE REVIEW

This section will analyze the diverse applications of microstrip patch antennas and the methodologies adopted by the authors. This antenna has been used in multiple situations up to this point. Current technology is augmenting the requirement for its utilization. The development of wireless communication technology has made it possible to increase the speed at which data can be transferred and provide clients with higher-quality services, which has led to the creation of more effective and less complicated ways [8]. The number of consumers using various wireless networks is growing at an alarming rate, and to adequately meet this growing demand, incoming wireless systems will need to be improved. The study analyzes many previously published works on the subject of 2.45 GHz. The article [5], presents a multi-slot patch antenna with an octagonal ring shape operates at 2.45 GHz. To achieve the octagonal ring shape, a single slot in the shape of an octagon and many slots in rectangles, squares, or triangles are added. The primary focus of this investigation [9] is on two objectives: increasing amplification through the creation of an array and fabricating a graphene antenna array using a basic and economical printing method. Both objectives might be accomplished by increasing the gain compared to a single patch and producing and verifying the performance of the graphene antenna.

This article [10] provides an overview of the design and construction of a switching beam antenna operating at 2.45 GHz. The antenna is designed for applications involving wireless sensor networks within the industrial, scientific, and medical bands. The gain measured for the proposed antenna in the steering direction is higher than the gain reported for a conventional microstrip patch antenna on the same size substrate and ground plane. Within the scope of this investigation [11], a microstrip patch antenna for applications operating at 2.45 GHz is designed using the transmission line approach. This method is considered one of the most precise for wire and planar antennas in the frequency domain, and the design is optimized by applying the method of moments. Additionally, simulations and comparisons are made between the four different feeding strategies. Research by Memon *et al.* [12], explores the fabrication of a rectangular ring microstrip patch antenna for textiles, designed to enhance water vapor permeability. This modification was made to enhance the antenna's capability to enable the passage of water vapor. This research work [13] includes a comprehensive analysis of a patch antenna design and simulation that operates at 2.45 GHz. Regarding the operational frequency range, both the theoretical and experimental findings reveal an outstanding level of performance. In addition, the data suggest that the antenna can be enhanced in size, bandwidth, return loss, efficiency, and high gain potential. The research presents [14] an innovative design for a mobile radio frequency identification (RFID) reader that operates at a frequency of 2.45 GHz. The plan calls for a circularly polarized, wideband antenna of compact dimensions. The proposed antenna comprises two square patches layered in a configuration with an air gap to achieve a broad impedance bandwidth. The reader antenna features outstanding performance in terms of return loss, bandwidth, and gain. This article aims to investigate [15] a monopole antenna configuration capable of working across a wide range of frequencies and performing the circular polarization of electromagnetic waves. Additionally, the device uses an f-shaped radiating monopole design to obtain a wide bandwidth while maintaining a high axial ratio. The ground plane of the device is below average. The recommended antenna guarantees excellent return loss, gain, and efficiency and possesses consistent radiation properties. It is an excellent choice for applications involving WLAN and WiMAX.

A microstrip matching circuit has been developed and implemented to further improve the low-band response at a frequency of 2.45 GHz [16]. Simulations of electromagnetic fields were performed in great detail as part of the design process. The calculated values of the proposed antenna's design parameters agree with the measurements. This article presents [17] the design of a small modified wideband microstrip antenna. The antenna design that has been developed delivers all of these benefits: a wide frequency range, decreased signal reflection, higher amplification, and optimal efficiency. This investigation [18] aims to improve the antenna's performance by enhancing gain, directivity, S_{11}, and bandwidth metrics. The design process began with creating a patch antenna consisting of a single element. Utilizing gain and directivity as the key criteria; the primary outputs of the antenna design were examined. Based on the data, the antenna array constructed compared to the single-element antenna demonstrates improved gain performance. The research and development of a circular patch antenna that is versatile and implanted on a substrate manufactured from renewable materials is described in this work [19]. Industrial, scientific, and medical applications are all possible with the antenna. This examination aims to study several ways to improve the antenna's gain and measure the antenna's return loss and radiation patterns.

3. ANTENNA DESIGN AND SIMULATION RESULTS

There are two occurrences of a CST-designed microstrip patch antenna in that section. The antenna has been constructed utilizing two distinct substrate materials. The substrate material used for antenna design I is Rogers RT5880, which has a dielectric permittivity 2.2. Furthermore, FR-4 was employed to construct antenna design II, which had a dielectric permittivity of 4.3. Copper is also utilized in subsurface applications. Design I has a substrate depth of 1.57 mm, whilst design II has a substrate depth of 1.6 mm. Furthermore, the transmission line has been fine-tuned to produce a line impedance matching of 50 ohms Figures 1 illustrate the design of the antenna using CST software with design 1 in Figure 1(a) and design 2 in Figure 1(b). Table 1 displays data about the various parameters associated with the projected antenna. To design the rectangular patch antenna, the elements (1) to (7) that are defined in the technique get utilized. Both the substrate thickness (H_S) and the relative permittivity (ε_r), as well as the frequency (f_r), are taken into consideration by [18], [20].

Step: 01: an indication of the patch's width,

$$\mathrm{Wp} = \frac{c_0}{2f_r \sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

Step: 02: the equation for the effective dielectric constant is,

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} \times \sqrt{\left(1 + \frac{12h}{w}\right)} \tag{2}$$

Step: 03: the extended of the length equation are,

$$L_{ext} = \frac{c_0}{2f_r\sqrt{\varepsilon_{reff}}} \tag{3}$$

Step: 04: extension of the length of an antenna,

$$\Delta L = 0.412\, \frac{\left(\frac{w}{h}+0.264\right)(\varepsilon_{reff}+0.3)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h}+0.813\right)} \tag{4}$$

Step 05: calculation of antenna's length,

$$\mathrm{Lp} = L_{ext} - 2 \times \Delta L \tag{5}$$

Step: 06: antenna ground plane dimensions, including its length and width:

$$Lg = 6h + L_P \tag{6}$$

$$Wg = 6h + Wp \tag{7}$$

(a) (b)

Figure 1. Utilizing CST software, the physical construction of antenna design I and II is implemented (a) antenna design I (Rogers RT5880) and (b) antenna design II (FR-4)

Table 1. The optimized measurements of the recommended antenna

Parameter	W_g(mm)	L_g(mm)	W_P(mm)	L_P(mm)	h_S(mm)	$Inset_W$(mm)	$Inset_L$(mm)
Design-I	100	100	73	39.53	1.57	1.4	7.5
Design-II	50	50	37.67	28.84	1.6	1.5	5.75

3.1. Return loss, bandwidth, and voltage standing wave ratio

The simulation results indicate that the constructed antenna successfully achieves the target return loss of -10 dB, which is optimal for transportation or wireless electrical technologies. Figure 2 shows the antenna return loss (design I and II), which has been carefully tuned to function at a frequency of 2.45 GHz. The return loss of an antenna is defined as the ratio of incident power to reflected power [21]. Voltage standing wave ratio (VSWR) is a numerical metric that assesses the efficiency of transmitting radio frequency power from a power source to a load through a transmission line. An optimal gearbox requires the VSWR value to fall between 1 and 2. A value closer to one suggests a better impedance matching. The antenna and transmission lines achieve optimal matching when minimizing the VSWR [21]. Figure 3 illustrates the VSWR plots for the proposed antenna designs I and II.

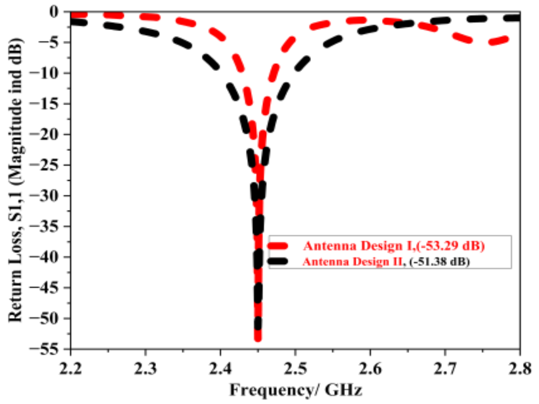


Figure 2. Views of frequency vs return loss (design I and II)

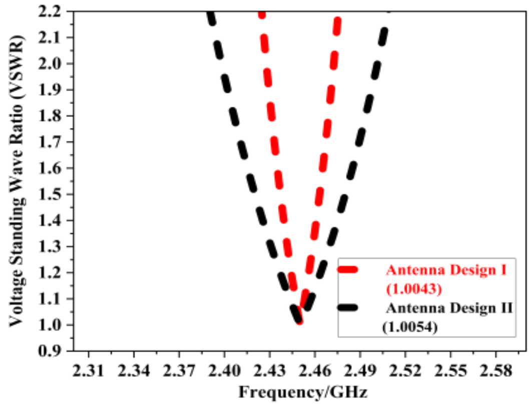
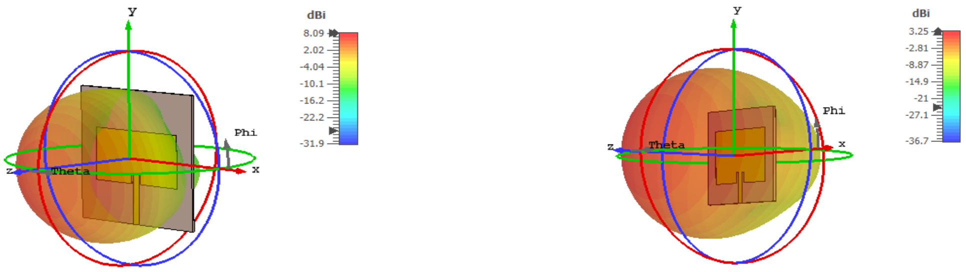


Figure 3. Views of VSWR vs frequency (design I and II)

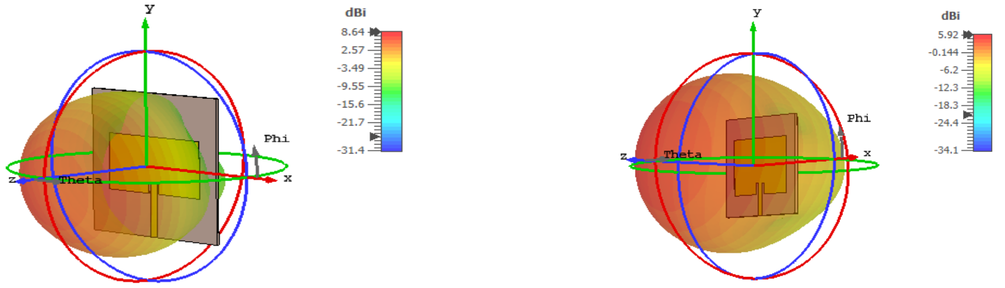
3.2. Gain and directivity

Gain and directivity are two factors that are strongly related to one another. When referring to an antenna, the phrase "antenna directivity" refers to the capability of the antenna to transmit or receive waves within a certain area rather than travelling in all directions. An antenna can demonstrate directivity if it possesses one or two significant lobes larger than the other sections of the antenna [22]. Directivity is the measure of the ratio between the intensity of radiation emitted in a specific direction by an antenna and the average intensity of radiation emitted in all directions [23]. Figure 4 shows the proposed antenna gain (design I (Figure 4(a) and II (Figure 4(b)), and Figure 5 shows directivity (design I (Figure 5(a) and II (Figure 5(b)). At 2.45 GHz, the gain of antenna design I and II is 8.09 dBi, 3.25 and the directivity of antenna design I and II is 8.64 dBi, 5.92 dBi.



(a) (b)

Figure 4. View of the gain (a) antenna design I and (b) antenna design II

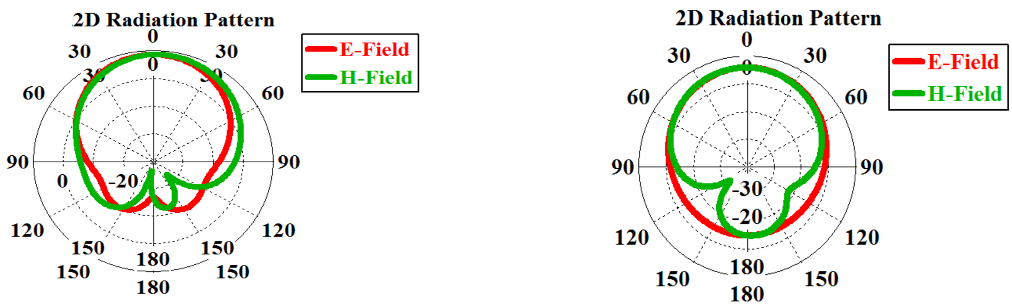


(a) (b)

Figure 5. View of the directivity (a) design I and (b) design II

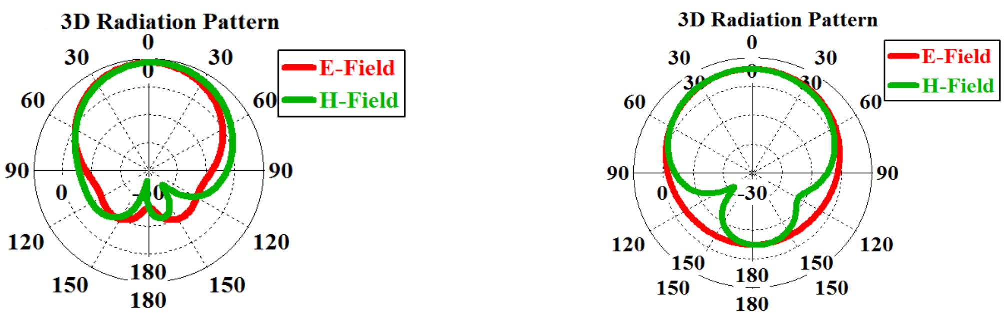
3.3. Radiation pattern

An antenna's radiation pattern is a visual depiction of its radiation fields, illustrating the distribution of power across different spatial directions. By graphically showing the radiation pattern, one can understand how the antenna distributes its impact across a wide area and in various spatial direction [24]. Figure 6 illustrates the two-dimensional radiation pattern of the antenna design I in Figure 6(a) and design II in Figure 6(b) at a frequency of 2.45 GHz. Figure 7 depicts the three-dimensional radiation pattern of the proposed antenna design I in Figure 7(a) and design II in Figure 7(b) at a frequency of 2.45 GHz.



(a) (b)

Figure 6. The radiation pattern in two dimensions of antenna designs I and II is depicted below. Phi=0^0 (E-Field) and phi = 90^0 (H-Field) (a) 2D radiation pattern (design I) and (b) 2D radiation pattern (design II)



(a) (b)

Figure 7. Illustrates the radiation pattern in two dimensions for antenna designs I and II. Phi=0^0 (E-Field) and phi = 90^0 (H-Field) (a) 3D radiation pattern (design I) and (b) 3D radiation pattern (design II)

3.4. Efficiency, radiation efficiency, and surface current

The ratio of the total power emitted by an antenna to the power supplied to it is described as the antenna's "antenna efficiency". The losses occurring in both the polarizing network and the radiating elements influence the system's efficiency [22]. The efficiency of an antenna can be assessed by analyzing the power input and power output or dissipation. Most of the power sent to an antenna with low efficiency is either dissipated within the antenna or redirected due to an impedance mismatch [25]. Plot of the antenna gain and directivity are shows Figures 8 and 9 (antenna design I and II). The ratio of the total power that an antenna produces to the net power it receives from a connected transmitter is how the radiation efficiency of an antenna can be determined [23]. Surface current is an electric current that arises when an electromagnetic field is applied, mainly observed in metallic antennas. Figures 10 and 11 display the plot diagram's radiation efficiency and total efficiency (antenna design I and II). Also, the surfaces current are shows Figure 12 (antenna design I in Figure 12 (a) and design II in Figure 12(b)).

$\therefore$ Antenna efficiency= $\frac{\text{Gain (dBi)}}{\text{Directivity(dBi)}} \times 100\%$

For Rogers RT5880 material, efficiency=$\frac{8.0853211}{8.6352535} \times 100\%$=93.64%

For Rogers Fr-4 material, efficiency=$\frac{3.2514827}{5.9167605} \times 100\%$=54.96%

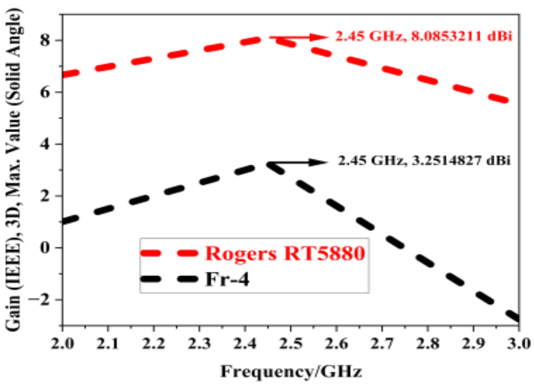


Figure 8. Plot of the antenna gain (design I and II)

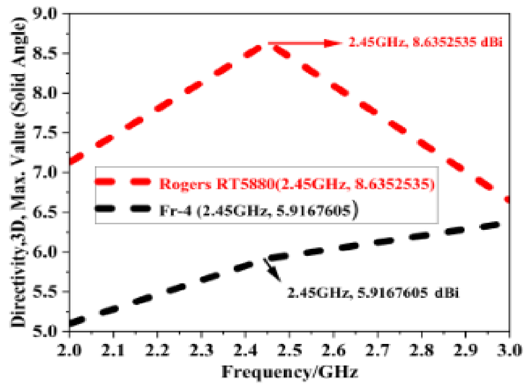


Figure 9. Plot of the antenna directivity (design I and II)

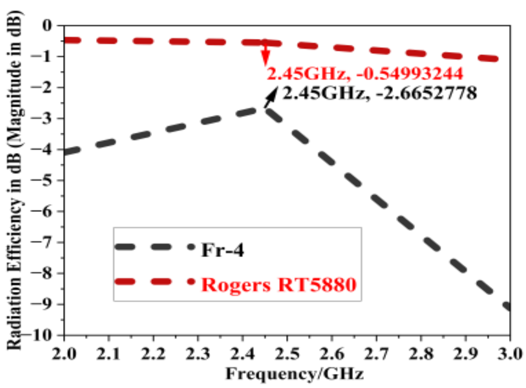


Figure 10. The radiation efficiency of the antenna designs I and II

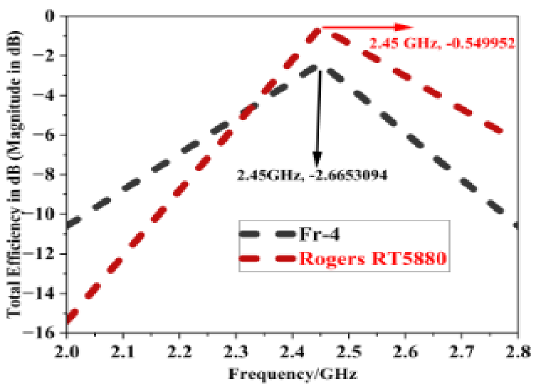
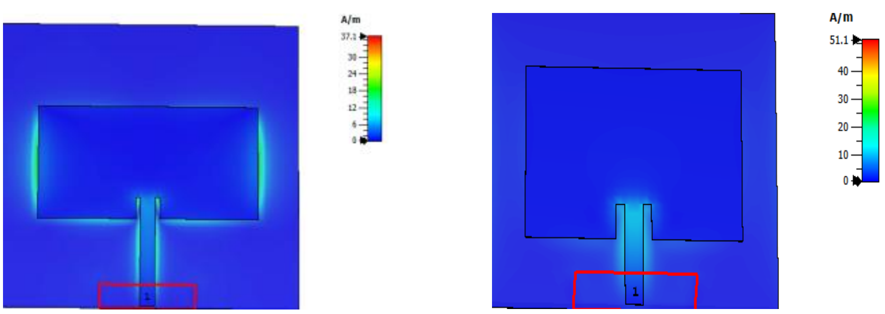


Figure 11. Total efficiency of the antenna designs I and II



(a) (b)

Figure 12. Surface current of (a) antenna design I and (b) antenna design II

3.5. Impedance test

Impedance-matching circuits generate supplemental resonances, increasing the antenna's transmission bandwidth. An antenna's input impedance is the impedance it presents at its terminals. It has the following mathematical expression: Z_{in}=R_{in}+jX_{in}, where Z_{in} represents the impedance presented by the antenna at its terminals, R_{in} represents the antenna resistance, which is composed of the radiation resistance R_r and the loss resistanceR_L, and jX_{in} represents the antenna's loss resistance. Impedance test of the antenna design I and II is shown in Figures 13 and 14. Real part is shown in Figure 13 and imaginary part is shown in Figure 14.

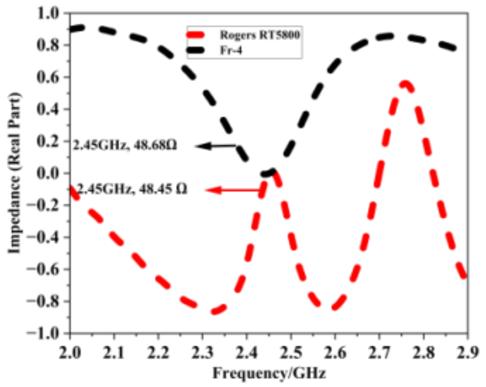


Figure 13. Figure real part (antenna I and II)

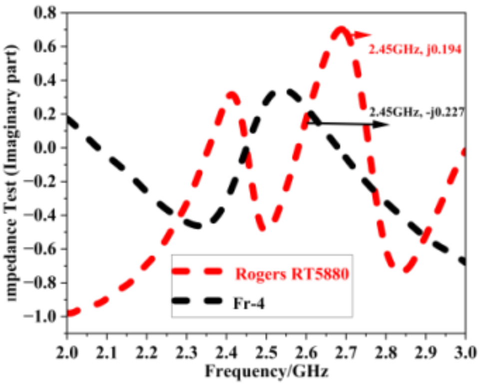


Figure 14. Figure imaginary part (antenna I and II)

4. RESULT ANALYSIS

There has been an increase in the need for compact antennas utilized in wireless communication. Because of this, engineers who work with microwaves and wireless technology have demonstrated a great desire to acquire the skills and knowledge required to design and construct small microstrip antennas. When it comes to providing easy mobility, wireless communication equipment frequently demands small and lightweight antennas. An application that is among the best is using a microstrip antenna. An antenna for wireless communication must be built to function at numerous frequencies. Several parametric analyses carried out on the planned work are shown in this section, along with the results of those studies. The ideal values for each antenna parameter are presented in Tables 2 and 3. Table 2 analyzes earlier papers' substrate materials, loss tangent, thickness, directivity, and efficiency. Also, Table 3 presents the results of return loss, gain, voltage standing wave ratio, and bandwidth acquired from previously published studies.

Table 2. Comparison between the proposed designs with the previously published works

Reference	f_r (GHz)	Substrate	(ε)	H_S (mm)	Directivity (dBi)	Efficiency (%)
[19]	2.45	Polyester	3.2	0.3	5.8	96.55
[26]	2.45	Roger RT5880	2.2	0.035	8.587	94.24
[27]	2.45	Rogers RT5880	2.3	0.787	8.012	83.06
[28]	2.45	FR-4	1.2	0.46	9.0	73
[29]	2.45	Rogers RT5880	2.2	1.5	6.534	93.45
Proposed work	**2.45**	**FR-4**	**4.3**	**1.6**	**5.92**	**54.96**
		Roger RT5880	**2.2**	**1.57**	**8.64**	**93.64**

Table 3. Comparison between other published works and proposed designs

Reference	f_r (GHz)	S_{11}(dB)	Gain (dBi)	VSWR
[5]	2.45	-23.18	2.91	-
[19]	2.45	-13.26	5.6	-
[26]	2.45	-12.542	8.092	1.617
[30]	2.42	-16.207	5.44	1.5
[29]	2.45	-45.992	6.115	1.01
[31]	2.4	-19.35	9.2	1.2414
[32]	2.45	-17.85	8.1	1.29
[33]	2.45	-20.18	-	Less than 2
[34]	2.45	-22	5.37	-
	2.45	**-51.38**	**3.25**	**1.0054**
Proposed work		**-53.29**	**8.09**	**1.0043**

5. CONCLUSION

This study evaluated the performance of a microstrip patch antenna designed for utilization in wireless applications. The modelling results of the proposed MPA include the parameters of return loss (S_{11}), VSWR gain, directivity, and efficiency. The antenna exhibits a notable efficiency level, providing a competitive edge compared to other antenna designs. This strategy significantly enhances broadband performance, gain, return loss (S_{11}), and radiation efficiency compared to other systems. It additionally addresses the impedance matching of these suggested systems. Consequently, the antenna developed in this study is an excellent choice for wireless applications. The increasing demand for practical antennas in remote networks, particularly in wireless applications, has successfully met the standards for antenna performance. Based on the simulation's results, the suggested antenna design may effectively fulfil the demands of wireless communication systems. Further validation can be achieved by constructing the antenna and comparing the measured findings with the anticipated outcomes. This round of experimental validation will yield significant insights and further substantiate the antenna's suitability for real-world applications.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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Md. Sohel Rana	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
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Saikat Mondal	✓	✓	✓	✓		✓	✓		✓		✓			✓
Samanta Mostafa Chooyan	✓	✓	✓	✓		✓	✓		✓		✓			✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no competing interests. This work was not supported in part by a grant.

DATA AVAILABILITY

The data that has been used is confidential.

REFERENCES

[1] M.-A. Chung, D. Udris, C.-W. Lin, and C.-W. Yang, "A 28-GHz vivaldi array antenna with power divider structure for achieving wide band and gain enhancement," *International Journal of Antennas and Propagation*, vol. 2024, no. 1, pp. 1–13, Jan. 2024, doi: 10.1155/2024/9935054.

[2] S. Zhu, H. Liu, P. Wen, Z. Chen, and H. Xu, "Vivaldi antenna array using defected ground structure for edge effect restraint and back radiation suppression," *IEEE Antennas and Wireless Propagation Letters*, vol. 19, no. 1, pp. 84–88, Jan. 2020, doi: 10.1109/LAWP.2019.2953912.

[3] M. Rana, S. M. R. Islam, and S. Sarker, "Machine learning based on patch antenna design and optimization for 5 G applications at 28GHz," *Results in Engineering*, vol. 24, p. 103366, Dec. 2024, doi: 10.1016/j.rineng.2024.103366.

[4] S. Jana, R. K. Singh, and K. Mamta, "Design and evaluation of performance metrics of a pentaband broadband microstrip patch antenna for mm wave applications," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 37, no. 2, pp. 859–866, Feb. 2025, doi: 10.11591/ijeecs.v37.i2.pp859-866.

[5] N. N. Tawfeeq and S. D. Mahmood, "Simulation study of microstrip antenna for 2.45 GHz applications based on octagon shaped," *Materials Today: Proceedings*, vol. 42, pp. 2448–2456, 2021, doi: 10.1016/j.matpr.2020.12.560.

[6] P. M. Ridoy, K. M. Elme, R. Shihab, P. Saha, M. Jawad-Al-Mursalin, and N. Alam, "A simple design of microstrip patch antenna for WLAN application using 5.4 GHz band," in *Lecture Notes in Electrical Engineering*, vol. 878 LNEE, 2022, pp. 574–581.
[7] M. U. Khan, M. S. Sharawi, and R. Mittra, "Microstrip patch antenna miniaturisation techniques: a review," *IET Microwaves, Antennas and Propagation*, vol. 9, no. 9, pp. 913–922, Jun. 2015, doi: 10.1049/iet-map.2014.0602.
[8] A. Gaid and M. Ali, "Tri-band rectangular microstrip patch antenna with enhanced performance for 5G applications using a π-shaped slot: design and simulation," *Iraqi Journal for Electrical and Electronic Engineering*, vol. 19, no. 2, pp. 179–190, Dec. 2023, doi: 10.37917/ijeee.19.2.20.
[9] P. Ram, A. Yadav, M. K. Suman, and A. Kumar, "Graphene based circular shaped micro strip patch antenna array for 2.45 GHz ISM band application," *Wireless Personal Communications*, vol. 116, no. 3, pp. 1613–1620, Feb. 2021, doi: 10.1007/s11277-020-07751-y.
[10] A. R. Chandran, S. Morris, S. Raman, N. Timmons, and J. Morrison, "Microstrip patch based switched beam antenna at 2.45 GHz for wireless sensor network applications," *Journal of Electromagnetic Waves and Applications*, vol. 31, no. 13, pp. 1333–1341, Sep. 2017, doi: 10.1080/09205071.2017.1348260.
[11] O. Barrou, A. E. Amri, and A. Reha, "Comparison of feeding modes for a rectangular microstrip patch antenna for 2.45 GHz applications," in *Lecture Notes in Electrical Engineering, vol 397. Springer, Singapore.*, 2017, pp. 457–469.
[12] A. W. Memon, I. L. de Paula, B. Malengier, S. Vasile, P. V. Torre, and L. V. Langenhove, "Breathable textile rectangular ring microstrip patch antenna at 2.45 GHz for wearable applications," *Sensors*, vol. 21, no. 5, p. 1635, Feb. 2021, doi: 10.3390/s21051635.
[13] E. T. Y. R. Rashwan, A. S. Abd El-Hameed, G. M. Dousoky, "Design of an efficient 2.45 GHz antenna array for rf energy harvesting," *SVU-International Journal of Engineering Sciences and Applications*, vol. 5, no. 2, pp. 175–183, 2024, doi: 10.21608/svusrc.2024.285453.1217.
[14] A. Birwal, K. Patel, and S. Singh, "Circular slot-based microstrip circularly polarized antenna for 2.45-GHz RFID reader applications," *IEEE Journal of Radio Frequency Identification*, vol. 8, pp. 10–18, 2024, doi: 10.1109/JRFID.2024.3354515.
[15] A. G. Chandar, S. Kannadhasan, R. Nagarajan, P. Subbian, and M. M. Tonmoy, "Performance analysis of an f-shaped antenna for wireless applications," *International Journal of Antennas and Propagation*, vol. 2023, pp. 1–12, Mar. 2023, doi: 10.1155/2023/8723069.
[16] F. C. Acıkaya and B. S. Yıldırım, "A dual-band microstrip patch antenna for 2.45/5-GHz WLAN applications," *AEU - International Journal of Electronics and Communications*, vol. 141, p. 153957, Nov. 2021, doi: 10.1016/j.aeue.2021.153957.
[17] R. K. Verma and A. Kumar, "A compact slot and notch loaded microstrip antenna for wireless applications," in *Microwave and Wireless Technologies. Lecture Notes in Electrical Engineering, vol 877. Springer, Singapore.*, 2023, pp. 283–296.
[18] A. Youssef, I. Halkhams, R. E. Alami, M. O. Jamil, and H. Qjidaa, "Study and design of a microstrip patch antenna array for 2.4 GHz applications," in *Digital Technologies and Applications. ICDTA 2023. Lecture Notes in Networks and Systems, vol 668. Springer, Cham.*, 2023, pp. 309–317.
[19] S.-E. Didi *et al.*, "Creation of a soft circular patch antenna for 5G at a frequency of 2.45 GHz," in *Artificial Intelligence, Data Science and Applications. ICAISE 2023. Lecture Notes in Networks and Systems, vol 838. Springer, Cham.*, 2024, pp. 473–479.
[20] M. S. Rana and M. M. Rahman, "Study of microstrip patch antenna for wireless communication system," in *2022 International Conference for Advancement in Technology (ICONAT)*, Jan. 2022, pp. 1–4. doi: 10.1109/ICONAT53423.2022.9726110.
[21] S. K. Hassan and Z. M. Khudair, "Design and analysis of a microstrip antenna for superior 5G communication performance," *Salud, Ciencia y Tecnología - Serie de Conferencias*, vol. 3, p. 867, Jun. 2024, doi: 10.56294/sctconf2024867.
[22] S.-E. Didi, I. Halkhams, A. Es-Saqy, M. Fattah, S. Mazer, and M. E. Bekkali, "Creation of a soft circular patch antenna for bio-medical applications for 5G at frequency 2.45 GHz," *Results in Engineering*, vol. 22, p. 102319, Jun. 2024, doi: 10.1016/j.rineng.2024.102319.
[23] S. K. Ibrahim and Z. T. Jebur, "A high gain compact rectangular patch antenna for 5G applications," in *International Conference on Communication and Information Technology, ICICT 2021*, Jun. 2021, pp. 156–160, doi: 10.1109/ICICT52195.2021.9568415.
[24] S. K. Ezzulddin, S. O. Hasan, and M. M. Ameen, "Microstrip patch antenna design, simulation and fabrication for 5G applications," *Simulation Modelling Practice and Theory*, vol. 116, p. 102497, Apr. 2022, doi: 10.1016/j.simpat.2022.102497.
[25] Chandan and B. S. Rai, "Bandwidth enhancement of wang shape microstrip patch antenna for wireless system," in *2014 Fourth International Conference on Communication Systems and Network Technologies*, Apr. 2014, pp. 11–15, doi: 10.1109/CSNT.2014.11.
[26] M. S. Rana, B. K. Sen, M. T. A. Mamun, S. I. Sheikh, M. S. Mahmud, and M. M. Rahman, "Design of s-band microstrip patch antenna for wireless communication systems operating at 2.45GHz," in *2022 13th International Conference on Computing Communication and Networking Technologies, ICCCNT 2022*, Oct. 2022, pp. 1–6, doi: 10.1109/ICCCNT54827.2022.9984490.
[27] Y. I. N. A. Muhammad, "Design and analysis of rectangular microstrip patch antenna for global WLAN applications using matlab and CST microstudio software," *International Journal of Engineering Science and Computing*, vol. 6, no. 4, pp. 3732–3737, 2016, doi: 10.4010/2016.865.
[28] S.-E. Adami *et al.*, "A flexible 2.45-GHz power harvesting wristband with net system output from −24.3 dBm of RF power," *IEEE Transactions on Microwave Theory and Techniques*, vol. 66, no. 1, pp. 380–395, Jan. 2018, doi: 10.1109/TMTT.2017.2700299.
[29] M. S. Rana *et al.*, "For wireless applications, design and analysis of patch antenna at 2.45 GHz," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 22, no. 4, pp. 799–811, Aug. 2024, doi: 10.12928/telkomnika.v22i4.25751.
[30] N. K. S. Wah, "Development of microstrip patch antenna design for S-band application," *American Journal of Electromagnetics and Applications*, vol. 6, no. 1, p. 17, 2018, doi: 10.11648/j.ajea.20180601.13.
[31] J. Jayanth, H. K. Ravikiran, M. Shivakumar, M. Mahadevaswamy, and K. S. Gururaj, "Antenna gain improvement for Wi-Fi applications using parasitic patch," *SN Computer Science*, vol. 4, no. 2, p. 97, Dec. 2022, doi: 10.1007/s42979-022-01520-3.
[32] H. Sediq, "Design of coaxial feeding elliptical microstrip patch antenna for wireless communication," *International Journal of Advanced Research in Computer and Communication Engineering*, vol. 7, no. 1, pp. 1–7, 2018, doi: 10.17148/IJARCCE.2018.711.
[33] M. M. Hasan and M. Cheffena, "Adaptive antenna impedance matching using low-complexity shallow learning model," *IEEE Access*, pp. 1–1, 2023, doi: 10.1109/ACCESS.2023.3296459.
[34] F. A. Omara, W. A. E. Ali, A. S. Eltrass, and N. H. Abbasy, "Design of 2.45 GHz rectenna based on high-gain 2-element array antenna and 7-stage voltage-doubler rectifier for energy harvesting applications," *Physica Scripta*, vol. 99, no. 12, p. 125503, Dec. 2024, doi: 10.1088/1402-4896/ad881c.

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