A 3.5 GHz microstrip patch antenna design and analysis for wireless applications

Md. Sohel Rana[1,2,3], Md. Naheen Khurshid[1], Sanjay Kumar Joy[1], Md. Soriful Islam Sourav[1], Md. Jakaria Hassan[1], Md. Jubaer Nazmul[1]
[1]Department of Electrical and Electronic Engineering, Northern University of Business and Technology Khulna, Khulna, Bangladesh
[2]Department of Computer Science and Engineering, Bangladesh University of Professionals, Mirpur, Bangladesh
[3]Department of Electrical and Electronic Engineering, Independent University, Bangladesh (IUB), Dhaka, Bangladesh

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ABSTRACT

The design, simulation, and analysis of a 3.5 GHz rectangular microstrip patch antenna (RMPA) have been carried out for this research article. The substrate material employed for the design is a lossy form of FR-4, which has a thickness of 0.5 mm, a dielectric permittivity of 4.3, and a loss tangent of 0.0005, respectively. The antenna receives power through a feeding line with an impedance of 50 Ω. The simulation was ultimately finished off with the help of some computer simulation tools. Following completion of the simulation, the findings revealed a directivity gain of 6.05 dBi, a voltage standing wave ratio (VSWR) of 1.0607, and a bandwidth of 144.1 MHz. The return loss was determined to be -30.611 dB. The suggested antenna's primary purpose was to attain a standard value for the VSWR while lowering the return loss. This antenna improves directivity gain and bandwidth and has applications in radars, mobile phones, and wireless local area networks (WLANs). The results of this proposed antenna were superior to those of a variety of studies that had been published in the past.

Corresponding Author:

Md. Sohel Rana
Department of Electrical and Electronic Engineering
Northern University of Business and Technology Khulna
Khulna-9100, Bangladesh
Email: sohel.rana@uits.edu.bd

1. INTRODUCTION

People increasingly use phones, tablets, laptops, global positioning system (GPS), radio navigators, and other wireless handheld devices. This has led to tremendous technological advances in modern communication. They are connected to other wireless access points so that data and information can be exchanged across the wireless channels without any disturbance. When it comes to the technical operation of this communication, an antenna plays a crucial role at both the transmission and receiving ends. This is true for both ends of the transmission. Because many people use these communication tools, there is a pressing need for small antennas that still work well despite being smaller.

Over the past two to three decades, the microstrip patch antenna (MPA) has become a good choice for these wireless communication systems because it can fit any shape, doesn't cost much to make, is light, and is easy to make using printed circuits. It has good qualities, like being light and easy to make printed circuit boards [1]. The radiating patch and the ground plane of a microstrip patch antenna are mounted on opposite sides of a dielectric substrate. The radiating patch is mounted on one side of the substrate, and the ground plane is mounted on the other. The patch is often made from a conductive material such as copper or gold, and its shape can be moulded into anything imaginable. The capacity of wireless technology has been expanding at breakneck speed. It is now possible to manufacture complex structures in a way that is both efficient and cost-effective using methods known as additive manufacturing rather than the traditional subtractive manufacturing methods. A group of researchers recently showed that conductive and non-conductive filaments could be used to make microstrip transmission lines and patch antennas [2]. Both the frequency range that an antenna can receive and the bandwidth it can transmit depend on the antenna's dimensions and shape. Because they only consist of two sizes, microstrip antennas are typically inexpensive, simple, and straightforward to construct. Because of this, quite a few people use them [3]. The microstrip patch antenna's actual physical structure is seen in Figure 1. The microstrip patch antenna, also known as an MPA, comprises a three-layer stack that includes the substrate and the metal. The ground structure is the bottommost layer, and it is often constructed out of copper or another material that is a good conductor [4]. The many different configurations of microstrip patch antennas are depicted in Figure 2. It explains how to analyze and compare the performance of that antenna with a square patch, a dipole patch, a rectangle patch, a circular patch, a triangular patch, and an elliptical patch with a coaxial probe feed [5]. Additionally, it uses a rectangle patch, a circular patch, a triangular patch, and an oval patch.

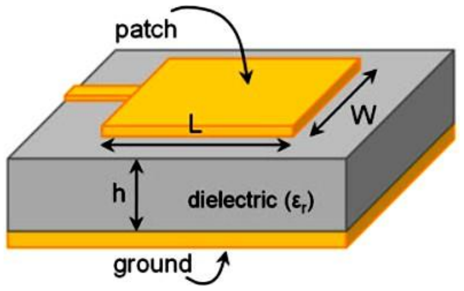

Figure 1. Structure of microstrip patch antenna

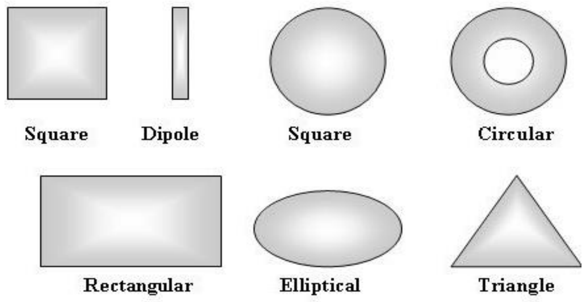

Figure 2. Several distinct configurations for microstrip patch antennas

The paper is divided into five chapters. Where the introduction is in the first chapter and the second chapter discusses in literature review, proposed antenna design and simulation results are discussed in the third chapter. In chapter four, the results are analysis of results, and in chapter five, the conclusion is given. Finally, references to various papers are given in the next section.

2. LITERATURE REVIEW

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]. In recent years, more studies have focused on microstrip patch antennas with resonant frequencies in the wireless application frequency band. In addition, currently, researchers are working strongly on microstrip patch antennas. Various papers published on 3.5 GHz are discussed in the said section. Various research gaps in previously published papers are also discussed in that section.

Rana *et al.* [7] introduces a patch antenna for future wireless communications operating at 3.5 GHz and explains its design. The researchers thought pursuing this line of inquiry would achieve a minor return loss, enhance the ratio of directivity, gain, and voltage standing wave ratio (VSWR), and improve the bandwidth. This antenna has been fabricated and validated for various wireless communication applications operating at 3.5 GHz. Pushpalatha *et al.* [8] demonstrated how to construct a low-profile microstrip antenna with a wide band that can be utilized for S-band telemetry. The proposed design investigates the idea of a wide-band antenna with improved omnidirectional gain and a smaller size. The telemetry signals from satellites in low-earth orbit (LEO) are the primary focus of the antenna. The operational impedance bandwidth of the partial annular radiating patch design should range from 2.7 GHz to 3.8 GHz.

Rana *et al.* [9] designed and analyzed an S-band microstrip patch antenna that can be used for wireless applications. FR-4 has been utilized as a substrate material even though it possesses a lossy dielectric constant of 4.3. The purpose of this research is to design a brand-new antenna that is suitable for implementation in wireless local communication systems. This antenna was developed to minimize return loss while preserving an average VSWR. The software included in the 2019 edition of the computer simulation technology (CST) suite was applied so that the simulation could be carried out effectively and the appropriate values for gain, VSWR, and bandwidth could be determined. Cirik and Yildirim [10] designed a high-gain microstrip patch-type worldwide interoperability for microwave access (WiMAX) antenna with a parasitic radiator and an elevated ground plane has been made. It operates at a speed of 3.5 GHz and the gain of antenna is 3.6 dB. The gain is increased by approximately 1.5 dB due to the elevated ground plane.

Rana *et al.* [11] design and simulation of a microstrip patch antenna operating at 3.5 GHz. The substrate material for this design is Rogger RT5880, which has a dielectric constant of 4.3. In addition, the substrate material's dielectric constant is 4.3. This antenna aims to get a standard VSWR, raise its directivity gain, and give it an acceptable bandwidth. In addition, it should reduce its return loss. In addition, the antenna's return loss will decrease. Singh *et al.* [12] talk about a single-layer slotted microstrip patch antenna in the shape of an arrowhead that has been simulated in great detail for use in 3.5 GHz wireless communication systems. The simulations were done to use the antenna in wireless communications systems. Throughout these investigations, a probe feed was discovered. It was a microstrip patch antenna with slots shaped like an arrowhead. It was in the shape of a rectangle. The proposed aerial has a small footprint and can cover a wireless local area networks (WLAN), as well as the Bluetooth application, very well. In addition to that, it is capable of utilizing a wide variety of different wireless communication systems.

Ferdous *et al.* [13] designs and constructs a low-profile patch antenna for implementing 5G communication systems. After much thought, the 5G application's resonant frequency of 3.5 GHz was chosen. The primary radiating patch is an ellipse, and the mechanism utilized is called "line feeding". Several parameters have been observed, including the reflection coefficient of antenna gain, directivity, and efficiency. This has made it feasible to make observations on these parameters. Because it has a gain greater than 5 dB, the antenna is a valuable accessory for making and receiving communications. The antenna design is based on making it suitable for applications requiring access to 5G networks.

Ibrahim *et al.* [14] demonstrate how a rectangular patch antenna array could be utilized in a 5G application. The antenna design produces a decent return and an acceptable insertion loss when operating at a frequency of 3,500 MHz. It‘s also compared to the others design, the performance of the array structure was much better. Ramli *et al.* [15] the construction of a microstrip patch antenna that can function at 3.5 GHz. The antenna is constructed using three different substrate materials, each with a relative permittivity that differs from the others. CST microwave studio can simulate, analyze, and compare the performance of different aerial configurations. One must consider their bandwidth, gain, gain efficiency, and reflection coefficient to accomplish this. According to the data, since the commencement of the experiment, both the growth and the bandwidth have undergone discernible modifications in their respective patterns.

Gupta *et al.* [16] investigate the characteristics of the proposed antenna, this research suggests employing a model of a rectangular microstrip patch antenna (RMPA) with air serving as the substrate. The planned antenna will have a frequency of 3.525 GHz and dimensions of 17 mm by 16.66 mm, including the substrate. It will also function at this frequency. Several aspects of the intended antenna were analyzed, including its return loss, bandwidth, directivity, gain, radiation pattern, and VSWR. Given its prospective uses in the field, there is reason to be optimistic about this antenna's application in microwave communications. Al-Gburi *et al.* [17] built and simulated a hexagonal microstrip patch antenna that operates at 3.5 GHz and is used for wireless backhaul applications. The creation of a single component was the first step in the procedure. After that, it proceeded to manufacture 1×8 array elements, which proved beneficial for the base station in terms of its ability to provide high-quality and high-capacity network connectivity. In addition, the point-to-point connections made over long distances are the primary focus of this particular sort of antenna, and it is a strong choice for 5G communication due to its capabilities.

Prabha *et al.* [18] demonstrate how to construct and investigate microstrip patch antennas, which are suitable for use in wireless communication operating in the sub-6 GHz frequency region. The designed patch antenna can be utilized in WiMAX applications with a frequency of 3.55 GHz. Its primary objective is to provide users throughout a large area with access to high-speed data and the internet. The rectangle patch design reported in this study displayed superior performance regarding area depreciation, gain enhancement, and directivity. In comparison, the square patch design demonstrated excellent performance. Chowdhury *et al.* [19] aims to examine a recently developed planar rectangular slot antenna for a 5G wireless application that operates at frequencies lower than 6 GHz. The architecture that has been proposed is compatible with 5G networks that use at sub-6 GHz, as well as those that operate on the long term evolution (LTE) Band 42 and WiMAX. The radiating slot is open on the higher side of the place. The antenna under consideration uses the 5G N77 frequency, which is 3.5 gigahertz. It also has excellent impedance matching and good properties for the reflection coefficient. The recommended antenna performs exceptionally well for all frequencies and has a total bandwidth of 19 MHz. In conclusion, the antenna given here is an excellent option for 5G wireless applications operating at frequencies lower than 6 GHz.

Saraswat and Kumar [20] demonstrate how Moore and Koch curves can be included in wireless standards to create a metamaterial-loaded hybrid fractal multiband antenna. When the results of the simulation and the measurements are compared, there is likely a high level of agreement. The frequency-selective surface (FSS), abbreviated FSS, is created and then tested in this step. FSS has been integrated into the antenna structure to optimise the antenna gain across all the different operating bands. Hossain *et al.* [21] presents a unique new patch antenna type with a rectangular form as its main physical characteristic. The frequency of 3.5 GHz, used for applications in the S-band, is the focus of its development for this system. Compared to its performance at lower frequencies, the antenna's performance at 3.5 GHz resulted in a lower return loss and a wider bandwidth. The width of the substrate's bandwidth is boosted by increasing the thickness of the substrate. To examine the simulation results, the results are utilized to calculate several essential performance parameters. These characteristics include gain, radiation pattern, and return loss.

3. PROPOSED ANTENNA DESIGN AND SIMULATION RESULTS

In recent years, microstrip patch antennas have emerged as one of the most common antennas used in wireless communication. They can be attached to the exterior of space-borne applications like aero planes and missiles, in addition to the surfaces of numerous wireless communication systems, the internet of things (IoT), biomedical devices, and other applications [22]. Figure 3 illustrates a RMPA made using CST software. Different software is used for antenna design, like high-frequency structure simulator (HFSS), matrix laboratory (MATLAB), *Feldberechnung Für Körper Mit Beliebiger Oberfläche* (FEKO), and but computer simulation technology (CST) software can be used most easily and efficiently. Return loss, VSWR, directivity gain, bandwidth, and surface current, are some of the simulation results for the designed antenna.

The following discussion presents an overview of the findings of the simulated aerial procedures for the intended microstrip patch antenna (MPA). This discussion aims to analyze and evaluate the aerial performance of the proposed aerial design utilizing these characteristics. The suggested method for a rectangular microstrip antenna is depicted in Figure 3, along with a prototype. The patch is sewn onto a substrate produced using FR-4 (lossy). This particular substrate has a thickness of 0.5 millimeters and a dielectric constant of 4.3. The process of simulating something entails selecting the materials that will be used for the substrate, tracing and selecting the ground plane dimension, drawing the models, selecting the excitation port, and setting up the optimal geometric measurement to meet the desired center frequency and the bandwidth requirement for each band to meet the specified VSWR and return loss requirements. These are just some of the steps involved in the process. The method of simulation incorporates each of these elements into its overall workflow [23]. Also, Figure 4 shows the physical construction of proposed design.

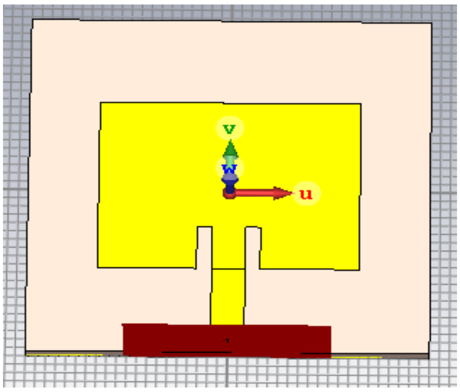

Figure 3. The proposed MPA design was done using CST software

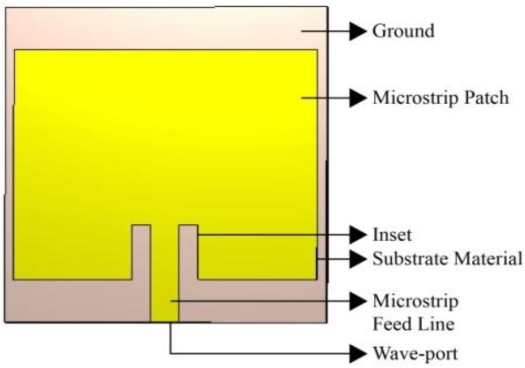

Figure 4. Physical construction of proposed antenna design

For this investigation, the equations shown further down the page are utilized to determine the values of the parameters. In the microstrip format, it is measured across the whole width of the patch antenna as shown in (1):

$$Wp = \frac{c_0}{2f_r \sqrt{\frac{\varepsilon_r + 1}{2}}} \quad (1)$$

the effective potential divided by the dielectric constant as shown in (2):

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1 + 12 \times \frac{h}{w}\right)^{-0.5} \quad (2)$$

lengthened measurement as shown in (3):

$$L_{ext} = \frac{c_o}{2f_r\sqrt{\varepsilon_{reff}}} \quad (3)$$

by applying the following equation, will be able to eliminate the fringe effect and determine the length of the patch as shown in (4).

$$\Delta L = 0.824h \frac{\left(\frac{w}{h}+0.264\right)(\varepsilon_{reff}+0.3)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h}+0.8\right)} \quad (4)$$

$$L = L_{ext} - 2 \times \Delta L \quad (5)$$

3.1. Antenna parameter

Designing of any well-structured microstrip patch antenna for communication applications requires a proper selection of the resonating frequency, dielectric permittivity (ε), and the thickness of the substrate (h). Table 1 shows the various parameters of the designed antenna. One of the parameters is the length and width of the antenna patch and the ground. Besides, height, loss tangent, the transmission line's width, and the inset's length and width are also discussed.

Table 1. Measurements concerning the geometry of the antenna

Parameter	Wg	Lg	Wp	Lp	Hs	t	I_L	I_W	Tx
Dimension (mm)	40	40	26	20	1.65	0.5	5	1.5	3.313

3.2. Return loss

The S-parameters model the input-output interactions that exist between ports or terminals. The reflection coefficient, which is often referred to as the S_{11} coefficient, is a measurement that determines how much power an antenna reflects [24]. The peak S-parameter for this antenna at 3.5 GHz is -30.611 dB, corresponding to a value of -10 dB. From 3.4268 GHz to 3.5709 GHz lies the frequency spectrum that a bandwidth of 0.1441 GHz covers. The VSWR characteristics are depicted here in Figure 5.

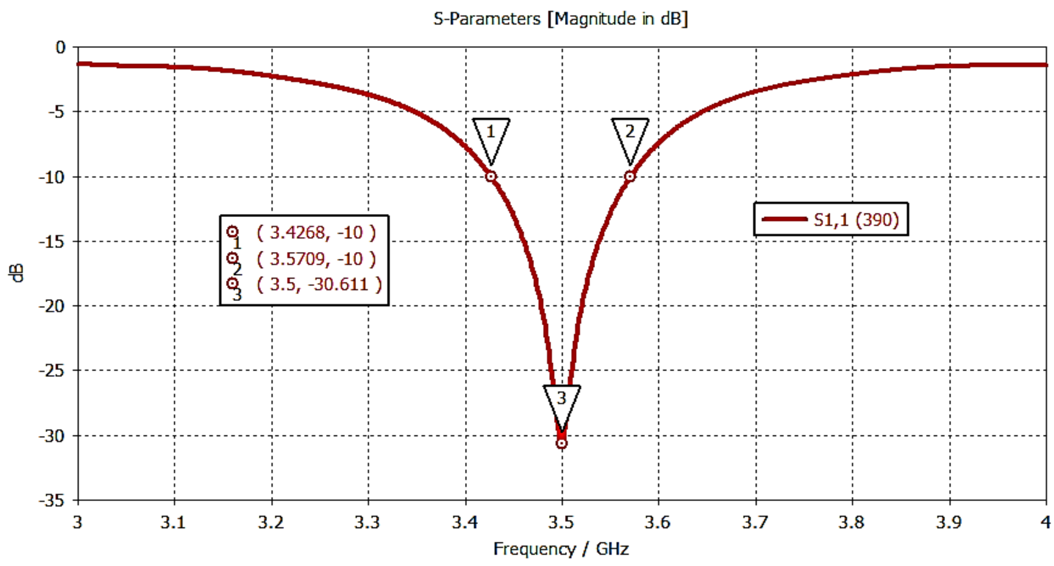

Figure 5. A graph showing return loss versus frequency is presented below

3.3. VSWR

The power reflected by an aerial is denoted by the VSWR, which stands for the VSWR. The antenna's performance improves as the VSWR value goes down [25]. Figure 6 presents the VSWR value calculated based on the simulation results. The value of VSWR must be between 1 and 2, inclusive. It must never be less than 1. In the best possible scenario, it is 1 [26]. The value of VSWR is plotted versus frequency in Figure 6, which reveals that the value of 1.0033 is reached at 3.5 GHz. This antenna has a frequency coverage range of 3.4223 GHz to 3.5752 GHz.

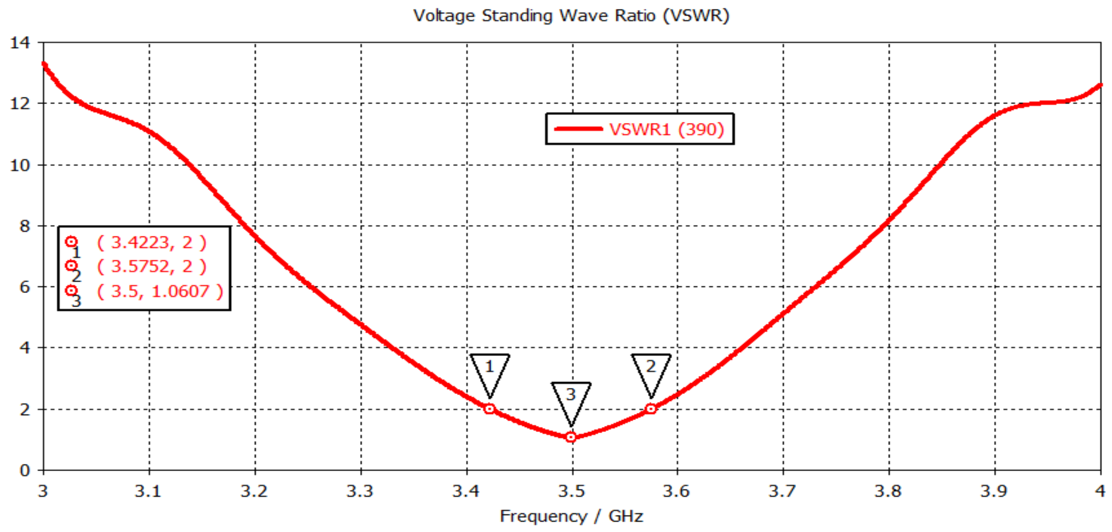

Figure 6. Frequency vs VSWR graphical representation

3.4. Radiation pattern

One of the most important things to consider when figuring out how well a microstrip patch antenna works is its radiation pattern. It is one of the essential characteristics. This metric is important because it shows how well the antenna does what it is supposed to do [27]. At 3.5 GHz the directivity gain of the antenna is shown to be 6.05 dBi in Figure 7, which depicts the three-dimensional radiation patterns produced by the antenna. Another representation Figure 8 shows the antenna's polar far-field pattern and the size of the primary beam, which is 6.05 dBi. In addition, it demonstrates that the antenna's main beam has an angular width of 97.8 degrees and is directed at -12.7 degrees.

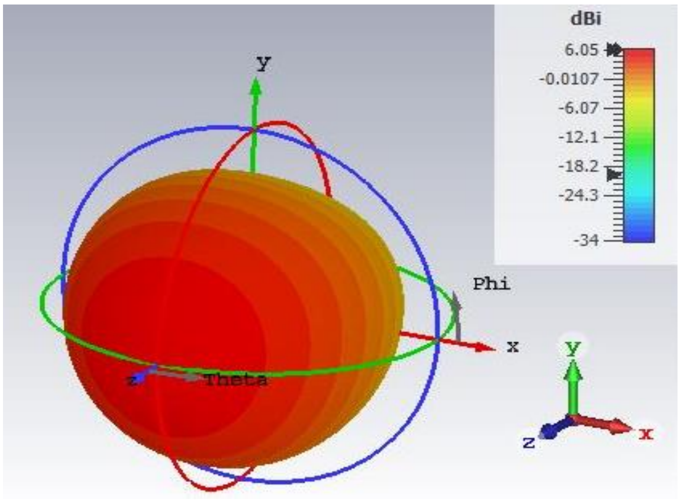

Figure 7. 3D radiation pattern of the proposed antenna

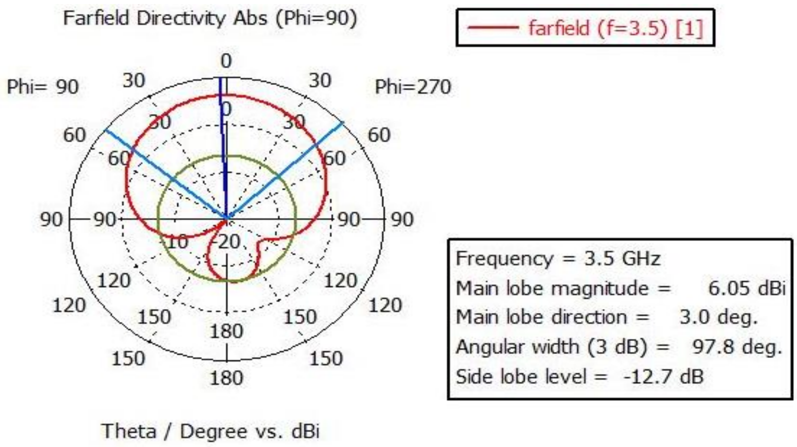

Figure 8. Farfield directivity of the proposed antenna

4. RESULT ANALYSIS

In this inquiry, simulations are run for wireless applications that use the "lossy" FR-4 material and run at a frequency of 3.5 GHz. Following the completion of the simulation, the return loss, VSWR, directivity gain, and bandwidth of the FR-4 (lossy) material were found to be -30.611 dB, 1.0607, and 6.05 dB, respectively. The bandwidth of the material was found to be 0.1441 GHz. The simulation came up with these values as its conclusion. As a consequence of this, this MPA has the potential to develop into a viable alternative for wireless applications.

Table 2. Proposed antenna simulation results

Parameter	Value
Return loss (dB)	-30.611
VSWR	1.0607
Bandwidth (GHz)	0.1441
Directivity (dBi)	6.05

The findings of the suggested publication are significantly more impressive than the findings of the numerous other journal and conference papers that have been published in the past. These findings are also suitable for use in wireless applications because they are superior to those of other papers. The complete results of the simulation are presented in Tables 2 and 3, comparing the proposed work with previously published works.

Table 3. Comparing other designs

Ref.	Operating frequency	Dielectric permittivity (ε)	Return loss (dB)	VSWR	Directivity gain (dBi)	BW (GHz)
Ridoy *et al.* [6]	3.5 GHz	2.2	-13.772	1.5152	-	-
Rana *et al.* [7]	3.5 GHz	4.3	-17.264	1.3176	-	116.6 MHz
Pushpalatha *et al.* [8]	3.5 GHz	4.6	-31.77	-	1.6	-
Rana *et al.* [9]	3.5 GHz	4.3	-18.89	1.22	-	128.9 MHz
Rana *et al.* [11]	3.5 GHz	2.2	-	1.5	6	-
Singh *et al.* [12]	3.5 GHz	4.3	-30	-	5.5	-
Ramli *et al.* [15]	3.52 GHz	1.5	-	-	-	140.6 MHz
Chowdhury *et al.* [19]	3.5 GHz	4.3	-26.5	-	4.2	19 MHz
Irfansyah *et al.* [28]	3.5 GHz	4.3	-12.54	1.6	5.5	66.5 MHz
Abdulbari *et al.* [29]	3.5 GHz	2	-29	Below 2	6	-
Wildan *et al.* [30]	3.5 GHz	2.2	-26.385	1.09	-	72 MHz
Ajay and Mathew [31]	3.5 GHz	2.2	-15.8	-	-	67.4 MHz
Cheekatla and Ashtankar [32]	3.5 GHz	4.4	-29.5	1	3	-
Abdulbari *et al.* [33]	3.6 GHz	2	-28.76	Below 2	2.52	-
Paragya and Siswono [34]	3.5 GHz	-	-17.436	1.31	-	65.2 MHz
Kumar *et al.* [35]	3.5 GHz	4.6	-19	-	-	20 MHz
Rana *et al.* [36]	3.6 GHz	2.2	-17.626	1.302	-	206 MHz
This work	3.5 GHz	4.3	-30.611	1.0607	6.05	144.1 MHz

5. CONCLUSION

In this investigation, wireless application antennas are designed and simulated with a RMPA that operates at 3.5 GHz. The simulation results were as follows: a return loss of -30.61 dB, a VSWR of 1.0607, a gain in directivity of 6.05 dBi, and a bandwidth of 0.1441 GHz, respectively. Applications that use wireless communication may profit from the antenna that has been built. The fact that the proposed antenna produced results that were superior to those that had been published in the past demonstrates that it has the potential to be a strong candidate for future wireless applications. The simulation results can be compared to those obtained when the antenna is built. The combination of these technologies may be employed in the work that will be done in the future to create and improve the performance of various microstrip antennas that may be used in wireless communication systems. This work will be carried out in anticipation of future work.

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BIOGRAPHIES OF AUTHORS

Md. Sohel Rana received a B.Sc. Engineer degree in Electrical and Electronic Engineering from Prime University (PU), Bangladesh, in 2015. In 2018, he graduated with a Master of Science in Telecommunication Engineering from the University of Information Technology and Sciences (UITS) in Bangladesh. In the year 2022, a second Master's Degree was awarded by the Bangladesh University of Professionals (BUP), which is located in Bangladesh. He is currently studying for a M.Sc. program at Independent University, Bangladesh (IUB), in the Department of Electrical and Electronic Engineering. His research interests include microstrip patch antennas, wireless communications, image processing, renewable energy, solar cell, and power electronics. Mr. Rana authored and co-authored in 34 papers regarding to his research works. Currently, he is a lecturer at the Northern University of Business and Technology Khulna, Khulna-9100, Bangladesh, in the Department of Electrical and Electronic Engineering. He can be contacted at email: sohel.rana@uits.edu.bd.

Md. Naheen Khurshid is a student in the Electrical and Electronic Engineering department at the Northern University of Business and Technology in Khulna, where he is in his final year of study as an undergraduate. His scientific interests include antenna design as well as wireless communication and renewable energy. He can be contacted at email: naheen0612b@gmail.com.

Sanjay Kumar Joy is an undergraduate final-year student at Northern University of Business and Technology Khulna in the Electrical and Electronic Engineering department. His research interests are antenna design, renewable energy, and wireless communication. He can be contacted at email: joysarker584@gmail.com.

Md. Soriful Islam Sourav is currently in his final year of studies as an undergraduate at the Northern University of Business and Technology in Khulna. He is majoring in the Electrical and Electronic Engineering department of the university. The design of antennas, VLSI, wireless communication, and renewable energy are some of his scientific areas of interest. He can be contacted at email: sorifulislamsourav1999@gmail.com.

Md. Jakaria Hassan is currently in his final year undergraduate student at the Northern University of Business and Technology Khulna in the Electrical and Electronic Engineering department of the university. His scientific areas of interest include the design of antennas, power system, wireless communication, and renewable energy. He can be contacted at email: mdjakariahassan58@gmail.com.

Md. Jubaer Nazmul is currently in his fourth and final year of studies as an undergraduate at the Northern University of Business and Technology in Khulna. He is majoring in the Electrical and Electronic Engineering department of the university. His scientific pursuits of interest include the design of antennas, wireless communication, power system and alternative energy sources. He can be contacted at email: nazmul3676@gmail.com.