Design, simulation, and analysis of microstrip patch antenna for wireless applications operating at 3.6 GHz

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ABSTRACT

In this study, a microstrip patch antenna that works at 3.6 GHz was built and tested to see how well it works. In this work, Rogers RT/Duroid 5880 has been used as the substrate material, with a dielectric permittivity of 2.2 and a thickness of 0.3451 mm; it serves as the base for the examined antenna. The computer simulation technology (CST) studio suite is utilized to show the recommended antenna design. The goal of this study was to get a more extensive transmission capacity, a lower voltage standing wave ratio (VSWR), and a lower return loss, but the main goal was to get a higher gain, directivity, and efficiency. After simulation, the return loss, gain, directivity, bandwidth, and efficiency of the supplied antenna are found to be -17.626 dB, 9.671 dBi, 9.924 dBi, 0.2 GHz, and 97.45%, respectively. Besides, the recreation uncovered that the transfer speed side-lobe level at phi was much better than those of the earlier works, at -28.8 dB, respectively. Thus, it makes a solid contender for remote innovation and more robust communication.

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1. INTRODUCTION

Technology is rapidly advancing and making many tasks more manageable. As people become more creative, they develop new ways to communicate wirelessly. Wireless fidelity (Wi-Fi) is the most popular of these new methods [1]. A Wi-Fi network lets you access the internet from anywhere at high speed and conveniently. This technology enables computers and phones to send and receive data from anywhere in the world as long as they are within range of a base station. It does this by using radio technologies based on the standard level. The antenna is the most critical hardware for systems that send and receive electromagnetic waves wirelessly [2]. Because their size is directly related to the wavelength of the resonant frequency, they are usually used at high frequencies and ranges [3]. This is because their size is directly proportional to their wavelength [4]. Deschamps came up with the idea for the patch antenna in the early 1950s [5]. Some years later, an antenna patent was issued through button and bassinet. In the 1970s, thin, surface-suited antennas were made for army packages, missiles, and space shuttles. Since wireless communication systems need small antennas, microwave engineers have recently become more interested in researching how to make compact microstrip antennas. This has grown in interest over recent years [6].

Microstrip antennas are becoming increasingly popular because they have unique features that make them stand out from other antennas. When it comes to the benefits of microstrip patch antennas (MPAs) in the scientific community, the devices have interesting physical properties that make them an appealing source for researchers because they are low cost, lightweight, conformable, low profile, relatively compact, mechanically robust, and have a variety of other characteristics [7]. Even though the microstrip component has many good qualities, such as moo taking a toll, quick generation, adaptability on bent surfaces, and so on, it is limited by a problem with the speed at which impedance transfers [8]. There are different ways to progress the execution of a microstrip-fixed radio wire, including expanding the substrate's thickness, utilizing moo dielectric substrate, and using different impedance coordinating and bolstering methods [9]. Microstrip antenna structures are divided into four main parts i.e, ground plane, dielectric substrate, patch and feeding line [10]. Ground plane is etched on the bottom side of dielectric substrate and conducting in nature. There are various dielectric substrates which are used for designing of this antenna and the value of dielectric constant generally used ranges between $2.2 \leq \varepsilon_r \geq 12$ [11]. This paper is targeted at publishing channel characterizations within the 3.55 GHz band. The antenna should be small enough to work with new small speech devices [12]. The goal is to have a high advantage and performance so that the original records can switch in any wireless communication space [13].

To better organize the content that has been presented, this work has been split into five parts. Also, the first part is an introduction, the second part is a review of the relevant literature, the third part is about materials and methods, the fourth part is about designing and simulating antennas, the fifth chapter is an analysis of the results, and the sixth chapter is the conclusion. The references for this section can be found in the next part.

2. LITERATURE REVIEW

Over the years, several studies have been done on microstrip patch antennas. High-gain antennas send more power to the receiver, which is one of the problems. This is done to make the signal that is received stronger. Due to their reciprocity, high-gain antennas can also increase the strength of received signals by 100 when transmitting. Due to their directivity, directional antennas deliver fewer signals from directions other than the main beam. This characteristic lessens interference. With this method, wireless communication can have a high gain, which means that data can be sent at a much higher power level than in previous research.

Swarna *et al.* [14], a new slot-loaded microstrip patch antenna with a ground modification that looks like a helipad as a solution for the lower frequency spectrum of the 5G network, around 3 GHz. The antenna performs its function at the resonance frequency located inside the S-band. The simulation came up with a bandwidth of around 1.78 GHz, almost eighteen times greater than a standard MPA with a full ground plane. This increase comes as a result of the MPA's higher capacity. Both the current and proposed MPAs have radiation patterns that are not spherical and go in both directions. The proposed MPA has a radiation pattern that works in both directions and could be used for beamforming, wireless local area network (WLAN), and communication between satellites, among other things.

Bae and Yoon [15] proposed, an S-/Ka-band shared-aperture antenna has been proposed for use in 5G applications in this particular piece of research. This paper has been made by putting sixteen Ka-band slotted cavity antennas inside an S-band thick patch. This has resulted in the antenna array's increased bandwidth. A separate coaxial cable feeds each part of the slotted cavity antenna within the Ka-band. Within the framework of the TPCSCA, an S-band driving frequency microstrip-fed slot has been added. The experiments proved that the idea was correct, and it is expected that this will improve how well 5G dual-band applications use the aperture. Mathuri *et al.* [16] proposed, introduces S-Band and C-Band antennas with shorting pins, holes, and ground plans with a meandering pattern have been made. Within this work's scope, the geometry's inductance is optimized. Analytical models are utilized to model the antenna. This measurement shows the wide range of operating impedance in the S and C bands. This antenna works well in the 5G sub-6 GHz band and the Bluetooth and Wi-Fi bands.

Rana and Rahman [17] proposed, conceived and reported on constructing a microstrip patch antenna to employ it in the realm of upcoming wireless communication technologies. The goal of this study was to find a way to reduce the total amount of return loss while also increasing gain and lowering the voltage standing wave ratio (VSWR). In [18], there was research done on a 5G high-band slotted microstrip antenna. Using the antenna can lead to high bit rates, less traffic, and more users sticking around. The return loss, gain, and bandwidth can all be improved by putting a square slot on top of a circular slot in a rectangular microstrip antenna. The antennas that are provided have a positive effect on return loss, gain, and bandwidth.

Rana and Smieee [19], a microstrip patch antenna is looked at and modeled so that it can be used in future 5G communication technologies. Rogers RT/Duroid5880 was chosen to serve as the antenna substrate for this particular piece of work. The thickness of the substrate is 0.3451 mm, and the dielectric has a value of 2.2. Based on the simulation, it was discovered that the return loss, gain, radiation efficiency, and side-lobe level were correspondingly -38.348 dB, 8.198 dB, 77%, and -18.3 dB. The findings that were obtained by running this simulation performed significantly better than the work that had been done in the past. Because of this, it has a chance of being a strong contender for 5G wireless technology.

Abdulbari *et al.* [20] proposed, describes a microstrip patch antenna with a T-shaped rectangular design. The T-shaped patch operates within the frequency range of 3.6 GHz, making it suitable for 5G applications. The antenna's dimensions are 22×24×0.25 mm^3, and it utilizes a 50 Ω feed line for signal transmission. The proposed antenna offers several advantages, such as its compact size, low profile, and simplified structure. The paper discusses antenna characteristics, including radiation pattern, reflection coefficient, gain, current distribution, and efficiency. By incorporating a slot in the rectangular T-shaped patch antenna design, the researchers achieved a lower frequency with 98.474% radiation efficiency and a peak gain of 2.52 dBi. The antenna exhibits a fractional bandwidth of 42.81% (ranging from 2.90 GHz to 4.48 GHz), a resonant frequency of 3.6 GHz, and a return loss of 28.76 dB. This frequency band is well-suited for 5G mobile applications.

Sharmin and Rahaman [21] proposed, a microstrip patch antenna for 5G technology that has a "slotted octagonal" shape patch. It is intended for use in future electronic devices. The antenna has an operating frequency of 4.43 GHz, which places it inside the C-band of the frequency spectrum for 5G communications. The design that has been offered is a good option because it has a gain of 3.05 dBi and a radiation pattern that is aesthetically pleasing. This study looks at the antenna's geometry and several metrics, such as the reflection coefficient, gain, radiation characteristics, and input impedance plot. 5G connectivity might be achieved using the antenna that was built.

This article used the computer simulation technology (CST) microwave studio to make a microstrip patch antenna for the 5.4 GHz band [22]. Copper has been selected for the construction of the patch, the ground plane, flame retardant 4 (FR-4) material, has been selected for the substrate, and a microstrip line has been used for feeding the antenna. As shown by the size of the primary lobe is 6.16 dBi at the centre resonant frequency of 5.38 GHz, the small and simple design gives the antenna excellent directivity. In addition, it has been determined that the efficiency is 41.938% and that the bandwidth has a sufficient value of 200.6 MHz. The results of the simulations show that the proposed antenna works well and can be used in wireless local area network applications, even though it has a simple design.

Ezzulddin *et al.* [23] proposed, antennas are proposed that have better gain, directivity, and bandwidth than antennas that has been studied before. With the help of the CST and high-frequency structure simulator (HFSS) software simulators, the antenna's properties, such as return loss (S_{11}), VSWR, gain, directivity, bandwidth, and radiation pattern, is measured experimentally. These evaluations are done for each of the microstrip patch shapes mentioned earlier. Also, it has been shown that the proposed antenna parameters produce results close to those of earlier research studies done at the same frequency. This makes it perfect for use in 5G wireless communication systems.

Rana *et al.* [24], the design and analysis of a microstrip patch antenna operating at 3.5 GHz, intended for future wireless communication. Through this investigation, the researchers hoped to achieve the following goals: a reduced return loss; a more significant gain; a lower VSWR; improved directivity; and more efficient operation. This antenna has been developed and validated for several wireless communication applications. In communication satellites, weather radar, surface ship radar, wireless local area networks (LANs) (802.11b and 802.11g), multimedia applications in mobile TV and satellite radio, optical communications at wavelengths ranging from 1460 to 1530 nm, and other wireless fidelity applications, it is utilized as a reference antenna.

3. MATERIALS AND METHODS

The physical dimensions of the structures and the properties of the materials used to build them dictate how the MPA is carried out. In this consideration, a fixed rectangular shape is used because it is easy to make and look at. Also, compared to other types of receiving wire, it has a faster impedance transfer speed because it is more extensive. The capacitance effect of a conductor placed in or around insulation material changes how an electromagnetic wave moves through it. This effect estimates how much a conductor's capacitance effect changes how an electromagnetic wave moves through it. The entire viability of the receiving wire is affected by the dielectric constant. Length, characteristic impedance, and width all affect the reverberation frequency, which lowers the transmission rate and lengthens the time it takes for reverberation to happen again. The dielectric field includes controlling the adjacent area, the primary radiation source in microstrip fix receiving wires, and the dielectric consistency.

The borders will be more extensive and the radiation will be way better with lower esteem of r, driving to upgraded transmission capacity and productivity. The bordering field, which is the essential source of radiation in microstrip fixed radio wires, is additionally controlled by the dielectric steady. The borders will be more extensive and the radiation will be superior with lower esteem of r, driving to upgraded transmission capacity and productivity. The arrangement support approach has been connected, which frequently includes a ceaseless transmission line in which a modest amount of energy is combined with each individual portion to make up a continuous stream of power. It makes fabricating straightforward and the planning is clear. There are different kinds of feeding techniques for designing microstrip patch antennas.

In this research, the microstrip line inset feeding technique is used for a 50-ohm transmission system. The behavior of a microstrip antenna is controlled by the inset gap and inset length, and the inset feeding approach is straightforward to use and understand. This feeding technique helps regulate the antenna's impedance because of its flat structure. The length, width, fix, ground, and feedline are the pivotal variables that must be computed after the substrate Rogers RT/Duroid 5880 is finalized. Equations used in this research to identify the dimensions of the antenna [25].

3.1. Width of the microstrip patch antenna

In order to calculate this, we used the (1). Frequency and dielectric constant play vital roles in this regard.

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

3.2. The effective dielectric constant

Air and substrate are two dielectrics that are isolated by a microstrip. Since of this, the larger part of the electric field lines is found within the substrate, even if a few do reach the surface [26]. Because the propagation speeds between the air and the substrate would vary, this transmission line cannot support precise microwave engineering. So, it is essential to decide on a compelling dielectric constant in order to require periphery areas into thought. Since the bordering areas around the patch's border are not contained inside the dielectric substrate but are instep scattered all through the encompassing air, the viable dielectric steady is less than the dielectric constant of the substrate [27]. This compelling dielectric constant's esteem is:

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

3.3. Extended length

Here is the (3) of extended length of antenna:

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

The real measurement is diverse as a result of the bordering impact. To decide the patch's genuine length, this aberrance is subtracted from the extended length utilizing the taking after (4), (5), dan (6):

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

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

$$W_f = \frac{7.48\times h}{e^{\left(z_0\frac{\sqrt{\varepsilon_r+1.41}}{87}\right)}} - 1.25 \times t \tag{6}$$

4. ANTENNA DESIGN AND SIMULATION RESULTS

Most communication devices today use microstrip patch antennas instead of traditional antennas. This is mostly due to the smaller size of microstrip patch antennas. Recent changes in the wireless communication industry have kept up the demand for small, interoperable, and affordable microstrip patch antennas that are small [28]. The actual construction of the patch antenna is depicted in Figure 1. The metal and substrate that make up the MPA are stacked in three layers its construction. At the bottom of the building, copper is one example of a material used to build the ground structure layer. The substrate layer, also called the intermediate layer, can be made of any dielectric material, like air, FR4, and Rogers. Copper or another highly conductive material is used as the foundation for the top layer, which is also referred to as the patch and design layers [29]. There are various softwares to design and simulate antennas. In this research, CST Studio has been used with a view to obtaining the parameters of the antenna and optimizing in a way by which high performance is achieved. Figure 2 shows the proposed antenna designed using computer simulation technology software.

In order to get better results parameters are optimized which are in Table 1 and contains the various measurements that were taken of the antenna. The notations W_g and L_g, respectively, are used to indicate the width of the ground as well as the length of the ground. In addition, the antenna patch's dimensions in width and length are given, as well as the height and thickness of the substrate (t). Several different factors portray the values of the several components.

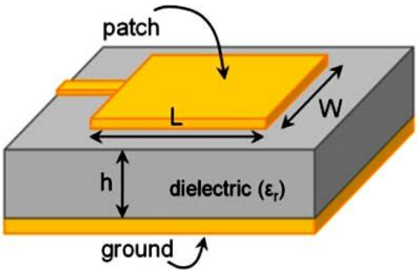

Figure 1. Geometry of microstrip patch antenna

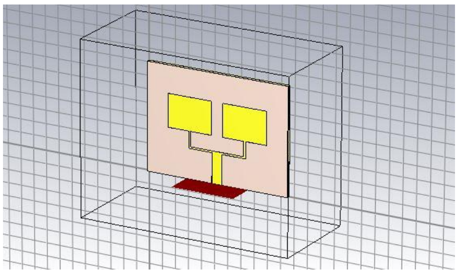

Figure 2. Simulation of the microstrip patch antenna in CST

Table 1. Parameters of the antenna designed

Parameter	Dimension (mm)
Width of the ground surface, W_g	64.4
Length of the ground surface, L_g	81.25
Width of the patch, W_p	32.94
Length of the patch, L_p	25
Substrate height, H_s	2.5
Width of the feedline, W_f	7.7
Intersection of the feedline, F_i	25.3
Thickness of the ground, t	0.035
Gap, g	0.783

4.1. Return loss and bandwidth

When impedance coordination is vital in radio frequency (RF) circuits, return loss could be a number that's regularly utilized. The rate of a flag that's reflected as a result of an impedance jumble is known as the return loss. The return loss approach is comparative to the voltage standing wave proportion, but it is habitually utilized in applications where feeders are not utilized or are utilized in greatly little amounts relative to wavelengths, making the standing wave thought unseemly. The base value is taken at -10 dB which is ideal for mobile or wireless technologies as most of the power is received by the antenna. The antenna is operated at the desired frequency. From Figure 3 where the S_{11} parameter is visualized, the antenna operates with a -17.626 dB return loss at 3.6 GHz. The bandwidth of the antenna in this work is calculated as 0.2063 GHz at -10 dB which is ideal for use in wireless communication technology.

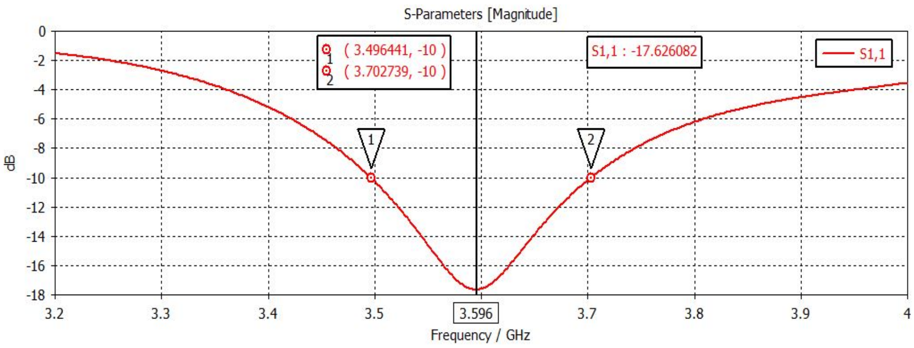

Figure 3. Return loss vs frequency of the antenna

4.2. VSWR

An indication of the degree of mismatch between an antenna and the feed line connecting to it is the VSWR. The standing wave ratio is another name for this (SWR). A value of VSWR between 1 to 2 is good. But ideally its value is 1. The majority of antenna applications are thought to be viable for VSWR values under 2. The antenna has what is known as a “good match”. As a result, when an antenna is said to be “poorly matched”, it typically indicates that the VSWR value exceeds 2 for the desired frequency. From Figure 4 VSWR value achieved is 1.3026 which is excellent for the purpose of wireless technology. Also, Figure 4 shows the VSWR vs frequency (GHz), where the vertical edge is reffered to as VSWR and frequency (GHz) is noted on horizontal edge.

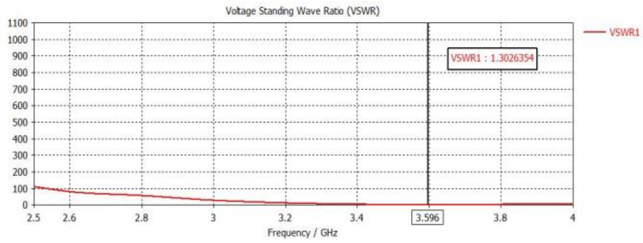

Figure 4. Shows the VSWR vs frequency of the antenna

4.3. Gain

Among the vital parameters, radiation pattern is very important as it defines how accurately the antenna can transmit data [30]. It also verifies the transmission power in the waveguide without losing data [31]. Figure 5 shows the 3D radiation pattern of the antenna and the gain is 9.671 dB which is very effective for wireless communication technology. In addition to that, Figure 6 farfield gain of microstrip patch antenna at phi = 90°, the main-lobe direction and the side-lobe level at phi 90 degrees are 9.68 dBi and -17.8 dB respectively, from Figure 7 fairfield gain of the microstrip patch antenna at phi = 90 degrees, main-lobe direction and the side lobe level are 9.65 dBi and -28.8 dB respectively and, Figure 8 fairfield gain of the microstrip patch antenna at theta 90 degree main lobe direction and the side lobe level is -1.51 dBi and -2.8 dB respectively.

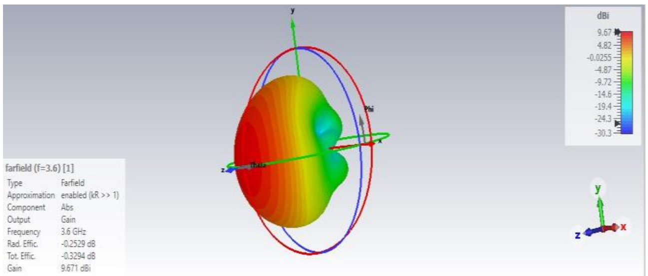

Figure 5. 3D Fairfield gain of the microstrip patch antenna

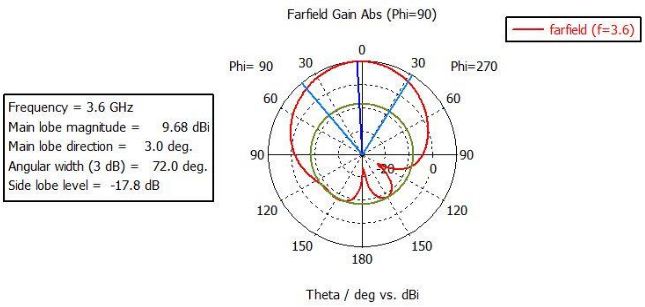

Figure 6. Fairfield gain of the microstrip patch antenna at phi 90 degrees

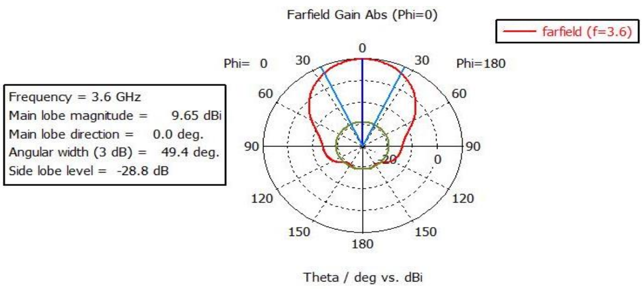

Figure 7. Fairfield gain of the microstrip patch antenna at phi 0 degree

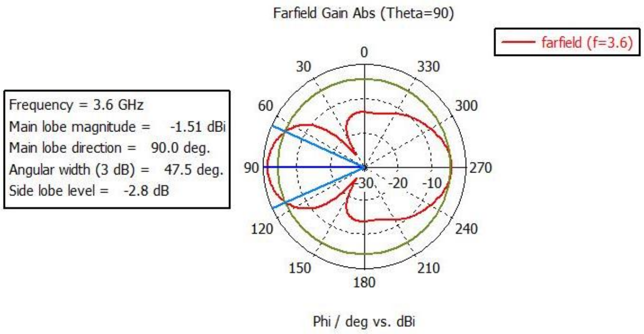

Figure 8. Fairfield gain of the microstrip patch antenna at theta 90 degrees

4.4. Directivity

The degree to which the radiation emitted is concentrated in a single direction is measured by the directivity property of an antenna or optical system in electromagnetism. Since many antennas and optical systems are made to radiate electromagnetic waves across a restricted angle or in a single direction, directivity is a crucial measurement. From Figure 9, the farfield directivity from 3D Fairfield is 9.924 dBi. Figure 10 also found that the main lobe, main lobe direction, angular width, and side lobe are 9.93 dB, 3.0 degrees, 72.0 degrees, and-17.8 dB at an operating frequency of 3.6 GHz, respectively.

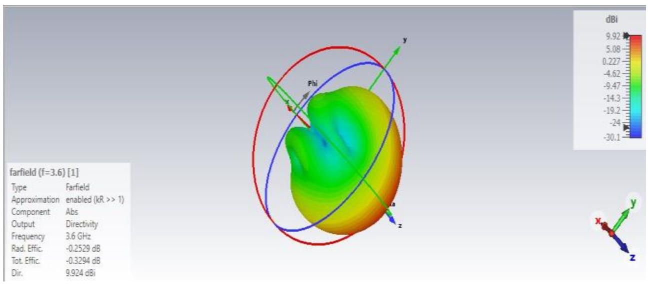

Figure 9. Farfield directivity

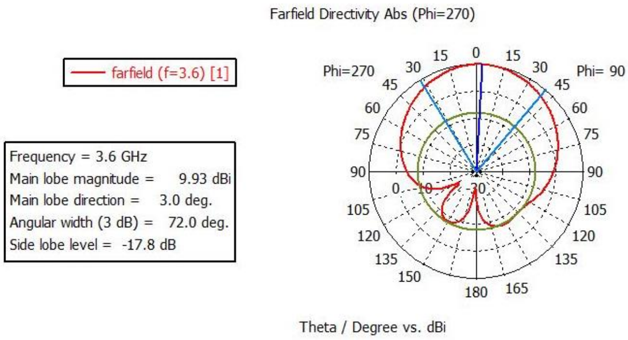

Figure 10. Polar form Farfield directivity

4.5. Radiation efficiency

Radiation efficiency is a measurement used in antenna theory to describe how successfully a radio antenna transforms the radio-frequency power received at its terminals into radiated power and it is denoted as the ratio of the gain and the directivity of an antenna. From the results as stated above, we get 97.45% radiation efficiency where the gain is 9.671 dBi and the directivity is 9.924 dBi. Thus, the designed antenna is a competent choice for wireless communication technology.

5. RESULT ANALYSIS

In this investigation, simulations were carried out for wireless applications using an operating frequency of 3.6 GHz and material made from Roggers RT Duroid 5880. As a result of the simulation, the gain, directivity, return loss, bandwidth, VSWR, and efficiency of the Roggers RT/Duroid 5880 material are, respectively, 9.671 dBi, 9.924 dBi, -17.62611 dB, 0.2063 GHz, 1.3026, and 97.45%. Because of this, this MPA could become a good option for wireless applications and 5G deployments.

The reenactment comes about for the arranged antenna and prior logical investigations are recorded in Table 2. It causes an impedance jumble because it proliferates into the radio wire, which is what employs the control. Negligible control utilization, diminished warmth, and solid information exchange are the results of an ideal plan. In case the impedance is balanced, it produces the specified moo VSWR, permitting the source to convey its full control to the stack. Each antenna parameter has been balanced such that the examined radio wire performs way better in terms of pick up and transmission capacity. In Table 3 and Table 4 compare the proposed work with previously published work.

Table 2. Results of antenna

Parameter	Value
Return loss (dB)	-17.622
Bandwidth (GHz)	0.2063
Gain (dBi)	9.671
Directivity (dBi)	9.924
Efficiency (%)	97.45%
VSWR	1.3026

Table 3. Comparision between previous works

Ref.	Gain (dBi)	Directivity (dBi)	Efficiency (%)
[24]	7.55	8.43	89.56%
[32]	–	6.81	–
[33]	6.72	–	–
[34]	5.23	–	–
[35]	–	6.98	–
[36]	7.88	–	–
[37]	7.54	–	–
[38]	6.8	–	–
[39]	6.4	–	–
[40]	6.61	–	–
[41]	12.56	12.98	96.76%
[42]	5.17	–	–
	6.69	–	–
[43]	6	–	–
[44]	9.24	–	–
[45]	8.98	10.83	82.92%
[46]	–	4.62	–
		7.35	
This work	9.671	9.924	97.45%

Table 4. Comparision between previous works

Ref.	Dielectric material	Dielectric permittivity	Return loss (dB)	VSWR
[24]	Rogers RT/Duroid5880	2.2	-13.772	1.5152
[33]	FR-4	4.6	–	Below 2
[35]	Rogers RT/Duroid5880	2.2	-15.8	–
[40]	FR-4	4.4	-17.436	1.30
[42]	FR-4	4.4	-16.4277	–
		2.2	-16.0151	–
[44]	Rogers RT/Duroid5880	2.2	-7.25	2.54
[47]	Rogers RT/Duroid5880	2.2	-12.54	1.6
[48]	FR-4	4.4	-16	1.42
[49]	Rogers RT 5880	2.2	-14.18	1.48
[50]	Rogers RT 5880	2.2	-17.15	1.325
			17.58	1.304
This work	Rogers RT/Duroid5880	2.2	-17.622	1.30

6. CONCLUSION

A novel antenna design, simulation, and analysis have been carried out for this paper for 3.6 GHz frequency which is used for the applications of S-band. The return loss, gain, directivity, bandwidth, VSWR, and antenna efficiency were all simulated and found to be -17.622 dB, 9.671 dBi, 9.924 dBi, 206.3 MHz, and 1.3023, respectively. The efficiency of the antenna was found to be 97.45%. This antenna can be used in radars, cell phones, and wireless local area networks (LANs). The antenna can be a good candidate for future wireless applications. The next antenna will be fabricated, and the results of the simulation will be compared to the results of the experiment. Utilizing alternative approaches, such as circular and ring-type array patches, is one way to achieve more improvement. Future researchers may use various methods and tools to get the desired results.

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