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Design of 28 GHz Microstrip Patch Antenna for Wireless Applications

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ABSTRACT

This research paper presents a 28 GHz microstrip patch antenna design and analysis for mobile phone applications. Fr-4 (lossy) material, whose dielectric permittivity is 4.3 and loss tangent is 0.025, has been used as a substrate material for the antenna. Besides, copper annealed has been used in the ground, and the thickness of the patch is 0.035. CST software creates and simulates the complete antenna. Among the results obtained from the simulation, return loss, VSWR, directivity gain, and bandwidth are -24.507 dB, 1.126, 7.19 dBi, and 1.352 GHz, respectively. The main objective of this proposed antenna is to achieve an excellent VSWR value by reducing the return loss, increasing the antenna's directivity gain, and improving the bandwidth. As a result, this proposed design can be used on super-high-frequency devices (mobile phones) in the future. The fact that the results obtained from the suggested antenna design are superior to those reported in papers published in the past hints that the research has achieved increased performance compared to studies already conducted in the field.

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1. INTRODUCTION

The antenna performs the function of a device that converts electrical energy into electromagnetic energy, enabling the signal to travel through the air. Its principal purpose is to serve as an interface between two different guided devices to facilitate communication. An antenna is a material that can both emit and transmit radio waves, according to the definition by the Institute of Electrical and Electronics Engineers (IEEE). An alternative explanation of an antenna may be found in Webster's dictionary. According to this interpretation, an antenna is a metallic apparatus, like a wire or rod, that is designed to receive and transmit radio waves [1]. Antennas are of different types, such as Array antennas, horn antennas, dipole antennas, microstrip patch antennas, wire antennas, Vivaldi antennas, etc. Researchers are currently leaning more towards microstrip patch antennae for research. Because of its low cost, designing, simulating, and manufacturing is also straightforward. Various software programs are used to create and simulate the antenna. The software is CST (Computer Simulation Technology), HFSS (High-frequency structure simulator) Antenna Magus, FEKO

(Feldberechnung für Körper mit beliebiger Oberfläche), MATLAB, ADS (Advanced Design System), etc. However, researchers mostly use CST or HFFS software.

Although its development picked up significant steam in the 1970s, the microstrip antenna began in the 1950s. However, its origins can be traced back to that decade. Microstrip antennas, defined by their unique nature, have emerged as a critical subject in antenna theory and design over the past few years. This development took place. Utilizing printed circuit technology for the components of circuits, transmission lines, and the radiating elements of electronic systems is the core idea that underpins a microstrip antenna. This technology is also used in several other types of antennas. These antennas have various uses in contemporary microwave contexts due to their ease of use and compatibility with printed-circuit technology [2].

The microstrip patch antenna, also known as an MPA, is constructed using three layers of substrate materials and metal. The first layer, known as the ground structural layer, is built out of a material that conducts electricity, such as copper. Fabrication of the middle and substrate layers is possible with various dielectric materials, including air, FR4, Rogers, and others. In the final step, a highly conductive or copper-based substance is utilized to generate the top layer, the patch or design layer [3]. The construction of the microstrip patch antenna is depicted in Figure 1, and this antenna is designed by CST software. Microstrip patch antennas come in various shapes. Some shapes are square, rectangular, elliptical, circular, triangle, dipole, etc. The many designs of microstrip patch antennas are depicted in Figure 2 [4].

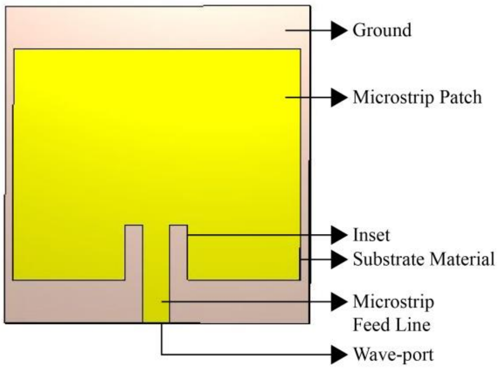

Figure 1. Physical construction of Microstrip patch antenna

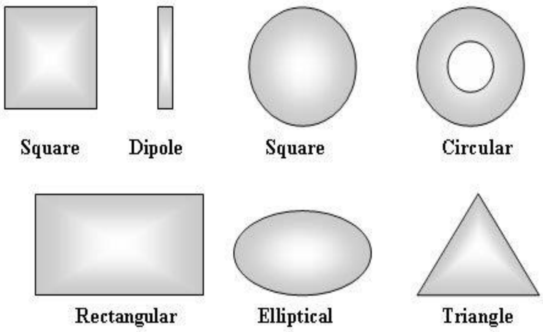

Figure 2. shows some representative shapes for microstrip patch elements [4].

The printed dipole antenna, the microstrip patch antenna, and the microstrip slot antenna are the three types of microstrip antennas available. An individual's desires can shape the three microstrip patch antennas mentioned before. In most cases, the microstrip slot that is utilized in a traveling antenna is shaped like a grid that is either rectangular or circular. Due to their versatility, triangles and rectangles are the two most typical shapes for printed dipole antennas. In the process of designing antennas, the most crucial factor is selecting the substrate material that is appropriate for the antenna. [5]. This antenna is very critical components of wireless communication systems and comprises a ground plane, a dielectric substrate, and a metallic patch made of very thin copper. Although the circular and rectangular shapes are the ones that are used most frequently, the rectangular shape was selected for this particular paper [6]. Also, microstrip patch antennas are quite common in applications involving wireless communication. Because they have a small footprint, are easy to manufacture, and are compatible with planar circuits. In particular, rectangular microstrip patch antennas are utilized rather frequently in wireless applications because they have a high gain, are efficient, and are compatible with super high-frequency bands.

The document has been divided into six distinct sections so that the information being supplied can be presented in a manner that is easier to understand. In addition to this, the organization of the document is comprised of the following elements: The presentation of the introduction can be found in Section I; the expression of a literature review can be found in Section II; the research methodology can be found in Section III; the discussion of proposed antenna design and simulation can be found in Section IV; the presentation of an analysis of the results can be found in Section V; and the expression of a conclusion can be found in Section VI. The following chapter contains the complete list of references for this section, which can be found in the table of contents.

2. LITERATURE REVIEW

In this section of the paper, the authors discuss various previously published articles that focus on microstrip patch antennas operating at a frequency of 28 GHz. This discussion aims to provide a review and comparison of the existing literature on microstrip patch antennas specifically designed for this frequency. The discussion may cover various topics, including antenna designs, materials, feeding techniques, substrate choices, and performance parameters such as gain, directivity, bandwidth, and efficiency. The authors may highlight the strengths and weaknesses of each paper and draw comparisons to identify trends, common challenges, and potential areas for improvement.

Research by M.S Rana *et. al*, [7], investigates and constructs a microstrip patch antenna that can function at a frequency of 28 GHz. The end goal of this research is to assist future communication technologies that use 5G. Several characteristics, including return loss, gain, radiation efficiency, and side-lobe level, were investigated and analyzed using simulation. The results of this simulation outperform other efforts that have been done in this area, which positions the proposed antenna as a strong candidate for the development of 5G wireless technology. In addition, the performance of this antenna is superior to that of other antennas that have been published in more recent scientific papers.

This research presents [8], a group of antennas that have been purposefully developed for 5G mobile connectivity and operate at 28 GHz. The antennas come in a single-element or array design, with two or four elements in the array. The effectiveness of the microstrip and inset feed lines is evaluated using a combination of these two distinct feeding methods. The findings show that array antennas have high gain and directivity, making them an excellent choice for addressing the difficulties brought about by the high free-space path loss in millimeter-wave communication. According to the research findings, the mutual coupling between the two-element and four-element array antennas is greatly reduced. The greater reflection coefficient values demonstrate this. The inset feed line antennas surpass the microstrip feed line antennas in terms of gain, directivity, reflection coefficient, and dimensions. In addition, the inset feedline antennas are more compact. As a result, the array antennas proposed for use in 5G mobile communications provide a workable option.

Research by M. D. Fernandez *et. al,* [9], presents a novel design for a patch antenna that does not require a dielectric substance to function properly. An empty substrate integrated waveguide, also known as an ESIW, is used in its place as the feeding waveguide. To accomplish this, plastic support created using a 3D printer is used to anchor the patch above the ESIW, producing an air-dielectric atmosphere. The aperture-coupled approximation is utilized to achieve the feeding, which is done through a slot. At a frequency of 28 GHz, a prototype of a single-element antenna was designed, constructed, and optimized to display excellent performance in terms of bandwidth, directivity, gain, and beam width. This prototype offers a potentially useful solution for millimeter-wave wireless applications. This research presents [10], a novel concept for a beam antenna that would be used for 5G communications and would operate at a frequency of 28 GHz. In contrast to the more traditional method of beam scanning, which uses array techniques, this antenna provides radiation inclined on an elevation plane. Instead, the design combines two independent radiating parts to produce a moderately wide beam with a high gain focusing on an inclined target direction. The method uses patches to generate two powerful split beams on the azimuth plane, and the aperture further improves the antenna's gain on the elevation plane.

This article proposes [11], the design of a single rectangular microstrip antenna (RMPA) capable of performing efficiently at 28 GHz and is suitable for use in 5G communication systems. The design chooses a durable conductor patch material and reduces the patch's overall dimensions as much as possible. The high radiation performance of the RMPA antenna is achieved after the optimization process. The antenna has a frequency of operation of 28 GHz with patch parameters that have been optimized, and it has ideal properties like bandwidth, return loss, gain, and voltage standing ratio. Research by F. Mahbub *et. al,* [12], a rectangular microstrip patch antenna that satisfies the stringent requirements of future 5G communication systems has been constructed. In particular, the work focuses on the antenna's gain and efficiency. The developed strategy achieves high efficiency while solving the issues brought on by return losses. Regarding 5G communication, the antenna's ability to operate at a frequency of 28.5 GHz, sometimes called the Ka-band.

This paper introduces [13], the design and performance analysis of a 28 GHz microstrip patch antenna (MSPA) for fifth-generation (5G) communication systems. The antenna's characteristics, including beam gain, directivity, radiation efficiency, and bandwidth, were evaluated through simulation. This signifies that the proposed antenna exhibits highly competitive performance compared to previous works, making it a promising candidate for wireless applications. This article outlines [14], a microstrip antenna design specifically tailored for fifth-generation (5G) mobile communications. The antenna is small, can be tweaked, and can be reconfigured. The proposed antenna has a collection of PIN diodes built into it. The results of the simulation and the measurements show a good agreement, with just a small amount of variance. Tolerances in the manufacturing process and improperly matched connectors are likely to blame for any discrepancies that have been spotted. The developed antenna demonstrates that it can meet the requirements of 5G wireless applications.

This paper introduces [15], a patch antenna with high gain and enhanced bandwidth designed for 5G operations. The high gain of the patch is attained by incorporating two rectangular slots on the radiating element. Additionally, the antenna's bandwidth is improved by incorporating three steps at the edge of the rectangular patch. Although the antenna consists of a single element, cutting it at the edges demonstrates favorable gain and return loss characteristics. Considering its features, the proposed antenna proves to be well-suited for 5G applications. This paper proposes [16], a microstrip line-fed broadband microstrip patch antenna designed for wireless applications, specifically operating at 28 GHz. The proposed antenna exhibits excellent return loss, wide bandwidth, strong gain, and directivity across the entire operating band, as evidenced by a VSWR value 1. Comparing it to existing antennas discussed in recent scholarly studies, this antenna demonstrates superior performance. This antenna is expected to be suitable for 5G wireless communication systems.

3. RESEARCH METHOD

Designing and analysing a microstrip patch antenna (MPA) that makes use of FR-4 substrate material is the primary topic of this research work. Different shapes for microstrip patch antennas allow for compactness in various applications. The analysis considers the dielectric constant values of the FR-4 substrate material. The first step of the research involves designing the microstrip patch antenna with a rectangular shape. The dimensions of the patch antenna are determined based on the desired operating frequency and other specifications. Once the design is complete, Computer Simulation Technology (CST) software simulates the antenna's performance. During the simulation, various antenna parameters are evaluated and recorded. These parameters include gain, directivity, return loss, and bandwidth. Gain measures the antenna's ability to radiate electromagnetic energy in a particular direction. Directivity measures the concentration of radiated energy in a specific order, while return loss indicates the amount of power reflected to the source due to an impedance mismatch. The results are analyzed and compared after simulating the antenna design and obtaining the parameter values. Figure 3 shows the flow chat diagram of proposed microstrip patch antenna (MPA) design.

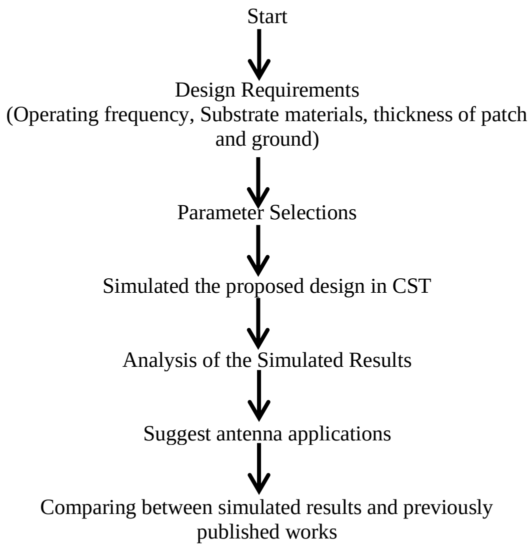

Figure 3. Flow chat of the proposed design

The goal is to identify the desired design that best meets the requirements and objectives of the research. By comparing the performance characteristics of different designs, the researchers can determine which design exhibits the desired properties, such as higher gain, better directivity, lower return loss, and wider bandwidth. A series of equations are utilized in the study work to compute the values that should be assigned to the various parameters for the microstrip patch antenna design [17], [18]. Using these equations, one may more accurately determine the required dimensions and characteristics of the antenna

Step: 01: Utilizing the following formula, the width of the patch was determined:

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

Step: 02: During the process of antenna design, one of the most important calculations is determining the effective dielectric constant of the substrate.

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

Step: 03: In the process of designing an antenna, one of the most important aspects to consider is the efficient length of the antenna.

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

Step: 04: The process of calculating the length extension of an antenna

$$\Delta L = 0.412h \frac{\left(\frac{Wp}{h} + 0.3\right)(\varepsilon_{reff} + 0.264)}{(\varepsilon_{reff} - 0.258)\left(\frac{Wp}{h} + 0.8\right)} \quad (4)$$

Step: 05: One of the most basic calculations in antenna design is the antenna's length.

$$L_p = Leff - 2\Delta L \quad (5)$$

After that, the dimensions of the ground plane, including its length and width, as well as the rectangular microstrip patch, may be calculated as follows:

$$Lg=6h+L_p \quad (6)$$

$$Wg=6h+ Wp \quad (7)$$

4. PROPOSED ANTENNA DESIGN AND SIMULATION RESULTS

Figure 4 shows the proposed antenna design for wireless applications. It was designed and simulated by using CST software. The microstrip patch antenna that has been proposed is printed on a substrate made of FR-4, which has a dielectric constant of 4.3. The dimensions of the substrate are 8.50×8.50 millimeters, and its height is 0.45mm. The loss tangent is 0.025. Copper is used for the surface that conducts electricity. The parameters used for the proposed antenna design are listed in table 1. This antenna is more compact and has a high level of directiveness, both of which are necessary for wireless applications. It also has very little return loss compared to other antennas already in existence. This antenna is much better suited for wireless communication systems due to its vast bandwidth [19].

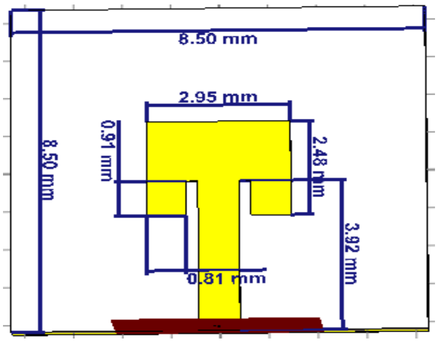

Figure 4. Proposed designed of Microstrip patch antenna using CST

Table 1. Measurements Concerning the Geometry of the Antenna

Parameter	Dimension (mm)
Wg	8.50
Lg	8.50
Wp	2.95
Lp	2.48
Hs	0.35
t	0.035
I_L	0.9054
I_W	0.239
T_W	0.85

4.1. Return Loss

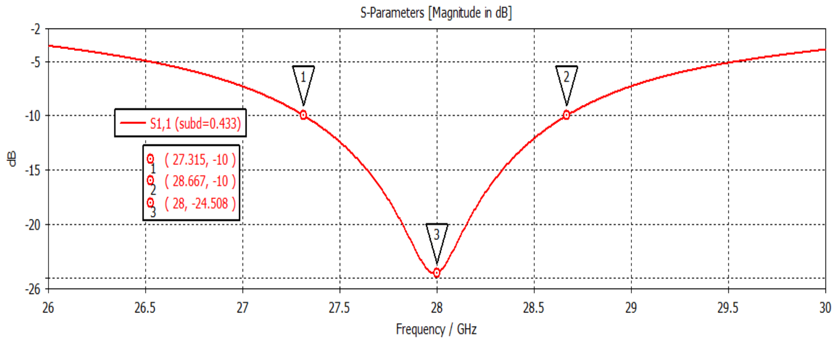

Figure 5. Return vs frequency of the proposed antenna

The reflection coefficient is the ratio of the reflected signal magnitude to the incident signal magnitude. In telecommunication systems, return loss refers to the measurement of signal reflection or the amount of signal reflected from an antenna, optical fiber, or transmission line system due to impedance mismatches or other discontinuities. Return loss is typically measured in decibels (dB) and is used to assess the effectiveness of signal transmission and the quality of the connection. A high return loss value indicates that most of the signal is transmitted without significant reflection, which is desirable for efficient signal propagation. On the other hand, a low return loss value suggests that a substantial portion of the signal is being reflected, indicating poor impedance matching or signal loss [12]. The research report stated that the S-parameter values of the microstrip patch antenna were observed within the frequency range of 26 GHz to 30 GHz. In contrast, the simulation of the antenna was being run. The S-parameter represents the scattering parameters, which define the relationship between the waves that are incident on different ports of an antenna and the waves that are reflected from those ports. Figure 5 depicts the whole S-parameter analysis result for your reference. At 28 GHz, the return loss of proposed antenna is -24.507 dB.

4.2. Voltage Standing Wave Ratio

The voltage standing wave ratio (VSWR) measures the power an antenna or transmission line reflects. A lower VSWR value implies that the antenna is performing better, that the impedance matching has been improved, and that there is more efficient power transmission. It contributes to evaluating and optimizing the impedance match between the antenna and the transmission line. When the voltage standing wave ratio (VSWR) value is closer to 1:1, the antenna or transmission line transfers power effectively and does not have substantial reflections. On the other hand, a greater VSWR value implies poor impedance matching and increased signal reflections, which can result in a loss of power and a reduction in performance [20]. The VSWR value of the proposed antenna at 28 GHz is 1.26, as shown in figure 6.

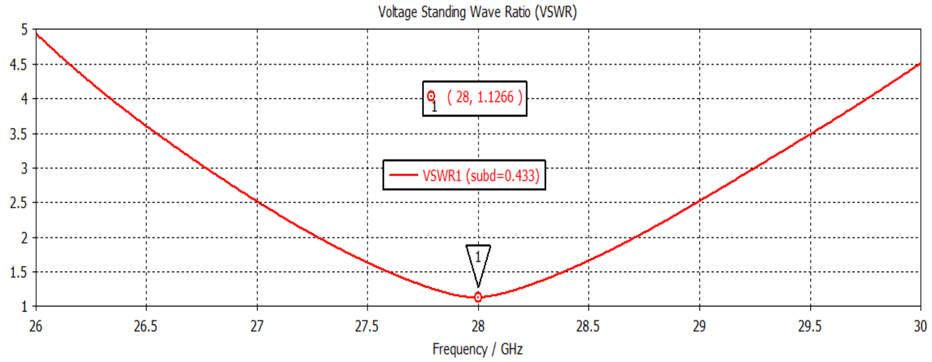

Figure 6. The proposed antenna's return vs frequency graph.

4.3. Radiation Pattern and Directivity Gain

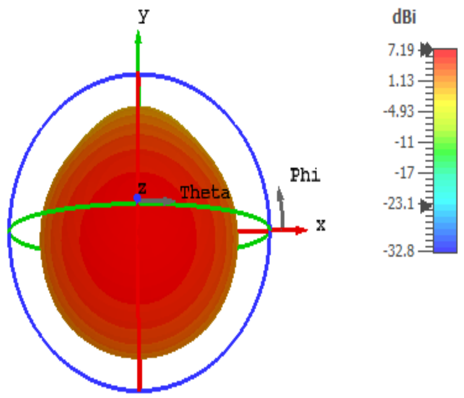

Figure 7. Directivity gain of proposed antenna (3D)

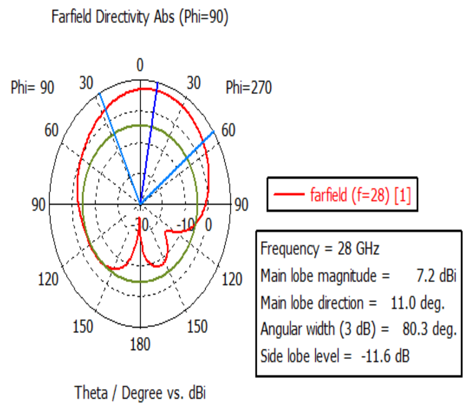

Figure 8. Polar form of radiation pattern

The radiation pattern of a microstrip patch antenna is indeed a significant parameter that helps evaluate its performance. It provides information about how the antenna radiates electromagnetic energy in space. Figure 7 and Figure 8 in the research paper showcase the 3D and 2D radiation patterns of the microstrip patch antenna, respectively. The Directivity Gain is a measure of how focused the antenna's radiation pattern is in a particular direction compared to an isotropic radiator. A higher directivity gain indicates a more concentrated radiation pattern in the desired direction, enabling improved communication range and signal strength [21]. In this case, the research paper states that the Directivity Gain of the microstrip patch antenna is found to be 7.19 dBi (decibels relative to isotropic). A positive dBi value indicates that the antenna's radiation pattern is more focused in the desired direction compared to an isotropic radiator. A Directivity Gain of 7.19 dBi is considered to be quite effective for wireless communication, as it suggests a well-directed radiation pattern with enhanced signal strength and coverage in the desired direction.

5. RESULT ANALYSIS AND RESEARCH GAP

In that section, the results of the proposed antenna are presented. From the simulation results, the return loss of -24.507 dB, VSWR of 1.26, directivity gain of 7.19 dBi, and bandwidth of 1.352 GHz, respectively. Besides, the results of the proposed antenna have been compared with those of previously published international standard journals and conference papers. The comparison shows that the quality of the presented results is much better than the previously published results, which can be used in wireless applications. Besides, it is possible to get a better value than the proposed antenna value by changing the different parameters of the antenna, and the researchers can make it and compare the results with the simulated results. Table 2 provides a Synopsis of the results of the simulation and Table 3 compares the proposed results with previously published results.

Table 2. Summarize of the simulation results

Parameter	Value
Return Loss (dB)	-24.507
VSWR	1.12
Bandwidth (GHz)	1.352
Directivity gain (dBi)	7.19

Table 3 Comparison of the proposed work with the previously published works

Ref	Operating Frequency	S11 (dB)	Directivity Gain (dBi)	VSWR	BW (GHz)
[22]	28GHz	-14.60	6.52	-	0.503
		-26.24	6.31	-	0.708
[23]	28GHz	-20.95	-	1.197	1.06
[24]	28GHz	-	7	-	0.9
[25]	28.1GHz	-19.3	7.02	1.24	0.9
[26]	28GHz	-18.25	6.72	1.278	1.10
[27]	28GHz	-17.28	7.09	1.31	0.967
		-33.22	6.82	1.04	0.807
		-22.97	6.47	1.15	0.629
[28]	28GHz	-13.66	-	1.52	-
[29]	28GHz	-24	3.12	1.24	0.280
This Works	28GHz	-24.50	7.193	1.12	1.352

6. CONCLUSION

In this study, a microstrip patch antenna was designed and analyzed for wireless communication applications. The primary objective was to minimize power loss and optimize the antenna's performance. The research investigated various parameters to assess the antenna's effectiveness. The return loss was measured to be -24.507 dB, the VSWR value was determined to be 1.12, the directivity gain was calculated to be 7.19 dBi, and the bandwidth was 1.352 GHz, respectively. The reported results indicate that the microstrip patch antenna designed in this study achieved a higher gain, a lower VSWR, improved bandwidth, and a lower return loss. These outcomes demonstrate the antenna's improved performance regarding power transfer efficiency, impedance matching, and radiation pattern directionality. The researchers suggest that future investigations explore alternative methods and materials to enhance the antenna's performance further. This could involve different design configurations, substrate materials, or fabrication techniques. The simulated results from this study suggest that the proposed microstrip patch antenna has the potential to be a promising candidate for wireless communication systems. The next step would involve fabricating the antenna and conducting experimental measurements to compare the actual outcomes with the simulated results, ensuring the antenna's practical feasibility and performance.

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