JOURNAL OF SCIENCE AND TECHNOLOGY
ISSN: 2229-8460 e-ISSN: 2600-7924

Vol. 16 No. 2 (2024) 20-29
https://publisher.uthm.edu.my/ojs/index.php/jst

JST

Dual Band Antenna for Wi-Fi and 5G Communication

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DOI: https://doi.org/10.30880/jst.2024.16.02.003

Article Info

Received: 14 March 2024
Accepted: 4 September 2024
Available online: 21 November 2024

Keywords

5G, microstrip antenna, dual band

Abstract

The objective of this project is to design a microstrip antenna that operates in both the Wi-Fi and 5G frequency bands, specifically at 2.4GHz for Wi-Fi and 3.5GHz for 5G communication. The antenna design pattern on a FR4 substrate has been selected to be a rectangular microstrip patch antenna due of its low-profile form. The square patch antenna incorporates slot and inset feed techniques to achieve dual band operation and improve antenna performance. The antenna operates at the resonant frequencies of 2.4GHz and 3.5GHz. The S11 values at these frequencies are -19.948dB and -26.151dB, respectively. The antenna's gain is 2.698dB at 2.4GHz and 1.359dB at 3.5GHz. The antenna design was simulated using CST Microwave Studio, and the measurements were conducted using a Vector Network Analyzer (VNA).

1. Introduction

The current progress in communication systems is mostly centered around the advancement of 5G technology. To achieve this advancement, it is essential to use dual band antennas that have the capability to handle 5G communication applications. Nevertheless, certain antennas lack the inherent capability to operate simultaneously at numerous frequencies.

Modern communication systems today consider dual-band antennas to be indispensable, as they enable simultaneous operation at two distinct frequency bands. This feature is particularly beneficial in scenarios when several communication standards or protocols are employed, such as the coexistence of Wi-Fi networks operating at both 2.4 GHz and 5 GHz frequencies, or cellular networks that support both 4G and 5G technologies. Dual-band antennas offer increased flexibility and versatility in comparison to single-band antennas, as they have the capability to operate over a broader spectrum of frequencies [1-4]. This allows a solitary antenna to carry out numerous distinct jobs.

Dual-band antennas provide a notable advantage by allowing the simultaneous use of many applications without the need for separate equipment. This feature aids in reducing system intricacy and expenses. Furthermore, this flexibility allows for the most efficient use of space, making dual-band antennas very appropriate for compact systems with little physical space. However, the addition of more features can lead to increased complexity in both the design and production processes, often resulting in larger physical dimensions and a greater need for precise tuning and impedance matching. Dual-band antennas may experience a decrease in performance due to their inherent complexity, resulting in lower gain and efficiency compared to single-band antennas [5] [6].

Recent research in the field of dual-band antennas has focused on improving efficiency while simultaneously reducing size and complexity [7] [8]. Studies have examined many categories of antennas, such as microstrip patch antennas and dipole antennas, as well as innovative materials and design techniques to enhance bandwidth and gain [9-11]. Ongoing endeavors are being undertaken to improve the design and efficiency of dual-band antennas, with a particular focus on achieving outstanding performance across both frequency bands while maintaining a compact and efficient size. The importance of dual-band antennas in contemporary wireless communication systems and the ongoing endeavors to overcome their inherent challenges are further exemplified by these achievements.

In response to this difficulty, this study introduces an innovative dual band antenna that is specifically engineered for Wi-Fi and 5G communication. The antenna is capable of efficient operation at both 2.4GHz for Wi-Fi and 3.5GHz for 5G connectivity. The suggested antenna design, with dual-band operating frequencies, represents a significant advancement in antenna technology as it enables simultaneous operation at several frequency bands. This enables a solitary antenna to perform many roles, which is advantageous for applications that want concurrent communication across various frequencies. The concept demonstrates the ability to operate at several frequencies with a single antenna, making it suitable for versatile and adjustable communication systems.

The inclusion of dual-band capabilities decreases the level of complexity and cost associated with the system. The utilization of a solitary antenna for several working frequencies streamlines the system architecture. Reducing the number of hardware components decreases both manufacturing and maintenance expenses, as well as the required area for antenna installation. Compactness and integration are crucial in mobile devices, IoT systems, and contemporary communication infrastructures. The use of a dual-band antenna has the potential to decrease the overall dimensions and mass of a system, which is of utmost importance in airplane and vehicle applications, where even the slightest reduction in weight and volume is significant. This design streamlines communication networks by consolidating multiple antennas into a single unit. The ability to function at several frequencies with a single antenna enables a wide range of applications. This adaptability may be harnessed in sophisticated wireless networks, satellite communications, and multi-frequency radar systems. The suggested antenna enhances communication solutions for many sectors and technology by enabling several working frequencies, making it more adaptable and cost-effective.

2. Antenna Design

The patch antenna design method utilized Computer Simulation Technology (CST) software, a robust simulation tool capable of precisely evaluating high-frequency devices like antennas and filters. The software provides a range of solvers, such as the Time Domain and Frequency Domain solver, which allow for the study of parameters given in Table 1 and the execution of simulations with accuracy and efficiency.

Table 1 *Specifications of patch antenna*

Antenna parameters	Value
Resonant frequency	2.4 GHz and 3.5GHz
Return loss	<-10dB
Dielectric constant	4.3
Feeding point	Microstrip line

Choosing the patch shape was a critical stage in the process of designing the patch antenna. For this instance, a rectangular patch shape was selected, with copper as the chosen material. The selection of copper was based on the anticipation of potential losses that may arise during the fabrication process. Subsequently, mathematical analysis was utilized to ascertain the suitable width and length measurements for the patch. Subsequently, the dimensions for the substrate and ground of the antenna were determined to be 80mm in width and 60mm in length. The dimensions were established to ensure ample room for altering the antenna's length, as modifications to the patch or ground can impact the resonant frequency observed in the S11 graph. The ground plane, which is a complete ground plane, acts as a reflector for radio waves.

Using an inset feed approach improves the antenna's bandwidth and S11 characteristics. The overall enhancement of the S11 parameter is achieved by enhancing the impedance matching using the inset feed.

Parametric research was undertaken to identify the ideal length of the inset feed that produces favorable S11 performance.

Slots on a patch antenna are defined as small apertures or discontinuities in the metallic patch. The slots on the patch are of different shapes and sizes and are purposefully positioned to improve the performance of the antenna. Introducing slots alters the distribution of the electromagnetic field and the radiation properties of the antenna. An investigation was carried out to find the ideal dimensions of the slot that would result in good S11 parameters, using a parametric study. The completed design of the antenna showcases a rectangle patch with an embedded feed and a rectangular slot, as illustrated in Figure 1. The dimensions employed for the patch antenna are outlined in Table 2.

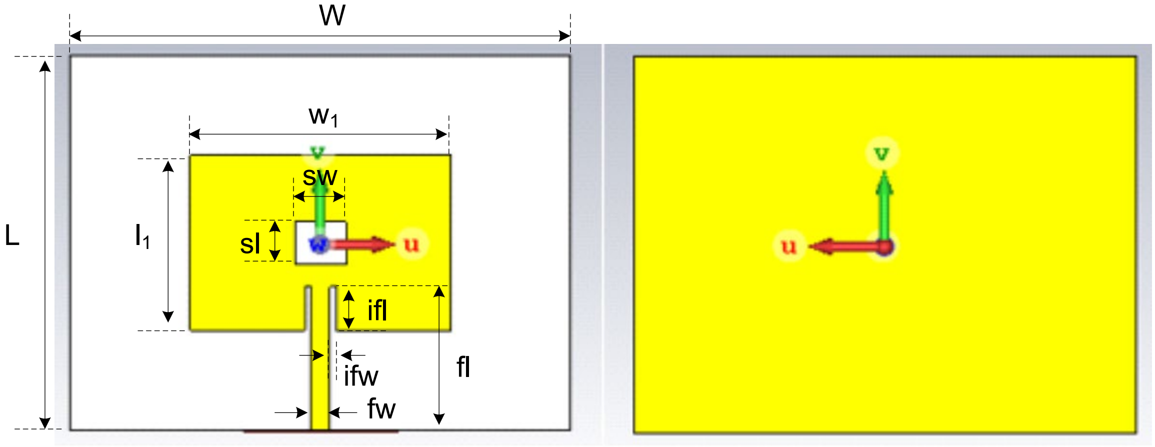


Fig. 1 *Patch antenna front and back view*

Table 2 *Dimensions of patch antenna*

Parameter	Design Value
Patch Width, w1	41.8mm
Patch Length, l1	28mm
Ground Width, W	80mm
Ground Length, L	60mm
Feedline Width, fw	3.05mm
Feedline Length, fl	16.29mm
Copper Thickness	0.035mm
FR-4 Thickness	1.6mm
Insed Feed Width, ifw	1mm
Insed Feed Length, ifl	7mm
Slot Width, sw	8.1mm
Slot Length, sl	6.7mm

3. Results And Discussion

This section will provide a comprehensive analysis of the acquired data, which encompass the S-parameters, gain, directivity, and radiation pattern. The completed design of the antenna, depicted in Figure 1, exhibits resonance at frequencies of 2.4GHz and 3.5GHz. The S11 parameter, often known as the return loss, is a critical metric for assessing the efficiency of an antenna. It measures the amount of power that is reflected back from the antenna rather than being transmitted. The S11 parameter results, shown in Figure 2, demonstrate the resonant frequencies of the antenna at 2.4 GHz and 3.5 GHz. The simulation results indicate a return loss of -19.498 dB at 2.4 GHz and -26.151 dB at 3.5 GHz, indicating a high-quality signal transmission with minimal power loss. The results confirm the effective functionality of the antenna in a dual-band configuration, with negligible interference from signals of varying frequencies. The S11 values at both resonant frequencies are less than -10 dB, showing that the antenna is well optimized for dual-band operation. In addition, it is clear that there is minimal signal interception at frequencies other than the stated ones, as indicated by the S11 values approaching zero. This indicates that the antenna does not resonate or reflect significant power beyond its specified frequency ranges.

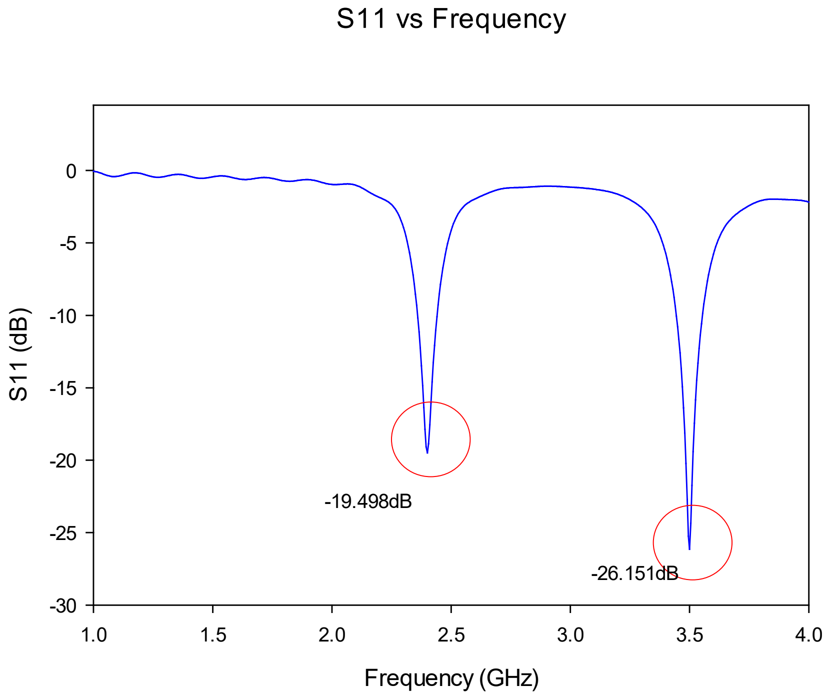


Fig. 2 *Simulated S11 of designed antenna*

Figure 3 and Figure 4 illustrate the behavior of electromagnetic fields at a distance from their source, providing vital insights into the propagation characteristics of the system. The images demonstrate a consistent arrangement of field distribution as the waves move away from the source. The comprehension of the scope and effectiveness of electromagnetic transmission is highly dependent on this phenomenon.

At the precise frequency of 2.4 GHz, the simulated gain is calculated to be 2.698 dB, indicating a moderate level of signal amplification in the desired direction. Similarly, when the frequency is set at 3.5 GHz, the gain decreases somewhat to 1.359 dB, suggesting that the signal experiences less amplification at this specific frequency.

Directivity, a crucial characteristic of antennas, refers to the extent to which radiated radiation is concentrated in a specific direction. The antenna exhibits a directivity of 6.913 dBi at a frequency of 2.4 GHz, and a slightly lower directivity of 6.304 dBi at a frequency of 3.5 GHz. At both frequencies, the antenna has a tendency to focus energy in a specific region, which can be advantageous for accurate signal transmission or reception.

Furthermore, the antenna's emission pattern is concentrated inside a 90-degree sector directed towards the patch. The pattern demonstrates that the antenna exhibits a pronounced directionality, focusing its energy inside a restricted angle. This attribute is beneficial in circumstances that require focused transmission. The amalgamation of these elements and statistics yields a comprehensive understanding of the antenna's performance and its suitability for various applications.

The efficiency of the antenna, which is a measure of its overall effectiveness, was simulated using the farfield monitor in CST. The simulated gain at a frequency of 2.4GHz is 2.698 decibels, while at a frequency of 3.5GHz is 1.359 decibels. The directivity at a frequency of 2.4GHz is 6.913dBi, and at a frequency of 3.5GHz is 6.304dBi, as depicted in Figures 3 to 4. The details of these factors are presented in Table 3. Furthermore, Figures 3 to Figure 7 depict the radiation pattern specifically at phi = 0°, 90°, and theta = 90°.

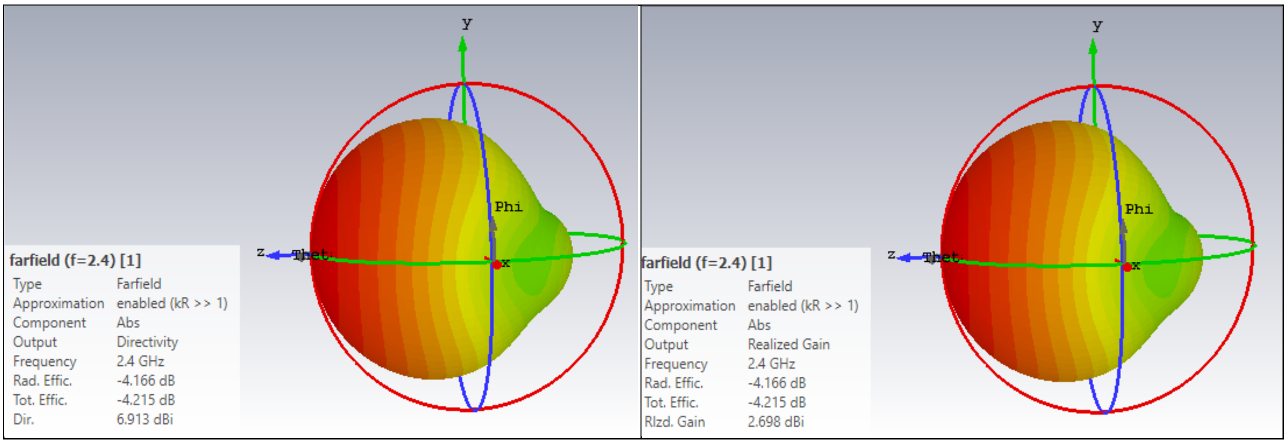


Fig. 3 *Farfield monitor of antenna at 2.4GHz*

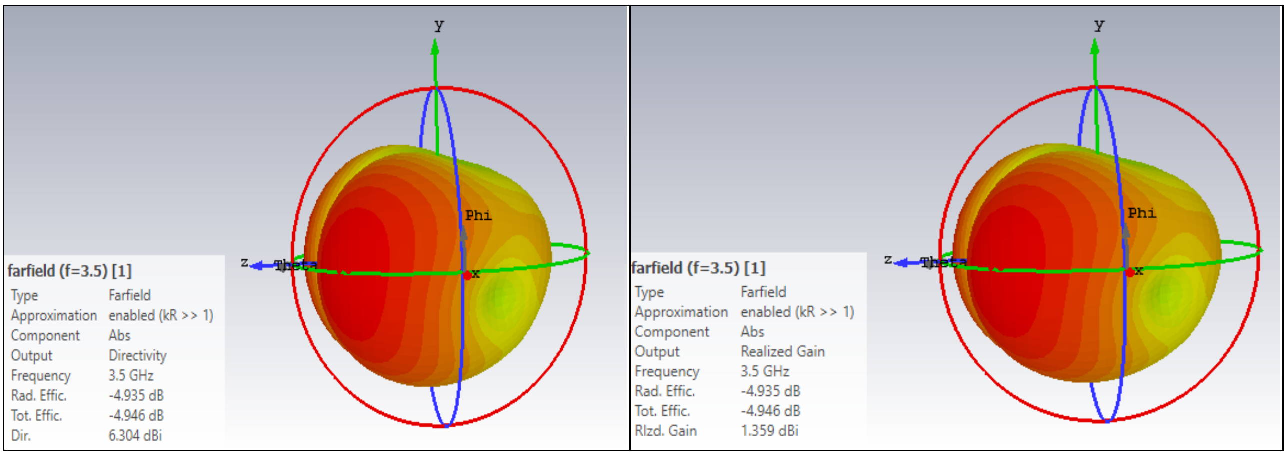
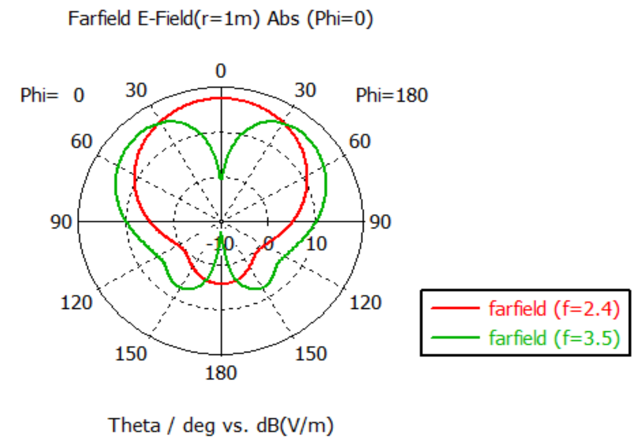


Fig. 4 *Farfield monitor of antenna at 3.5GHz*

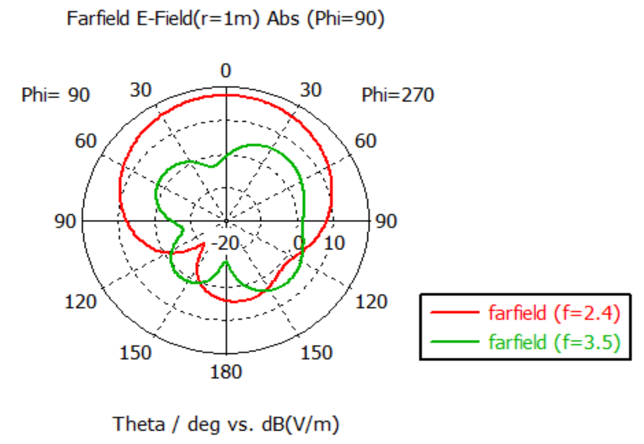
Table 3 *Summary of simulated parameters*

Frequency (GHz)	S_{11}/dB	Gain/dB	Directivity/dBi
2.4	-19.498	2.698	6.913
3.5	-26.151	1.359	6.304

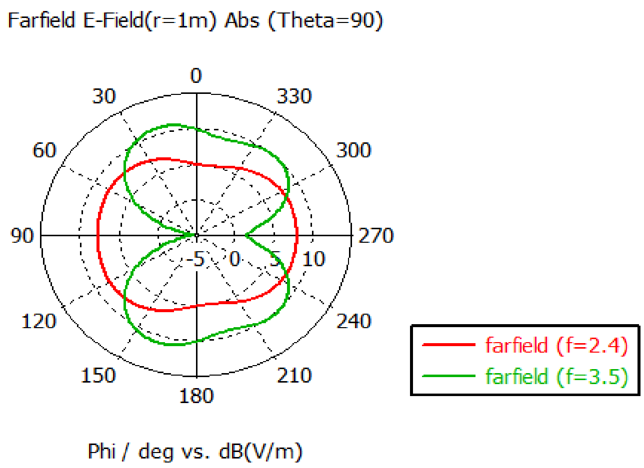
Figure 5 shows the radiation patterns at specific angular positions: phi = 0°, phi = 90°, and theta = 90°. Studying these patterns is crucial for understanding how the antenna distributes its radiated power and identifies its most efficient orientations. The patterns demonstrate that the primary lobe, which signifies the primary route of radiation, is oriented in the desired direction, precisely perpendicular to the surface of the patch antenna at a 90-degree angle. The positioning of the antenna indicates that it is specifically designed to emit its energy in a directed manner from its frontal surface, making it suitable for applications that require a clear and concentrated signal in a certain direction.



(a)



(b)



(c)

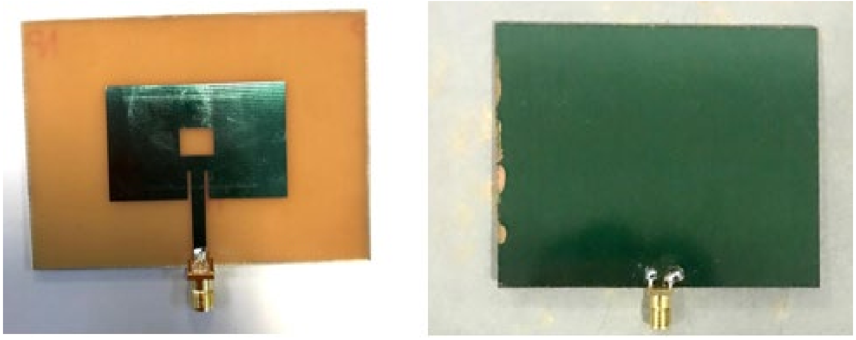
Fig. 5 *Radiation pattern of the antenna at (a) Phi=0°, (b) Phi=90°, (c) Theta=90°*

One interesting observation is the presence of posterior lobes in these radiation patterns. A rear lobe refers to the emission of radiation in the opposite direction of the main lobe, typically indicating the undesired release of energy. The existence of a posterior lobe in these illustrations suggests that the amount of radiation radiated from the back is insignificant. This aids in reducing any possible interference or signal degradation caused by backscatter. This characteristic is advantageous in scenarios when the primary focus is on one-way communication, thereby reducing the emission of unwanted radiation behind the antenna.

The efficacy of this antenna design is demonstrated by its optimal functionality across a specified range of angles, specifically spanning from 20 degrees to 160 degrees relative to the surface. The antenna effectively covers a wide field of vision while maintaining a strong focus in the forward direction, as demonstrated by its broad range of effectiveness. This feature is particularly useful in scenarios when there is a requirement for broad coverage, yet it is crucial to have a concentrated signal in a specific direction for the intended purpose, such as in directional communication systems or targeted wireless networks.

Upon achieving favorable simulation outcomes for the microstrip patch antenna, the design was exported from CST (Computer Simulation Technology), a renowned electromagnetic modeling software. Afterwards, the design was prepared for manufacturing on a FR-4 substrate, which is commonly utilized for printed circuit boards due to its versatility, cost-efficiency, and advantageous dielectric properties. Figure 6 visually illustrates the constructed antenna, displaying its design and general layout based on the produced simulation data.

Following the fabrication procedure, the next step entailed verifying the performance of the antenna through a series of measurements. A specialized testing setup was devised to assess the antenna's amplification and focus, as depicted in Figure 7. Usually, this setup involves utilizing a test chamber or a controlled environment to minimize any external disturbances, thus ensuring accurate measurements. The equipment used in this technique often includes network analyzers, power meters, and antenna measuring software to precisely measure and evaluate various aspects such as gain, directivity, and radiation pattern.



(a) **(b)**

Fig. 6 *Fabricated microstrip patch antenna (a) front; (b) back view*

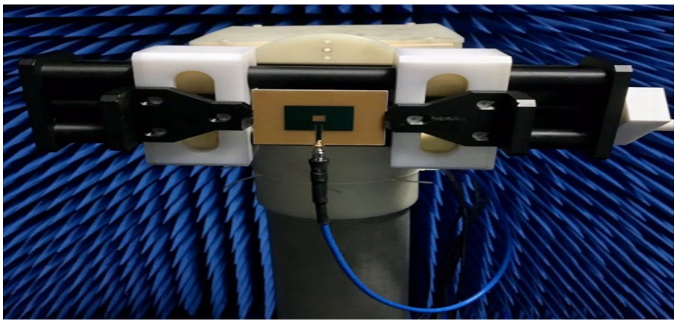


Fig. 7 *Gain and directivity measurement*

Figure 8 illustrates the S11 parameter obtained from the observed data using a Vector Network Analyzer (VNA), enabling a direct comparison with the simulated findings. The data demonstrates a similar pattern with minimal inconsistencies, indicating a high level of concurrence between the simulation and real observations. The return loss was measured to be -12.012 dB at a frequency of 2.4 GHz and -17.537 dB at a frequency of 3.5 GHz. The difference in return loss between the simulation and measurement is -7.486 dB at 2.4 GHz and -8.614 dB at 3.5 GHz. These mistakes usually occur within acceptable limits, considering the natural variability in experimental setups and environmental variables.

According to the simulation results, the bandwidth is 96 kHz when the frequency is 2.4 GHz and 75 kHz when the frequency is 3.5 GHz. The measurements reveal a bandwidth of 95 kHz at a frequency of 2.4 GHz and a bandwidth of 70 kHz at a frequency of 3.5 GHz. The disparities in bandwidth between the simulation and measurement are 1 kHz for 2.4 GHz and 5 kHz for 3.5 GHz, which are rather small, suggesting the accuracy of the simulation models.

Figures 9 and 10 illustrate the antenna's amplification and directional characteristics across a broad frequency spectrum, ranging from 1 GHz to 4 GHz. As the frequency rises, the gain also rises. This is due to the fact that higher frequencies frequently result in more focused radiation and increased amplification in antennas. The antenna's directivity demonstrates fluctuations, ranging from a minimum of 2.8 dBi to a maximum of 8.4 dBi, demonstrating variability in its capacity to direct power. The directivity values at the resonant frequencies are significantly beneficial, with a measurement of 7.4 dBi at 2.4 GHz and 5.4 dBi at 3.5 GHz. These scores demonstrate a notable degree of focus and efficiency within these particular frequency ranges. To summarize, the observed patterns and outcomes indicate that the antenna functions well when utilized in a dual-band configuration, delivering consistent amplification and focused signal direction within its specified frequency ranges.

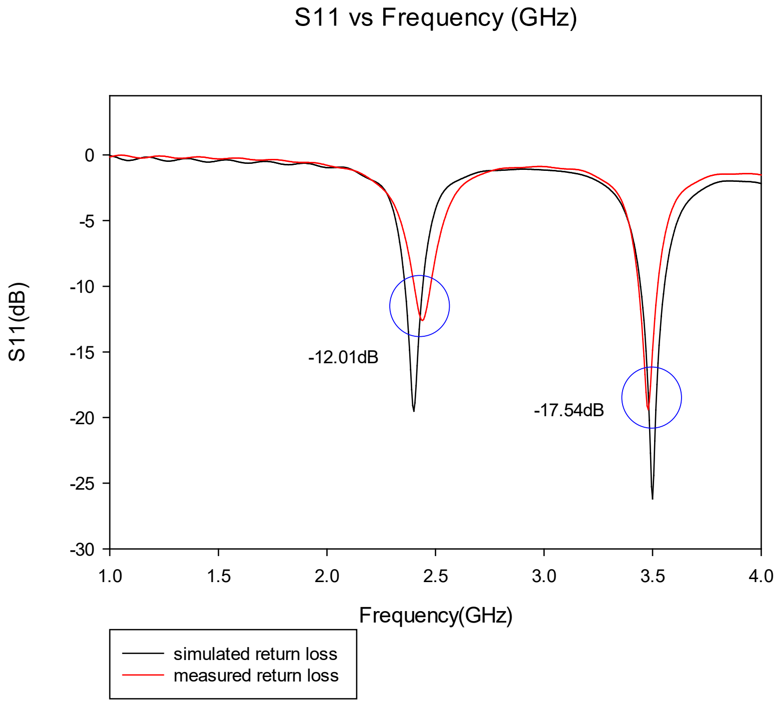


Fig. 8 *Comparison of S11 between simulation and measured*

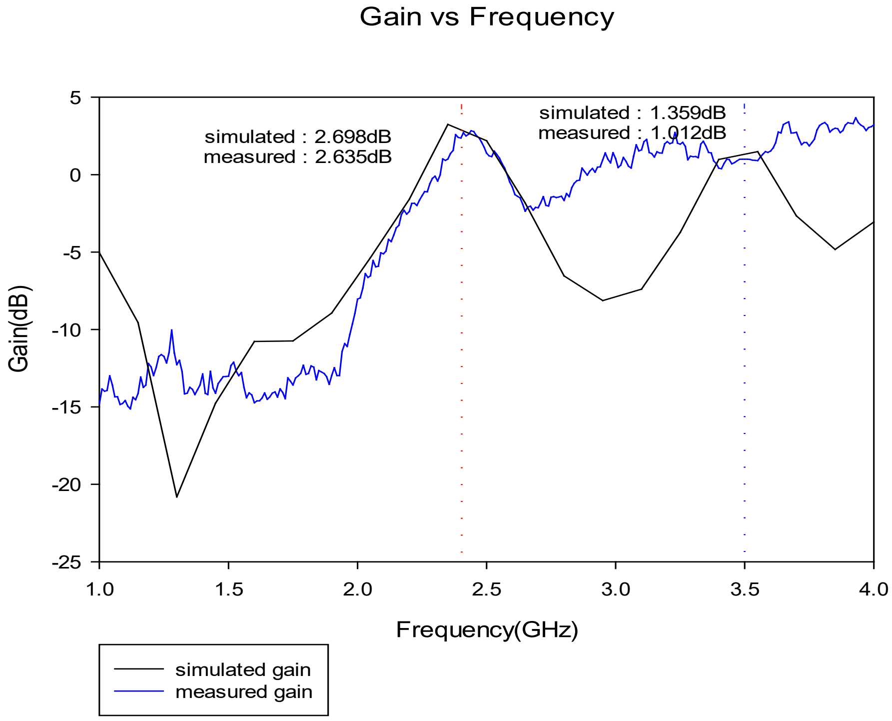


Fig. 9 *Comparison of gain between simulation and measured*

Table 4 *Gain measurement*

Frequency (GHz)	Gain/dB
2.4	2.635
3.5	1.012

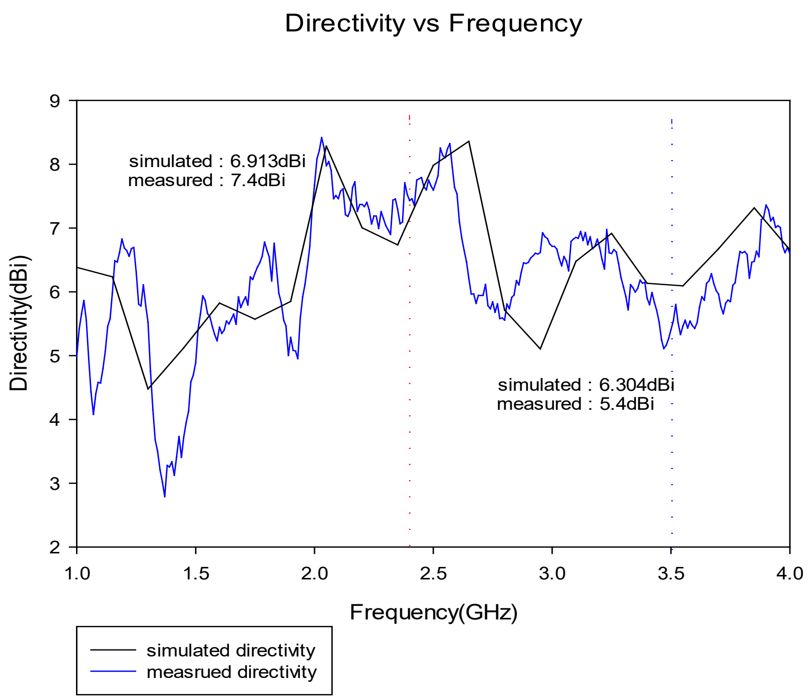


Fig. 10 *Measured directivity*

Table 5 *Directivity measurement*

Frequency (GHz)	Directivity/dBi
2.4	7.403
3.5	5.404

Table 6 *Comparison between parameters of measurements and simulations*

Resonance Frequency (GHz)	Type of results	S_{11} (dB)	Gain (dB)	Directivity (dBi)
2.4	Simulation	-19.498	2.698	6.913
	Measurement	-12.012	2.365	7.403
3.5	Simulation	-26.151	1.359	6.304
	Measurement	-17.537	1.012	5.404

Upon conducting a thorough investigation into the correlation between the S11 parameter derived from the simulation and the measured outcomes depicted in Figure 10, it is apparent that the two datasets bear a striking similarity, with the exception of a decline in the measured S11 parameter specifically at the resonant frequency. Furthermore, the simulated antenna exhibits superior performance in terms of return loss and gain in comparison to the manufactured antenna. Given its lightweight structure and compact size, this device has the potential to be used in 5G applications provided improvements are made to enhance its gain and efficiency.

4. Conclusion

To summarize, the dual-band antenna has been specifically engineered to vibrate at both the 2.4 GHz and 3.5 GHz frequencies. This feature enables its efficient utilization in Wi-Fi and 5G wireless communication applications. The antenna has a gain of 2.365dB and 1.012dB at frequencies of 2.4GHz and 3.5GHz, respectively. While a 2 dB or 1 dB increase may be adequate for specific uses such as short-range communication, indoor wireless networks, or applications that necessitate a broad radiation pattern, it may prove insufficient for long-range communication, scenarios that demand focused signals, or environments with substantial interference. In order to determine the appropriateness of these gain values, it is essential to evaluate the application environment and the overall system requirements. This study showcases the practicability of constructing a dual-band patch antenna. Future efforts will focus on conducting further research to enhance the antenna's gain and integrate circular polarization capabilities, hence enhancing its versatility and performance.

Acknowledgement

The authors would like to acknowledge the Ministry of Higher Education, Centre for Research and Innovation Management (CRIM), Fakulti Teknologi dan Kejuruteraan Elektronik dan Komputer (FTKEK) and Universiti Teknikal Malaysia Melaka for financing this project.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Maizatul Alice Meor Said, Mohamad Harris Misran;* ***data collection:*** *Mohd Azlishah Othman;* ***analysis and interpretation of results:*** *Abd Shukur Jaafar, Redzuan Abd Manap;* ***draft manuscript preparation:*** *Shadia Suhaimi, Nurmala Irdawaty Hassan. All authors reviewed the results and approved the final version of the manuscript.*

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