RESEARCH & INNOVATION DIVISION
IJIST

Low Aperture High Gain Antenna for Wi-Fi Applications

Muhammad Nasir[1], Muhammad Akram[1], Ali Hussain[1], Muhammad Hanzala[1], Muhammad Awais[1], Faisal Zia[2]

[1]University of Engineering and Technology Lahore Faisalabad Campus

[2]Nayatel Private Limited Sheikhupura Road Faisalabad

[*]**Correspondence:** Muhammad.nasir@uet.edu.pk

Citation | Nasir. M, Akram. M, Hussain. A, Hanzala. M, Awais. M, Zia. F, "Low Aperture High Gain Antenna for Wi-Fi Applications", IJIST, Special Issue. pp 14-21, Oct 2024

Received | Oct 02, 2024 **Revised |** Oct 06, 2024 **Accepted |** Oct 09, 2024 **Published |** Oct 16, 2024.

This article proposes a design for a low-aperture, high-gain antenna specifically tailored for Wi-Fi applications. This project aims to enhance the performance of Wi-Fi networks by increasing signal strength and coverage area. Conventional dielectric rod antennas face three main challenges: first, they typically have low gain and excessive length; second, they exhibit high side lobe levels; and third, as the antenna length increases, side lobe levels also rise alongside gain. The proposed antenna structure effectively addresses these issues. The novelty of the proposed antenna lies in its ability to achieve greater gain at the same length compared to conventional antennas while maintaining low side lobe levels that do not increase with antenna length. The proposed design features a Yagi-Uda configuration on a printed circuit board (PCB) made from FR4 epoxy with a dielectric constant of 4.4, combined with a tapering dielectric Teflon rod with a dielectric constant of 2.1. The antenna was simulated using HFSS software, fabricated, and then tested to compare simulated and experimental results, which indicate that the proposed structure primarily operates at a frequency of 5 GHz. It achieves performance within the frequency band of 4.8–5.3 GHz, with a fractional bandwidth of 10%. At these frequencies, the structure provides a directivity of 16.4 dBi. A comparison of results demonstrates that the presented antenna outperforms traditional antennas in the same class, making it suitable for Wi-Fi, WLAN, and satellite applications. This revision enhances clarity, coherence, and overall readability while preserving the original intent and details.

Keywords: Yagi Uda Antenna; Wi-Fi/WiMAX; Dielectric Antenna; Front to Back Ratio; Gain of Antenna.

Introduction:

Antennas are critical components in wireless communication systems. Common types include patch antennas, slot antennas, reflector antennas, helical antennas, Yagi-Uda antennas, and dielectric rod antennas. Each antenna possesses specific properties and applications. Helical, Yagi-Uda and dielectric rod antennas are particularly renowned for their high gain, with the gain being directly proportional to their length [1][2][3]. The Yagi-Uda receiver, also known as the Yagi-Uda wire, is a popular choice in mobile communication systems due to its appealing planar and directional structure, which contributes to its effective radiation pattern.

The Yagi-Uda antenna is a sophisticated combination of elements including driven elements, reflectors, and directors, providing significant advantages across various applications. Different Yagi-Uda antennas cater to diverse requirements in various fields, showcasing their versatility. In communication domains such as transmission, TV broadcasting, Wi-Fi networks, and early wireless systems, the Yagi-Uda antenna's high gain and directional efficiencies make it a preferred choice. Additionally, the Yagi-Uda antenna is utilized in satellite communication structures, delivering reliable and focused signal transmission to specific satellites. The military relies on Yagi-Uda antennas for their directional attributes and strength, which are essential for establishing secure and reliable communication links.

Aerospace manufacturing also incorporates Yagi-Uda antennas in spacecraft for communication with ground stations, ensuring reliable data transmission. The advantages of the Yagi-Uda antenna stem from its compact size, cost-effectiveness, and ability to transmit high gain with a directional radiation pattern. Its adaptability to various frequency bands further enhances its appeal for different communication applications [4].

The exceptional directivity of the Yagi-Uda array is a result of the constructive interference patterns created by the individual Yagi elements, which reinforce signals in the desired direction while suppressing radiation in unwanted directions [5]. Several researchers have focused on enhancing the gain of these antennas [6][7][8][9]. Microstrip Yagi antennas are popular due to their planar structure, while dielectric antennas are recognized for their high gain. However, their gains remain limited when used in WLAN, Wi-Fi, and WiMAX applications [13][14][15][16].

In this paper, we introduce a novel type of antenna designed for Wi-Fi applications, which features a printed Yagi antenna as the primary feeding element operating at 5 GHz. The gain of this Yagi antenna is enhanced through dielectric loading, achieved by placing a hollow dielectric rod around the printed Yagi. Results indicate that this method nearly doubles the gain. This paper is structured into three sections: Section 1 discusses the simulation and theoretical background, Section 2 presents the results and discussion, and Section 3 concludes with final remarks.

This revision improves clarity, structure, and overall readability while maintaining the original intent and details.

Objectives:

The primary objective of the proposed antenna is to enhance its gain, thereby improving network performance, coverage, and signal reliability compared to other antennas in the same class. Additionally, suppressing side lobe levels is a key aspect of this objective.

Novelty:

The novelty of the antenna is outlined below:

- The proposed antenna exhibits a gain that surpasses other antennas in the same class for a specific electrical length.
- A novel technique is introduced to enhance the antenna's gain without increasing its physical length.

- The antenna features a compact and low-profile design, making it suitable for Wi-Fi applications. Additionally, the gain can be further increased by lengthening the dielectric rod, which adds versatility to its application.
- This method also effectively reduces side lobe levels.

Simulation and Theoretical Background:

The proposed antenna comprises two components: the Yagi antenna and the dielectric rod antenna, as illustrated in Figures 1 and 2, respectively. The Yagi antenna is designed using HFSS software for a frequency of 5 GHz. In the final simulation, the Yagi features 16 directors spaced at $\lambda/4$ intervals, while the length of the active element is set to $\lambda/2$. Additionally, a circular metal reflector optimized at $\lambda/4$ is positioned at the bottom side. The simulated gain of this antenna is approximately 13 dBi, as shown in the results presented in Figure 5.

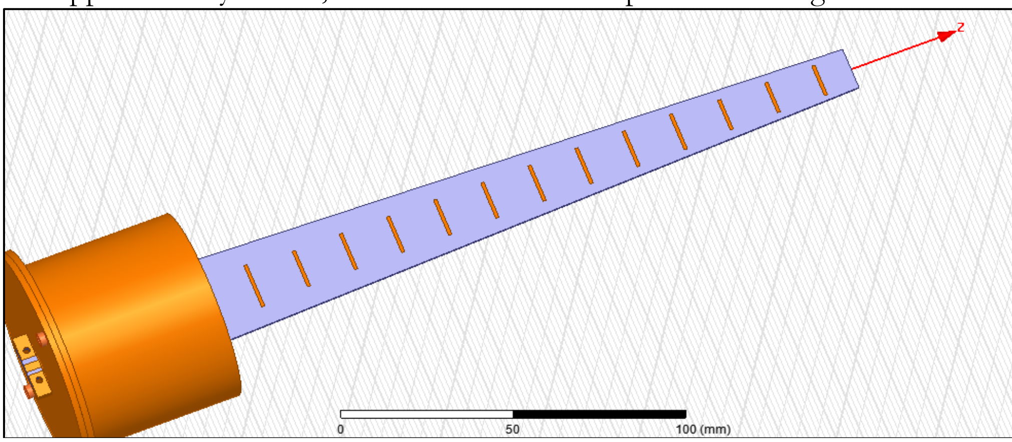


Figure 1. It explains the simulated picture of the first part Yagi antenna

Figure 2 illustrates the antenna's second component, the dielectric rod. The dielectric rod and the Yagi substrate have relative permittivities of $\varepsilon_{r2} = 2.1$ and $\varepsilon_{r1} = 2.55$, respectively. The final optimized dimensions of the dielectric rod are detailed in Figure 2. The theoretical gain of the dielectric rod will be calculated using Equation 1, as discussed in [10].

$$\text{Gain} = 8L / \lambda_{eff} \quad (1)$$

"where $\lambda_{eff} = \lambda 0 / \sqrt{\varepsilon e}$"

Where \(L\) is the length of the rod, and \(\varepsilon_e\) is the effective dielectric constant of the entire antenna structure. \(\lambda_0\) represents the wavelength in free space, while \(\lambda_{\text{eff}}\) denotes the effective wavelength in the final configuration. The electrical length of the structure increases due to the dielectric loading of the printed Yagi antenna. The directors of the Yagi antenna function as extended feeding elements within the long dielectric rod, which helps suppress side lobe levels and enhance the gain of the overall structure. Due to the small thickness of the dielectric cover, the main dominant frequency of the structure is primarily determined by the active feeding element of the Yagi, as illustrated in Figure 4(b). Table 1 outlines the final optimized dimension parameters of the antenna, which were optimized using HFSS software.

Table 1. This table describes the dimensions parameters of the dielectric rod

Description	Length(mm)	Description	Length(mm)
L1	50	D2	28
L2	245	d1	51
L3	55	d2	22
D	57	TL	306

To begin using HFSS, click on the HFSS software icon. Then, select "A Soft HFSS" from the options that appear. This action will open the main window for the high-frequency software. Next, generate the project by executing or debugging the HFSS simulator. To start working with drawings or shapes, you need to add HFSS files. You can do this by right-clicking on the file and selecting "Insert" and then "Insert HFSS." In HFSS, you can specify a range of values with a fixed step, which facilitates convenient optimization of designs. The next step in the design process is to click on HFSS and select design properties. This will display a variable table where all variables with units in millimeters can be properly added using the "Add" option.

Now, you can draw the 3D model of the dielectric rod antenna by clicking the "Draw Box" button for the ground plate and specifying the required thickness. Once the drawing of the object is complete, the properties dialog can be viewed on the screen. The size and position of the object can be adjusted using this dialog box. Finally, excitations are described in different ways, with electromagnetic fields generated by currents, charges, and voltages on the surfaces of the objects. By following these steps, a final model is designed, and various materials are selected and tested for optimal performance, as discussed in the results.

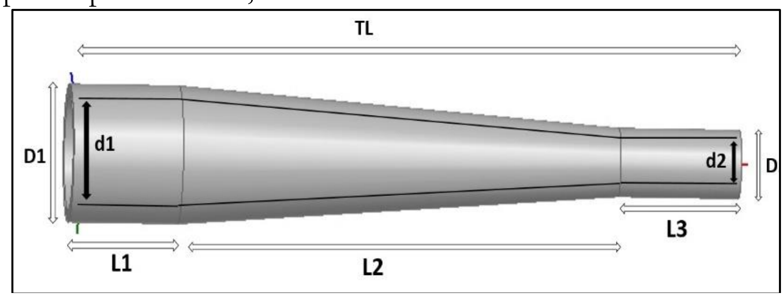


Figure 2. Description of the dielectric part of the antenna

Results and Discussion:

In this section, various materials are utilized and compared to determine which one yields the highest gain when operating at a frequency of 5 GHz. We will conduct this comparison using software to analyze and evaluate their performance. In Figure 3, we present two graphs generated using HFSS software. We assessed the gain with and without dielectric materials, specifically using Teflon as the dielectric. This analysis was conducted through experimentation, and the resulting graphs were thoroughly examined. The PCB material used is FR4 epoxy, which has a relative permittivity of 4.4.

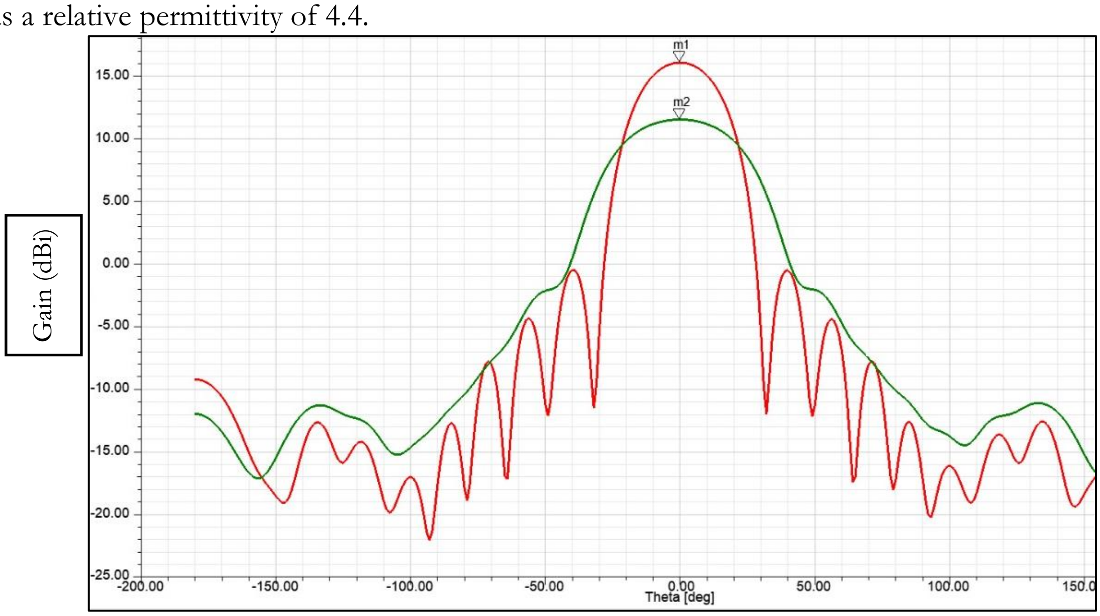
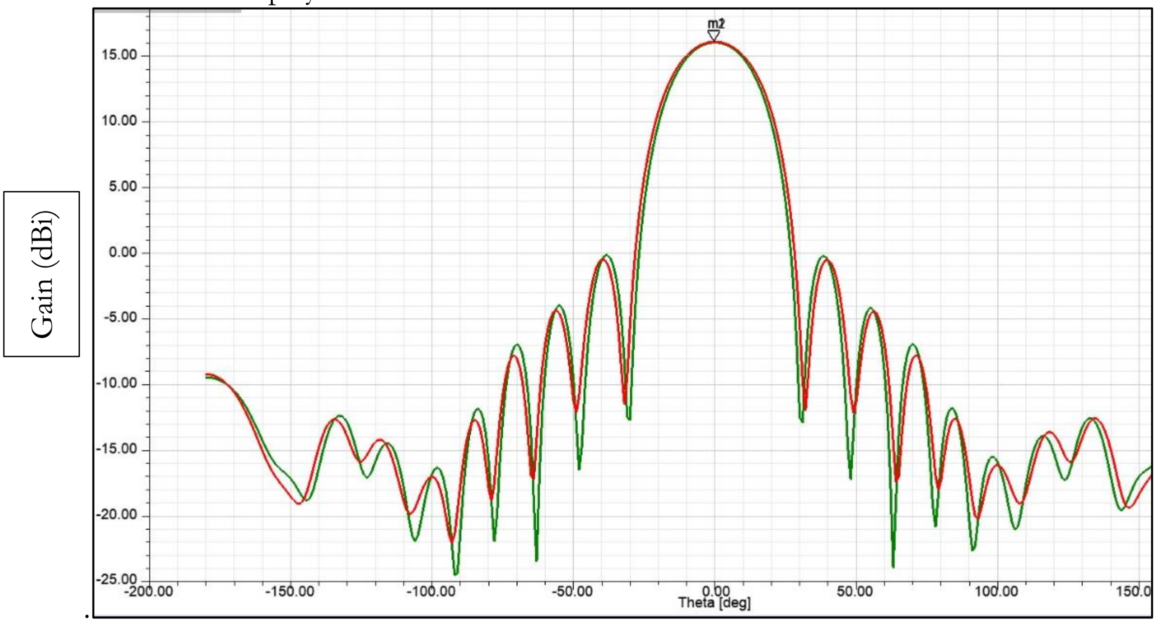


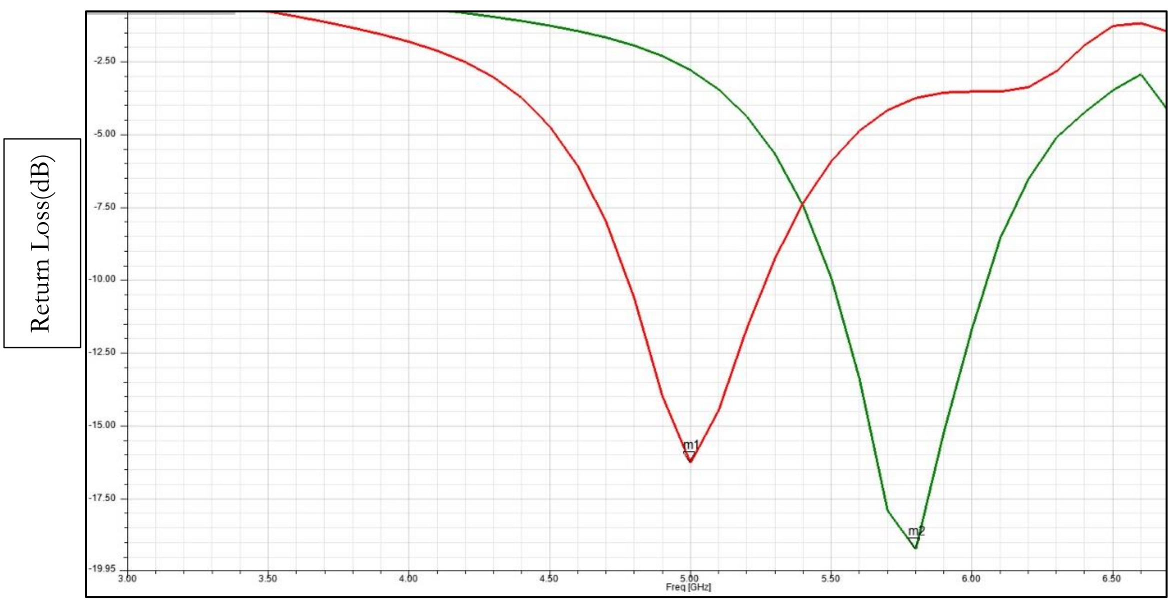
Figure 3. Gain a comparison of alone Yagi and hybrid antenna

The horizontal axis represents angle theta, while the vertical axis indicates gain in dBi. The green line represents the scenario without the dielectric cover, whereas the red line depicts the scenario with the dielectric cover on the Yagi antenna. This analysis demonstrates that the gain increases with the addition of the dielectric material on the Yagi antenna.

In Figure 4(a), we modified the PCB material and compared its gain characteristics. In Figure 4(b), we present a comparison of the frequency characteristics. The FR4 epoxy, represented by the red line, has a relative permittivity of 4.4, while the FBR, depicted by the green line, has a relative permittivity of 2.55. We will analyze whether the frequency dependency primarily relates to the relative permittivity of the PCB material or if other material characteristics also play a crucial role.



(a)



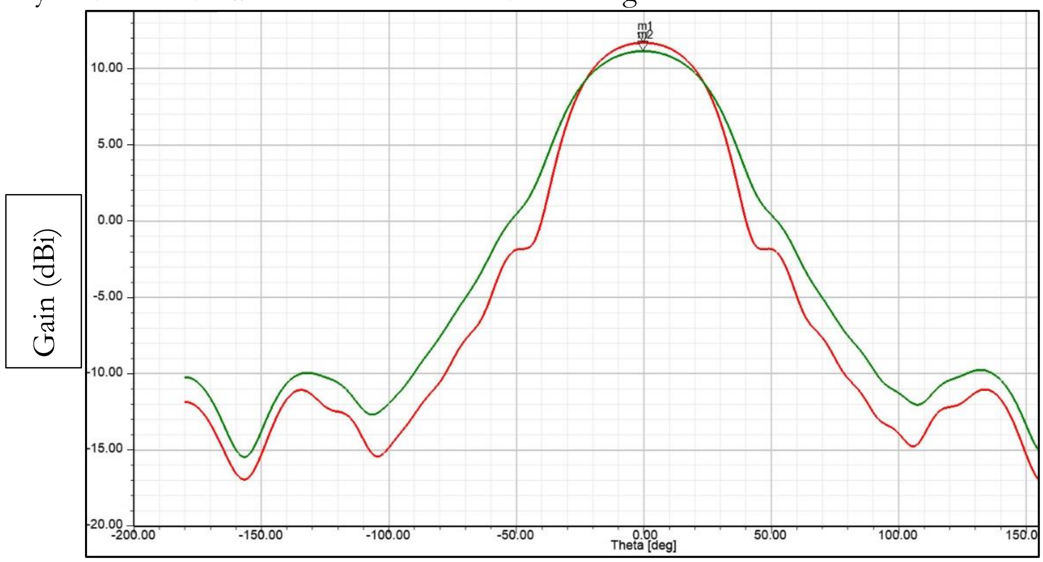
(b)

Figure 4. (a) Gain comparison with different materials of Yagi PCB like FR4 Epoxy (4.4) and FBR (2.55) (b) Frequency comparison with different materials of Yagi PCB like FR4 Epoxy (4.4) and FBR

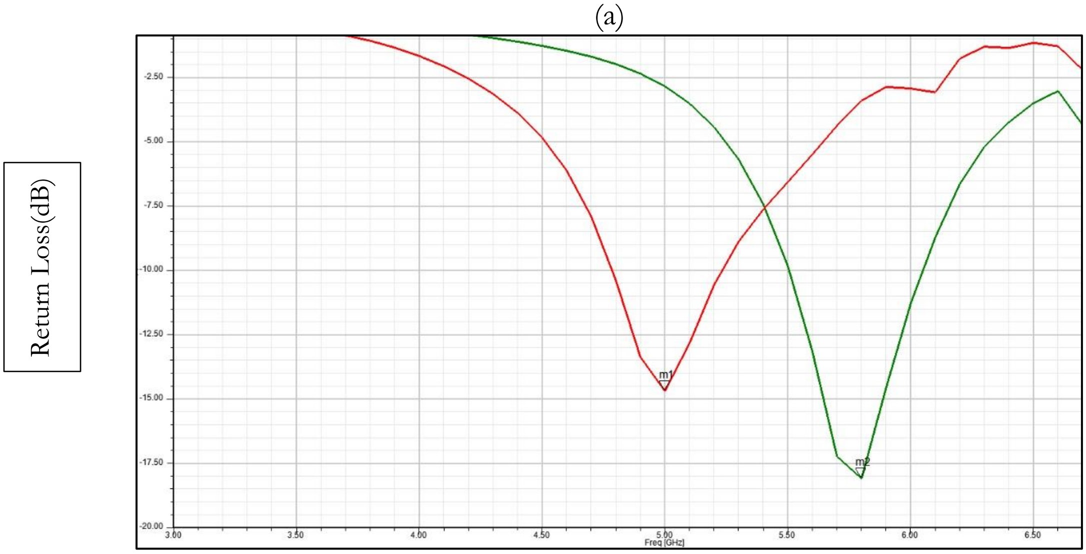
This antenna achieves a gain of 16.09 dB, as discussed in Figure 4(a). The frequency achieved with FR4 epoxy is precisely 5 GHz, with a minimum S11 value of -16.25 dB. In contrast, the frequency with FBR is 5.8 GHz, with an S11 of -19.21 dB, as shown in Figure 4(b).

In Figure 5, we analyze without using dielectric material. Our focus is on modifying the PCB material and examining its gain characteristics. Subsequently, we will explore its frequency characteristics. Specifically, we'll compare FR4 epoxy, which has a relative permittivity of 4.4 (indicated by the red line), with FBR, which has a relative permittivity of 2.55 (represented by the green line).

In Figure 6, we discuss the simulated 3D radiation pattern, where low side lobe levels and a high main lobe gain of approximately 16 dBi can be observed. Our objective is to ascertain whether the primary dependency lies solely on relative permittivity or if other material properties also exert a significant influence on the outcomes. It is important to note that materials sharing identical relative permittivity values may still exhibit distinct gain and frequency responses due to their unique material characteristics. In this analysis, a gain of 11.68 dB is achieved with FR4 epoxy and 11.18 dB with FBR for the standalone Yagi antenna.



(a)



(b)

Figure 5. (a) Gain and radiation comparison of alone Yagi antenna with PCB FR4 Epoxy and PCB FBR 2.55(b)Frequency response of Printed Yagi alone with PCB FR4 Epoxy and PCB FBR 2.55

In comparison, Table 2 demonstrates that the proposed antenna achieves superior gain with specific dimensions. In other words, the proposed antenna can attain the same gain with smaller dimensions.

Table 2. Reference table for improvement comparison

Description	Dimension (λ^2)	Gain (dB)	Side lobe-level (dB)
[This Work]	5.8 λ *0.8 λ	16.25	-18
[12]	6λ *0.83 λ	15	-20
[11]	8 λ *4.5 λ	11	-25
[10]	1 λ *0.6 λ	9	-7

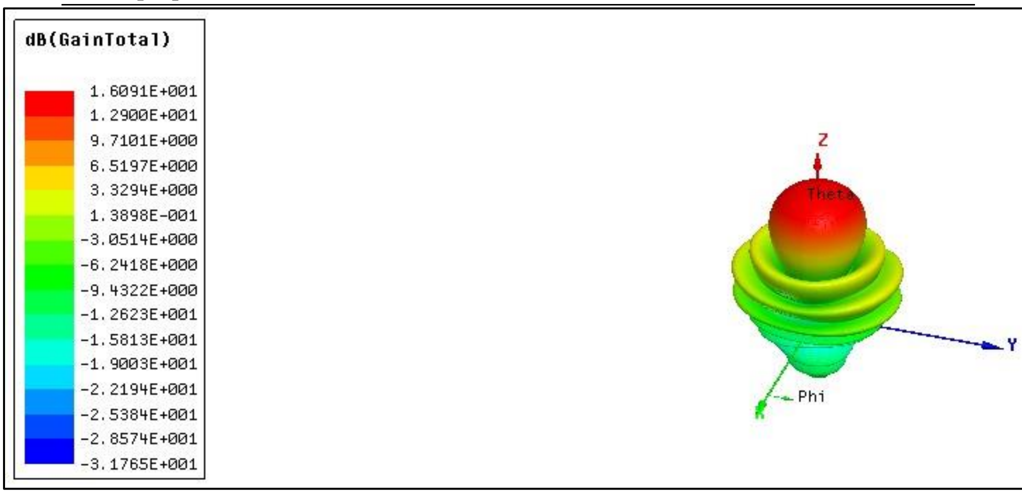


Figure 6. The simulated 3D radiation pattern of the presented antenna

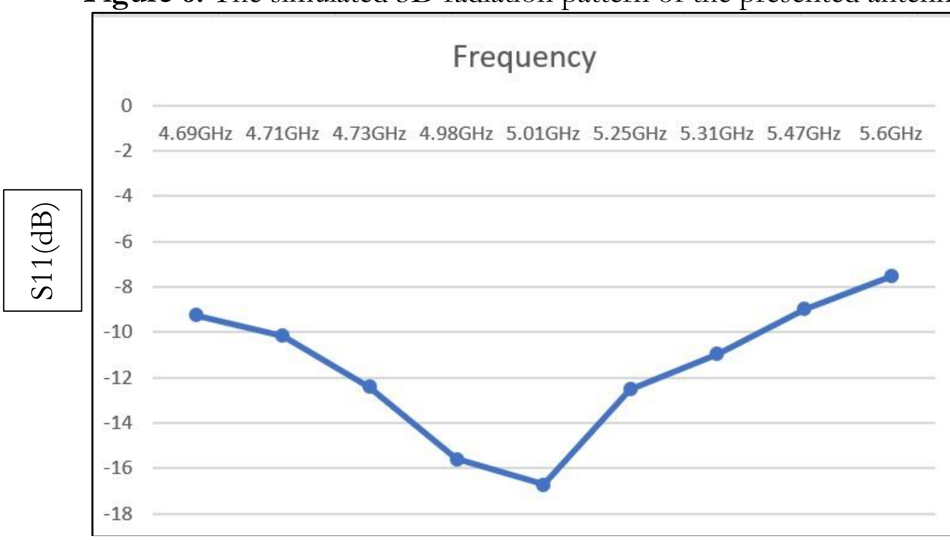


Figure 7. shows the measured return loss using vector network analyzer (VNA)

Figure 7 shows the measured return loss using network analyzer. Both simulated and measured results are compared which are almost same with working range of frequency is 4.70 to 5.30GHz and 5GHz central frequency.

Conclusion:

In conclusion, the development of a directional receiver for Wi-Fi, achieved by integrating Yagi and dielectric rod elements, demonstrates a significant improvement in antenna gain. This effective combination of two distinct types has resulted in a compact yet high-gain solution that addresses key challenges in Wi-Fi design. As mentioned in Comparison Table 2, the proposed antenna achieves high gain with a smaller structure. By analyzing the results and comparing them with existing research, it is clear that this new antenna is highly beneficial for 5G applications, as well as for Wi-Fi and WLAN systems.

References:

[1] Nursultan Meirambekuly., et al. "A High Gain Deployable L/S Band Conical Helix Antenna Integrated with Optical System for Earth Observation CubeSats" "IEEE Access" 2023, Vol.11 23097-23106.

[2] Haoming Li; Wenhua Cao; Botao Feng; Li Deng. "A High-Gain Yagi Antenna for 5G-C Band" "4th International Conference on Electronic Information and Communication Technology (ICEICT)" 2021 IEEE.

[3] Renato Cicchetti, Valentina Cicchetti, et al. "A Wideband High-Gain Dielectric Horn-Lens Antenna for Wireless Communications and UWB Applications" "IEEE Transactions on Antennas and Propagation" 2023, Volume: 71, Issue: 2.

[4] Bing-Long Zheng; Guang-Hua Sun, et al. "A radiation pattern reconfigurable yagi antenna" "Sixth Asia-Pacific Conference on Antennas and Propagation (APCAP)", 2017.

[5] Wenzhang Zhang; Yuan Zhuang; Chaoyun Song; Yi Huang; Jiafeng Zhou, "A dual-band Quasi-Yagi wearable antenna with high directivity" "IEEE MTT-S International Wireless Symposium (IWS) 2018".

[6] M Shanmugapriya; J Zuvairiya Parveen; M Ushasornapriya, "Design of Polarization Reconfigurable Antenna for WiFi and WiMAX Applications" "Third International Conference on Intelligent Computing Instrumentation and Control Technologies (ICICICT)" ,2022.

[7] Huansong Xu; Zhixi Liang; Yuanxin Li; Kuang Wang; Qi Cao; Yunliang Long, "A High-Gain Microstrip Magnetic Dipole Antenna Utilizing Slot-Loaded High-Order Mode for WLAN Applications" "IEEE Transactions on Antennas and Propagation" (Volume: 70, Issue: 10, October 2022.

[8] J. Jayanth, H. K. Ravikiran, M. Shivakumar, Manasa Mahadevaswamy & K. S. Gururaj, "Antenna Gain Improvement for Wi Fi Applications Using Parasitic Patch" SN computer science 2022.

[9] Paul, LC, et al. "A compact wideband slotted hexagonal patch antenna with a modified ground structure for WiFi-5/6 communication" "emerging technology in computing, communication, and electronics (ETCCE). IEEE", 2021.

[10] Panpan Chen, Ru Meng, and Qi Zhu, "Design of Compact High Gain Dielectric Rod Antenna and Array in Lossy Medium," "Microwave and Optical Technology Letters", Vol. 55, No. 10, October 2013

[11] M. Sporer, R. Weigel, and A. Koelpin, "A 24 GHz dual-polarized and robust dielectric rod antenna," "IEEE Trans. Antennas Propag.", vol. 65, no. 12, pp. 6952–6959, Dec. 2017.

[12] T. Lonsky and P. Hazdra, "Design of a plexiglass rod antenna,"" in Proc. Conf. Microw. Techn. (COMITE)", Apr. 2017, pp. 1–5.

[13] Amir Mohsen Ahmadi Najafabadi et al., "Plug-in Plug-Out Multibeam Dielectric Rod Antenna for Target Dedicated mm-Wave RF-WPT Applications," " 18th European Conference on Antennas and Propagation (EuCAP)" 17-22 March 2024

[14] SAEED FAKHTE et al. "Enhancing the Radiation Pattern of Circularly Polarized Dielectric Rod Antenna Using Planar Excitation Method" "IEEE Access" October 2023.

[15] J. Jayanth H. K. Ravikiran, M. Shivakumar, Manasa Mahadevaswamy, K. S. Gururaj, "Antenna Gain Improvement for Wi-Fi Applications Using Parasitic Patch," SN Computer Science 2023.

[16] M. Sai Santhosh Kumar, Morri Bharath, Jayshree Das, B. R. Sanjeeva Reddy, "Design of a High Gain Antenna for WiFi/6E Application," International Conference on Distributed Computing and Optimization Techniques (ICDCOT), 15-16 March 2024.