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Development and Analysis of a Highly Compact Microstrip Patch Antenna for WiFi 6E Applications

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Abstract*: This research article presents and analyses a microstrip patch antenna optimised for WiFi 6E applications. The antenna, constructed with an FR4 substrate measuring 20 × 24 × 1.53 mm³, features a rectangular shape and was designed using CST MWS software. An equivalent circuit model is formulated and simulated with ADS software to ensure accurate representation. Operating at 6 GHz, simulated results from CST MWS software indicate a bandwidth of 343 MHz (5.861 GHz to 6.204 GHz), while ADS software suggests a bandwidth of 339 MHz (5.848 GHz to 6.187 GHz). In contrast, the measured results exhibit a bandwidth of 196 MHz (5.827 GHz to 6.023 GHz). Despite slight discrepancies, satisfactory alignment is observed between computational and experimental outcomes, supported by the equivalent circuit model. Radiation patterns, gain, and efficiency are measured in an anechoic chamber and compared with the results of simulations. The E-plane exhibits directionality, while the H-plane demonstrates omnidirectionality, aligning well with the simulated patterns. The simulated gain is 5.77 dBi, while the measured gain is 5.61 dBi, resulting in a simulated efficiency of 93% and a measured efficiency of 88%. The antenna is deemed suitable for cost-effective WiFi 6E applications.

***Keywords*: Compact Antennas, Large Bandwidth, Patch Antenna, WiFi 6E.**

I. INTRODUCTION

An increasing number of devices, connections, and bandwidth-intensive applications propels the evolution of wireless technology. This encompasses various aspects such as the Internet of Things (IoT), critical communication systems, advanced broadband-enabled mobile devices, and numerous other innovations [1], [2]. The forthcoming networks will need more stable and efficient wireless, and this is where the 6G of Wi-Fi, referred to as Wi-Fi 6E, becomes crucial [3], [4]. The new IEEE 802.11ax protocol represents the latest advancement in a long history of development. Building on the advantages of 802.11ac, it offers reliability and adaptability, allowing both old and new networks to support future technologies. IEEE 802.11ax combines the reliability of licensed cellular (LTE) with the flexibility and speed of gigabit wireless. With the help of the businesses above and service providers, the level of service for previous applications simultaneously accommodating emerging applications on the identical Wireless LAN (WLAN) architecture [5].

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Several Wi-Fi protocols covering the 2.4 GHz and 5 GHz bands have been developed over time. The most recent Wi-Fi 6 expansion, known as Wi-Fi 6E, is situated in the 6.925 – 7.125 GHz range. The inclusion of the 6 GHz band offers a potential solution to the congestion issues observed in other bands. However, this expansion also introduces challenges in antenna design due to the broad bandwidth involved [6]. The US Federal Communications Commission (FCC) authorised the unlicensed use of the 6-GHz band in the country in April 2020. By making this choice, 1200 MHz of bandwidth became available for use by Wi-Fi 6E devices. Such devices include a further radio that allows them to communicate in the 6-GHz band.

This channel has over two times the capacity compared to the 5-GHz band, which is accessible via Wi-Fi. To encourage new cellular ideas, especially in encouraging intelligent residences, workplaces, and extension activities, the FCC expanded Wi-Fi to include the 6-GHz bands [7], [8]. In the diverse types of antennas available, the microstrip patch antenna stands out as a well-established design for implementing 5G wireless communications. This preference is attributed to its numerous advantages, including its lightweight nature, compact size, cost-effectiveness, low profile, smaller dimensions, and ease of fabrication [9]. Despite these benefits, conventional microstrip antennas are not without their drawbacks, as they often exhibit narrow bandwidth and low gain [10]. In a separate study [11], Loop-type antennas employed compact dimensions and a meandering shape. Alternative studies have delved into configurations like PIFA or monopole antennas designed explicitly for Wi-Fi applications [12]–[15]. In [16]–[19], To create a small dimension and thin boundary antenna layout, chip elements were employed. However, adding inductors makes the hardware more complicated and creates issues for the production process.

Each of these techniques has demonstrated its effectiveness in constructing diverse resonant structures aligned with various frequencies. Nevertheless, the uncertainty remains as to whether the current approaches can effectively address the challenge of coverage for the expansive 6 GHz band. When it comes to the Wi-Fi 6E frequency band, the broader high-frequency band poses difficulties in implementation [20], [21].

Similarly, Wi-Fi connection antennas should be omnidirectional to offer broad coverage and convenient connectivity for users. Nevertheless, incorporating additional antennas introduces complexity into device design and necessitates the allocation of extra space. This paper presents and analyzes highly compact microstrip patch antenna for WiFi 6E applications.

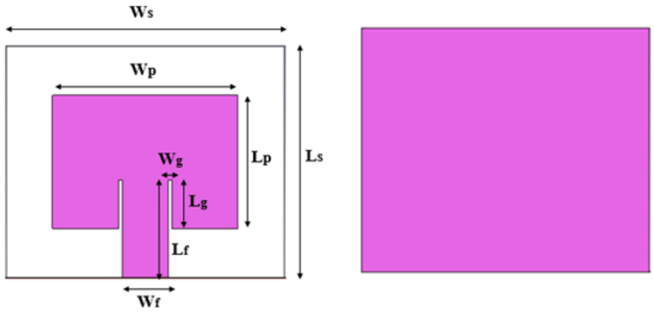
The second step involves creating an equivalent circuit model, which is designed analytically and then validated using Keysight ADS software, ensuring its alignment with the desired frequency range. The Wi-Fi 6E band addresses the spectrum shortage challenges faced by current Wi-Fi technology. Additionally, this new technology aims to meet future 5G standards, offering key features such as low latency and high-speed data, while remaining compatible with existing Wi-Fi technology. Leveraging the 6 GHz spectrum, the proposed design provides both high speed and coverage without requiring a complex design, occupying minimal dimensional space, and facilitating easy and cost-effective implementation.

II. ANTENNA DESIGN

The proposed antenna's foundational design relies on the computation approach outlined in [22]. The antenna is suggested to have a rectangular shape. Utilising CST MWS software, an examination is conducted to determine how the dimensions of length, width, and inset feed gaps surrounding the rectangular patch affect the resonant frequency and bandwidth. Parametric analyses are carried out to determine the optimal antenna dimensions, aiming to achieve the maximum bandwidth at the desired frequency simultaneously

A. Configuration and Geometry

During the initial design phase, the suggested antenna is formulated using a conventional patch antenna configuration. It consists of a rectangular patch, and an inset microstrip feed line is utilized on a practical FR-4 substrate. The substrate possesses a height (h) of 1.53 mm, a dielectric constant (εr) of 4.3, and a loss tangent (tan δ) of 0.025. The procedures listed next serve to establish the size for the patch, which relies upon the transmission line model that is demonstrated in [22]. The antenna's size and structure are displayed in Fig. 1.

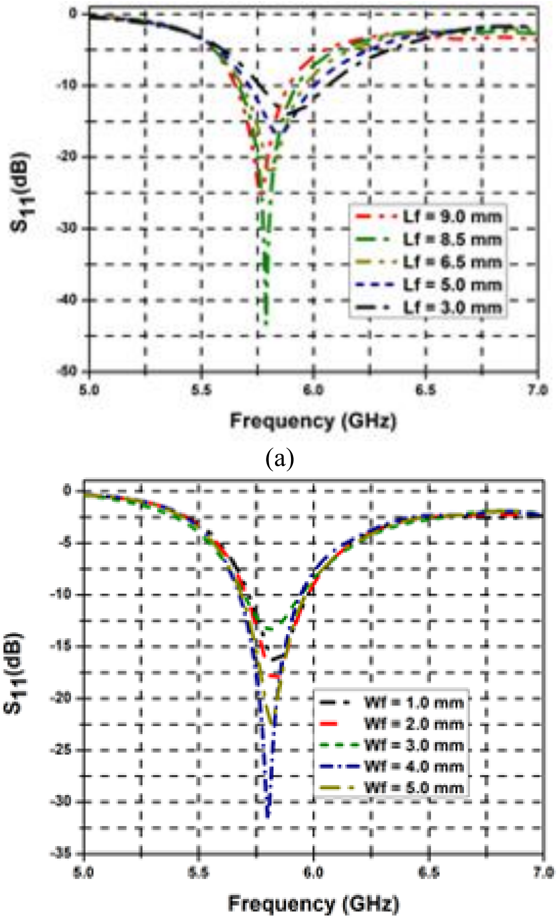


(a) (b)

Fig. 1. Antenna Configuration and Geometry: (a) top view, (b) Bottom view. The Dimensions of the Antenna are: L_s = 20 mm, W_s = 24 mm, W_p = 16 mm, L_p = 11.5 mm, W_f = 4 mm, L_f = 8.5 mm, W_g = 0.3 mm, L_g = 4.3 mm.

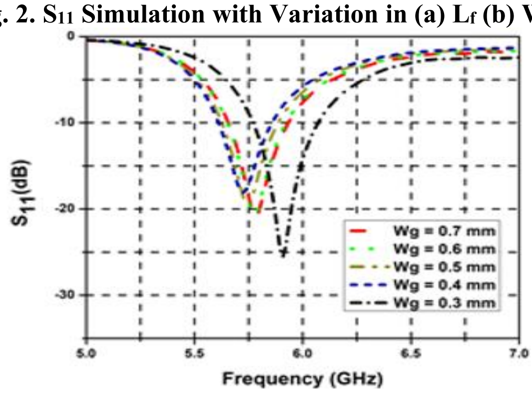
B. Parametric Study

The size of the antennas affects their performance; therefore, it is essential to give them careful consideration. To solve this, the ideal feed length and width (L_f and W_f) were determined by parametric research as depicted in Fig. 2. In Fig. 2(a), the simulated S_{11} is presented with L_f ranging from 5.0 mm to 9.0 mm, revealing that an optimal S_{11} is attained with an L_f of 8.5 mm, as indicated by the parametric study. Conversely, Fig. 2(b) displays the simulated S_{11} with W_f varying from 1.0 mm to 5.0 mm. Through parametric analysis, it was determined that a Wf of 4.0 mm results in the most favourable S_{11}. Additionally, the inset feed size (L_g and W_g) has an impact on the antenna's resonant frequency. Consequently, a separate investigation was undertaken, as illustrated in Fig. 3. In Fig. 3(a), the simulated S11 is presented with variations in Wg, ranging from 0.7 mm to 0.3 mm, revealing that an optimal S_{11} is achieved with a W_g of 0.3 mm, as indicated by the parametric study. Conversely, Fig. 3(b) depicts the simulated S_{11} with varying L_g values from 2.0 mm to 4.3 mm. Following a parametric analysis, it was determined that L_g of 4.3 mm yields the most advantageous S_{11}.



(b)

Fig. 2. S_{11} Simulation with Variation in (a) L_f (b) W_f.



(a)

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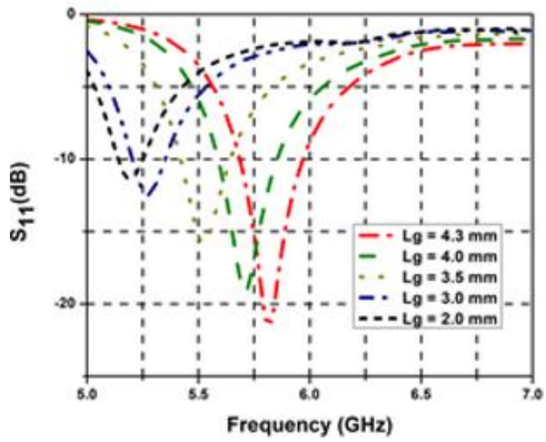
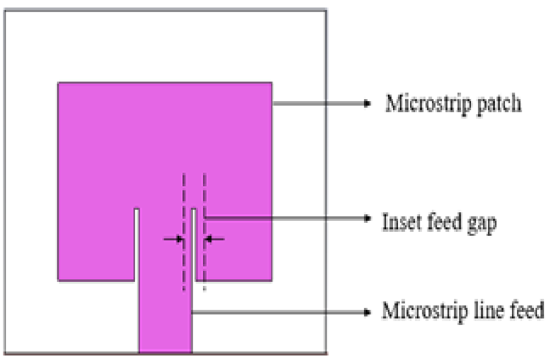


(b)

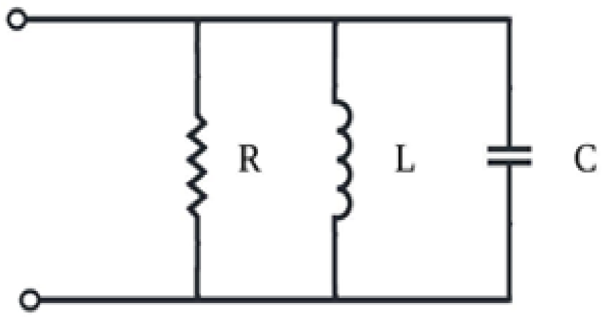
Fig. 3. S_{11} Simulation with Variation in (a) L_g, (b) W_g.

C. Equivalent Circuit Model

The equivalent circuit model serves as an initial estimation tool for crucial parameters, such as resonance frequency, bandwidth, and impedance matching, guiding the design process before more detailed simulations or measurements are conducted. [23]. To accurate.ly mod.el the antenna, it is imperative to determine the correct value for each element. Therefore, in this research, a circuit model of the suggested antenna is created and simulated using ADS software. An extensive circuit model is employed, which incorporates modelling for various parts of the antenna. The patch antenna is similar to an open-ended transmission line in general [24]. The patch, line feed, and gap equivalent circuits are also known as discontinuities. Having small capacitances and inductances results from these discontinuities. When applied to the frequency range of the antenna, the values of capacitance (C), inductance (L), and resistance (R) are obtained from equations in [25], [26]. Fig. 4 illustrates the total equivalent circuit of the proposed antenna.



(a)



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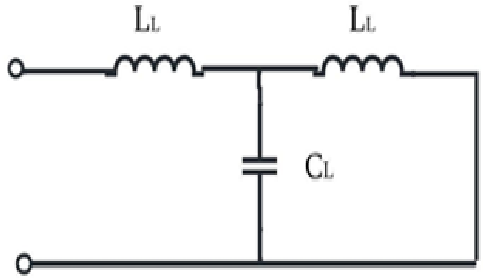

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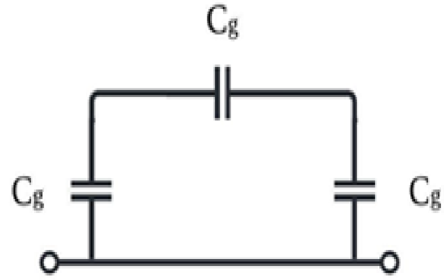

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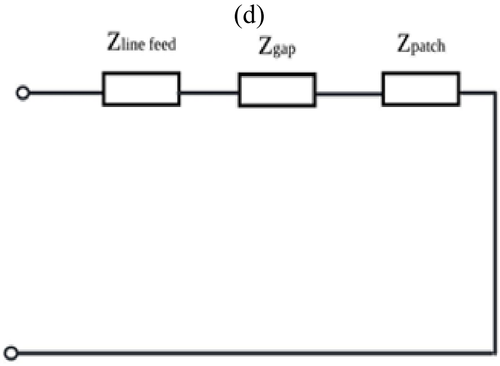

(e)

Fig. 4. Proposed Antenna and its Equivalent Circuits: (a) Front View, (b) Patch Model, (c) Feed Line Model, (d) Inset Feed Gap Model, (e) Overall Circuit Model. The Equivalent Circuit Values Are: R = 98 Ω, L = 0.8 nH, C = 7.9 pF, L_L = 0.5 nH, C_L = 0.3 pF, C_g = 0.15 pF.

III. RESULTS AND DISCUSSION

The proposed design was validated through fabrication, as depicted in Fig. 5(a), utilising a 50-Ω SMA connector to facilitate the connection. The antenna's performance was measured using Keysight's Vector Network Analyzer (VNA) PNA-L, as shown in Fig. 5(b). Simulation and measurement techniques were employed for S_{11} analysis. The results, depicted in Fig. 5(c), reveal a slight frequency deviation in the measured outcomes, attributed to fabrication defects and measurement variations. The simulated results obtained using CST MWS software indicate a bandwidth of 343 MHz, spanning from 5.861 GHz to 6.204 GHz, while ADS software suggests a bandwidth of 339 MHz, from 5.848 GHz to 6.187 GHz.

In contrast, the measured results show a bandwidth of 196 MHz, ranging from 5.827 GHz to 6.023 GHz. Despite these slight discrepancies, there is a satisfactory alignment between the computational results and the results obtained from both simulation and measurement.

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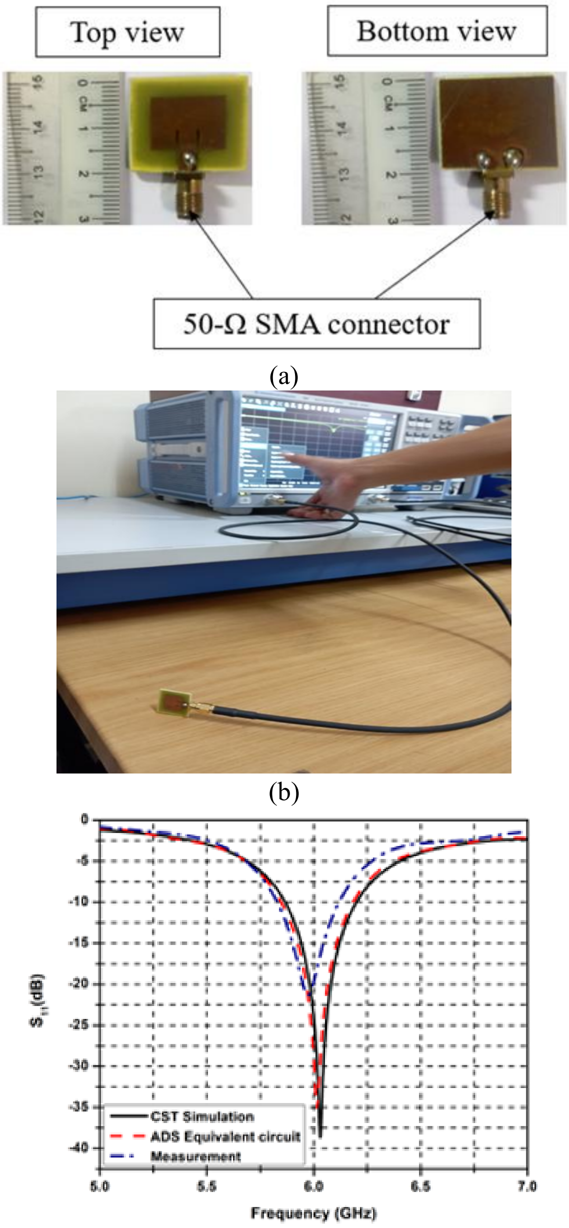


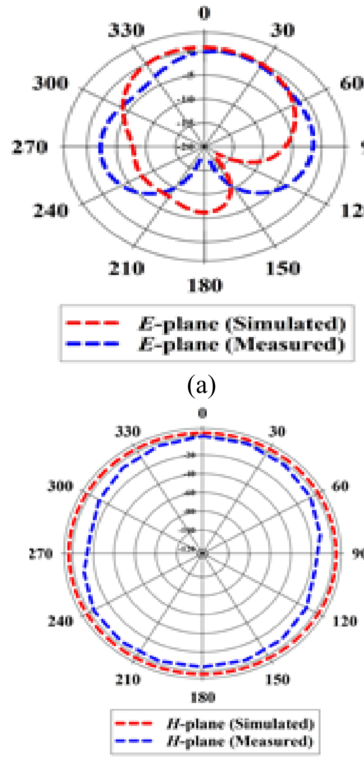
(a)

(b)

(c)

Fig. 5. Proposed Antenna (a) Prototype (b) S11 Measurement Setup (c) S11 Comparison

The proposed antenna's radiation patterns, gain, and efficiency are measured and then compared with simulated results. In Fig. 6, a comparison is presented between the simulated and measured radiation patterns. As anticipated, at 6 GHz, the measured radiation patterns exhibit directionality in the *E*-plane, as shown in Fig. 6(a), and omnidirectionality in the H-plane, as shown in Fig. 6(b), aligning well with the simulated patterns. Conversely, the simulated gain is 5.77 dBi, while the measured gain is 5.61 dBi, resulting in a simulated efficiency of 93% and a measured efficiency of 88%, as depicted in Fig. 7(a). Additionally, Fig. 7(b) displays 3D far-field radiation patterns for the relevant frequency band, providing further confirmation of the maximum gain achieved by the antenna.



(a)

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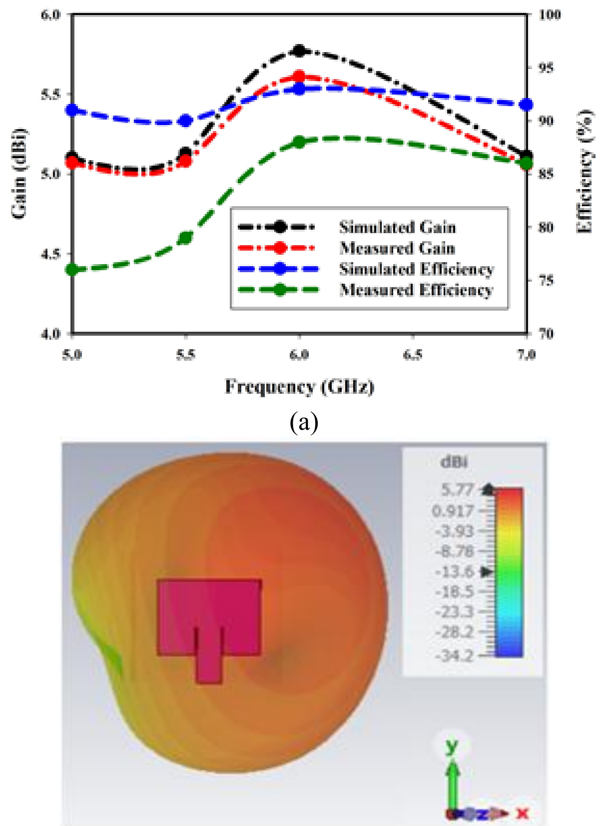
Fig. 6. Radiation Patterns (a) *E*-plane (b) *H*-plane



(a)

(b)

Fig. 7. Proposed Antenna (a) Gain and Efficiency (b) 3D Radiation Pattern

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Table I provides a comparative assessment between the antenna proposed in this study and those discussed in earlier research. The results reveal that the recommended antenna features considerably reduced dimensions compared to antennas employed in previous studies. Furthermore, the antenna exhibits excellent results at the frequency that resonates for impedance bandwidth, gain, and efficiency. The table clearly shows that the suggested antenna offers several benefits over past antennas.

Table I: Comparative Analysis of the Performance of the Antenna with Antennas Employed in Prior Studies

Reference	Size (mm^2)	Frequency (GHz)	Material	Bandwidth (MHz)	Gain (dBi)	Efficiency(%)
[10]	36× 37	6	FR-4	220	0.54	59
[27]	52.92 × 55.56	5.65	Arlon	135	7.15	NA
[28]	20× 30	5.55	FR-4	2400	2.69	68.4
[29]	45× 50	4.9	F4B	480	5.12	77
[30]	77× 70.11	4.97	Rogers	NA	4.57	80
[31]	50× 50	6	FR-4	900	5.3	85
[32]	66× 30.8	5	Rogers	NA	7.7	89
[33]	19× 13.4	6	Rogers	180	5.3	NA
This work	**20× 24**	**6**	**FR-4**	**343**	**5.77**	**93**

IV. CONCLUSION

This research article presents a highly compact patch antenna designed and explicitly analysed for Wi-Fi 6E applications. The antenna, constructed using FR4 substrate material, features compact dimensions of 20 × 24 × 1.53 mm^3 and adopts a rectangular shape, as determined by CST Microwave Studio (MWS) software. To ensure accurate modelling, an equivalent circuit model was formulated and simulated using ADS software. The antenna operates at a frequency of 6 GHz. Simulated results obtained through CST MWS® software reveal a bandwidth of 343 MHz (5.861 GHz to 6.204 GHz), while ADS software suggests 339 MHz (5.848 GHz to 6.187 GHz). In contrast, measured results exhibit a bandwidth of 196 MHz (5.827 GHz to 6.023 GHz). Although there are slight differences, a satisfactory correlation exists between the simulation and measurement results. The research further measured the radiation patterns, gain, and efficiency and compared them with simulated results. The measured radiation patterns closely match the simulated ones, displaying directional patterns in the E-plane and omnidirectional patterns in the H-plane. The simulated gain is 5.77 dBi, measured at 5.61 dBi, resulting in a simulated efficiency of 93% and a measured efficiency of 88%. Consequently, the research concludes that the proposed antenna is suitable for cost-effective WiFi 6E applications.

DECLARATION STATEMENT

Funding	No, I did not receive.
Conflicts of Interest	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval or consent to participate, as it presents evidence that is not subject to interpretation.
Availability of Data and Materials	Not relevant.
Authors Contributions	I am the sole author of the article.

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