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RESEARCH ARTICLE

Design and Development of an L-shaped rectangular Microstrip Patch Antenna With Slot for Wi-Fi 6E Applications

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Abstract

This research aims to design and develop an L-shaped rectangular microstrip patch antenna with a ground slot optimized for Wi-Fi 6E applications. The primary focus is to ensure that this antenna can deliver optimal radiation efficiency, sufficient bandwidth, and signal reliability across the 2.4 GHz, 5 GHz, and 6 GHz frequency bands. Based on the 802.11a, 802.11b, and 802.11ax standards, each offers speeds up to 11 Mbps, 54 Mbps, and 9.6 Gbps in the 2.4 GHz and 5 GHz bands, respectively. Wi-Fi 6E offers more channels with broader bandwidth and minimal interference, enhancing performance for applications such as 4K/8K streaming, online gaming, and the Internet of Things (IoT). To fully exploit Wi-Fi 6E's potential, an antenna that can operate across these three frequency bands (2.4 GHz, 5 GHz, and 6 GHz) must be designed. The design and Development of a rectangular microstrip patch antenna with a ground slot provide a solution that delivers optimal radiation efficiency, bandwidth, and signal reception capability thanks to its compact and efficient design. The measurement results show that the antenna's bandwidth in the first band ranges from 1.150 to 3.091 GHz, reaching 1.941 GHz, and in the second band ranges from 3.688 to 7.243 GHz, reaching 3.555 GHz. The radiation pattern remains omnidirectional, and total efficiency for frequency 2.436 GHz at 82.27%, 5.3 GHz at 90.42%, and 6.56 GHz at 91.95%, respectively. Gain of 2.4 GHz is 4.19 dB, 5 GHz is 4.87 dB, and 6 GHz is 5.23 dB. These measurement results agree with the simulation results. Therefore, the proposed antenna can be used as a candidate for Wi-Fi applications.

Keywords: Microstrip Antenna, L-Shaped Patch, Wi-Fi 6E, FR-4 material

1. Introduction

Wi-Fi 6, or 802.11ax, was developed to address the limitations of previous Wi-Fi standards such as 802.11ac. The IEEE introduced this standard to meet the increasing demand for connectivity [1]. It supports gigabit throughput, essential for applications such as 4K/8K streaming, uninterrupted gaming, and fast data transfer [2]. Significant improvements brought by Wi-Fi 6 include uplink Multi-User MIMO (MU-MIMO), Orthogonal Frequency Division Multiple Access (OFDMA), and 1024-QAM modulation [1].

The 6 GHz spectrum (Wi-Fi 6E) extends the frequency range up to 6 GHz, providing an additional 1200 MHz bandwidth for greater capacity and lower latency [3]. The technological advantages of Wi-Fi 6 include up to four times the throughput and network capacity compared to Wi-Fi 5, accommodating numerous connected devices, particularly for IoT and smart home applications [4]. Wi-Fi 6E operates in the 2.4 GHz, 5 GHz, and 6 GHz frequency bands, offering wider bandwidth and high performance. These frequency bands are regulated by the Federal Communications Commission (FCC), which recommends Wi-Fi 6E in the 5.925-7.125 GHz range[5].

In many wireless communication systems, microstrip patch antennas are preferred due to their small size. Wi-Fi antennas mainly focus on handling high data rates with short-range coverage within short periods. Currently, there are three bands used for Wi-Fi applications: 2.4 GHz (2.400 - 2.4835GHz), 5 GHz (5.150 - 5.875GHz), and 6 GHz (5.925-7.125 GHz) [6]. A critical aspect of implementing Wi-Fi 6E is the Development of efficient antenna designs [7]. A rectangular microstrip patch antenna with an L-shaped slot on the ground has been recognized as a potential solution. This design enhances bandwidth and gain and reduces antenna size without compromising performance [8]. It can provide stable gain, bandwidth, and radiation pattern performance across various operating frequency bands. Microstrip antennas are an effective solution to keep pace with technological advancements [9]. Implementing Defected Ground Structures (DGS) in antenna design has also proven effective in enhancing bandwidth and radiation performance [10]. DGS helps to reduce antenna size and improve impedance matching, which is crucial for ensuring stable connectivity and high-speed applications in Wi-Fi 6E [11].

Research by [12] designed a compact wideband slotted hexagonal patch antenna (CWSHPA) with a modified ground plane for Wi-Fi 5/6 communications. Using a Rogers RT5880 substrate with a thickness of 0.79 mm, this modification reduced the antenna size and improved performance. With a volume of $34 \times 20 \times 0.79$ mm^3, this antenna covers the 5.1697 - 7.5388 GHz frequency range with radiation efficiency between 79.19% and 89.37%, averaging 85%. The gain ranges from 3.1 to 4.1 dB, and directivity is between 3.6 and 4.9 dBi. At a center frequency of 6.33 GHz, the antenna increases by 3.995 dB with an omnidirectional radiation pattern. Simulations were conducted using CST Microwave Studio.

In another study [13], a circularly polarized edge microstrip antenna was designed for 5G smartphones and Wi-Fi 6 applications. This antenna features multiple microstrip paths to support dual-band operation, covering the 5.32 – 5.52 GHz and 6.15 – 6.36 GHz frequency ranges, with respective bandwidths of 200 MHz and 210 MHz. The antenna is a single element mounted on the top edge of an FR-4 substrate and is fed by a coaxial SMA connector. Testing reveals that the antenna performs strongly in reflection, gain, efficiency, radiation pattern, and impedance matching within both resonance bands.

Based on theoretical analyses and prior research, this antenna shows significant promise for improving the performance of wireless communication systems by offering rapid and dependable connectivity. The design can achieve the desired performance benchmarks with careful optimization, making it well-suited for Wi-Fi/WiMAX applications. Developing an antenna that operates across the 2.4 GHz, 5 GHz, and 6 GHz frequency bands is essential for maximizing the capabilities of Wi-Fi 6E.

1.1 Antenna Design

The initial antenna design is based on [14] Circular Polarization Quad-Band Antenna for GNSS, 5G, and WiFi-6E Applications are shown. The geometry of the proposed antenna is schematically illustrated. The antenna is fed through a 50 Ω microstrip feedline. The feedline is connected to an L-shaped patch, acting as the field excitation and radiator. The L-shaped patch is printed on an FR-4 substrate with εR = 4.4 and tan δ = 0.02, and the ground plane is created at the bottom of the medium, as shown in Figure 1.

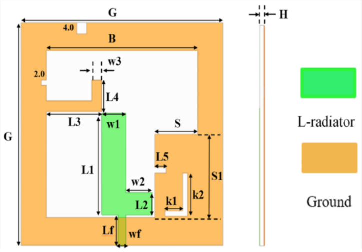


Figure 1. Geometry and Parameters of the Proposed Antenna

This article considers the final design of this antenna the best. The optimized antenna design is shown below.

1.2 Evolution I

Figure 3 below illustrates the addition of a slot labeled K1 to the antenna's back view. The inclusion of slot K1 in the antenna design enhances antenna performance by improving impedance matching, broadening bandwidth, tuning the resonant frequency, controlling the radiation pattern, and increasing return loss. These improvements enable the antenna to operate more efficiently at the desired frequency and reduce signal reflection.

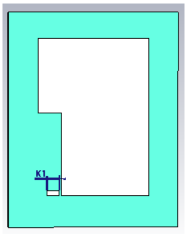


Figure 2. The first slot added to the antenna

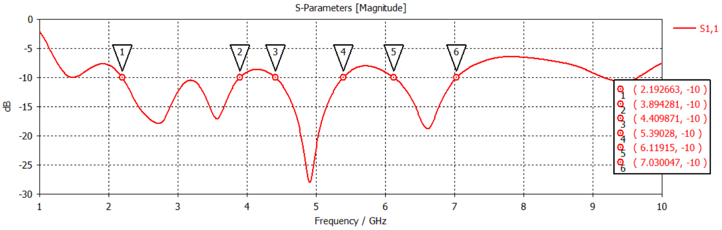


Figure 3. S_{11} of Evolution I

Based on the S-Parameter graph above, it can be observed that at a frequency of 2.4 GHz, the S_{11} value approaches -10 dB, indicating that the antenna has fairly good reflection performance near this frequency. At 5.25 GHz, although not strictly at one of the minimum points, the S_{11} value remains below -10 dB, indicating that the antenna is still sufficiently efficient in transmitting signals at this frequency. However, at 6.525 GHz, the graph shows an S_{11} value above -10 dB, which means there is an increase in reflection or a decrease in antenna efficiency at this frequency, suggesting that further optimization is required to achieve the desired performance.

1.3 Evolution II

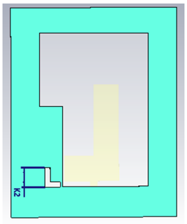


Figure 4. The second slot added to the antenna

The S_{11} parameter measures the reflection coefficient, indicating how much power is reflected to the source due to impedance mismatch. Critical frequencies such as 2.4 GHz, 5.25 GHz, and 6.525 GHz are likely interesting because they correspond to standard wireless communication bands (e.g., Wi-Fi). At these frequencies, the

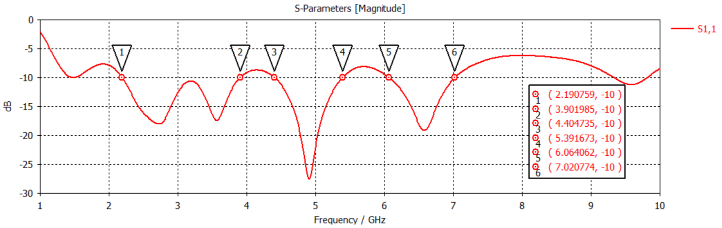
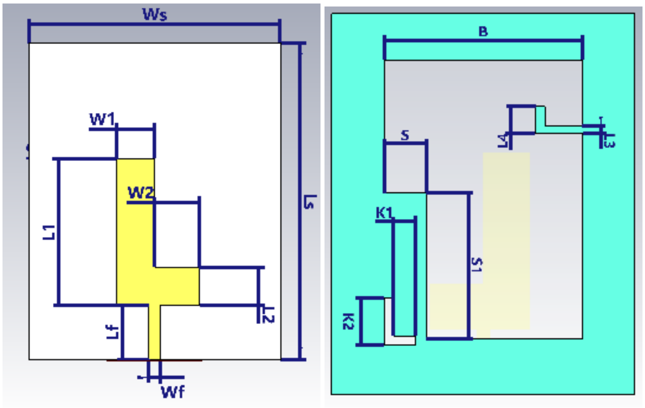


Figure 5. S_{11} result of Evolution II

S_{11} values are near or below -10 dB, suggesting that the antenna or network has good impedance matching. This means that most of the input power is being effectively radiated or transmitted rather than reflected. This is desirable in wireless communication systems to ensure efficient performance.

Evolutions 1 and 2 show that at 2.4 GHz, both Evolutions show reflection coefficients slightly above -10 dB, indicating moderate impedance matching but not optimal tuning for this frequency. Near 5.25 GHz, both figures 4 and 5 display a resonance dip around 5.39 GHz, suggesting good impedance matching and efficient power transmission in this band. However, at 6.525 GHz, the S_{11} values are above -10 dB, showing less optimal performance with no significant resonance dip. This indicates that the system needs to be tuned explicitly for efficient operation at this frequency.



(a) (b)

Figure 6. Final design Proposed antenna (a) front view and (b) back view of ground

In this design, Figure 6 shows the optimal dimensions and shape of the patch (yellow), substrate (white), and conductor (green). The three-dimensional visualization of the microstrip antenna shape from the simulation results can be observed. Based on the antenna design simulations, the dimensions of the microstrip antenna for Wi-Fi 6E applications are determined, as shown in Table 1.

The design of the square microstrip patch antenna is determined through calculations using equations (1) and (2). The dimensions of the substrate and ground plane are using equations (3) and (4) [15].

$$W_p = \frac{C}{2_f}\sqrt{\frac{2}{\epsilon_r + 1}} \tag{1}$$

$$L_p = \frac{c}{2f_0\sqrt{\epsilon_{rff}}} - 2\Delta l \tag{2}$$

$$L_s = 6_h + L_p \tag{3}$$

$$W_s = 6_h + W_p \tag{4}$$

Table 1. Dimensions of the proposed antenna

Symbol	Mark	Observation	Symbol	mark	Observation
Ws	65 mm	Substrate width	B	42.5 mm	Stub width
Ls	82 mm	Substrate length	K2	7.8 mm	Length slot L
L1	37 mm	Patch length	K1	8 mm	slot L width
W1	9.9 mm	Patch width	L3	1.5 mm	slot L length
L2	10 mm	Patct2 length	L4	11.5 mm	slot l length
W2	11.5 mm	Patch2 width	S	18 mm	stub
Wf	3 mm	Feed width	S1	35 mm	Length stub
Lf	14 mm	Feed length			
h	1,6 mm	Substrate thickness			
t	0,035 mm	Ground thickness			

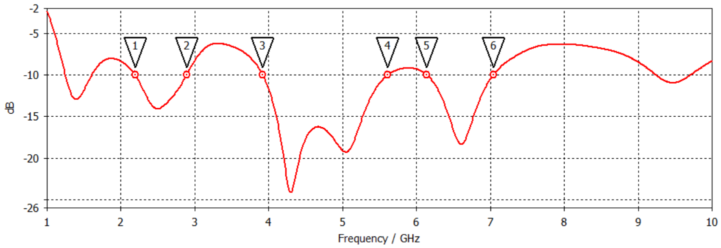
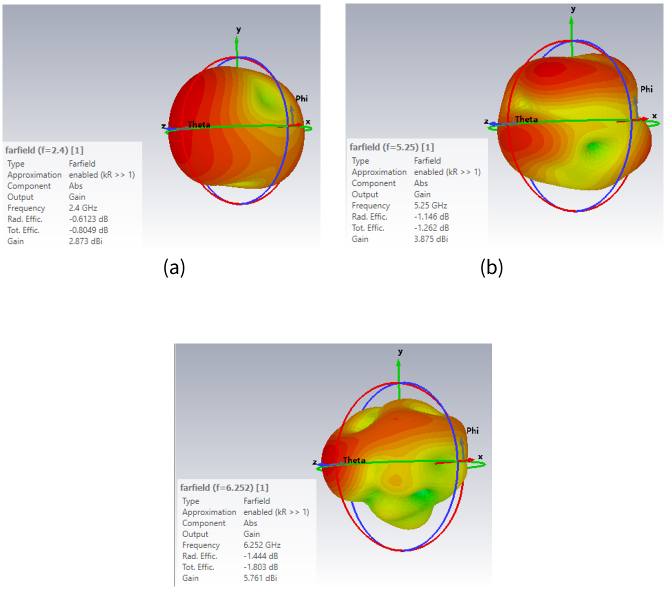


Figure 7. S_{11} parameter of the proposed antenna

From Figure 7 above, three significant bandwidth ranges indicate the antenna's performance across various frequency bands. The first bandwidth, from 2.19 GHz to 2.88 GHz, is 0.69 GHz, demonstrating good performance for lower-frequency applications such as mobile communications. The second bandwidth, from 3.91 GHz to 5.61 GHz, is 1.700 GHz, covering medium to high-frequency bands, ideal for Wi-Fi applications and data communications requiring higher capacity and speed. The third bandwidth, from 6.13 GHz to 7.03 GHz, is 0.9 GHz, covering higher frequency bands that can support advanced Wi-Fi technologies, offering enhanced data rates and reduced latency. The high efficiency of the antenna within these frequency ranges indicates its ability to maintain good performance across different frequency conditions, with low reflection (S_{11} < -10 dB), meaning more power is radiated than reflected to the source. This reflects an optimal antenna design suitable for modern Wi-Fi applications, ensuring reliable and efficient wireless communication.

The simulation quantitatively analyses the antenna's performance across Wi-Fi-relevant frequency bands. Figure 8 shows that as frequency increases, gain improves from 2.87 dB at 2.4 GHz, 3.87 dB at 5.25 GHz, and 5.76 dB at 6.525 GHz, enhancing signal strength and coverage. However, total efficiency decreases from 78.5% at 2.4 GHz to 60% at 6.525 GHz. Radiation patterns shift from omnidirectional at 2.4 GHz, ideal for broad coverage, to more complex and focused at higher frequencies, suitable for targeted communication. These results highlight the antenna's ability to balance gain and efficiency for optimal performance in various Wi-Fi applications.



farfield (f=2.4) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	2.4 GHz
Rad. Effic.	-0.6123 dB
Tot. Effic.	-0.8049 dB
Gain	2.873 dBi

(a)

farfield (f=5.25) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	5.25 GHz
Rad. Effic.	-1.146 dB
Tot. Effic.	-1.262 dB
Gain	3.875 dBi

(b)

farfield (f=6.252) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	6.252 GHz
Rad. Effic.	-1.444 dB
Tot. Effic.	-1.803 dB
Gain	5.761 dBi

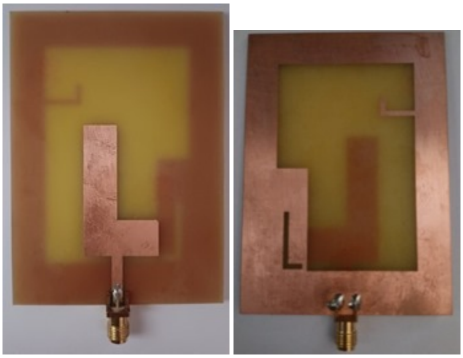
(c)

Figure 8. 3D model of Fairfield parameter at (a) 2.4 GHz, (b) 5.25 GHz, and (c) 6.525 GHz

Figure 8 illustrates the antenna gain at frequencies of 2.4 GHz, 5.25 GHz, and 6.525 GHz. At 2.4 GHz, the main gain is 2.87 dBi with an omnidirectional radiation pattern and total efficiency of 78.5%. This calculated from the simulation results in a total efficiency of -0.8, then converted to percentage using the decibel formula to linear conversion, indicating good efficiency. At 5.25 GHz, the principal gain increases to 4.21 dBi with a more complex radiation pattern and multiple lobes and a total efficiency of 61.9%, showing a slight decrease in efficiency but an increase in gain. At 6.525 GHz, the main gain reaches 5.76 dBi, the highest among the three frequencies, with a more directive higher radiation pattern and total efficiency of 60%, indicating a drop in efficiency but with a significant gain. Increasing the frequency results in a higher main gain, though radiation and total efficiency decrease, and the radiation pattern becomes more complex, reflecting a more focused energy distribution.

2. Result and Discussion

After conducting simulations and obtaining optimal results for the antenna, the next step is the fabrication and measurement of the antenna design, as shown in Figure 9. Measurements are performed to assess the antenna's performance. The measurements were carried out in two places Radar Laboratory Department of Electrical Engineering (DoEE), Faculty of Engineering, Universitas Indonesia and the large Telecommunication Equipment Testing Center (BBPPT: Balai Besar Pengukuran Peralatan Telekomunikasi) of the Ministry of Communication and Information of the Republic of Indonesia (Kominfo: Kementerian Komunikasi dan Informasi), and the results can be seen on the display monitor in Figure 10.



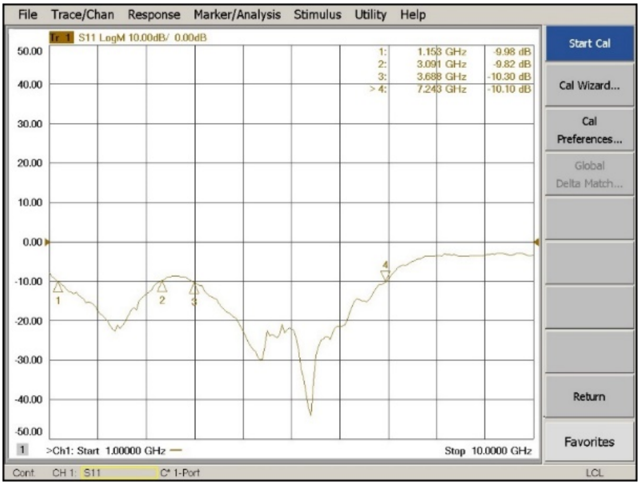
(a) (b)

Figure 9. antenna fabrication result (a) front view (b) back view

2.1 Bandwidth

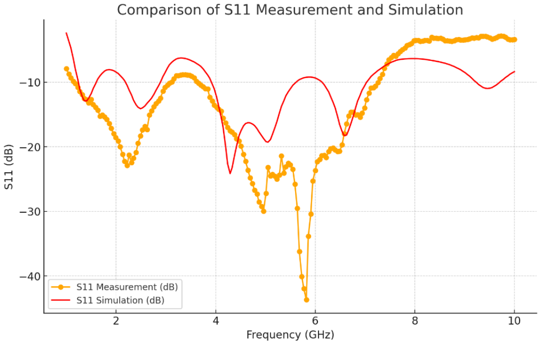
The bandwidth measurements are conducted in the Radar Laboratory, Department of Electrical Engineering (DoEE), Faculty of Engineering, Universitas Indonesia. The measurement and simulation results display monitor can be seen in Figure 10a, and the comparison of bandwidth results can be seen in Figure 10b.

The measurement results can be seen in Figure 10a, where the blue line represents the simulated bandwidth and the red line represents the VNA-measured bandwidth. The analysis shows the following bandwidth results within the frequency range of 1 - 10 GHz: from 1.153 - 3.091 GHz, a bandwidth of 1.938 GHz is achieved, and from 3.688 to 7.243 GHz, a bandwidth of 3.555 GHz is achieved. In the simulation results using the frequency range of 1 - 10 GHz, from 1.190 - 2.830 GHz, a bandwidth of 1.640 GHz is obtained, and from 3.688 - 7.243 GHz, a bandwidth of 2.900 GHz



1:	1.153 GHz	-9.98 dB
2:	3.091 GHz	-9.82 dB
3:	3.688 GHz	-10.30 dB
> 4:	7.243 GHz	-10.10 dB

Figure 10. (a) Measurement result in S_{11} bandwidth VNA

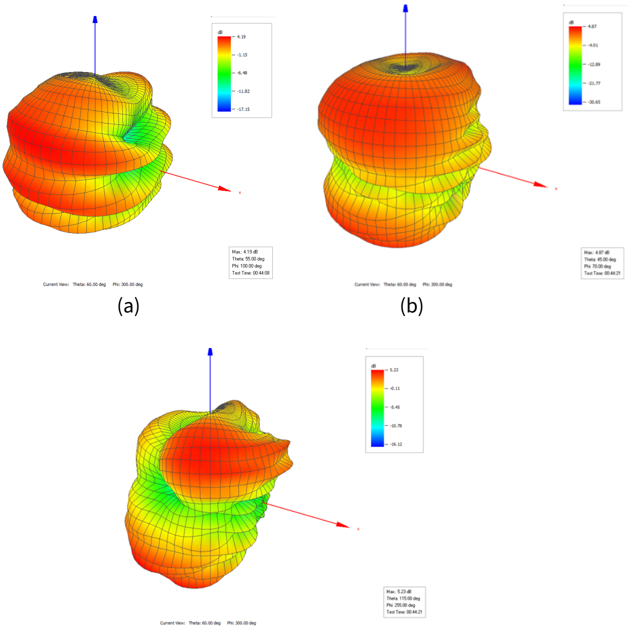


(b) Simulated bandwidth Comparison

is obtained. This analysis indicates that the measured bandwidth of the fabricated antenna is broader in the higher frequency band compared to the simulation results while slightly narrower in the lower frequency band. The simulation and measurement results indicate that the L-shaped microstrip patch antenna with a slot is designed for Wi-Fi 6E applications at 2.4 GHz, 5 GHz, and 6 GHz.

2.2 Dual-Port Measurement

The dual-port measurements were conducted at the Telecommunication Equipment Testing Center laboratory (BBPPT), the Ministry of Communication and Information (Kominfo: Kementerian Komunikasi dan Informasi), the Republic of Indonesia. Figure 11 shows the measurement results for the radiation pattern and gain, and Table 2 compares the gain results.



(a) (b)

(c)

Figure 11. Gain and Radiation Pattern Measurement Results at Frequencies: (a) 2.4 GHz, (b) 5 GHz, and (c) 6 GHz

Antenna efficiency formula

The total efficiency (P_{total}) of an antenna is typically calculated using equations (5):

$$n_{total} = \frac{P_{radiation}}{P_{input}} \tag{5}$$

Table 2. Comparison result

Operation frequency (GHz)	Gain (dB)		Total efficiency		Radiation pattern
Frequency (GHz)	Simulated	Measured	Simulated	Measured	Omnidirectional
2.4 GHz	2.87 dB	4.19 dB	78.5%	82.27%	Omnidirectional
5.25 GHz	3.87 dB	4.87 dB	60%	90.42%	Omnidirectional
6.525 GHz	5.76 dB	5.23 dB	61.9%	91.95%	Omnidirectional

3. Conclusion

This research aims to design and develop a rectangular L-shaped microstrip patch antenna for Wi-Fi 6E applications operating at three frequency bands: 2.4 GHz, 5 GHz, and 6 GHz.

1. The simulation results show that the antenna has a first bandwidth in the frequency band ranging from approximately 1.190 to 2.830 GHz, reaching 1.640 GHz, and a second frequency band ranging from 4.12 to 7.02 GHz, reaching 2.900 GHz. The radiation pattern produced is consistently omnidirectional for both bands, and the total efficiency is at frequency 2.4 GHz at 78.5%, frequency 5.25 GHz at 60%, and frequency at 6.525 GHz at 61.9%, respectively. The antenna achieves a gain of 2.4 GHz is 2.87 dB, 5.25 GHz is 4.217 dB, and 6.525 GHz is 6.766 dB.
2. The measurement results show that the antenna's bandwidth in the first band ranges from 1.150 to 3.091 GHz, reaching 1.941 GHz, and in the second band ranges from 3.688 to 7.243 GHz, reaching 3.555 GHz. The radiation pattern remains omnidirectional, and total efficiency for frequency 2.436 GHz is 82.27%, 5.3 GHz is 90.42%, and 6.56 GHz is 91.95%, respectively. The gain of 2.4 GHz is 4.19 dB, 5 GHz is 4.87 dB, and 6 GHz is 5.23 dB.

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References

[1] Afdhal and Elizar. "IEEE 802.11ac sebagai Standar Pertama untuk Gigabit Wireless LAN". In: *J. Rekayasa Elektr.* 11.1 (2014), pp. 36–44.

[2] E. Mozaffariahrar and F. Theoleyre. "A Survey of Wi-Fi 6: Technologies, Advances, and Challenges". In: (2022), pp. 1–52.

[3] J. J. Percy et al. "Wideband Printed Monopole Antenna for Wi-Fi 6E Devices with Broadband Matching Network". In: *IEEE Access* 4.3 (2021), pp. 309–314. doi: 10.1109/WiSPNET51692.2021.9419462.

[4] S. Noghanian. "Dual-Band Wearable MIMO Antenna for Wi-Fi Sensing Applications". In: *Sensors* 22.23 (2022). doi: 10.3390/s22239257.

[5] P. Pradeep, K. Jaya Sankar, and P. Chandra Sekhar. "A Compact Semi-circular Slot MIMO Antenna with Enhanced Isolation for Sub-6 GHz 5G WLAN Applications". In: *Wireless Personal Communications* 125.4 (2022), pp. 3683–3698. doi: 10.1007/s11277-022-09730-x.

[6] Kominfo. *SE 595 2018 wifi AG2018*. Tech. rep. 2018.

[7] R. S. H. K. A. B. A. Mustafa. "Wi-Fi 802.11 ac vs. 802.11 ad Comparative Study". In: *Int. J. Sci. Res.* 4.6 (2015), pp. 1082–1083. url: https://www.ijsr.net/archive/v4i6/SUB155500.pdf.

[8] A. Sharma et al. "Quad-Band Quad-Sense Circularly Polarized Dielectric Resonator Antenna for GPS/CNSS/WLAN/WiMAX Applications". In: *IEEE Antennas Wirel. Propag. Lett.* 19.3 (2020), pp. 403–407. doi: 10.1109/LAWP.2020.2969743.

[9] $Microstrip_Antenna_Design_Handbook$. Book title provided without specific details.

[10] F. Y. Zulkifli et al. “Pengembangan Antena Mikrostrip Susun Dua Elemen Dengan Penerapan Defected Ground Structure Berbentuk Trapesium”. In: *MAKARA Technol. Ser.* 12.2 (2010), pp. 80–85. DOI: 10.7454/mst.v12i2.512.

[11] M. W. Iqbal. “Peningkatan Bandwidth dan Gain Antenna Mikrostrip-Leaky Wave dengan Multislot dan Defected Ground Structure = Bandwidth and Gain Enhancement of Microstrip Leaky-wave Antennas with Multislot and Defected Ground Structure”. Details on this thesis are incomplete. PhD thesis. Year Not Provided.

[12] L. C. Paul et al. “A Compact Wideband Slotted Hexagonal Patch Antenna with a Modified Ground Structure for WiFi-5/6 Communication”. In: *2021 Emerg. Technol. Comput. Commun. Electron. ETCCE 2021*. 2021, pp. 1–5. DOI: 10.1109/ETCCE54784.2021.9689801.

[13] M. Alsukour and Y. S. Faouri. “Side-Edge Dual-Band Antenna for 5G and Wi-Fi 6 Applications”. In: *2022 Microw. Mediterr. Symp.* 2022, pp. 1–4. DOI: 10.1109/MMS55062.2022.9825512.

[14] X. Liu et al. “Quad-Band Circular Polarized Antenna for GNSS, 5G and WIFI-6E Applications”. In: (2022), pp. 1–13.

[15] D. M. Pozar. *Microwave Engineering*. Available online at: https://books.google.co.id/books?id=JegbAAAAQBAJ. Wiley, 2012.