逢 甲 大 學

電 機 工 程 學 系

專 題 論 文

Wi-Fi 6E頻帶之

筆記型電腦天線設計

Laptop Antenna

Design for Wi-Fi 6E Band

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Abstract

The aim of this project is to design a low-profile laptop antenna that can operate in the 2400–2484 MHz and 5150–7125 MHz frequency bands. The antenna is placed on a metal screen with dimensions of 200 × 300 × 0.4 mm^3. The antenna chosen for this purpose is a PIFA (Planar Inverted-F Antenna) antenna with dimensions of 30 × 4 mm^2 and made of FR4 material with a thickness of 0.4 mm. Analyze and adjust the antenna structure so that the 6 dB impedance bandwidth can completely cover the Wi-Fi 6E frequency band. With the increasing popularity of narrow bezel notebook computers, it is necessary to compress the antenna's size within a certain range to accommodate these designs.

Key words : Low-profile、metal-screen、narrow bezel 、PIFA、Wi-Fi 6E

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Abbreviations and Symbol Key

5G	**5th Generation Mobile Communication**
Ant.	**Antenna**
Wi-Fi 6E	**Wireless Fidelity 6 Extension**
Ref.	**Reference**
GHz	**Gigahertz (units of frequency)**
MHz	**Megahertz (units of frequency)**
Ansoft HFSS	**Ansoft High Frequency Structural Simulator**

Chapter 1
Introduction

1.1 Research Motivation

In recent years, the development of new communication devices has been focused on achieving both slim and lightweight designs while enhancing overall quality. Compressing the dimensions of essential components like antennas has become a crucial problem in this endeavor. For the proposed project, which involves incorporating an antenna into narrow-bezel laptops while covering two frequency bands, 2400–2484 MHz and 5150–7125 MHz, the use of a PIFA (Planar Inverted-F Antenna) with the capability of multi-band operation and high design flexibility is indeed a suitable choice. It's worth noting that wavelength is a critical factor influencing antenna characteristics. Unlike other components, antennas can't be easily scaled down according to requirements. The most significant challenge in antenna design remains finding the optimal balance between size and antenna performance.

1.2 Research purposes

Designing this PIFA antenna to accommodate narrow-bezel laptop designs, metal enclosures, and adhere to the Wi-Fi 6E frequency bands (lower range: 2400–2484 MHz /higher range: 5150–7125 MHz). Additionally, the antenna's height needs to be compressed to just 4 mm to make the most efficient use of limited space.

Chapter 2
Design of Laptop Antenna for Wi-Fi 6E Frequency Band

2.1 Antenna Structure

Figure 2.1 illustrates the front view dimensions of the proposed antenna and its conceptual application in a laptop. To accommodate the trend of narrow-bezel laptop designs, the antenna element dimensions are 28 × 2.875 mm^2, and an FR4 substrate with a thickness of 0.4 mm is utilized. The substrate size is 30 × 8 mm^2 with a dielectric constant of 4.4 and a tangent loss of 0.02.

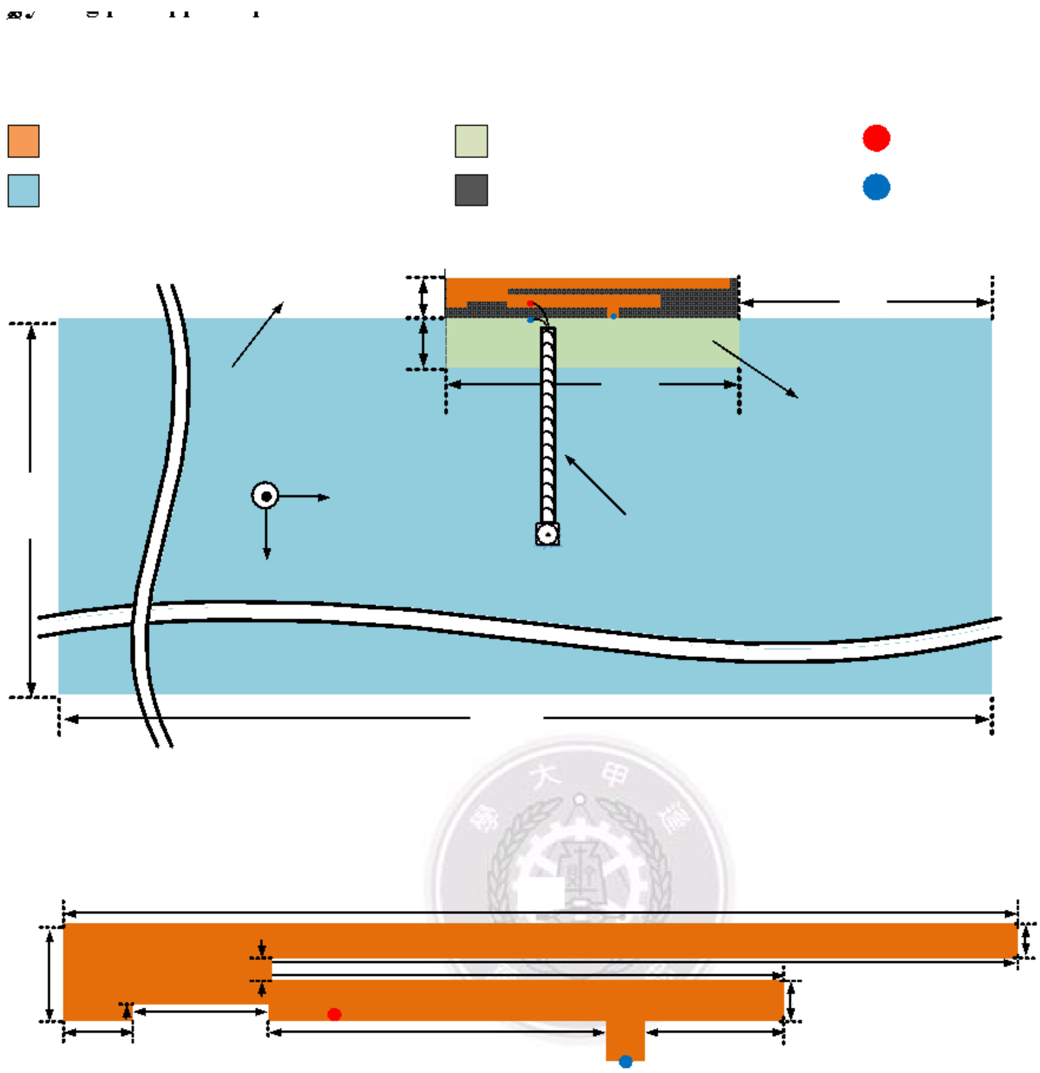


Figure 2.1 Structure of the Proposed Antenna

(a) Laptop Structure, (b) Front View Dimensions of Antenna Elements

(Units: mm)

2.2 Design Process of the Proposed Antenna

Figure 2.2 depicts the design process flowchart of the proposed antenna. Initially, Reference 1, a PIFA antenna, was designed to generate two modals at 4.12 GHz and 6.14 GHz. These two modals slightly exceeded the frequencies of the WLAN 5 GHz and 6 GHz bands at the higher frequency range and lacked coverage in the lower frequency range. Subsequently, in Reference 2, a groove was introduced in the middle section of the antenna element. This modification resulted in the emergence of four distinct modals at 2.28 GHz, 4.2 GHz, 5.9 GHz, and 7.28 GHz. While these changes managed to excite the lower frequency range, the design still fell slightly short of covering the WLAN 2.4 GHz band due to the lower frequency bias. In the higher frequency range, the modals were still slightly higher and unable to fully encompass the WLAN 5 GHz and 6 GHz bands. Continuing with Reference 3, the lower rectangular portion was shortened, resulting in three modals at 2.48 GHz, 5.68 GHz, and 6.52 GHz. Not only did this adjustment effectively cover the entire WLAN 2.4 GHz band in the lower frequency range, but more importantly, it optimized the matching in the higher frequency range. This refinement led to a bandwidth in the higher frequencies that was sufficient to encompass the WLAN 5 GHz and 6 GHz bands, albeit slightly higher. As a result, the final antenna design presented in this paper introduced an additional groove beneath the antenna element. This extension of the current path effectively shifted the higher frequency modals slightly towards the lower part. This adjustment precisely aligned all generated modals with the Wi-Fi 6E frequency bands.

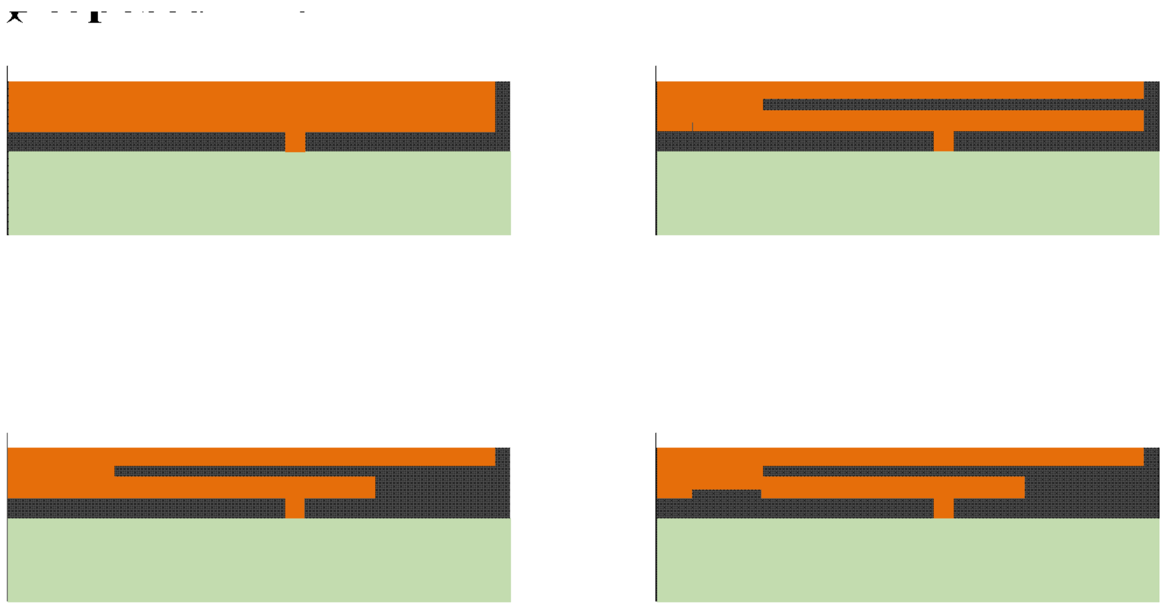


Figure 2.2 Figure of the Design Process for the Proposed Antenna

(a) Ref.1, (b) Ref.2, (c) Ref.3, (d) Proposed Ant.

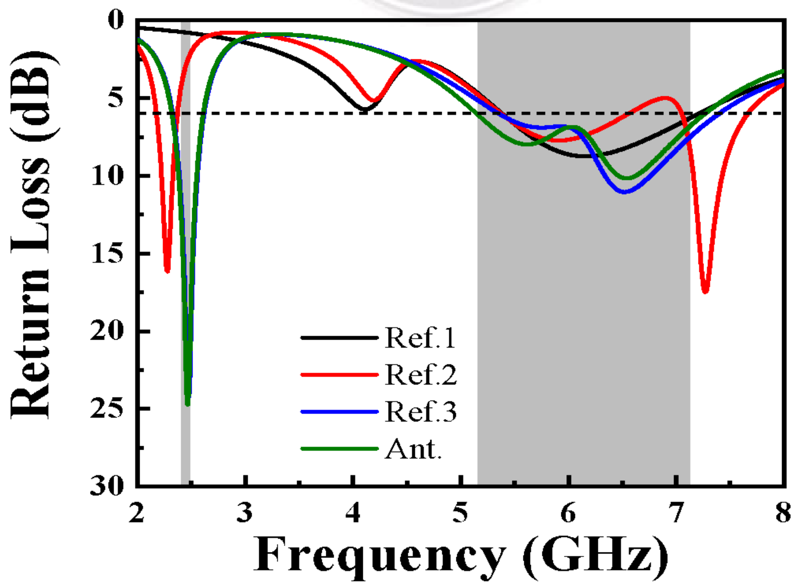


Figure 2.3 Figure of Return Loss Simulation in the Proposed Antenna Design Process

2.3 Simulation and Analysis of the Proposed Antenna Parameters

2.3.1 Analysis of the Impact of Parameter L_1

The parameter analysis of L_1 involves adjusting the length of the groove structure in the proposed antenna. The length of L_1 is modified in increments of 2 mm, ranging from 20 mm to 24 mm, and subjected to parameter analysis. It was observed that the main differences occurred primarily in the lower frequency range. When L_1 is set to 20 mm, the 6 dB impedance bandwidth in the lower frequency range covers 2450–2770 MHz, with the modal point around 2620 MHz; When L_1 is set to 24 mm, the 6 dB impedance bandwidth in the lower frequency range covers 2200–2470 MHz, with the modal point around 2340 MHz; However, when L_1 is set to 22 mm, it precisely achieves the 6 dB impedance bandwidth required for the lower frequency operation. Therefore, 22 mm is chosen as the length for L_1.

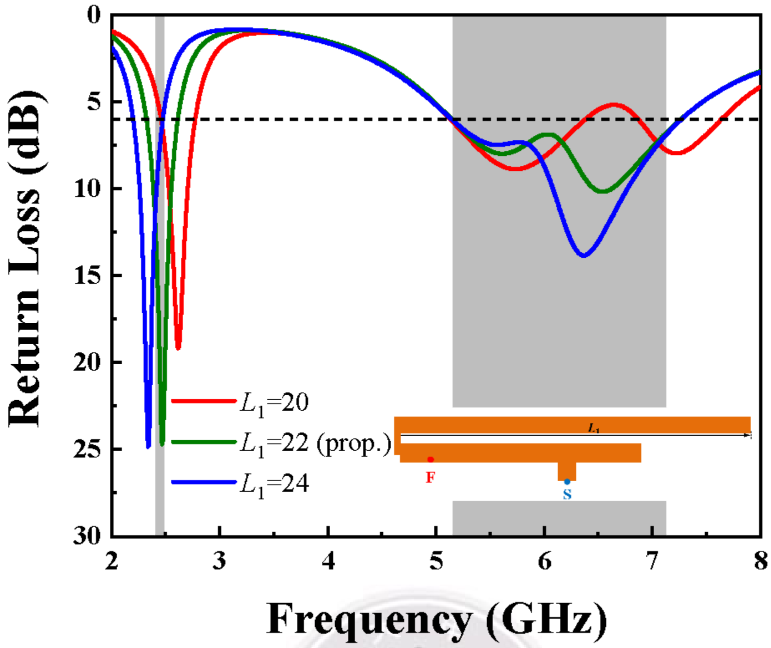


Figure 2.4 Figure of Return Loss Simulation for Analysis of Parameter L_1 in the Proposed Antenna Design (Units: mm)

2.3.2 Analysis of the Impact of Parameter L_2

The parameter analysis of L_2 involves adjusting the length of the rectangular structure in the proposed antenna. The length of L_2 is modified in increments of 1 mm, ranging from 14 mm to 16 mm, and subjected to parameter analysis. It was observed that the main differences occurred primarily in the higher frequency range. When L_2 is set to 14 mm, the 6 dB impedance bandwidth in the higher frequency range covers 5190–7480 MHz, with two modal points at 5640 MHz and 6840 MHz, respectively; When L_2 is set to 16 mm, the 6 dB impedance bandwidth in the higher frequency range covers 5170–7390 MHz, with two modal points at 5640 MHz and 6600 MHz, respectively; However, when L_2 is set to 15 mm, it precisely achieves the 6 dB impedance bandwidth required for the higher frequency operation. Therefore, 15 mm is chosen as the length for L_2.

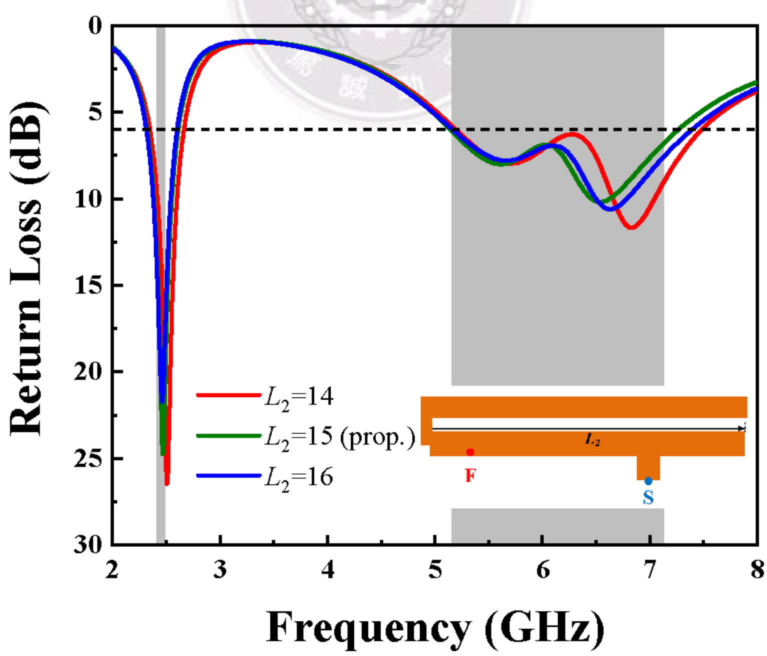


Figure 2.5 Figure of Return Loss Simulation for Analysis of Parameter L2 in the Proposed Antenna Design (Units: mm)

2.3.3 Analysis of the Impact of Parameter *W*

The parameter analysis of *W* involves adjusting the width of the rectangular structure inside the groove designed next to the feed point in the proposed antenna. The width of *W* is modified in increments of 0.3 mm, ranging from 0.2 mm to 0.8 mm, and subjected to parameter analysis. It was observed that the main differences occurred primarily in the higher frequency range. When *W* is set to 0.2 mm, the 6 dB impedance bandwidth in the higher frequency range covers 5290–7530 MHz, with two modal points at 5740 MHz and 6700 MHz, respectively; When *W* is set to 0.8 mm, the 6 dB impedance bandwidth in the higher frequency range covers 5060–6070 MHz and 6280–7310 MHz, with two modal points at 5540 MHz and 6740 MHz, respectively; However, when *W* is set to 0.5 mm, it precisely achieves the 6 dB impedance bandwidth required for the higher frequency operation. Therefore, 0.5 mm is chosen as the width for *W*.

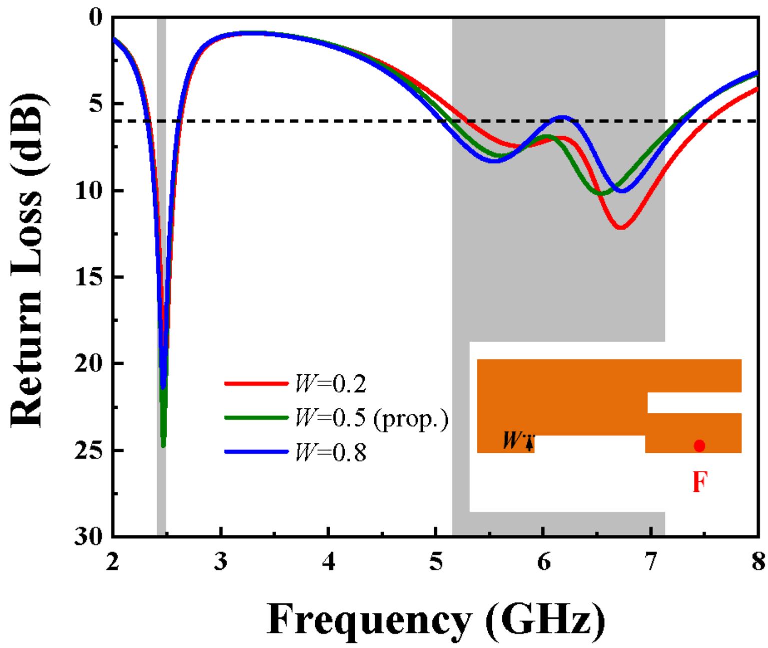
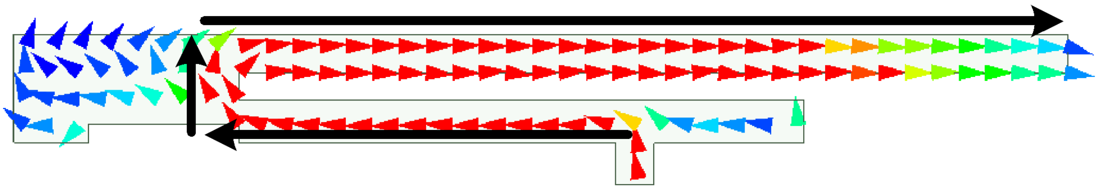


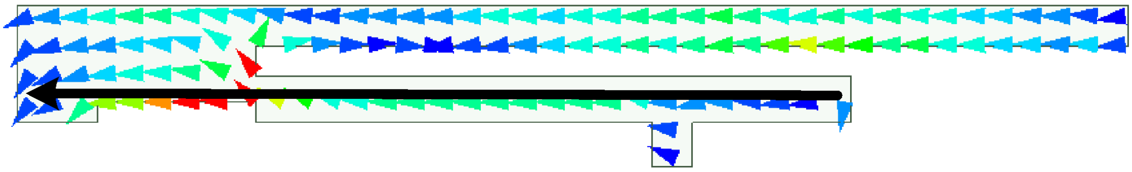
Figure 2.6 Figure of Return Loss Simulation for Analysis of Parameter *W* in the Proposed Antenna Design (Units: mm)

2.3.4 Current Analysis

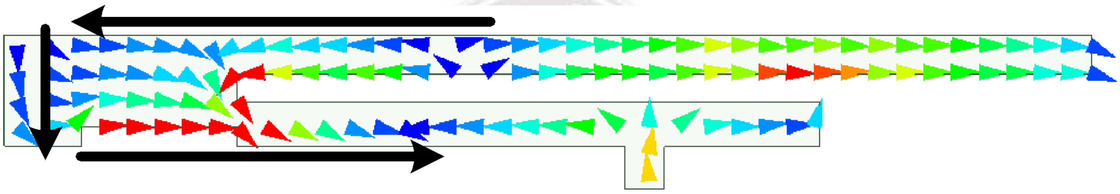
Figure 2.7 depicts the simulated current analysis of the proposed antenna at different frequencies. The analysis was conducted using Ansys HFSS 2021 R1 simulation software, providing insights into the excitation process of each resonant modal. Due to mutual coupling between antenna elements and the presence of dielectric material, the radiation characteristics of the antenna can be affected. As a result, the actual current path length may not correspond precisely to theoretical values. Therefore, the wavelength within the dielectric medium is used to estimate the current path. Figure 2.7(a) shows the current distribution at 2.46 GHz. It can be observed that the current flows from point A to point D along the indicated arrows, creating a resonant modal with a path length of approximately one-quarter wavelength, about 35 mm (0.28λg). Figure 2.7(b) shows the current distribution at 5.58 GHz. It can be observed that the current flows from point F to point E along the indicated arrows, creating a resonant modal with a path length of 21 mm (0.4λg). Figure 2.7(c) shows the current distribution at 6.52 GHz. The current flows from point G to point I, resulting in a resonant modal with a path length of approximately 21 mm (0.46λg).



(a)



(b)



(c)

Figure 2.7 Figure of Simulated Current Distribution of the Proposed Antenna (a)2.46 GHz, (b)5.58 GHz, (c)6.52 GHz

2.4 Antenna Simulation Results

Figure 2.8 presents the results of the 6 dB impedance bandwidth simulation for the proposed antenna using Ansys HFSS 2021 R1 software. As shown in Figure 2.8, the simulated 6 dB impedance bandwidth of the proposed antenna covers the lower frequency range of 2320–2610 MHz and the higher frequency range of 5140–7270 MHz. The mode centers are at 2460 MHz in the lower frequency range and 5580 MHz / 6520 MHz in the higher frequency range, which effectively encompasses the Wi-Fi 6E frequency bands (lower range: 2400–2484MHz/higher range:5150–7125MHz).

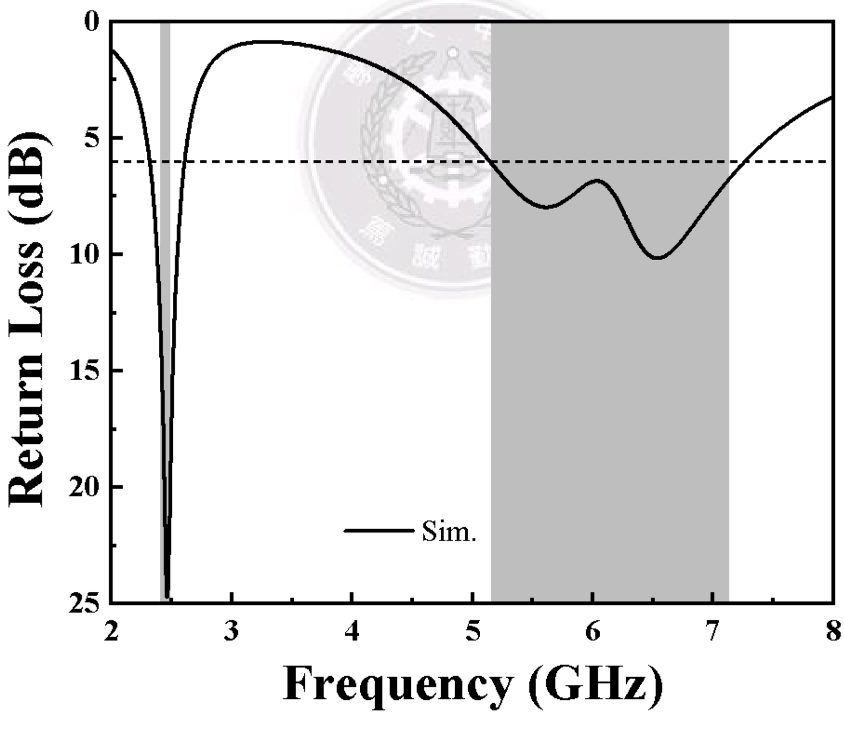


Figure 2.8 Figure of Simulated Return Loss of the Proposed Antenna

The measured gain of the proposed antenna within the low-frequency WLAN 2.4 GHz band ranges from 3.77 to 4.01 dBi, with an efficiency of approximately 80.69 to 84.03%. In the WLAN 5 GHz band, the measured gain falls between 3.30 and 4.81 dBi, with an efficiency of around 72.24 to 82.12%. Within the WLAN 6 GHz band, the measured gain ranges from 2.54 to 4.08 dBi, with an efficiency of about 75.77 to 89.22%.

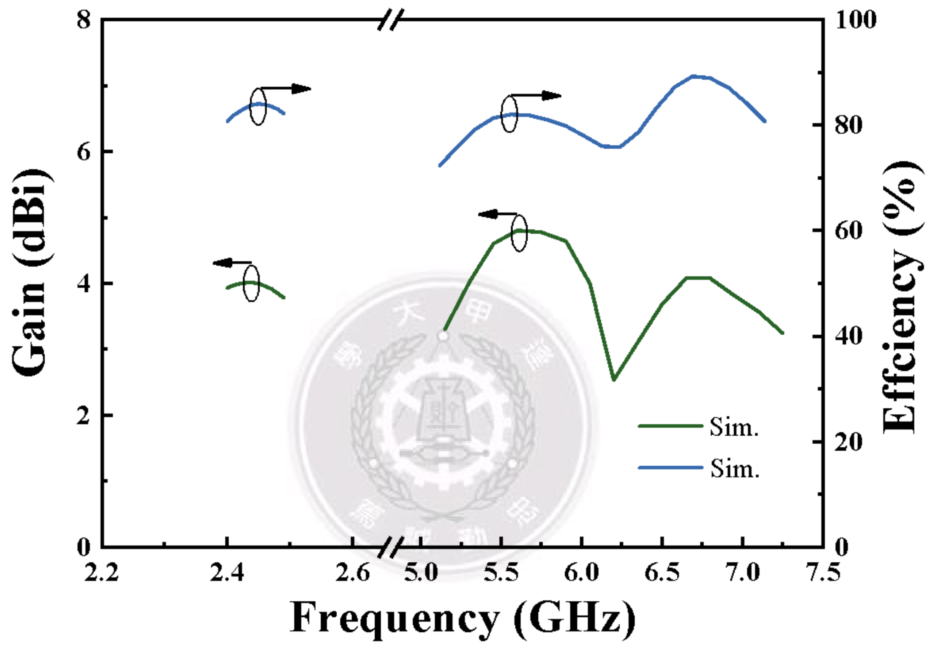
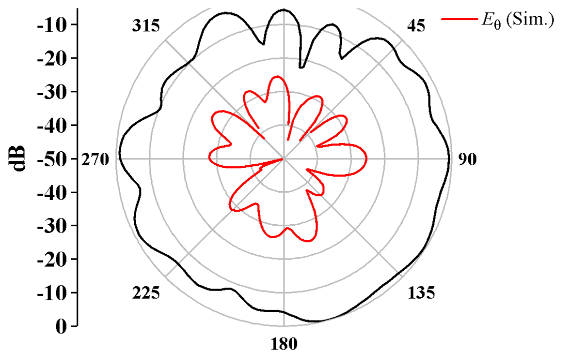
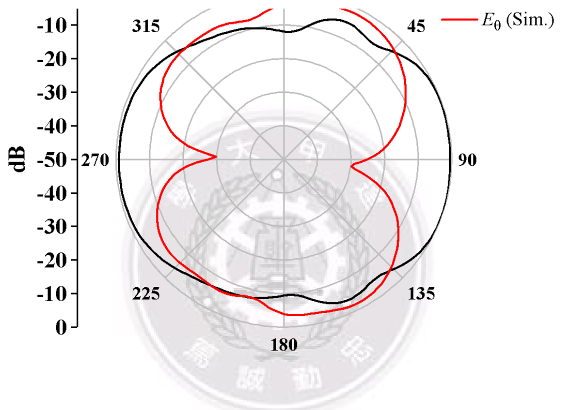


Figure 2.9 Figure of Simulated Gain of the Proposed Antenna

The simulated and measured radiation patterns of the proposed antenna are illustrated in Figures 2.10, 2.11, and 2.12, corresponding to frequencies f_1 (2.46 GHz), f_2 (5.58 GHz), and f_3 (6.52 GHz), respectively. The simulation and measurement results demonstrate a high degree of consistency. From Figure 2.10, it can be observed that the antenna radiates in the -X direction at f_1 (2.46 GHz). Similarly, Figure 2.11 indicates that the antenna radiates in the -X direction at f_2 (5.58 GHz), while Figure 2.12 reveals radiation in the -Z direction at f_3 (6.52 GHz).



(a)



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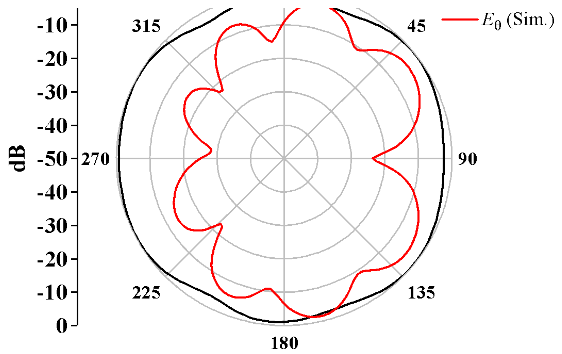
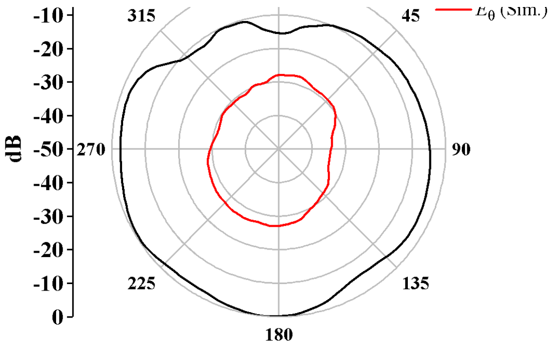
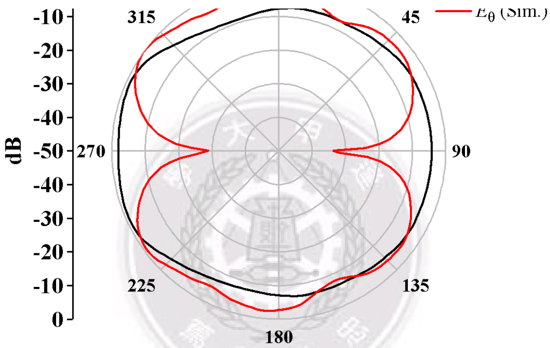


(c)

Figure 2.10 Figure of Simulated Normalized Radiation Pattern of the Antenna at 2.46 GHz (a)XY Plane, (b)YZ Plane, (c)XZ Plane



(a)



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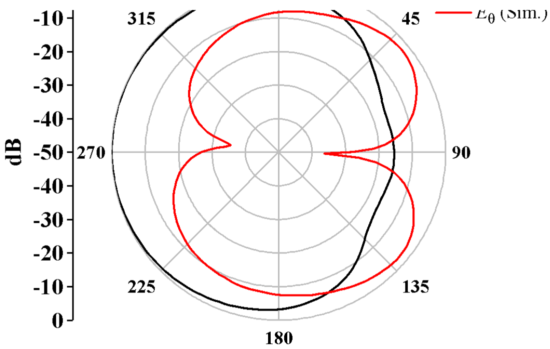
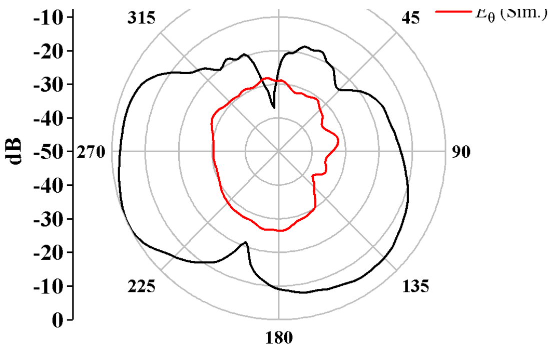
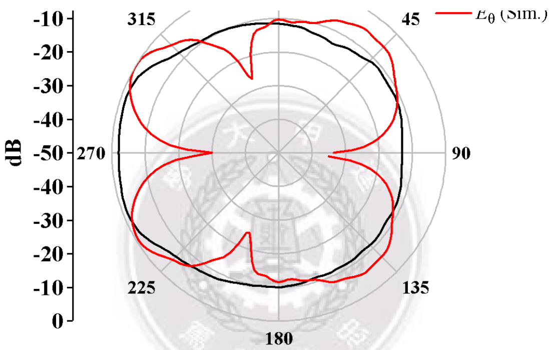


(c)

Figure 2.11 Figure of Simulated Normalized Radiation Pattern of the Antenna at 5.58 GHz(a)XY Plane, (b)YZ Plane, (c)XZ Plane



(a)



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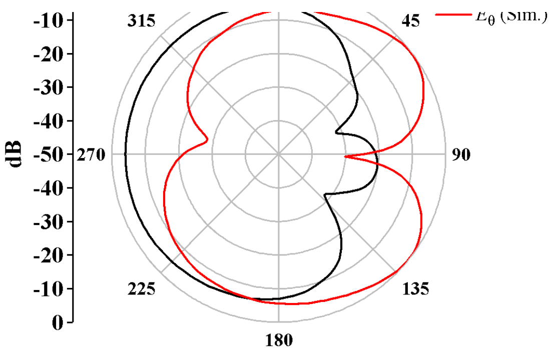

(c)

Figure 2.12 Figure of Simulated Normalized Radiation Pattern of the Antenna at 6.52 GHz (a)XY Plane, (b)YZ Plane, (c)XZ Plane

2.5 Comparison between Antenna Simulation and Measurement

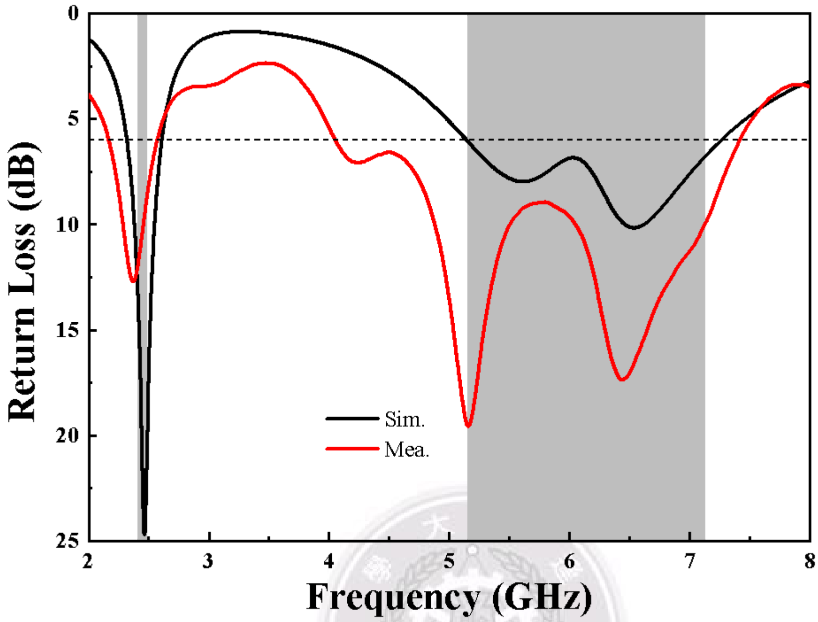

Figure 2.13 Proposed Antenna

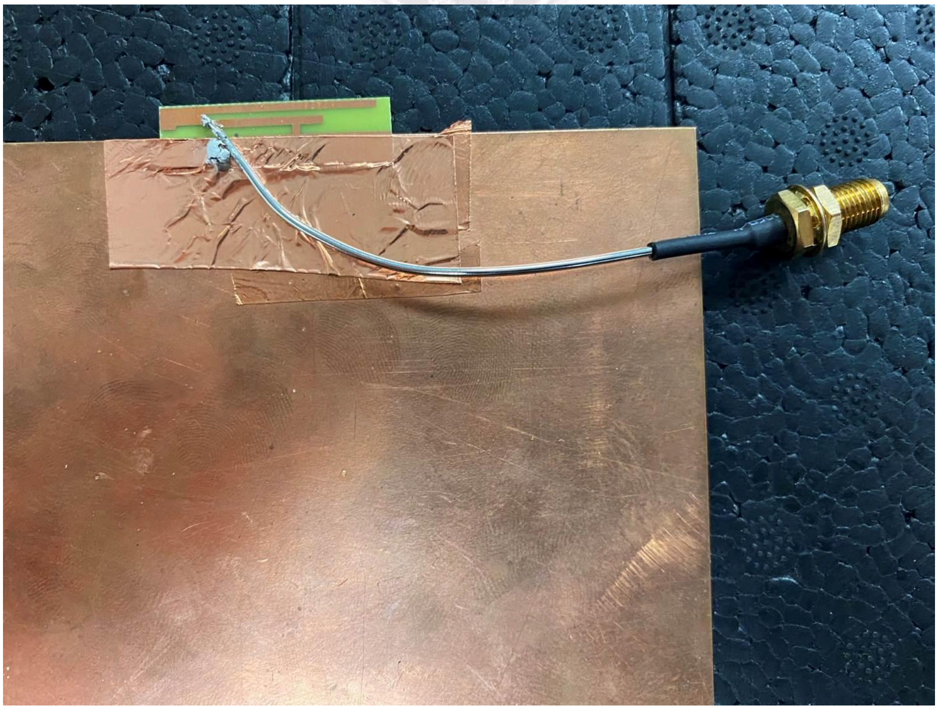

Figure 2.14 Figure of Implementation of the Proposed Antenna

Chapter 3
Conclusion and Future Outlook

3.1 Conclusion

This project introduces a low-profile PIFA antenna suitable for laptop applications, successfully covering the Wi-Fi 6E frequency bands (lower range: 2400 – 2484 MHz / upper range: 5150 – 7125 MHz). The antenna is designed to comply with the trend of narrow-bezel laptop designs, with the substrate height restricted to 4 mm and the antenna element height at just 2.875 mm.

3.2 Future Outlook

This project has successfully accomplished the design of antennas with a height below 4 mm. In the future, laptop designs are undoubtedly trending toward even narrower bezels. As such, compressing antenna dimensions will become increasingly crucial. Shrinking antenna size further is a challenging task due to the optimal balance that needs to be achieved between size and antenna performance, considering mutual coupling effects among antennas. Thus, the goal is to design antennas with heights compressed to 3 mm or even lower, pushing the boundaries of narrow-bezel laptop designs to new heights.

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