Compact Asymmetric T-Feed Closed-Slot Antennas for 2.4/5/6 GHz WiFi-7 MIMO Laptops

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Abstract: In this paper, we introduce a closed-slot WiFi-7 multi-input multi-output (MIMO) system equipped with six antennas, designed specifically for laptop integration. Positioned near the lower edge of the laptop’s display ground plane, the antennas are placed 2.5 mm from the hinge and 8 mm from the left side of the ground plane. Each antenna features a $44 \times 2 \text{ mm}^2$ closed-slot structure with a simple T-shaped feeder that stimulates half-wavelength and full-wavelength resonances via feed-in coupling. The six antennas are aligned in parallel, spaced 4 mm apart, forming a compact array without the need for additional isolation components. This setup supports dual-band functionality across both 2400–2500 MHz and 5150–7125 MHz WiFi-7 bands. Performance assessments indicate a minimum of 10 dB isolation between the antennas and envelope correlation coefficients (ECC) of the radiation patterns being below 0.04. Furthermore, the antenna array’s radiation efficiency was measured to be over 64%.

Keywords: laptop antennas; WiFi-7 antennas; slot antennas; multi-input multi-output (MIMO) antennas

1. Introduction

Recently, the Federal Communications Commission has approved additional unlicensed frequency spectrum in the 5925–7125 MHz range and provided 1.2 GHz of bandwidth for the new 6 GHz band. WiFi-7, an evolution of the IEEE 802.11 standard, introduces significant advancements in wireless communication by operating across multiple frequency bands, including 2400–2484 MHz, 5150–5825 MHz, and 5925–7125 MHz. Unlike WiFi-6E, which first unlocked the potential of the 6 GHz band, WiFi-7 expands on this foundation, offering even greater throughput and reduced latency. These enhancements position WiFi-7 to support gigabit-level data rates, making it suitable for many high-demand applications. Moreover, WiFi-7 leverages advanced technologies, such as wider channel bandwidths and improved modulation schemes, to deliver superior performance. Multiple-input multiple-output (MIMO) techniques are used to increase further transmission speed and throughput [1].

Recent rapid upgrades in technology products have resulted in the production of laptop computers with fast transmission speeds and increasing functional requirements that require the integration of additional modules. Moreover, most laptop consumers desire computers with narrow bezels. Installing an antenna with a sufficiently low profile to fit in the limited space of a narrow-bezel frame to achieve rapid transmission in a MIMO system configuration is challenging.

Before the addition of the 6 GHz (5925–7125 MHz) bands, laptop antennas mainly covered three wire local area network (WLAN) bands, which were 2400–2484 MHz, 5150–5350 MHz, and 5725–5875 MHz. Most laptop antennas are installed at the clearance area above the display ground plane [2–11]. These antennas are mainly planar inverted-F antennas with monopole and loop structure designs. In [7], the antenna with the lowest
profile height (3 mm) was developed. Its overall dimensions were 35 mm × 3 mm. In addition to its small dimensions and low-profile design, the antenna had a double-sided printed design that required multiple via holes. Hence, manufacturing this antenna is difficult. In [10], a novel asymmetric antenna structure design suitable for MIMO laptop applications covering WLAN 2.4/5.2/5.8 GHz and WRC 5G C-bands has been proposed. The antenna’s physical dimensions are 50 × 6.5 × 2.8 mm³. The design features two distinct structures: a PIFA (Planar Inverted-F Antenna) and a coupled-fed loop antenna. However, the design proportions still need optimization for devices with a high screen-to-body ratio. Closed-slot antenna designs are also suitable for laptop computers with metal backcases [11]. The slot antenna dimensions of 70 mm × 2 mm must be further reduced to facilitate multi-antenna configurations.

Recently, a few WiFi-6E/WiFi-7 antenna designs that can use multiple 2.4/5/6 GHz bands have been reported [12–19]. These antennas must not only cover the 6 GHz (5925–7125 MHz) bands and WLAN bands but must also maintain a low profile to be suitable for narrow-bezel displays. In [12], a hybrid slot-dipole-monopole antenna has been developed for Wi-Fi 7 notebook applications. This design features an open slot, a coupled strip resonator, and a T-shaped feed, which are all implemented on two layers of the substrate. In [13], a metamaterial-inspired antenna for Wi-Fi 7 bands is proposed. It features a meta-structured loop with series interdigital capacitors and a parasitic shorted strip, all integrated into a coplanar structure on a single substrate layer. In [17], the proposed antenna is positioned at the upper edge of a metallic ground plane measuring 200 × 300 × 0.4 mm³. With dimensions of 30.5 × 3.5 mm², this antenna is capable of exciting three resonance modes, ensuring comprehensive coverage of the Wi-Fi 7 operating band. However, the extended ground plane has two via holes for shorting to the system ground and has complicated structures. Among these studies, only refs. [15,18,19] have considered the compact configuration of dual antennas. However, none have explored a design that could be integrated within metal environments or addressed the needs of multi-antenna systems with at least four antennas.

In previous research work [20], a clearance space of 217 × 3 mm² at a position 1 mm from the upper edge and 40 mm from the left edge of the screen ground plane was intended for the installation of a 5G MIMO six-antenna system. However, this antenna configuration is positioned at the upper edge of the display, without considering placement near the hinge at the lower edge of the display. The hinge area is usually a relatively unused space in laptop design, and placing the antenna there can effectively utilize the available space. Nevertheless, the hinge and surrounding metal structures can interfere with the antenna’s radiation pattern, potentially leading to reduced efficiency and signal distortion, posing a design challenge.

This paper proposes a closed-slot antenna structure for closed-slot WiFi-7 six-antenna systems applicable in laptops. In the proposed configuration, the antennas are located near the bottom of the display ground plane with distances of 2.5 mm from the hinge and 8 mm to the left side of the ground plane. The dimensions of the six-antenna unit are 284 × 2 mm², and each closed-slot antenna exhibits the dimensions of 44 × 2 mm² as a rectangular structure. A simple T-shaped feeding part within the slot structure is installed to excite the resonance modes at half-wavelength and full-wavelength through coupling. Single-slot antennas are arranged to face the same direction, forming a six-antenna unit with a parallel layout and with an interval of 4 mm. Testing of the proposed configuration revealed that without using isolation components, the six-antenna system achieved dual-band operations covering the 2400–2500 MHz and 5150–7125 MHz WiFi-7 bands. The measured isolation was greater than or equal to 10 dB. From the measured radiation patterns, the envelope correlation coefficient (ECC) values were found to be less than 0.04, while the radiation efficiency of the six antennas achieved greater than 64%.
2. Proposed MIMO Antenna System Design

Figure 1a presents the overall structure of the closed-slot WiFi-7 MIMO six-antenna for a laptop. The design dimensions of the keyboard and display ground planes are $300 \times 200 \text{ mm}^2$, comparable to those of a commercial 13-inch laptop. The ground planes were created using copper sheets. The proposed six MIMO antennas are installed at a location near the bottom of the display ground plane. The antennas are located at distances of 2.5 mm and 8 mm from the hinge and the left side of the plane, respectively. The six antennas were separately named Ant 1, Ant 2, Ant 3, Ant 4, Ant 5, and Ant 6. The dimensions of the six-antenna unit are $284 \times 2 \text{ mm}^2$. The proposed six-antenna unit comprises six closed-slot antennas with identical structures and sizes, and the antennas are arranged to face the same direction in a parallel layout with 4-mm intervals. All the six antennas cover the 2400–2500 MHz and 5150–7125 MHz WiFi-7 bands. The width of the six-antenna unit is only 2 mm; hence, it is suitable for applications in laptops with high screen-to-body ratios and narrow-bezel frames, enabling maximizing usable display area.

Figure 1. (a) The overall structure and (b) the actual measurement configuration of the WiFi-7 MIMO six-antenna system.
Figure 2 presents the detailed schema of a single WiFi-7 closed-slot antenna. In this paper, Ant 1 is used for structural depiction of a single antenna because the other antennas have the same structure and dimensions. Each closed-slot antenna is a rectangular structure with dimensions of $44 \times 2 \text{ mm}^2$. An asymmetric T-shaped feeding part is installed in the slot structure to excite closed-slot resonance modes by coupling to cover the 2400–2500 MHz and 5150–7125 MHz WiFi-7 bands. The feeding part is printed on a FR4 glass fiber substrate with a thickness of 0.4 mm and an area of $10 \times 6 \text{ mm}^2$. The relative dielectric constant was measured to be 4.4, and the loss tangent was 0.02. The feeding part is installed at a location 13 mm from the left side of the slot on the display ground plane. On the upper and lower regions of the FR4 substrate, 2-mm-thick ground pads are closely connected to the ground plane. The T-shaped feeding part features a coupling metal part of 9 mm in length and 0.5 mm in width. The metal part exhibits a coupling interval of 0.3 mm from the upper ground pad. In Figure 2, point A represents the signal feeding point which connects to the inner conductor of the 50-Ω mini coaxial line. The 50-Ω mini coaxial line outer conductor was connected to the grounding point G on the metal ground plane of the display.

Figure 2. Detailed schematic of a single WiFi-7 closed-slot antenna.

The rectangular slot antenna is designed to use an asymmetric T-shaped coupling feeding part to excite the rectangular slot structure and cover the required bands of 2400–2500 MHz and 5150–7125 MHz. The antenna excites the quarter-wavelength resonance of the slot path (mode 1) at 2460 MHz to cover the 2400–2500 MHz low-frequency band. The antenna also excites the full-wavelength single mode and dual-resonance mode (mode 2 and mode 3, respectively) to cover the 5150–7125 MHz high-frequency band. Detailed information of the proposed configuration and relevant data analyses are described in subsequent sections.

3. Experiment and Measurement Results

Figure 1b illustrates the total configuration of the proposed MIMO six-antenna system. Figure 3 presents the structure a single closed-slot antenna. Its dimensions are as provided in Figure 1a. ANSYS HFSS (Version 18) was used to simulate the antenna design [21]. A threshold of lower than $-10 \text{ dB}$ was used to configure reflection coefficients [2–10]. This threshold was selected for the simulation and actual measurement of the antenna operation because it facilitates the measurement of antenna efficiency. In addition, the transmission coefficients for the proposed antennas were designed to be less than $-10 \text{ dB}$ [8].

Figure 3. Photograph of a single WiFi-7 closed-slot antenna.

Figure 4 shows the six-antenna MIMO system’s measured and simulated reflection coefficients. The results demonstrated that the system could cover the dual-band...
2400–2500 MHz and 5150–7125 MHz WiFi-7 operation. A resonance mode occurred at the low-frequency band, while two resonance modes were observed at the high-frequency band. The simulated and measured data were generally consistent. The measured reflection coefficients were all greater than $-10$ dB. Figure 5 presents the simulated and measured transmission coefficients of the MIMO six-antenna system. To avoid an excessive number of curves impairing the readability of the figure, the transmission coefficients were selected by considering the fact that the transmission coefficient of two neighboring antennas (i.e., $S_{12}$, $S_{23}$, $S_{34}$, $S_{45}$, or $S_{56}$) will be higher than that of two antennas that are more than one interval apart (i.e., $S_{13}$, $S_{24}$, $S_{35}$, $S_{46}$, or $S_{14}$). Thus, all transmission coefficients of two neighboring antennas are displayed in the figure. Nevertheless, to verify that the transmission coefficient of two antennas that are more than one interval apart is lower than that of two neighboring antennas, the transmission coefficient of Ant 1 and Ant 3 (i.e., $S_{13}$) was measured and compared with those of two neighboring antennas (i.e., $S_{12}$, $S_{23}$, $S_{34}$, $S_{45}$, and $S_{56}$). Figure 5 reveals that the simulated are measured transmission coefficients between Ant 1 and Ant 3 ($S_{13}$) were lower than those of the neighboring antennas ($S_{12}$, $S_{23}$, $S_{34}$, $S_{45}$, and $S_{56}$). Additionally, the simulated transmission coefficients of the MIMO six antennas in the 2400–2500 MHz and 5150–7125 MHz bands were typically better than $-10$ dB, with $S_{12}$ and $S_{56}$ demonstrating $-9.5$ dB or above. The measured transmission coefficients of these antennas can be above $-10$ dB, indicating their suitability for actual applications [12–17].

![Diagram](image-url)

**Figure 4.** MIMO six-antenna (a) simulated and (b) measured reflection coefficients.
Aside from the isolation between antennas, the associated ECC is another critical parameter in MIMO antenna systems. Generally, an ECC value lower than 0.5 (the log value of 0.5 taken as the base 10 is approximately $-0.3$) is considered suitable for practical applications [22]. Figure 6 presents the ECC (logarithmic scale) for the measured and simulated radiation patterns of the MIMO six-antenna system. The adopted antenna combinations were identical to those for measuring the transmission coefficients. The results revealed that the ECC (logarithmic scale) values of the simulated and measured radiation patterns were lower than 0.04 (the log value of 0.04 taken as the base 10 is approximately $-1.4$), verifying that the MIMO six-antenna system has a favorable channel independency between antennas. The values of Ant 2–Ant 3, Ant 3–Ant 4, and Ant 4–Ant 5 were higher than those of Ant 1–Ant 2 and Ant 5–Ant 6 primarily because of the configuration locations. Specifically, because Ant 1 and Ant 6 had no neighboring antenna on one side, they were less affected by other antennas. Thus, Ant 1–Ant 2 and Ant 5–Ant 6 exhibited superior ECC values than other antenna combinations. Moreover, variations in the simulated and measured ECC values were consistent. Although the six antennas shared the same structure, the ECC values of each antenna differed; this may be due to their differing locations on the ground plane.
Next, the radiation patterns of the six-antenna unit were determined. Figure 7 presents the simulated and measured three-dimensional (3D) radiation patterns of the six antennas operated at 2460, 5700, and 7100 MHz. The antenna radiation pattern measurements were conducted using a measurement system that includes the NSI 800F-10 measurement system, WavePro FFC-700 microwave anechoic chamber, and Agilent PNA-L microwave signal measurement equipment. The radiation patterns of the integrated MIMO antenna, simulated under Ant-1 excitation with 50 Ω load, are presented in a 2-D format in the xy, xz, and yz planes. Figure 7 shows the patterns for three frequencies. The $|E_\theta|$ and $|E_\phi|$ components are fairly comparable. For practical laptop applications, the pattern in the azimuth plane (i.e., the xy plane) is typically examined more closely than the patterns in the other two planes [23]. Figure 8 reveals that the MIMO antenna system’s far-field radiation patterns operating at 2460, 5700, and 7100 MHz were broadly similar but had some differences; these differences may be attributable to the slightly different locations of the antennas on the ground plane.

Figure 9 presents the measured antenna efficiency of the six MIMO antennas. These were 64–80% at the low-frequency band and 82–92% at the high-frequency bands, indicating favorable performance. In addition, at low-frequency bands, the efficiencies of Ant 1 and Ant 6 were substantially higher than those of other antennas. This might be attributable to the locations of Ant 1 and Ant 6. They had only one neighboring antenna, resulting in less interference from other antennas. Moreover, the side without a neighboring antenna had more ground plane intervals, which improved the uniformity of the ground plane current distribution. Hence, Ant 1 and Ant 6 had higher efficiency than the other antennas. The simulated and measured data had some inconsistencies. This may be because the transmission cable and its length were not considered in the simulation. Moreover,
in practice, soldering or FR4 substrate and copper sheet parameters might cause slight deviations between the simulation and reality.

**Figure 7.** Simulated 2D radiation patterns of the six antennas at 2460, 5700, and 7100 MHz when Ant 1 is excited in a 50 Ω load.

**Figure 8.** (a) Simulated and (b) measured 3D radiation patterns of the six antennas at 2460, 5700, and 7100 MHz.
Figure 9. (a) Simulated and (b) measured efficiency of the six antennas.

Table 1 presents a performance comparison between the proposed antenna with six MIMO antennas and those reported in [4,5,12–19]. Compared to related literature, this antenna system features a combination of up to six antennas and a low profile of only 2 mm, while maintaining excellent radiation efficiency. This makes it highly suitable for applications such as narrow-bezel laptop screens.

Table 1. Performance comparison of proposed six MIMO system and references.

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Single Antenna Size (mm)</th>
<th>Operating Bands</th>
<th>Efficiency</th>
<th>MIMO Antenna System</th>
</tr>
</thead>
<tbody>
<tr>
<td>[4]</td>
<td>6 × 20</td>
<td>2.4/5.2/5.8 GHz</td>
<td>≥84%</td>
<td>N/A</td>
</tr>
<tr>
<td>[5]</td>
<td>5 × 37.5</td>
<td>2.4/5.2/5.8 GHz</td>
<td>Not shown</td>
<td>N/A</td>
</tr>
<tr>
<td>[12]</td>
<td>4.6 × 15</td>
<td>2.4/5.2/6.4 GHz WiFi-7</td>
<td>≥55%</td>
<td>N/A</td>
</tr>
<tr>
<td>[13]</td>
<td>5.4 × 19.6</td>
<td>2.4/5.2/6 GHz WiFi-7</td>
<td>≥55%</td>
<td>N/A</td>
</tr>
<tr>
<td>[14]</td>
<td>4 × 16</td>
<td>2.4/5/6 GHz WiFi-6E</td>
<td>≥47%</td>
<td>N/A</td>
</tr>
<tr>
<td>[15]</td>
<td>5 × 14.5</td>
<td>2.4/5/6 GHz WiFi-6E</td>
<td>≥50%</td>
<td>Two MIMO antennas</td>
</tr>
<tr>
<td>[16]</td>
<td>5 × 10</td>
<td>2.4/5/6 GHz WiFi-6E</td>
<td>≥45%</td>
<td>N/A</td>
</tr>
<tr>
<td>[17]</td>
<td>3.5 × 30.5</td>
<td>2.4/5/6 GHz WiFi-7</td>
<td>≥49%</td>
<td>N/A</td>
</tr>
<tr>
<td>[18]</td>
<td>4 × 10.5</td>
<td>2.4/5.5/6.5 GHz WiFi-6E</td>
<td>≥64%</td>
<td>Two MIMO antennas</td>
</tr>
<tr>
<td>[19]</td>
<td>6 × 30</td>
<td>2.4/5.5/6.5 GHz WiFi-6E</td>
<td>≥70%</td>
<td>Two MIMO antennas</td>
</tr>
<tr>
<td>This Work</td>
<td>2 × 44</td>
<td>2.4/5.2/6 GHz WiFi-7</td>
<td>≥64%</td>
<td>Six MIMO antennas</td>
</tr>
</tbody>
</table>

4. Ergodic Channel Capacity of WiFi-7 MIMO Six-Antenna System

By averaging the capacities observed in a multipath Rayleigh fading environment, the ergodic channel capacity can be evaluated. When channel state information (CSI) is lacking
at the transmitter, power is equally distributed among all transmit antenna units. Using the following formula [24,25], the ergodic channel capacity $R$ can then be calculated.

$$R = E \left\{ \log_2 \left[ \det \left( I_{n_{rec}} + \frac{\xi}{n_{tra}} g g^\dagger \right) \right] \right\},$$

where $E$ represents the expectation over different channel realizations, $\det$ is the determinant, $n_{rec}$ denotes the number of receive antennas, $n_{tra}$ denotes the number of transmit antennas, $\xi$ denotes the signal-to-noise ratio (SNR), and $g$ represents the wireless channel matrix. The Hermitian transpose of the matrix is denoted by $(\cdot)^\dagger$.

Figure 10 illustrates the calculated ergodic channel capacity for a $6 \times 6$ MIMO system at a signal-to-noise ratio (SNR) of 20 dB. The ideal transmit and receive antennas possess 100% efficiency, zero envelope correlation coefficient (ECC), and operate under independent and identically distributed (i.i.d.) channels in a Rayleigh fading environment. To ensure convergence to a specific value, capacity results at each frequency point are averaged over 1000 channel realizations. In free space, the capacity for the 3300–3600 MHz range is between 29.97 and 30.28 bit/s/Hz. The maximum capacity within this band is 3 bit/s/Hz lower than the capacity of an ideal $6 \times 6$ MIMO i.i.d. system. At 4800–5000 MHz, the capacity approaches the ideal upper limit of 33.15 bit/s/Hz for a $6 \times 6$ MIMO operation, indicating excellent ECC and antenna efficiency for both the receiving and transmitting antennas in this frequency range.

![Figure 10. The ergodic channel capacities of the WiFi-7 antenna array prototype were calculated in a $6 \times 6$ MIMO system.](image)

5. Electric Field and Parametric Study

Figure 11 presents the simulated electric field distribution of Ant 1 at 2460 MHz (mode 1), 5700 MHz (mode 2), and 7100 MHz (mode 3). The closed slot of Ant 1 could be effectively excited at 2460, 5700, and 7100 MHz as closed-slot half-wavelength, full-wavelength, and full-wavelength resonance modes, respectively. The electric field distribution of the closed slots indicated that the electric fields at both the left and right sides were weaker than in the middle. Accordingly, the six antennas were arranged in a parallel pattern. This resulted in a lower coupling between two neighboring antennas and contributing to the favorable isolation of the antennas that are a short distance apart from each other in a multi-antenna configuration.

To better understand the contribution of each mode, two parameters of the Ant 1 structure were further analyzed to verify the design mechanism of the proposed antenna. First, the slot length $n$ was varied by fixing the left side and increasing the slot length to the right. Figure 12 compares the simulated reflection coefficients and impedance for various slot lengths $n$. When the slot length $n$ increased from 44 mm to 48 mm, mode 1 and mode 2 had lower frequencies. There was no clear frequency shift observed, but changes in impedance matching were noted for mode 3. As $n$ increased, the reduction in
frequency tended to change the impedance for modes 1, 2, and 3. Simulations of various feeding intervals of the T-shaped coupling $g$ were then conducted (Figure 13). A shorter coupling interval resulted in greater closed-slot antenna coupling. The real and imaginary impedance increased for all three modes, resulting in a substantial frequency reduction for both modes 1 and 2. Modes 2 and 3 both had closed-slot full-wavelength single-mode dual resonance. Thus, the imaginary impedance did not vary substantially. By contrast, the real impedance approached 50 $\Omega$, thereby resulting in the frequency increasing due to matching improving and bandwidth increasing.

![Figure 11. WiFi-7 simulated single-antenna electric field distribution at 2460, 5700, and 7100 MHz.](image)

**Figure 11.** WiFi-7 simulated single-antenna electric field distribution at 2460, 5700, and 7100 MHz.

![Figure 12. Comparison of simulated results: (a) reflection coefficients and (b) impedance for different slot lengths $n$.](image)

**Figure 12.** Comparison of simulated results: (a) reflection coefficients and (b) impedance for different slot lengths $n$.

![Figure 13. Comparison of simulated (a) reflection coefficients and (b) impedance with parameter $g$ variation.](image)

**Figure 13.** Comparison of simulated (a) reflection coefficients and (b) impedance with parameter $g$ variation.
Additionally, we analyze two other parameters of the Ant 1 structure to further understand the impact of the matching mechanism and feed position. First, we explore how changes in the length \( a \) of the right branch of the T-shaped feed affect mode matching. Figure 14 compares the simulated reflection coefficient and impedance for different right branch lengths \( a \). The imaginary part of the impedance increases without significant changes in the real part across all three modes, resulting in improved matching and increased bandwidth. Next, we investigate how changing the overall position of the T-shaped feed (i.e., changing parameter \( b \)) affects the resonant frequency of the modes, as shown in Figure 15. Mode 1 exhibits a lower frequency with no significant frequency shift observed. However, notable changes in the real and imaginary impedance matching of modes 2 and 3 are observed.

![Figure 14](image1.png)

**Figure 14.** Comparison of simulated (a) reflection coefficients and (b) impedance with parameter \( a \) variation.

![Figure 15](image2.png)

**Figure 15.** Comparison of simulated (a) reflection coefficients and (b) impedance with parameter \( b \) variation.

### 6. Six-Antenna Uni-Isolation Analysis

The isolation of the six-antenna unit was examined by analyzing its electric field distribution. Figure 16 presents the simulated electric field distribution of the six-antenna unit at 2460, 5700, and 7100 MHz. When one antenna was excited, the others were not, resulting in favorable isolation and ECC performance for the six-antenna system due to its design. The closed-slot structure used for the design could effectively excite closed-slot half-wavelength resonance modes at low frequencies and full-wavelength resonance modes at high frequencies. The electric field at both ends of the slot was weak. Thus, neighboring slot antennas were less likely to be coupled and excited. The characteristic enables a compact multi-antenna system configuration with favorable isolation and ECC values.
Figure 16. Simulated electric field distribution of the six-antenna unit at 2460, 5700, and 7100 MHz.

7. Conclusions

This paper proposes a closed-slot WiFi-7 dual-band MIMO six-antenna system applicable in laptop computers. The distance of the six-antenna system from the hinge is 2.5 mm on the display ground plane, and measurement demonstrated that a 4-mm interval between each antenna was sufficient to achieve favorable isolation and ECC performance. The antenna design features rectangular closed-slot structures. The antenna dimensions are $44 \times 2 \text{ mm}^2$. In a closed slot, T-shaped coupling feeding is installed to effectively excite the slot half-wavelength and full-wavelength single-mode dual resonance, thereby covering the dual band operation at 2400–2500 MHz and 5150–7125 MHz required for WiFi-7. Because the excited closed-slot structure was observed to exhibit a weak electric field at the left and right closed ends, the six-antenna system could be arranged in a compact configuration without the use of any isolation element. The slot width is only 2 mm, and the slot antennas are easily integrated with metals, allowing easy integration into laptop computers with high screen-to-body ratios and metallic back cases. The key results include a radiation efficiency of over 64%, a minimum of 10 dB isolation between antennas, and an ECC below 0.04, indicating excellent isolation and minimal signal interference. This design not only meets the requirements of WiFi-7 dual-band operation but also offers a compact, high-performance solution suitable for contemporary laptop designs.
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References


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