

Single-Layer, Compact, High Isolation Dual-Band MIMO Antenna for WiFi 6/6E Applications

Cuong Do-Manh , Thi Phuong Thao Hoang , Quyen Nguyen-Xuan , and Yem Vu-Van 

Abstract—This paper presents a compact single-layer dual-band MIMO antenna with high isolation characteristics for WiFi 6/6E applications. The dual-band response is realized by two closely spaced capacitively excited patch resonators operating in their fundamental modes, enabling independent control of the two operating bands within a single-layer architecture. In the MIMO arrangement, two identical dual-band elements are placed in an inverted configuration and effectively decoupled by grounded stubs. The proposed two-port antenna achieves an overall size of $0.61\lambda \times 0.61\lambda \times 0.03\lambda$ at 5.2 GHz. Experimental results show measured bandwidths of 3.8% (5.2–5.4 GHz) and 3.6% (6.60–6.84 GHz) for the lower and upper bands, respectively. The antenna consistently provides more than 20 dB isolation, together with a stable gain of about 5.0 dBi across both bands. Moreover, its favorable diversity performance highlights its strong potential for compact WiFi 6/6E MIMO systems.

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Index Terms—Dual-band antenna, MIMO, High isolation, Compact, WiFi 6/6E, Single-layer.

I. INTRODUCTION

WiFi 6E is an extension of Wi-Fi 6 (IEEE 802.11ax) into the newly opened 6 GHz band, which provides a large amount of additional unlicensed spectrum, wider 160 MHz channels, lower interference, and significantly higher throughput [1]. By operating over both the legacy 5 GHz WLAN band and the new 6 GHz band, Wi-Fi 6E enables multi-gigabit wireless communication with lower latency and improved performance in dense environments. To fully exploit these advantages, multiple-input-multiple-output (MIMO) antennas are essential [2]. Accordingly, there is a strong demand for dual-band MIMO antennas.

Extensive research has been conducted on single-band MIMO antenna systems [3]–[8], where microstrip patch radiators are widely adopted because of their low profile, ease of fabrication, and compatibility with planar wireless platforms. To improve the isolation performance in these closely spaced configurations, various decoupling techniques have been extensively investigated, including defected ground structures

(DGS) [3], [4], metasurfaces (MS) [5], neutralization lines [6], and parasitic resonator loading [7]. These methods effectively suppress surface-wave coupling, near-field interaction, or induced current leakage between adjacent elements, thereby enhancing the overall MIMO performance. Nonetheless, single band operation is the critical drawback of such designs.

Various dual-band MIMO antenna systems have been reported in the open literature. In [9], a two-port dual-band MIMO antenna was realized using a boat-shaped patch combined with a defected ground structure (DGS) to achieve high isolation. The dual-band MIMO design reported in [10] exhibits wide bandwidth and excellent isolation performance; however, its overall dimensions are relatively large. In [11], [12], MSs were introduced to enhance the isolation between dual-band patch antennas. Nevertheless, these designs rely on multilayer configurations, which significantly increase the antenna profile. A similar limitation is also observed in [13]–[15], where an air-gap layer is inserted between the ground plane and the radiating elements, leading to increased structural complexity and profile height.

To address the aforementioned limitations, several single-layer dual-band MIMO antennas have been reported in [16]–[21]. Compact dual-band operation in [16]–[18] is achieved by etching L- or U-shaped slots into the radiating patches, while mutual coupling is reduced using metallic walls or parasitic elements. In [19], a complementary split-ring resonator (CSRR) is integrated into the patch to realize dual-band behavior, whereas high isolation in the corresponding MIMO configuration is obtained by orthogonally arranging the antenna elements. Similar orthogonal decoupling strategies are also adopted in [20] and [21]. Despite their potential for dual-band MIMO applications, the aforementioned antennas still exhibit several drawbacks, including relatively large dimensions, low gain, and/or insufficient isolation performance.

This paper presents a compact single-layer dual-band MIMO antenna with high isolation characteristics. The dual-band response is realized by two closely spaced patch resonators operating in their fundamental modes. This dual-band realization mechanism enables the MIMO configuration to achieve high isolation at the upper band through the inverted element arrangement, while grounded stubs are incorporated to further enhance isolation at the lower band. The fabricated two-port prototype achieves an overall size of $0.61\lambda \times 0.61\lambda \times 0.03\lambda$ at 5.2 GHz. Measured results show impedance bandwidths of 3.8% and 3.6% for the lower and upper bands, respectively, together with isolation exceeding 20 dB and a stable gain of around 5 dBi over both bands. The contribution of the proposed can be summarized as follows:

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- Single-layer design, independent tuning the operating frequencies with low cross-sensitivity
- A dual-stage decoupling strategy combining inverted element arrangement and grounded stubs
- Favorable tradeoff among compactness, isolation, and radiation characteristics
- High isolation at both bands with small frequency ratio

II. DUAL-BAND ANTENNA

The geometrical configuration of the dual-band antenna is depicted in Fig. 1. The antenna is realized on a Taconic RF-35 substrate with a relative permittivity of 3.5. Dual-band operation is realized by integrating two radiating patches. The larger patch is designed to resonate at the lower frequency band, while the smaller patch is proportionally scaled to operate at the higher band. Both patches are electromagnetically excited through capacitive coupling from a probe-fed microstrip line that serves as the driven element. The resonant lengths of these patches (l_1 and l_2) are chosen about half-effective wavelength at the desired frequencies.

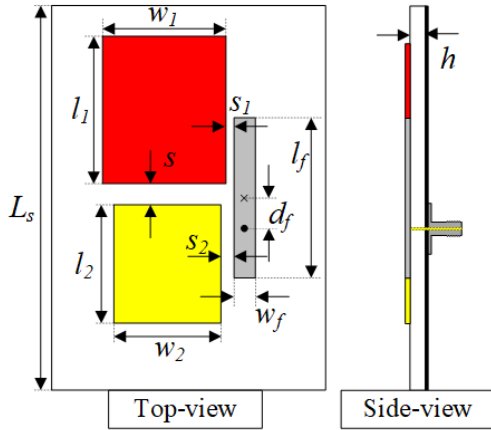


Fig. 1. Geometry of the dual-band antenna.

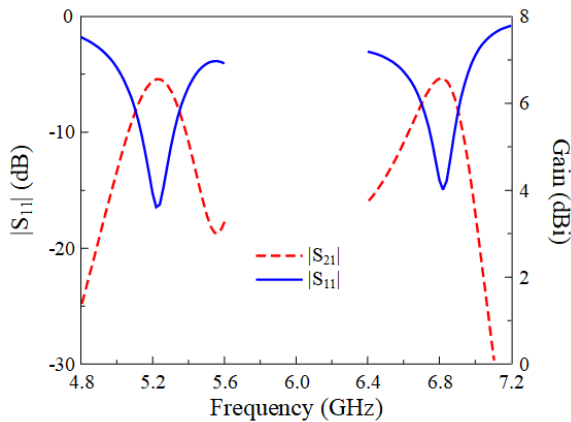
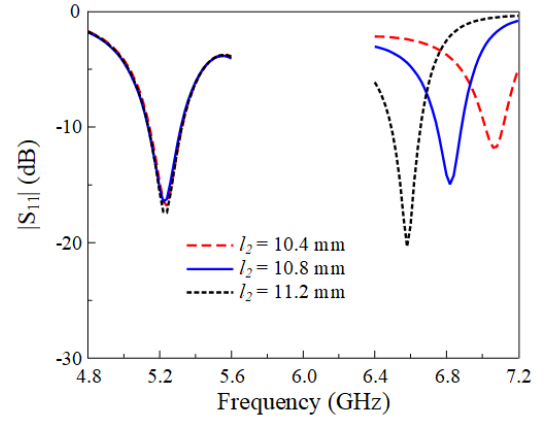
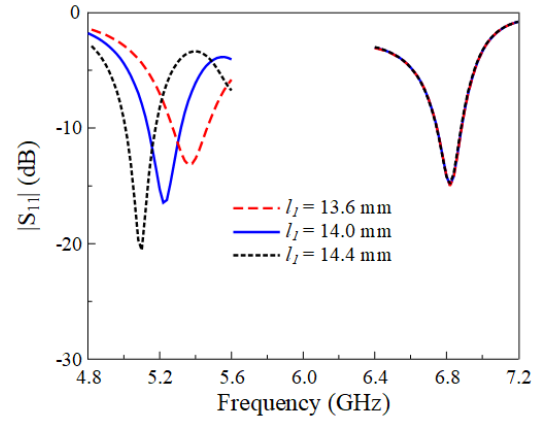


Fig. 2. Simulated $|S_{11}|$ and peak gain of the dual-band antenna.

The antenna is modeled and analyzed using the full-wave electromagnetic solver Ansys High-Frequency Structure Simulator (HFSS). The optimal dimensions are $L_s = 35$, $h = 1.52$,



(a)



(b)

Fig. 3. Simulated $|S_{11}|$ of the proposed dual-band antenna for different (a) l_1 and (b) l_2 .

$w_f = 2.0$, $l_f = 14.6$, $d_f = 2.2$, $s = 2.4$, $s_1 = 0.5$, $s_2 = 1.4$, $l_1 = 14$, $w_1 = 12.5$, $l_2 = 11$, $w_2 = 8$ (unit: mm). Fig. 2 illustrates the simulated reflection coefficient ($|S_{11}|$) and peak realized gain of the proposed dual-band antenna. As observed, two well-defined resonant modes are excited at approximately 5.2 GHz and 6.7 GHz. The corresponding -10 dB impedance bandwidths extend from 5.14 to 5.32 GHz for the lower band and from 6.63 to 6.78 GHz for the upper band. As also shown in Fig. 2, the antenna maintains a stable peak realized gain of approximately 6.7 dBi across both operating bands.

To validate the independent control of the two operating bands, Fig. 3 depicts the simulated $|S_{11}|$ characteristics as patch lengths l_1 and l_2 vary. Increasing l_1 lowers the first resonant frequency by extending the effective surface current path, whereas the second resonance remains almost unaffected. Conversely, modifying l_2 mainly shifts the upper resonant band with minimal influence on the lower band. The low cross-sensitivity observed in the parametric results confirms that each resonant mode is primarily governed by its associated patch length, which facilitates flexible and independent dual-band tuning.

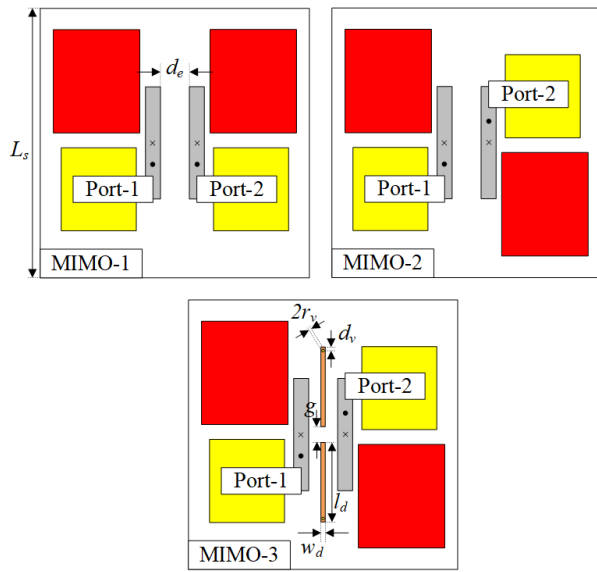


Fig. 4. Evolution to design final proposed dual-band MIMO antenna.

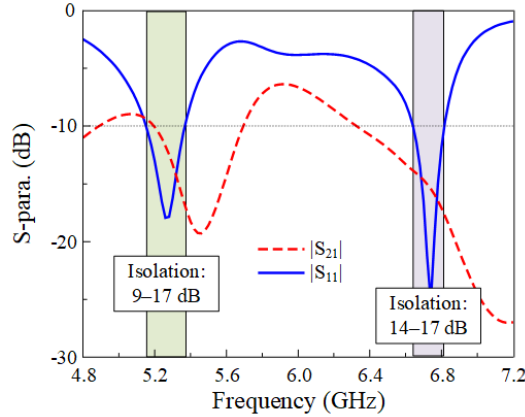


Fig. 5. Simulated S-parameter of MIMO-1.

III. DUAL-BAND MIMO ANTENNA

The design evolution of the proposed dual-band MIMO antenna is illustrated in Fig. 4. MIMO-1 consists of two dual-band antenna elements arranged in the same orientation. In MIMO-2, the two elements are reconfigured into an inverted arrangement to modify the mutual coupling behavior. Finally, MIMO-3, which represents the optimized design, further incorporates two grounded stubs to enhance inter-element isolation. For all MIMO arrays, the element distance is fixed at $d_e = 3$ mm. Noted that a 3-mm spacing balances compactness and isolation (> 20 dB) while providing sufficient space for the grounded stubs. The optimal dimensions of MIMO-3 are $L_s = 35$, $h = 1.52$, $w_f = 2.0$, $l_f = 14.6$, $d_f = 2.4$, $s = 1.6$, $s_1 = 0.5$, $s_2 = 1.0$, $l_1 = 14$, $w_1 = 10.5$, $l_2 = 10.8$, $w_2 = 8.8$, $l_d = 10.5$, $w_d = 0.5$, $r_v = 0.15$, $d_v = 0.5$, $g = 2$ (unit: mm).

The simulated S-parameter in terms of reflection and transmission coefficients ($|S_{11}|$ and $|S_{21}|$) of MIMO-1 is shown in Fig. 5. As shown, the lower band provides a -10 dB impedance bandwidth of 5.15–5.37 GHz, although the inter-

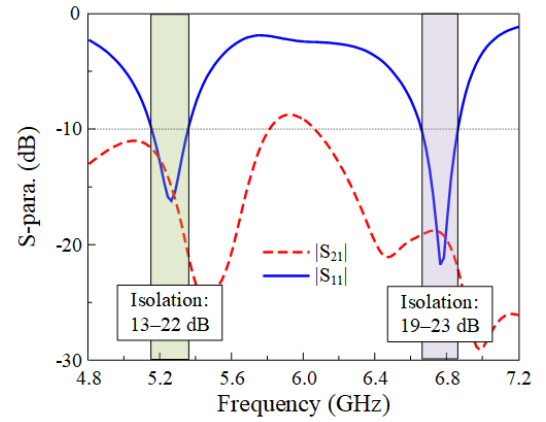


Fig. 6. Simulated S-parameter of MIMO-2.

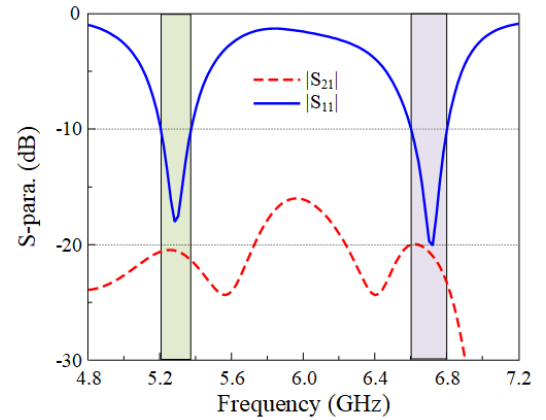


Fig. 7. Simulated S-parameter of the final design, MIMO-3.

element isolation is relatively poor, ranging from 9 to 17 dB. For the upper band, the antenna achieves a bandwidth of 6.64–6.82 GHz, with better isolation of 14–17 dB across the band. The better isolation performance at the upper band is mainly due to the greater physical separation between the smaller upper-band patch resonators than that between the larger lower-band patches.

To further improve the inter-element isolation, the two antenna elements are arranged in an inverted configuration, referred to as MIMO-2. Fig. 6 presents the simulated S-parameters of this design. It is evident that the impedance bandwidths at both operating bands remain nearly unchanged compared with those of MIMO-1. However, the isolation performance is noticeably improved. Specifically, the isolation at the lower band (5.15–5.35 GHz) ranges from 13 to 22 dB, while that at the upper band (6.65–6.86 GHz) varies from 19 to 23 dB. This improvement can be attributed to the increased physical separation between the radiating elements in the inverted arrangement, which effectively reduces mutual coupling.

Finally, two grounded stubs are incorporated in MIMO-3, and the corresponding simulated results are presented in Fig. 7. It can be clearly observed that the operating bandwidths are 5.20–5.37 GHz and 6.60–6.80 GHz for the lower and upper

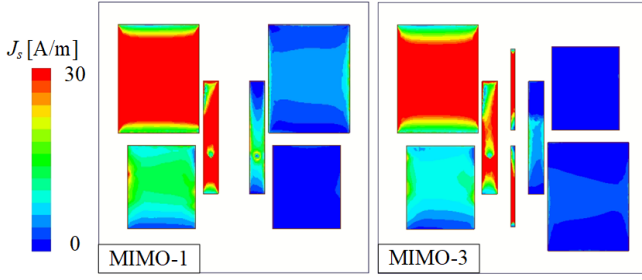


Fig. 8. Simulated surface current distribution at 5.2 GHz.

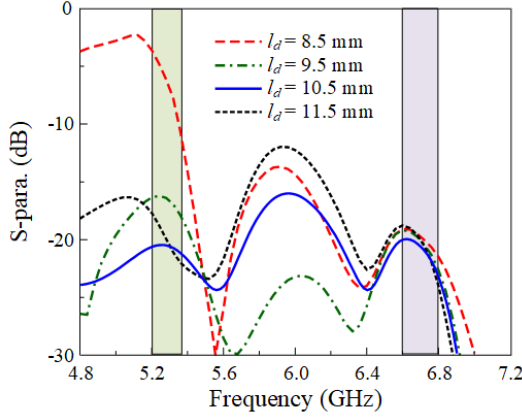


Fig. 9. Simulated transmission coefficient of MIMO-3 for different stub's length, l_d .

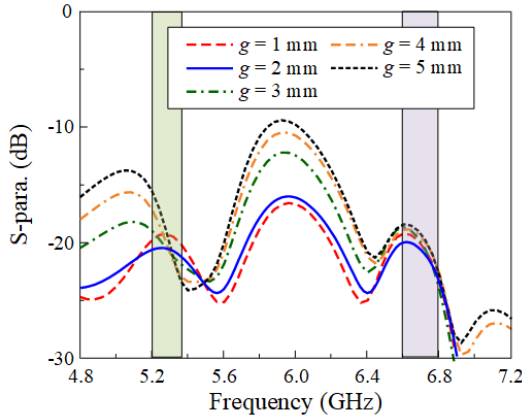


Fig. 10. Simulated transmission coefficient of MIMO-3 for different stub's position, g .

bands, respectively. In this configuration, the inter-element isolation remains consistently better than 20 dB across the lower band. This significant improvement is attributed to the grounded stubs, which effectively suppress the coupling fields propagating from the excited element to the adjacent element.

IV. DUAL-BAND MIMO ANTENNA OPERATION CHARACTERISTICS

A. Decoupling Principle

The decoupling mechanism of the proposed dual-band MIMO antenna is considered. It is noted that in many reported dual-band MIMO antennas [9]–[21], dual-band operation is realized by slots or defected structures, where the two resonances can be more strongly coupled. Alternatively, isolation can be improved by orthogonally arranging the antenna elements [18], [19], but this generally requires a larger footprint. In the proposed design, the use of separate resonant patches facilitates independent band control, while the inverted arrangement of the two MIMO elements improves isolation without requiring a 90° rotation, thereby maintaining a more compact configuration. Noted that the inverted arrangement increases the distance between the high-band patches, leading to high isolation, as demonstrated in Fig. 6. For lower band, isolation can be improved by using grounded stubs. Fig. 8 shows the simulated current distribution on MIMO-1 and MIMO-3 at two distinct bands. It is obvious that for MIMO-1, there is a strong field distributed around Port-2, leading to poor isolation around 5.2 GHz. When the grounded stubs are introduced, MIMO-3 shows significant enhancement in isolation at lower band. The reason behind is that the grounded stubs can be characterized by LC resonators with the resonant frequency $f_r = \frac{1}{2\pi\sqrt{LC}}$. These structures act as the band-stop filters, which prevent the coupling field in a specific frequency range [22], [23]. Here, a grounded stub behaves as a short-circuited transmission-line resonator with input impedance $Z_{in} = jZ_0 \tan(\beta l)$. Near $l \approx \lambda_g/4$, the impedance magnitude becomes large, producing a resonant blocking/trapping condition in the dominant coupling path. It can be verified by observing the data in Fig. 8. As observed, strong current is located at the grounded stubs, leading to small coupling field at Port-2 of the coupled MIMO element. As a result, the isolation at 5.2 GHz is significantly improved by about 10 dB.

B. Isolation Optimization

Further investigation into the effect of the grounded stub's length and position is implemented. Changing these parameters has minor effect on the impedance matching at both bands, which is not presented for brevity. Fig. 9 shows the simulated $|S_{21}|$ response for different values of the stub length, l_d . As observed, the isolation in the lower band is significantly influenced by this parameter. An appropriate choice of l_d results in enhanced isolation around 5.2 GHz. Furthermore, the effect of the grounded stub position is presented in Fig. 10. This parameter is mainly used to fine-tune the isolation across the desired bandwidth. It is worth noting that, in both parametric studies, the isolation in the upper-frequency band remains nearly unchanged. This behavior demonstrates that the introduced decoupling structure predominantly functions in the lower-frequency band, with negligible influence on the upper-band coupling characteristics.

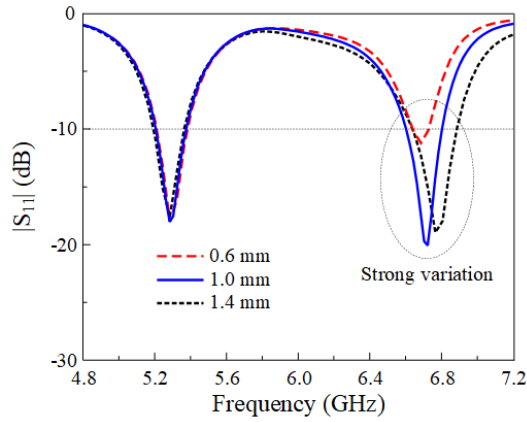


Fig. 11. Simulated reflection coefficient of MIMO-3 for different values of s_2 .

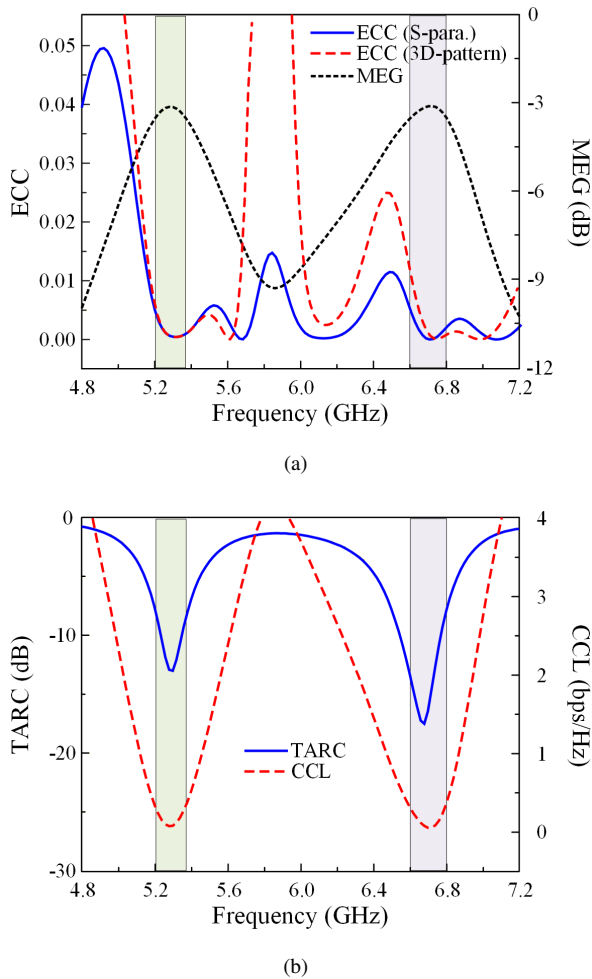


Fig. 12. Diversity performance of the proposed antenna. (a) ECC, MEG, and (b) TARC, CCL

C. Matching Optimization

The proposed antenna employs different patches operating at their fundamental modes, TM_{10} . They are capacitively fed through a microstrip line. This kind of structure provides

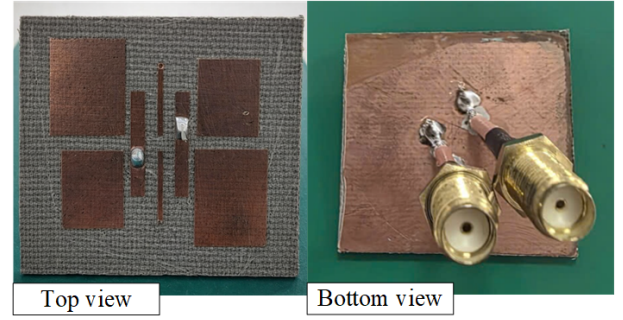


Fig. 13. Photographs of the fabricated antenna prototype.

independent controlling of the operation at both bands. As discussed in Section 2, the resonant frequencies at both bands can be conveniently adjusted by changing the patches' lengths (l_1 and l_2). In this section, the matching characteristics of the two operating bands are optimized through the gap parameters s_1 and s_2 . As shown in Fig. 11, s_2 mainly controls the impedance matching of the upper band, with negligible influence on the lower band. A similar independent tuning behavior is observed for s_1 , which predominantly affects the lower band. However, the corresponding results are omitted for brevity.

D. MIMO Diversity Performance

The MIMO diversity performance of the proposed antenna is evaluated using several key parameters, including the Envelope Correlation Coefficient (ECC), Mean Effective Gain (MEG), Channel Capacity Loss (CCL), and Total Active Reflection Coefficient (TARC). These parameters are calculated using the equations provided in [24].

Fig. 12 presents the calculated MIMO diversity parameters. The proposed antenna exhibits an ECC close to zero at both operating bands, indicating negligible correlation between the MIMO ports. The MEG remains close to -3 dB, demonstrating a balanced power distribution between the antenna elements. Moreover, favorable TARC and CCL characteristics are obtained, with TARC below -10 dB and CCL close to zero across both operating bands, indicating good active impedance matching and negligible degradation in MIMO channel capacity. Overall, these results demonstrate the satisfactory diversity performance of the proposed MIMO antenna.

V. MEASURED RESULTS

For verification, an antenna prototype is fabricated, as shown in Fig. 13, and measured. The simulated and measured performances in terms of S-parameter and peak realized gain are depicted in Fig. 14. As observed, the antenna shows good performance at both 5.2 and 6.7 GHz. The measured operating bandwidths with isolation of better than 20 dB are 3.8% (5.2–5.4 GHz) and 3.6% (6.60–6.84 GHz) at lower and upper bands, respectively. Across these bands, the peak realized gain at both bands are respectively from 4.6 to 5.0 dBi and 5.6 to 6.4 dBi. The simulated and measured radiation patterns at 5.3 and 6.7 GHz are shown in Fig. 15. Owing to the symmetrical antenna configuration, only the results for Port 1 excitation are

TABLE I
SIMULATED AND MEASURED PERFORMANCE OF THE PROPOSED ANTENNA

	Sim. Bandwidth GHz (%)	Mea. Bandwidth GHz (%)	Sim. Iso (dB)	Mea. Iso (dB)
1 st band	5.20–5.37 (3.2%)	5.20–5.40 (3.8%)	> 20	> 20
2 nd band	6.60–6.80 (3.0%)	6.60–6.84 (3.6%)	> 20	> 20
	Sim. Gain (dBi)	Mea. Gain (dBi)	Sim. beam tilt (°)	Mea. beam tilt (°)
1 st band	4.9–5.3	4.6–5.0	18	15
2 nd band	6.0–6.9	5.6–6.4	20	18

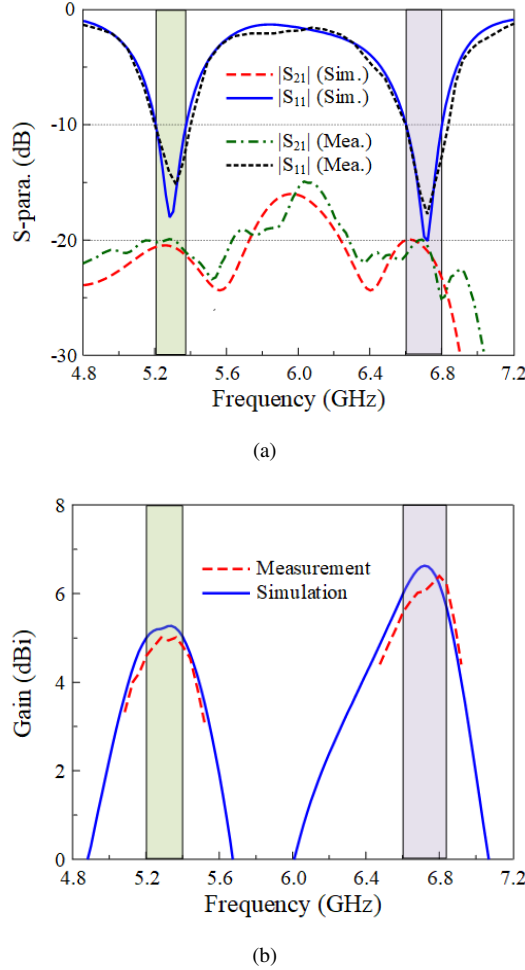


Fig. 14. Simulated and measured (a) S-parameter and (b) peak realized gain of the proposed MIMO antenna.

presented for brevity. The antenna exhibits stable and well-defined radiation patterns at both operating bands. The main beam is slightly tilted from the broadside direction, which can be attributed to the asymmetric feeding structure and the influence of the adjacent patch elements. The simulated radiation efficiency also indicates that the proposed design can achieve high radiation efficiency of about 94%.

The simulated and measured performance of the proposed antenna are summarized in Table I. The measured lower band

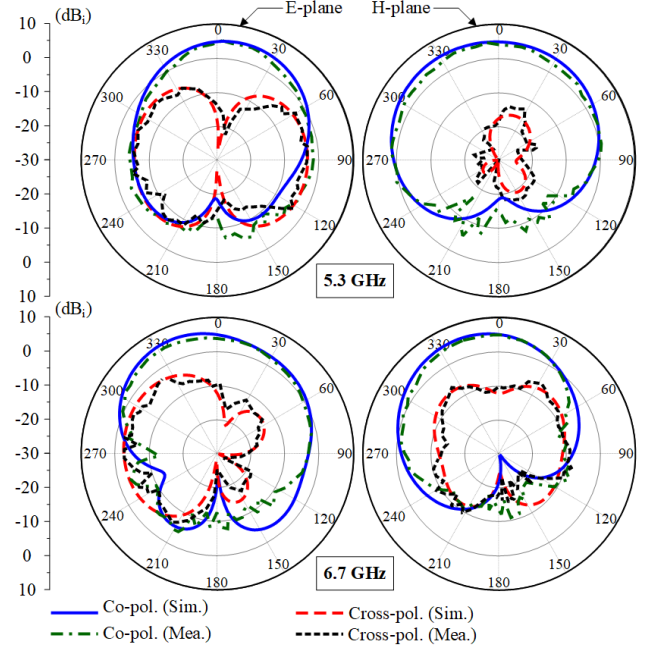


Fig. 15. Simulated and measured radiation patterns of the proposed MIMO antenna.

of 5.205.40 GHz provides a 200-MHz impedance bandwidth, which is sufficient to accommodate channel bandwidths of up to 160 MHz for Wi-Fi 6 operation. Similarly, the upper band of 6.606.84 GHz provides a 240-MHz impedance bandwidth, enabling coverage of multiple Wi-Fi 6E channels, including channel bandwidths of up to 160 MHz.

VI. PERFORMANCE COMPARISON

The advantages of the proposed design over related works are demonstrated in Table II. As can be observed, the designs in [11]–[14] suffer from relatively large dimensions and multilayer structures, which increase fabrication complexity and make the design process more challenging. Among the reported single-layer dual-band MIMO antennas, the proposed design is one of the most compact. Compared with [16], [19], and [20], which have similar overall dimensions, the proposed work achieves higher gain and better port isolation across the operating bands. Although the design in [18] provides better isolation, it requires a larger footprint than the proposed

TABLE II
PERFORMANCE COMPARISON AMONG 2-PORT DUAL-BAND MIMO ANTENNAS

Ref.	Dimensions (λ)	f_H/f_L ratio	Bandwidth f_L/f_H (%)	Peak gain f_L/f_H (dBi)	Iso. (dB)	FBR (dB)	Spacing (λ)	No. of layers	Decoupling structure
[11]	$1.30 \times 0.87 \times 0.16$	1.44	7.7/5.7	7.8/8.6	≥ 25	≥ 15	0.01	4	Metasurface
[12]	$0.75 \times 0.60 \times 0.25$	1.11	1.5/2.1	8.5/7.9	≥ 30	≥ 10	0.03	3	Metasurface
[13]	$0.63 \times 0.57 \times 0.25$	1.61	12.0/18.0	6.5/7.1	≥ 12	≥ 8	0	2	Capacitors
[14]	$0.96 \times 0.40 \times 0.06$	2.32	15.6/16.4	5.2/6.7	≥ 10	≥ 10	0	3	Probes
[16]	$0.42 \times 0.21 \times 0.05$	1.63	1.6/0.7	2.7/2.8	≥ 18	≥ 15	0.03	1	Metallic walls
[17]	N/A	1.38	2.5/2.2	N/A	≥ 20	≥ 15	0.06	1	C-shaped patch
[18]	$1.14 \times 0.68 \times 0.02$	1.24	2.9/2.4	5.9/5.9	≥ 25	≥ 10	0.06	1	Loop resonator
[19]	$0.60 \times 0.40 \times 0.03$	1.15	≤ 1.0	5.0/6.0	≥ 15	N/A	0.03	1	Shorting posts
[20]	$0.62 \times 0.40 \times 0.03$	1.38	11.4/4.5	3.6/2.4	≥ 15	≥ 15	0.06	1	90° rotation
[21]	$1.40 \times 0.70 \times 0.03$	1.59	25.7/20.4	8.9/8.7	≥ 20	≥ 15	0.42	1	90° rotation
Prop.	$0.61 \times 0.61 \times 0.03$	1.26	3.8/3.6	5.0/6.4	≥ 20	≥ 15	0.05	1	Grounded stub

antenna. Meanwhile, the wideband characteristic reported in [19] is achieved at the expense of significantly increased size. These comparisons confirm that the proposed design provides a favorable tradeoff among compactness, isolation, and radiation performance.

VII. CONCLUSION

This paper presents a single-layer, compact, high-isolation dual-band MIMO antenna for WiFi 6/6E applications. Dual-band operation is achieved by two capacitively excited closely spaced patches operating at their fundamental modes, enabling balanced performance and independent control of the two bands. Two dual-band elements are arranged inversely and effectively decoupled using grounded stubs. The measured bandwidths are 3.8% (5.2–5.4 GHz) and 3.6% (6.60–6.84 GHz). Across both bands, the antenna maintains isolation better than 20 dB, a stable gain of about 5.0 dBi, and low ECC, confirming good diversity performance. These results demonstrate its strong potential for compact WiFi 6/6E MIMO systems. Future work will focus on extending the proposed element to larger-scale massive MIMO arrays while preserving compactness, high isolation, and stable radiation performance.

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