



Dual Linearly Polarized Wide Beamwidth Antenna for Private-5G Supportive MIMO Applications

Kangjie Jin¹ · Seung-Soo Han¹ · Eunji Kim¹ · Han Lim Lee^{1,2,*}

Abstract

This paper presents a dual linearly polarized planar antenna element optimized for private 5G applications in the 4.6–4.9 GHz frequency band, targeting Korea's 4.7 GHz allocation. Wide beamwidth antenna elements are increasingly critical in private 5G (P5G) networks to simplify base station architecture and enable efficient MIMO implementation without sectorization, making them a cost-effective solution. Nevertheless, simultaneous improvement in both beamwidth and bandwidth for dual-polarized planar antennas has rarely been demonstrated, due to technical challenges associated with antenna volume, fabrication complexity, and cost constraints. To achieve wide angular coverage while addressing these design challenges, a dielectric grid layer (DGL) is integrated into the dual-polarization antenna design. The DGL refracts the radiated energy outward through angular phase transformation, effectively enhancing the half-power beamwidth (HPBW). The proposed antenna achieves an HPBW exceeding 131°, enabling single-element sector coverage well-suited for compact and high-performance deployments. The design offers high polarization purity, with cross-polarization discrimination greater than 25.2 dB and port-to-port isolation exceeding 28.6 dB, facilitating reliable dual-polarized MIMO operation. The peak realized gain surpasses 2.5 dBi across the operational band. Simulation results are validated through measurements, showing good agreement in radiation patterns, beamwidth, and polarization characteristics. With its broad angular coverage, dual linear polarization, and high isolation, the proposed antenna provides a cost-effective, compact, and fabrication-friendly solution for next-generation P5G-MIMO platforms, ensuring practical and efficient deployment.

Key Words: Dual Linear Polarization Antenna, MIMO Antenna, Planar Antenna Element, Private-5G (P5G), Wide Beamwidth Antenna.

I. INTRODUCTION

Private 5G (P5G) networks are being deployed in industrial, campus, and enterprise environments where demands for secure, low-latency, and high-reliability wireless connectivity are paramount—supporting applications such as smart manufacturing, autonomous logistics, and mission-critical IoT. South Korea's dedicated allocation of the 4.7 GHz band for P5G reflects its suitability for combining moderate coverage and high capacity.

Essential to P5G's performance is MIMO technology, which improves link capacity and resilience through spatial multiplexing and diversity. Realizing these benefits requires antenna sub-systems that offer wide angular coverage, robust polarization isolation, and the ability to support both TX and RX operations with minimal interference [1]. A higher number of antennas can enhance data capacity in MIMO systems. However, data transmission and reception remain limited to each antenna's beam coverage. To serve wide areas, base stations typically adopt sec-

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torized antennas, where multiple panels each cover a narrow region, as shown in Fig. 1(a). In practice, two 65° sector antennas are commonly deployed to achieve approximately 130° coverage, which is a standard field requirement. This work focuses on eliminating one of these two sector antennas, allowing a single panel to cover the entire 130° sector, as illustrated in Fig. 1(b). This approach maintains the same total coverage while reducing the number of antenna panels, resulting in a simpler and more cost-effective base-station configuration. Conventional P5G base stations rely on dual- or multi-sector narrow-beam antennas (approximately 65° per sector) to achieve wide coverage, but this increases system cost, hardware complexity, physical footprint, and calibration burden [2]. In contrast, a wide-beamwidth antenna (half-power beamwidth [HPBW] $>120^\circ$) can function as a single-sector radiator, enabling cost-effective P5G deployment without additional local antenna modules. If these are implemented with dual linear polarization (LP), they can foster compact MIMO arrays by facilitating parallel, isolated TX/RX streams while minimizing mutual coupling and avoiding additional RF leakage cancellation circuits. Although the leakage cancellation circuits can effectively improve isolation characteristics, they add complexity, insertion loss, and physical bulk, making them impractical for integrated MIMO antenna modules operating in the 4.7 GHz band [2–5].

To obtain wide beam antenna characteristics, various architectures have been investigated. Magneto-electric dipole designs, for example, yield symmetric patterns (100° – 120° HPBW) but often rely on stacked or volumetric structures [6]. Planar microstrip elements using capacitive fences or slots achieve beam widening and isolation with printed circuit board (PCB)-level simplicity, though with limited symmetry or frequency stability. Crossed-dipole antennas with parasitic directors have demonstrated exceptional beamwidths ($>150^\circ$ and approx. 168° in orthogonal planes) but require precise element tuning to optimize performance [7]. Also, wide-angle scanning phased arrays operating across 4.4–5.0 GHz have achieved $\pm 60^\circ$ scan using wide beam unit cells at the cost of complex feeding systems and larger footprint [8]. Furthermore, planar antenna structures have been

proposed that extend beamwidth significantly while maintaining a low profile [9–15]. These planar designs demonstrate wide angular illumination in a single radiator and allow array expansion for wide angle scanning performances, but they support only single LP, limiting their immediate applicability in dual-polarized MIMO systems.

Therefore, considering these challenges, this paper introduces a dual LP planar antenna element tailored to the aligned band of Korea's 4.7 GHz P5G allocation. The proposed design achieves an HPBW exceeding 130° , enabling seamless single sector coverage as shown in Fig. 1(b), while supporting dual slanted LP with high isolation to realize a compact MIMO configuration as depicted in Fig. 2. In addition, the proposed configuration provides structural symmetry, planar implementation, and straightforward integration with active modules, which would be difficult to achieve with most existing wideband antenna geometries. The fully planar, PCB-compatible structure can promote scalable and cost-effective deployment in next-generation P5G base stations.

II. Design AND ANALYSIS

The proposed dual LP patch antenna employs orthogonally arranged capacitive-coupling feeds positioned along the lateral and lower edges of the primary radiator, allowing separate excitation paths for horizontal polarization (HP) and vertical polarization (VP). To extend the HPBW for both polarizations, a modified implementation of a DGL configuration—originally introduced in [13] is integrated into the antenna structure. The following section presents a comprehensive theoretical framework detailing the antenna's operating principles, drawing upon transmission line modeling and cavity model interpretations [16], as well as key electromagnetic concepts underlying the DGL-based beam shaping mechanism.

1. Dual-Linearly Polarized Patch Antenna Design

The primary radiating element consists of a square metal patch with dimensions $W \times L$, positioned above a dielectric substrate of thickness h , relative permittivity ϵ_r , free space ϵ_0 and

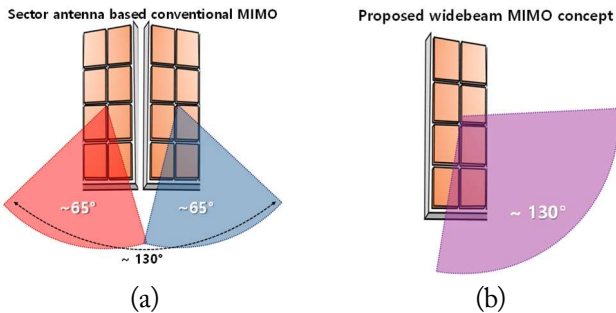


Fig. 1. MIMO antenna coverage with (a) reference sector and (b) proposed wide beamwidth configurations.

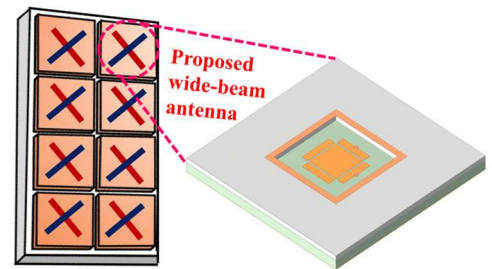


Fig. 2. Proposed dual linearly polarized wide beamwidth antenna element overview.

the permeability of free space μ_0 . The feed elements are rectangular strips of width w_f and length l_f , separated from the main patch by a narrow capacitive gap g . The structure is symmetric to support orthogonal polarization by placing feeds at the middle of each side. The gap between the feed and the patch introduces a capacitive coupling, and the overall input impedance can be modeled as

$$Z_{in} = \left(j\omega C_g + \frac{1}{Z_{patch}} \right)^{-1} \quad (1)$$

Here, Z_{patch} is the intrinsic input impedance of the patch without coupling, which for the fundamental TM_{10} mode is approximated by

$$Z_{patch} \approx \frac{1}{2} \sqrt{\frac{\mu_0}{\epsilon_0 \epsilon_r}} \cdot \frac{L}{W} \quad (2)$$

The coupling capacitance C_g between the feed strip and the patch (assuming parallel plate approximation) is given by

$$C_g = \frac{\epsilon_0 \epsilon_r A}{g} = \frac{\epsilon_0 \epsilon_r w_f \cdot l_{eff}}{g} \quad (3)$$

Here, A denotes the effective coupling area between the feed strip and patch and l_{eff} is the effective length of overlap between the feed strip and the patch edge, determined by fabrication precision. The overall matching condition is tuned by adjusting g , w_f , and the relative position of the feed strip. Stronger coupling corresponding to a larger C_g reduces Z_{in} and broadens the bandwidth. Then, using the cavity model, the resonant frequency f_0 of the patch for dominant TM_{10} or TM_{01} modes can be approximated as

$$f_{mn} = \frac{c}{2} \sqrt{\left(\frac{m}{W}\right)^2 + \left(\frac{n}{L}\right)^2} \cdot \frac{1}{\sqrt{\epsilon_{eff}}} \quad (4)$$

where m and n are the mode indices along the width and length directions of the patch, respectively, defining the resonant TM_{mn} . Then, using the cavity model, the resonant frequency f_0 of the patch for dominant TM_{10} or TM_{01} modes can be approximated as

$$f_0 \approx \frac{c}{2W\sqrt{\epsilon_{eff}}} \quad (5)$$

Assuming TM_{10} or TM_{01} mode excitation, the far-field electric field components of the patch antenna are expressed in spherical coordinates as [16]:

$$E_\theta(\theta, \phi) = j \cdot \frac{k_0 h V_0}{2\pi r} \cdot \cos\left(\frac{\pi W}{\lambda} \sin\theta \cos\phi\right) \cdot \text{sinc}\left(\frac{k_0 L}{2} \sin\theta \sin\phi\right) \quad (6)$$

and

$$E_\phi(\theta, \phi) = j \cdot \frac{k_0 h V_0}{2\pi r} \cdot \cos\left(\frac{\pi L}{\lambda} \sin\theta \sin\phi\right) \cdot \text{sinc}\left(\frac{k_0 W}{2} \sin\theta \cos\phi\right) \quad (7)$$

Here, V_0 is equivalent voltage across the patch, h is the height of the DGL. Also, θ and ϕ are elevation and azimuth angles in spherical coordinates and k_0 is free space wave number. Each polarization (HP or VP) results from exciting the corresponding gap-coupled feed, generating orthogonal current distributions.

2. Proposed Wide Beamwidth Antenna Design

Based on the design Eqs. (1)–(5), the dual LP patch antenna with equivalent circuit model can be designed as shown in Fig. 3(a) with FR-4 Taconic substrate having a relative permittivity of 4.3 and loss tangent of 0.02. To broaden the beamwidth, DGL [17] is added as depicted in Fig. 3(b). The fundamental theory of extended HPBW can be analyzed as follows. Referring to Eqs. (6)–(7), the beamwidth is inversely proportional to the aperture length. In the DGL-based antenna structure, dielectric wall is introduced around the radiating patch rather than physically reducing the aperture size. The DGL modifies the

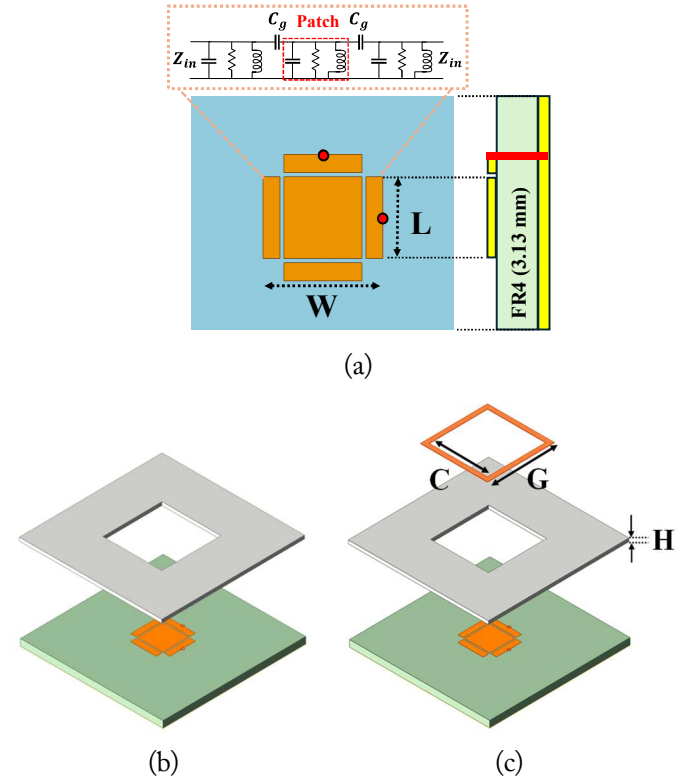


Fig. 3. Design configurations for (a) reference dual LP patch antenna with equivalent circuit model, (b) DGL-based dual LP antenna, and (c) proposed dual LP antenna ($W = 0.29\lambda_0$, $L = 0.19\lambda_0$, $H = 0.0074\lambda_0$, $C = 0.44\lambda_0$).

phase front of the radiated fields, bending the direction of propagation outward in the angular domain. This can be modeled by introducing an angular-dependent phase transformation as

$$\sin\theta \rightarrow \sin\theta' = \sin\theta/n(\theta, \phi) \quad (8)$$

where $n(\theta, \phi)$ denotes the effective refractive index in elevation and azimuth, induced by the dielectric geometry surrounding the patch. The value of $n(\theta, \phi)$ is primarily determined by the relative permittivity of the dielectric wall [17]. The effective refractive index helps describe how the radiated fields are directionally shaped. Substituting this into the original radiation function yields a modified field expression as

$$E_{\theta}^{DGL}(\theta, \phi) \propto \text{sinc}\left(\frac{k_0 L}{2} \cdot \frac{\sin\theta}{n(\theta, \phi)} \cdot \sin\phi\right) \quad (9)$$

and

$$E_{\phi}^{DGL}(\theta, \phi) \propto \text{sinc}\left(\frac{k_0 W}{2} \cdot \frac{\sin\theta}{n(\theta, \phi)} \cdot \cos\phi\right) \quad (10)$$

As $n(\theta, \phi) < 1$ in regions outside broadside due to dielectric boundary effects, the effective angular argument increases. As a result, the main lobe spreads, which leads to a broader HPBW. Lastly, to further optimize the beam spread by adding reflection on the DGL edge surface for refracted field, additional conductive ring pattern is added as shown in Fig. 3(c), resulting in the proposed wide beamwidth antenna element.

3. Simulated Results of the Proposed Antenna

As the proposed DGL structure evolves from the conventional patch (reference), the antenna exhibits progressively broader field expansion as depicted in Fig. 4. In the proposed configuration, a rectangular conductive ring is integrated along the DGL edge to reflect part of the refracted fields for further extending the field distribution. This reflection enhances the lateral field coverage and consequently broadens the HPBW as shown in Fig. 4(c), as evidenced by the more uniform and expanded E-field distribution compared to Fig. 4(a) and 4(b). The conductive ring thus improves beam shaping while preserving polarization purity, consistent with the design goals. In addition, the simulated S -parameters are presented in Fig. 5. Port 1 and Port 2 correspond to the VP and HP excitation ports, respectively. The results show that both polarizations achieve a 10-dB impedance bandwidth fully covering the desired 4.6–4.9 GHz band. Furthermore, the port-to-port isolation is better than 25 dB across the operating frequency band, which ensures excellent polarization decoupling performance of the proposed dual-pol antenna. Then, to optimize the beam expansion by using the conductive ring as described in Fig. 3(c), both realized gain and HPBW of the proposed antenna are simulated for different conductive ring pa-

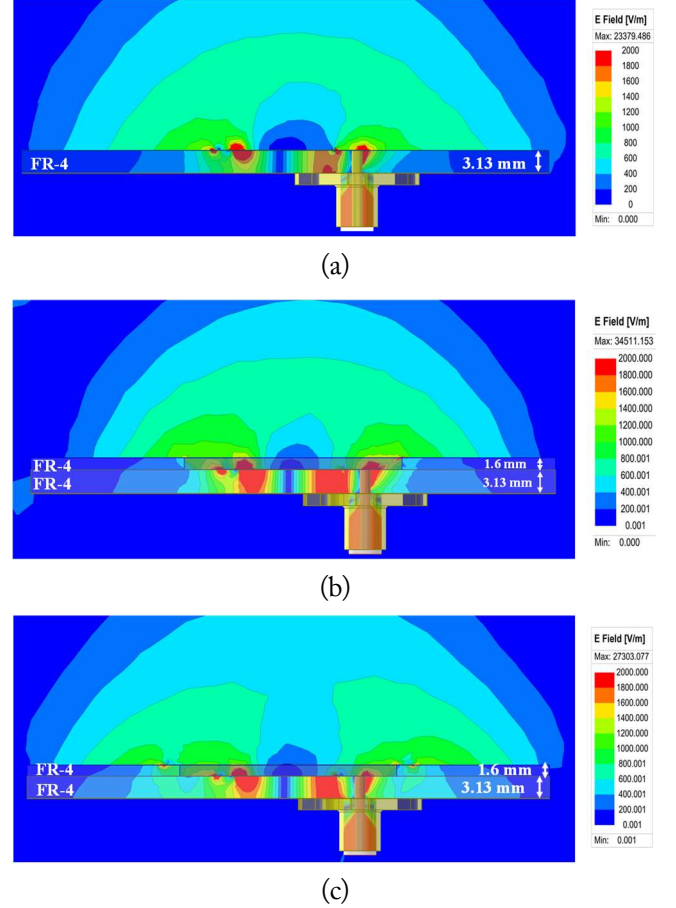


Fig. 4. A 3D electromagnetic simulation of the dual LP antenna with (a) reference (b) DGL-based dual LP antenna (c) proposed DGL configurations.

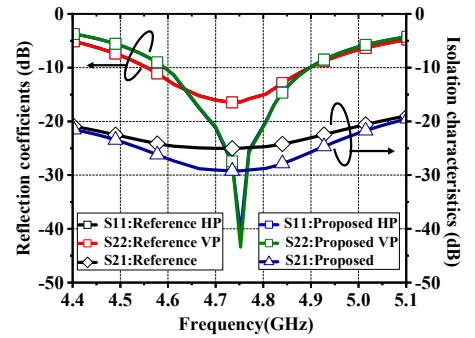


Fig. 5. Simulated S -parameters of the proposed antenna.

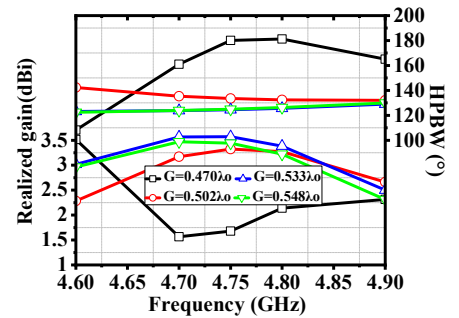


Fig. 6. Simulated realized gain and HPBW of the proposed antenna for different conductive ring parameters.

rameters as shown in Fig. 6. Based on the parametric analysis, the conductive ring size with $G = 0.502\lambda_0$ is chosen to ensure HPBW larger than 130° over the whole operation band.

Next, Fig. 7(a) and 7(b) illustrate the simulated radiation patterns of HP and VP at 4.7 GHz in both E-plane and H-plane. The proposed antenna demonstrates wider beam coverage than the reference antenna, particularly in the E-plane where the simulated peak gains are 3.4 dBi for both HP and VP, and the HPBW is extended to 134° and 131° , respectively. Such wide beamwidth is attributed to the DGL-induced beam expansion effect observed in Fig. 4. Moreover, Fig. 7(c) shows the simulated realized gain and HPBW of the reference and proposed antenna over the operating band. The proposed antenna maintains consistent wide beamwidths larger than 130° across the entire 4.6–4.9 GHz band, while preserving stable gain performance.

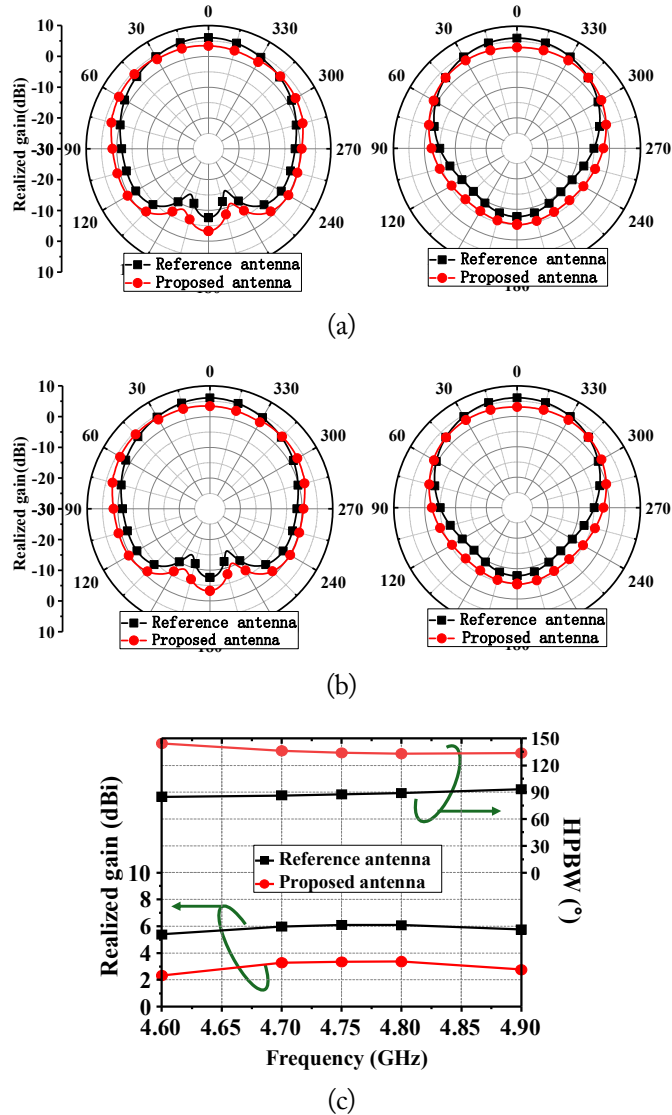


Fig. 7. Simulated (a) HP radiation patterns and (b) VP radiation patterns in E- and H-planes at 4.7 GHz, and (c) HP realized gain and HPBW over the operation band.

III. FABRICATION AND MEASUREMENT

The proposed antenna was fabricated using a standard PCB process, and photographs of the top and bottom views are shown in Fig. 8(a). The overall antenna size, including the ground plane and the DGL, is $67 \text{ mm} \times 67 \text{ mm} \times 4.74 \text{ mm}$, ensuring a compact profile suitable for potential P5G MIMO applications. The reflection coefficients of the HP and VP ports were measured, as shown in Fig. 8(b). The measured 10-dB impedance bandwidth was approximately 275 MHz, covering the operation band of 4.58–4.85 GHz, which is similar with the simulated results. Furthermore, the measured port-to-port isolation exceeded 25 dB across the operating bandwidth, confirming excellent isolation performance. Minor deviations between the measured and simulated S -parameters were observed, primarily due to fabrication tolerances and assembly variations, including the RF connector. However, the overall matching and

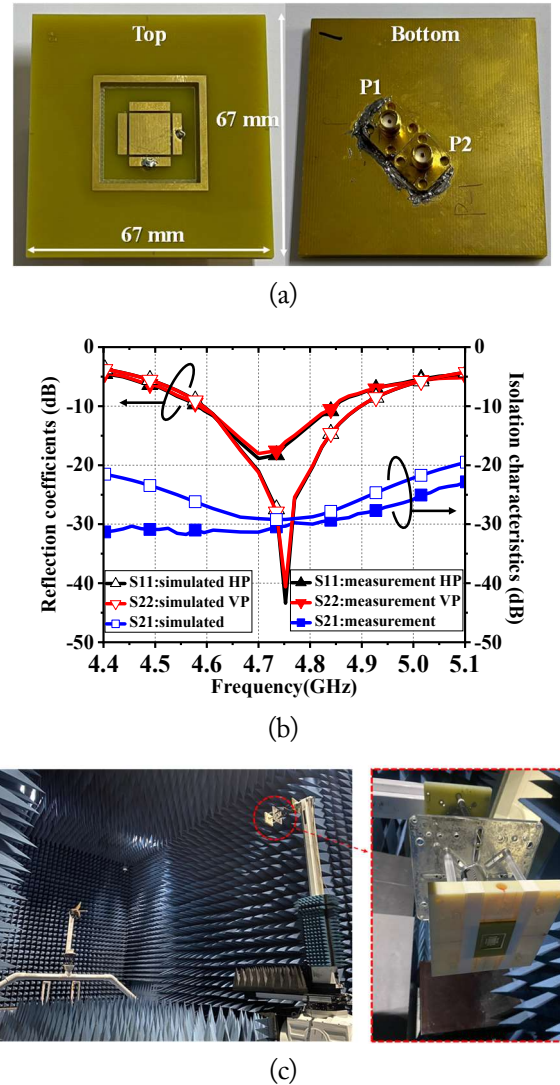


Fig. 8. Proposed antenna with (a) fabricated photo, (b) measured S -parameters and (c) radiation pattern measurement setup.

isolation trends match well with the simulation, validating the robustness of the proposed design. Radiation pattern measurements were conducted in a microwave anechoic chamber, as depicted in Fig. 8(c).

In Fig. 9(a)–9(h), both the co-polarization and cross-polarization radiation patterns are presented for the HP and VP excitations across 4.6–4.9 GHz. Across the measured band, both polarizations exhibited stable radiation patterns with

HPBW ranging from 131° to 138° , which is in good agreement with the simulated results. The beamwidth enhancement observed in simulation is clearly validated through these measurements, confirming the effectiveness of the DGL-based configuration in enabling wide-angle radiation. Also, the measured peak gains were 2.6 dBi, 3.2 dBi, 3.9 dBi, and 2.5 dBi at 4.6 GHz, 4.7 GHz, 4.8 GHz, and 4.9 GHz, respectively, while the simulated peak gains at these frequencies were 2.6 dBi, 3.4 dBi,

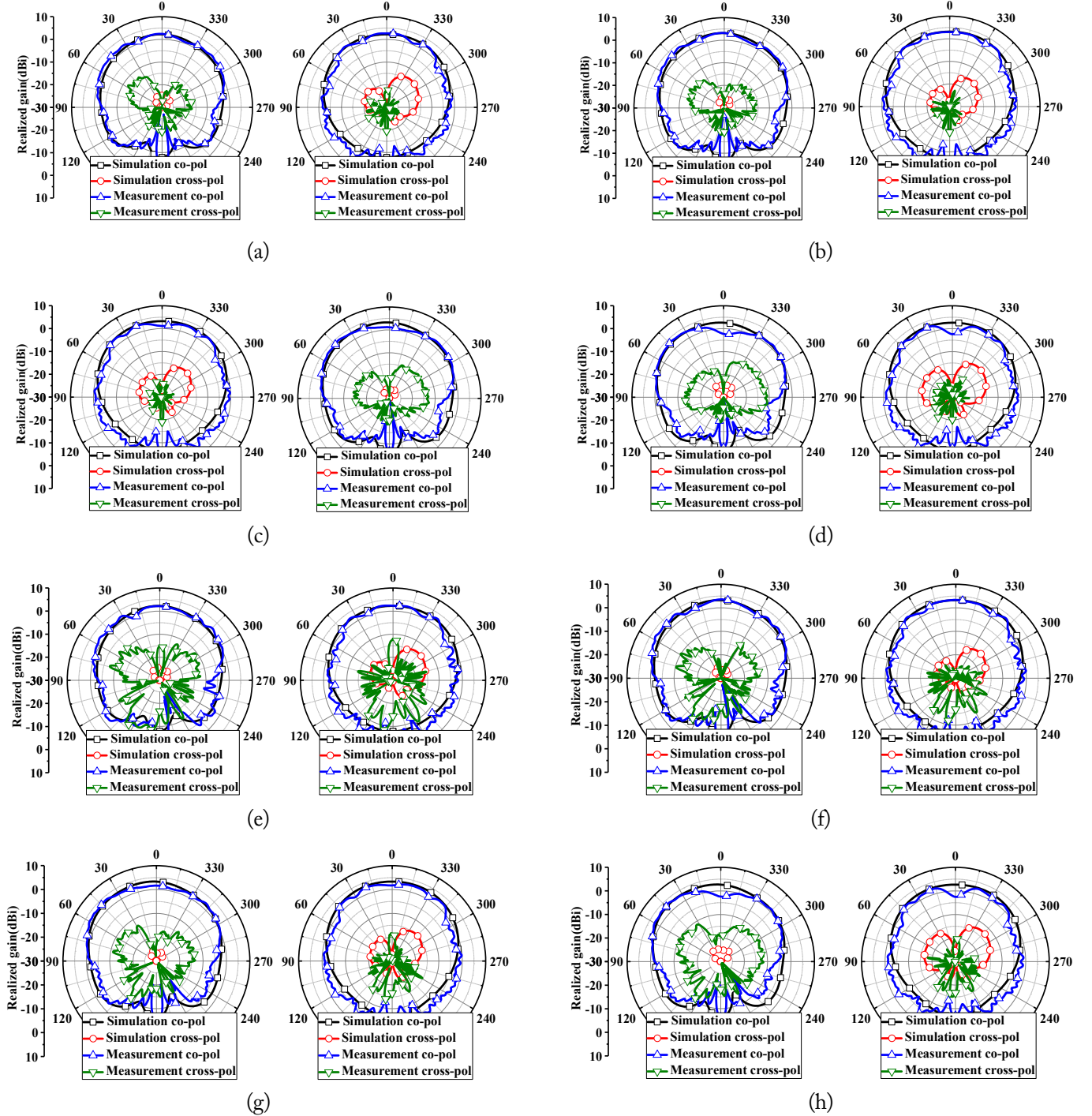


Fig. 9. Simulated and measured radiation pattern of HP at (a) 4.6 GHz, (b) 4.7 GHz, (c) 4.8 GHz and (d) 4.9 GHz, and VP at (e) 4.6 GHz, (f) 4.7 GHz, (g) 4.8 GHz and (h) 4.9 GHz.

3.5 dBi, and 2.5 dBi, respectively. The comparison between the simulated and measured radiation patterns confirms that the proposed DGL structure effectively broadens the radiation beamwidth for dual polarization.

However, minor discrepancies between the simulation and measurement were observed at 4.9 GHz. This was mainly attributed to 3D-printed fixture used to secure the antenna during measurement, as shown in Fig. 8(c). The fixture introduced additional scattering and slightly perturbed the DGL structure, particularly at the upper edge of the operating band, leading to partial field distortion and a dip in the main beam center. Additionally, dielectric loss increases and small variations in effective permittivity at higher frequencies can further reduce radiation efficiency. These effects collectively lead to partial field dispersion and reduced gain in the main lobe direction. To validate this effect, a 3D electromagnetic simulation was additionally performed with the antenna fixture included, as shown in Fig. 10. The simulated radiation pattern with the fixture exhibits a gain reduction at the center compared to the radiation pattern without the fixture. Despite these factors, the measured cross-polarization discrimination ranges from 25.2 dB to 32.9 dB across the operation band, and cross-polarization components remain consistently suppressed, as predicted by simulation, indicating high polarization purity of the proposed antenna. The angular phase transformation induced by the DGL structure contributes to spatial beam broadening and improves sector coverage while maintaining dual-polarization characteristics. These experimental results demonstrate that the DGL design principle observed in simulation can be reliably implemented in practical fabricated prototypes.

Lastly, Table 1 summarizes the measured performance of the proposed antenna compared with other recent designs. Compared with [9], [11] and [17], which are single-polarized antennas, the proposed DGL-based design offers the clear advantage of dual polarization, enabling more efficient integration into MIMO communication systems. In comparison with [18–20], the proposed antenna achieves a wider half-power beamwidth (131°) while maintaining a planar structure with reduced height

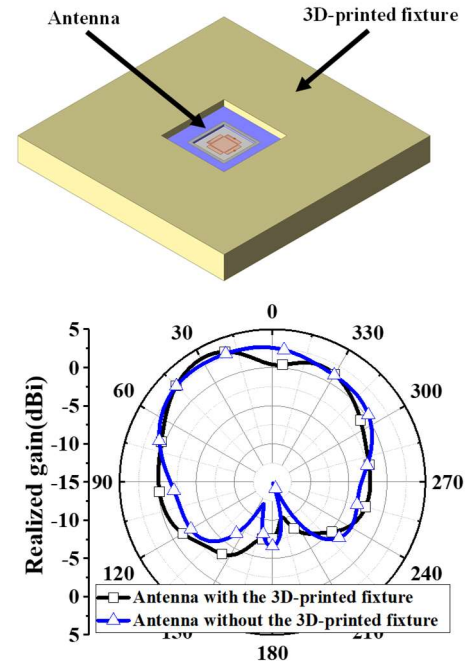


Fig. 10. Simulated verification for the measured radiation pattern discrepancy at 4.9 GHz.

($0.07\lambda_0$). This compact and low-profile configuration facilitates seamless integration into P5G MIMO base stations, providing wide-angle coverage and robust polarization purity for the cost-effective solution.

IV. CONCLUSION

This work presented a compact dual LP wide beamwidth antenna element optimized for P5G MIMO applications in Korea's 4.7 GHz band. To overcome the limitations of reference sector antennas, a DGL was employed to refract radiated energy outward through angular phase transformation, significantly enhancing the HPBW without compromising gain or polarization performance. The proposed antenna achieved the measured HPBW exceeding 131° in both polarizations, along with high isolation (>28.6 dB) and

Table 1. Comparison of wide beamwidth antennas

Study	Center freq. (GHz)	Impedance BW (%)	Polarization	Port isolation (dB)	Peak gain (dBi)	HPBW ($^\circ$)	Size (λ_0^3)
Kim et al. [9]	5.75	12.8	Single	N/A	6.3	111	$1.1 \times 1.1 \times 0.02$
Kim & Lee [11]	5.9	2.54	Single	N/A	5.5	124	$0.74 \times 3.7 \times 0.02$
Chang et al. [17]	1.5	94.9	Single	N/A	2.4	110	$0.34 \times 0.46 \times 0.2$
He & Li [18]	2.5	3.17	Dual	32	N/A	105	$1.42 \times 1.42 \times 0.07$
Feng et al. [19]	4.15	46.4	Dual	22	4.4	102	$0.43 \times 0.43 \times 0.16$
Chen et al. [20]	1.9	14.7	Dual	35	5.5	128	$0.63 \times 0.63 \times 0.38$
This work	4.7	5.73	Dual	28.6	3.9	131	$1.43 \times 1.43 \times 0.07$

cross-polarization discrimination (>25.2 dB), as confirmed through simulation and measurement. These results validate the proposed design as a highly effective solution for single-sector wide coverage and dual-polarized MIMO integration in next-generation 5G base station architectures. In addition, its planar structure and compatibility with standard PCB processes facilitate seamless integration with active modules, enabling compact and high-density deployments in next-generation communication systems. Future work will focus on large-scale MIMO implementation, where the proposed wide beam element can reduce the number of antenna units required for full coverage, simplify base station architecture, and eliminate the need for sectorization.

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