

A Miniaturized Single-Feed Dual-Band Dual-Orthogonally Polarized Antenna for U2V Communication Systems

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Abstract—This paper presents a compact single-fed dual-band dual-orthogonally polarized patch antenna for Unmanned Aerial Vehicle (UAV) to Vehicle (U2V) communication systems. The proposed square patch is loaded with multiple gaps and shorting vias to achieve significant size reduction. Dual-orthogonal polarizations are realized by properly exciting the radiator along the horizontal and vertical directions through a single input transmission line. By adjusting the gap dimensions, the effective capacitance of the radiator is conveniently controlled, thereby enabling two distinct resonant modes. The proposed antenna operates at 5.5 and 5.9 GHz with an electrical size of $0.18\lambda \times 0.18\lambda \times 0.04\lambda$ at the lower band. Notably, the frequency ratio between the two operating bands is only 1.07, which is smaller than that of most reported designs. In addition, the antenna exhibits symmetric radiation characteristics, with measured peak broadside gains of approximately 3.8 dBi and 3.2 dBi at the lower and upper bands, respectively. The proposed antenna is suitable for U2V systems, supporting high data rate transmission at 5.5 GHz and reliable low-latency communication at 5.9 GHz.

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Index Terms—Dual-band, dual-polarized, single-feed, patch antenna, miniaturization, capacitive loading.

I. INTRODUCTION

UNMANNED AERIAL VEHICLES (UAVs) are increasingly deployed in modern life for applications such as traffic monitoring, emergency response, surveillance, and intelligent transportation systems. In these scenarios, reliable communication between UAVs and ground vehicles plays a critical role in enabling real-time data exchange and coordinated operation. This UAV-to-vehicle (U2V) communication can be

considered an extension of Vehicle-to-Everything (V2X) communication, where both high data rate transmission and low-latency control are required simultaneously. Specifically, high-throughput links are needed for applications such as real-time video streaming and sensing, while robust and low-latency communication is essential for control signaling and safety-related information. Moreover, the antenna integrated into UAV systems must be compact and lightweight to satisfy strict payload and size constraints. Thus, using separate antennas for payload and control/safety links increases size, weight, and integration complexity. A single-feed dual-band design reduces feeding complexity and simplifies the antenna structure. In addition, the use of orthogonal polarization at the two operating bands helps mitigate mutual interference between the bands. Although ultra-wideband antennas can cover multiple applications, they may suffer from high interference levels [1], [2].

Various dual-band structures with similar polarization and broadside-radiations for both bands have been reported in [3]–[5]. However, these antennas commonly suffer from high inter-band interference. Dual-polarized antennas can be an effective solution since they can provide two orthogonal polarization modes, such as TM_{10} and TM_{01} , in a single radiator [6]–[9]. Dual-band antennas with orthogonal polarizations can be realized by exciting two orthogonal resonant modes at two distinct operating frequencies within a single radiator. Various dual-band dual-polarized antennas using microstrip patch structures with dual-fed technique have been reported [10]–[16]. Although dual-feed designs provide greater flexibility in independently optimizing impedance matching and polarization purity for each polarization, they require system complexity and cost to eliminate inter-port isolation.

Single-fed dual-band dual-polarized patches are preferred over dual-fed patches since they can reduce the complexity of the structure and provide easier integration into the communication system. Designing this type of antenna is highly challenging because independent frequency control with a single feed is difficult to achieve. There are a few designs published in the literature [17]–[22]. In [17], a dual-polarized dual-band patch with similar broadside radiation is realized by using a proximity coupled-feed. In [18], an approach of using Boolean particle swarm optimization on a patch antenna is reported. Alternatively, the desired operating characteristics can be obtained by the patches with various slots [19]–[21]. The simplest approach is proposed in [22], which employs

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a triangular patch with a proper feeding position. Although good performance for both bands can be achieved, such designs [17]–[22] suffer from a critical drawback of large size. Besides, acquiring a small frequency ratio in a single-feed antenna structure becomes a challenging task. Notably, a lower frequency ratio facilitates greater miniaturization, leading to a more compact dual-band antenna design.

This paper presents a single-fed dual-band dual-orthogonally polarized patch antenna with compact size and a small frequency ratio. The square patch is loaded with multiple gaps and shorting vias for miniaturization. This method allows strong miniaturization while preserving a physically interpretable TM_{10} -like operation. By tuning the gap size, the antenna can produce resonances at two different frequencies. Meanwhile, dual-orthogonal polarization is realized by exciting feeding points in horizontal and vertical directions through a single input transmission line. The proposed antenna operates effectively at 5.5 and 5.9 GHz, enabling high-data-rate WLAN transmission based on IEEE 802.11ac at the lower band and low-latency control/safety-related U2V/V2X communication based on IEEE 802.11p/DSRC at the upper band. It is worth noting that the ratio between the high and low bands is just 1.07, which is much smaller than the others [17]–[22]. Additionally, symmetrical radiation patterns are obtained, and the maximum broadside gains for lower and higher bands are about 3.8 and 3.4 dBi, respectively.

II. SINGLE-FEED MINIATURIZED PATCH

A. Antenna Design

The conventional microstrip patch works at the fundamental mode of TM_{01} with an electrical length of about half a waveguide wavelength. Various techniques have been reported for size reduction. Using patches with meandered [23] or curved edges [24], adding different slow-wave structures [25], [26], and cutting the radiating patch with various shaped slots are effective methods [27], [28]. This paper utilizes the method of capacitive loading for size reduction.

Fig. 1 shows the configurations of the proposed miniaturized patch antenna. It is printed on the top side of a Roger 4035 substrate with a dielectric constant of 3.5. The miniaturized patch is loaded with several gaps and four shorting pins. The 50- Ω SMA connector is utilized to excite the antenna. The optimized dimensions of the miniaturized patch antenna are as follows: $W_g = 30$ mm, $L = 9.8$ mm, $w_1 = 1.8$ mm, $w_2 = 2.0$ mm, $d = 1.0$ mm, $s_1 = 0.4$ mm, $s_2 = 0.4$ mm.

B. Antenna Operation Characteristics

Fig. 2 compares the simulated reflection coefficients of the conventional half-wavelength patch and the miniaturized patch. The results indicate that the conventional design resonates at a substantially higher frequency of approximately 7.5 GHz, which closely corresponds to the fundamental TM_{01} mode. In contrast, the miniaturized patch, incorporating multiple capacitive gaps and stronger electromagnetic coupling, exhibits a significantly reduced resonant frequency of about

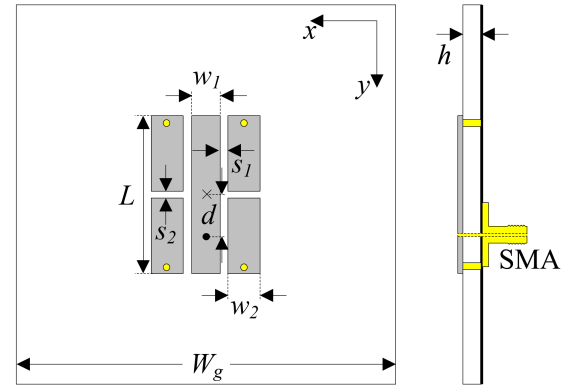


Fig. 1. Geometry of the proposed single-polarized miniaturized antenna.

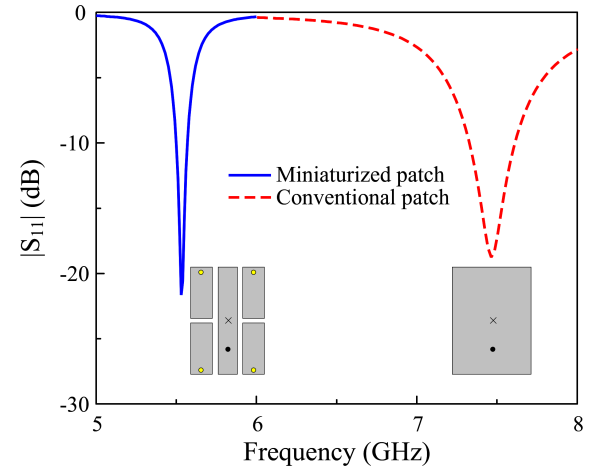


Fig. 2. Simulated $|S_{11}|$ of the conventional and miniaturized patches.

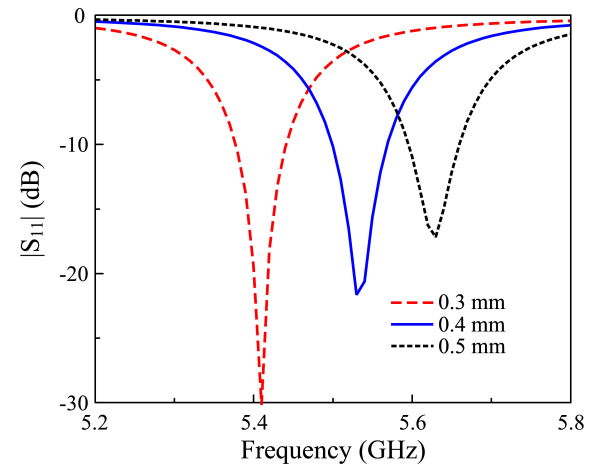


Fig. 3. Simulated $|S_{11}|$ of the miniaturized antenna for different values of s_1 .

5.55 GHz. This demonstrates the effectiveness of the proposed loading technique in achieving antenna miniaturization.

Since the introduced gaps increase the effective capacitance of the antenna, the gap dimension is a critical parameter governing the miniaturization level. Fig. 3 presents the simulated $|S_{11}|$ for different widths of the gap, s_1 . The capacitance associated with the coupled gaps is approximately inversely

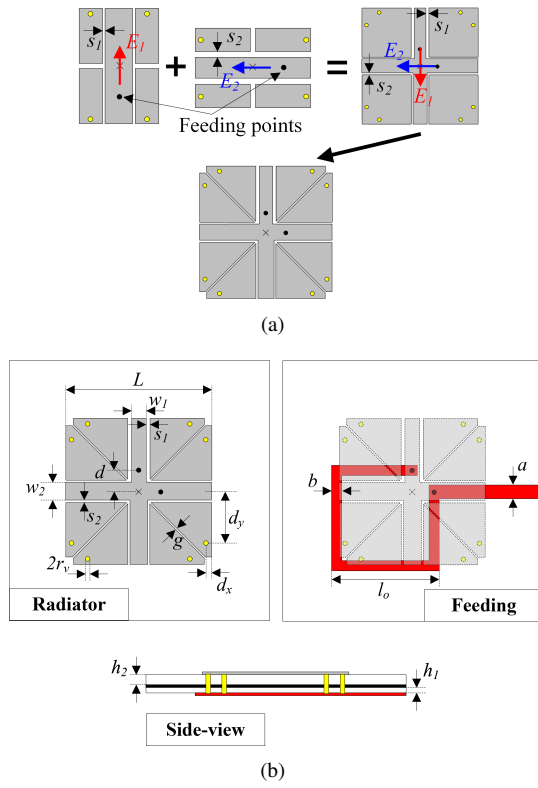


Fig. 4. (a) Dual-band dual-polarized antenna realization method and (b) geometry of the proposed antenna.

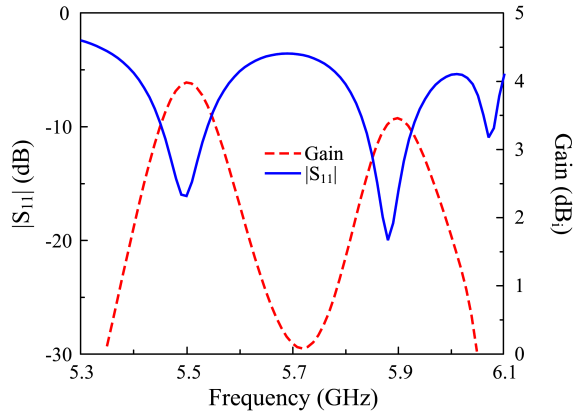


Fig. 5. Simulated $|S_{11}|$ and gain of the proposed antenna.

proportional to the gap size. As observed in Fig. 3, reducing s_1 increases the capacitive loading, which in turn shifts the resonant frequency toward lower values, thereby enhancing the compactness of the antenna design. To conclude, the utilized miniaturization approach can reduce the resonant length of the antenna from half-to about quarter-effective wavelength at the desired frequency.

III. SINGLE-FEED DUAL-BAND DUAL-ORTHOGONALLY POLARIZED MINIATURIZED PATCH

A. Antenna Design

Based on the single-polarized antenna described in the previous section, Fig. 4 shows the realization of the proposed

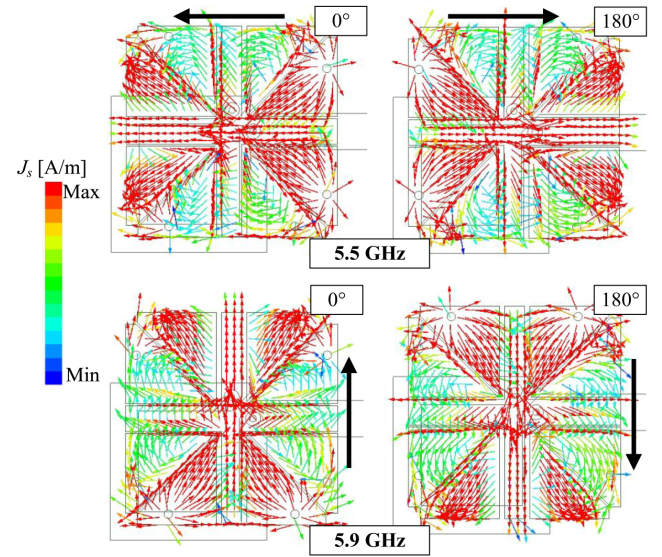


Fig. 6. Simulated surface current on the proposed antenna.

dual-band dual-polarized antenna. Two orthogonally oriented radiating elements are integrated to excite independent field components corresponding to horizontal and vertical polarizations. The two radiators share an identical physical structure except for the gap parameters s_1 and s_2 , which primarily control the additional capacitance, and thus independently determine the resonant frequencies of the two operating bands. To isolate the operation of the upper and lower bands, two diagonal slots are etched into the radiator. The antenna is excited through two orthogonal probe feeds connected to a transmission line, enabling efficient excitation of orthogonal modes with a single feeding scheme. The optimal design parameters are $L = 9.8$, $w_1 = 1.0$, $w_2 = 1.0$, $s_1 = 0.23$, $s_2 = 0.1$, $g = 0.1$, $d = 1$, $d_x = 0.5$, $d_y = 3.0$, $r_v = 0.2$, $a = 1.7$, $b = 1.3$, $l_o = 7.3$ (unit: mm).

B. Antenna Performance

The simulated reflection coefficient and gain of the proposed antenna are shown in Fig. 5, where obvious dual-band operation is observed. The lower band is centered at 5.5 GHz with an impedance bandwidth of 5.45–5.54 GHz, while the upper band resonates at 5.9 GHz and covers a bandwidth from 5.84 to 5.93 GHz. Across the lower band, the gain remains higher than 3.5 dBi and reaches a peak value of 4.0 dBi. For the upper band, the gain exceeds 2.4 dBi throughout the band, with a maximum value of 3.5 dBi. In addition, the simulated radiation efficiency indicates values greater than 58% for the lower band and above 50% for the upper band, demonstrating acceptable radiation performance despite the compact antenna size. Noted that radiation efficiency generally decreases with further size reduction due to the increased stored reactive energy.

To verify the dual-polarization operation, Fig. 6 illustrates the simulated surface current distributions at 5.5 and 5.9 GHz under excitation phases of 0° and 180°. At 5.5 GHz, the surface current reverses predominantly along the horizontal axis as the phase changes, indicating excitation of the fundamental transverse magnetic mode associated with horizontal

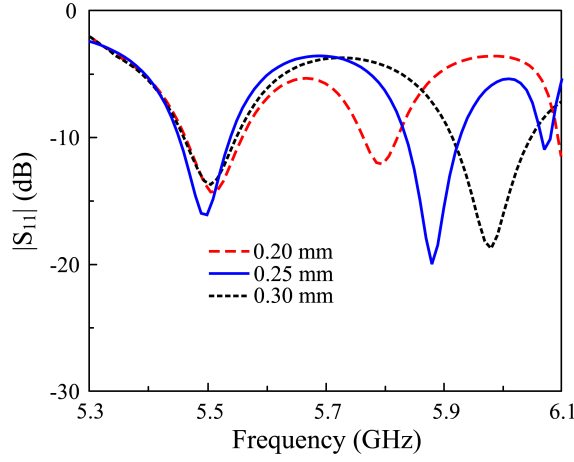


Fig. 7. Simulated $|S_{11}|$ of the proposed antenna for different s_1 values.

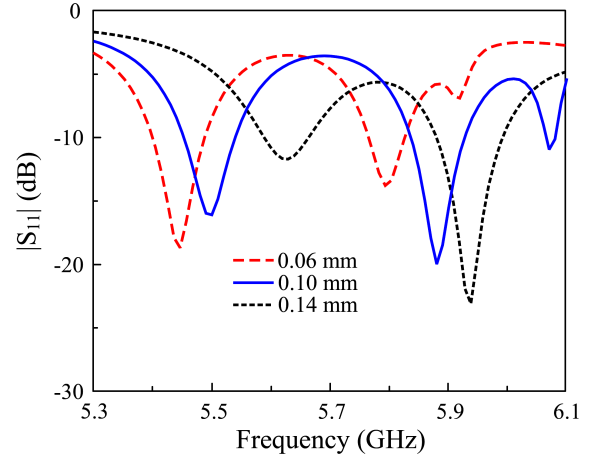


Fig. 9. Simulated $|S_{11}|$ of the proposed antenna for different g values.

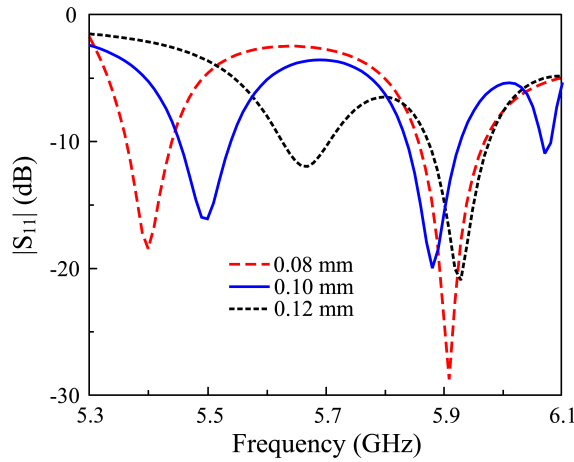


Fig. 8. Simulated $|S_{11}|$ of the proposed antenna for different s_2 values.

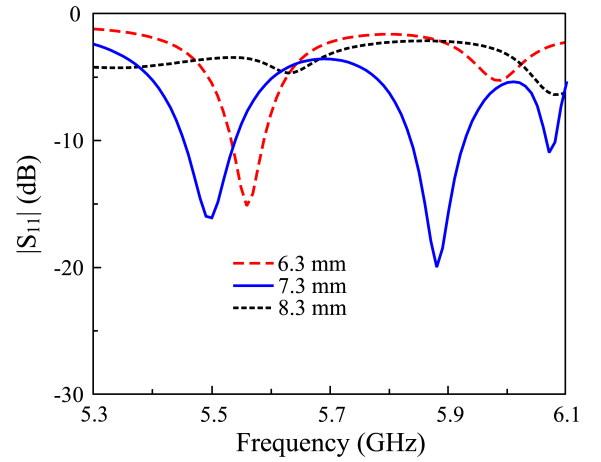


Fig. 10. Simulated $|S_{11}|$ of the proposed antenna for different l_o values.

polarization (TM₁₀-like mode). In contrast, at 5.9 GHz, the current is mainly concentrated along the vertical direction with phase reversal, corresponding to excitation of the vertical mode (TM₀₁-like mode) and resulting in vertical linear polarization. These observations confirm that the two operating bands are associated with orthogonal resonant modes.

C. Antenna Optimization

Precise control of the operating frequencies in the lower and upper bands is essential. Higher frequency independence between these two bands results in superior antenna characteristics. In this design, the resonant frequencies of the lower and upper bands can be tuned independently by adjusting the gap dimensions s_1 and s_2 , respectively. Fig. 7 and Fig. 8 illustrate the simulated $|S_{11}|$ under different values of s_1 and s_2 . It is observed that variations in s_1 have a significant impact on the higher-band resonance, whereas the lower-band response remains almost unchanged. Conversely, modifying s_2 effectively shifts the lower-band resonance while exerting negligible influence on the higher-band. These results confirm good frequency isolation and independent controllability between the two operating frequency bands.

Another critical parameter governing the resonant characteristics of both bands is the gap width of the diagonal slots, denoted as g . As shown in Fig. 9, variations in this parameter influence the resonant frequencies of both bands. A smaller gap corresponds to a higher capacitive effect, which in turn shifts both resonances toward lower frequencies.

Finally, the impedance matching is investigated. Since the proposed antenna employs a single-input port, the horizontal and vertical polarization excitations are implemented using a series-fed configuration. The electrical length between the two feeding points is designed to be one guided wavelength. Fig. 10 depicts the effect of l_o on the matching performance. Obviously, this parameter plays a critical role, as deviations from the one guided-wavelength condition result in significant degradation of the matching characteristics.

IV. MEASUREMENT RESULTS

For experimental validation, the fabricated dual-polarized antenna prototype was carefully characterized using a standard antenna measurement system. The prototype was fabricated using a standard PCB photolithography/chemical etching process. The expected tolerance of the etched gap dimensions is

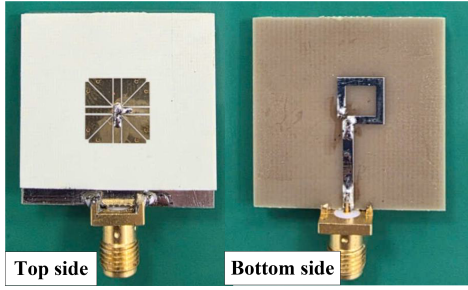


Fig. 11. Photographs of the fabricated antenna.

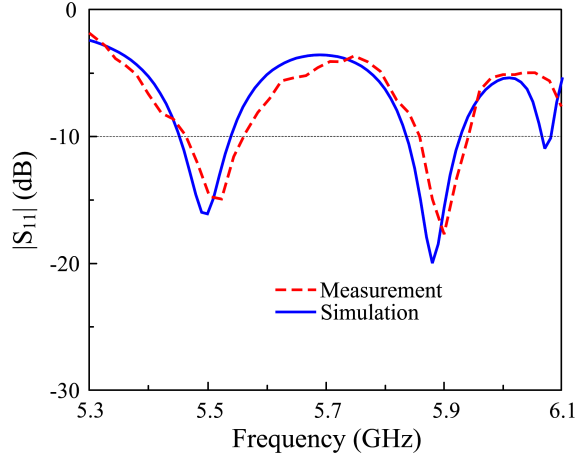


Fig. 12. Simulated and measured $|S_{11}|$ of the proposed antenna.

approximately ± 0.02 to ± 0.03 mm for the employed fabrication process, while ± 0.05 mm is considered as a conservative worst-case deviation. Although small frequency shifts may occur due to fabrication tolerances, the proposed antenna can still maintain acceptable dual-band operation for the intended U2V applications (as demonstrated in Figs. 7 and 8). The S-parameter is measured with the Vector Network Analyzer, while the far-field performance is characterized in the anechoic chamber. The photographs of the fabricated antenna are shown in Fig. 11. The simulated and measured reflection coefficients are presented in Fig. 12. The measured -10 dB impedance bandwidth of the lower band spans from 5.46 to 5.56 GHz, corresponding to a fractional bandwidth of approximately 1.8%. Meanwhile, the higher band exhibits a measured bandwidth of 5.86–5.94 GHz, equivalent to about 1.4%. These bandwidths are sufficient to support IEEE 802.11ac and IEEE 802.11p channels.

The simulated and measured gain results are plotted in Fig. 13. Within the operating range of the lower band, the measured gain varies from 3.0 to 3.8 dBi. For the higher band, the broadside gain remains above 2.6 dBi across the band, reaching a peak value of 3.2 dBi. Fig. 14 plots the simulated and measured gain radiation patterns at 5.5 and 5.9 GHz. Both co-polarization and cross-polarization components were recorded in the principal planes (E- and H-plane) to verify the radiation characteristics and polarization purity. The measured results indicate that the antenna exhibits stable radiation patterns with good symmetry around the broadside

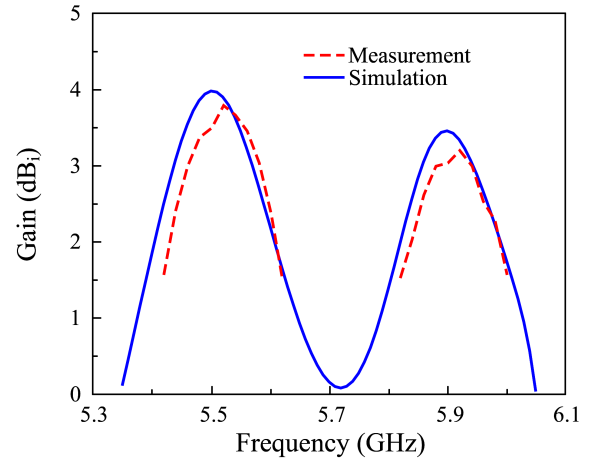


Fig. 13. Simulated and measured gain of the proposed antenna.

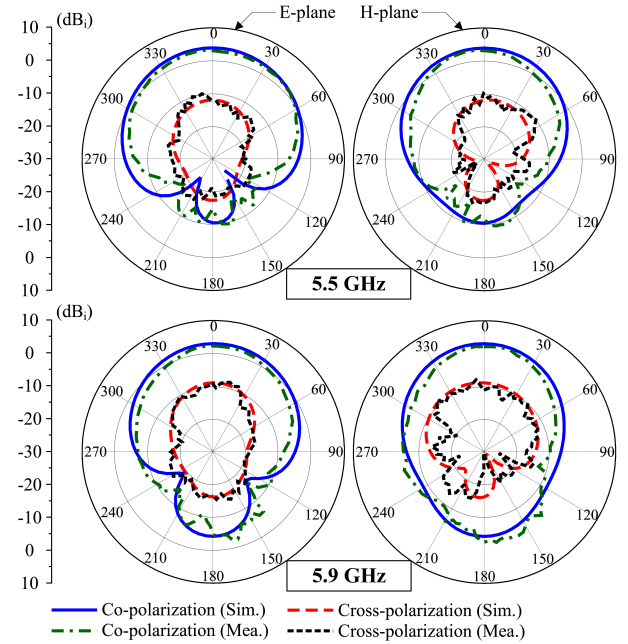


Fig. 14. Simulated and measured gain radiation patterns.

direction. Beside, the difference between the co- and cross-polarization levels in the broadside direction is better than 14 dB.

To highlight the advantages of the proposed work, a performance comparison among single-feed dual-band dual-orthogonally polarized antennas is summarized and given in Table I. Obviously, the proposed antenna has the most compact size and smallest frequency ratio, which is very challenging in designing dual-band antenna. The other designs can achieve higher gain, but larger sizes are their critical drawbacks.

V. CONCLUSION

A compact single-feed dual-band dual-orthogonally polarized patch antenna with a small frequency ratio has been investigated and presented in this paper. Miniaturization is achieved using multiple gaps and shorting vias, while dual resonances are realized through capacitive tuning. The antenna operates

TABLE I
PERFORMANCE COMPARISON AMONG SINGLE-FEED
DUAL-ORTHOGONALLY POLARIZED ANTENNAS

Ref.	Size (λ)	Frequency Ratio	f_H/f_L (GHz)	Bandwidth (%)	Gain (dBi)
[17]	$0.31 \times 0.24 \times 0.03$	1.25	7.5/5.7	NA	N/A
[18]	N/A	1.16	14.0/12.0	3.3/7.1	4.8/4.6
[19]	$0.21 \times 0.21 \times 0.12$	1.80	2.1/1.25	4.2/11.4	≥ 6.0
[20]	$0.19 \times 0.19 \times 0.03$	1.36	14.2/10.4	1.9/4.2	6.8/5.6
[21]	$0.23 \times 0.23 \times 0.03$	1.81	10.5/5.8	1.2/1.2	6.3/3.2
[22]	$0.25 \times 0.23 \times 0.01$	1.44	2.37/1.65	NA	6.1/5.0
Prop.	$0.18 \times 0.18 \times 0.04$	1.07	5.9/5.5	1.8/1.4	3.2/3.8

at 5.5 and 5.9 GHz with an electrical size of $0.18 \lambda \times 0.18 \lambda \times 0.04 \lambda$ and a frequency ratio of only 1.07. Dual-orthogonal polarizations are obtained using a single transmission-line feed to excite the radiators at two different points. The measured symmetric radiation patterns confirm that the proposed design is suitable for U2V communication systems. The antenna can support an 80 MHz channel bandwidth for IEEE 802.11ac and at least a 10 MHz channel bandwidth for IEEE 802.11p.

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