

A Broadband High-Isolation Dual-Polarized Antenna for 5G Application

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Abstract—In this paper, a novel broadband high-isolation dual-polarized antenna is proposed for 5G application. The proposed antenna consists of L-shaped elements, Γ -shaped feeding strips, and a box-shaped reflector. The use of simple L-shaped antenna elements not only simplifies the manufacturing process, but also greatly increases the isolation between the two ports. Stable gain and radiation patterns are achieved by using box-shaped reflectors. Results show that an impedance bandwidth of 50.6% for $S_{11} < -10$ dB & $S_{22} < -10$ dB from 3.1 to 5.2 GHz was achieved, and port to port isolation was higher than 45 dB within the bandwidth. The gains of the measured antenna were 8.7 ± 1.1 dBi in the whole operating frequency band. In addition, stable radiation pattern with low cross polarization, low back radiation was achieved.

1. INTRODUCTION

With the tremendous development of mobile communication systems, there has been increased interest in wideband, multiband, high gain, high-isolation antenna designs in base station antennas. Wideband antennas are needed to satisfy the increasing number of service bands, especially the WLAN, WiMAX, LTE, and 5G operating frequency bands. Due to the increased integration and complexity of 5G communication base stations, high-isolation base station antennas have been becoming an important research direction for antennas in 5G communication systems. Compared to the traditional base station antennas, high-isolation antennas can better form array integration. Compared with spatial-diversity technique, polarization-diversity technique only requires one antenna for operation, hence reducing the installation [1]. Over the last few years, dual-polarized antennas have become popular in base stations, which contributes to their good performance in reducing multipath fading and increasing channel capacity [2]. Meanwhile, wideband dual-band, high isolation, low cross-polarization, and compact size are huge challenges for a wideband dual-band dual-polarized antenna.

In recent years, several dual-polarized antennas with good performances have been designed based on patch antenna [3–7] and magneto-electric (ME) antenna [8–17]. Patch antennas became popular with advantages of low profile, low cost, and ease of mass fabrication. However, it is extremely difficult to achieve wide impedance bandwidth with patch antennas. Several types of magneto-electric dipole antennas have been reported: single-band [8–14] and dual-band [15–17]. Good electrical characteristics, such as wide bandwidth, low cross-polarized radiation, great front-to-back ratio, and symmetric E - and H -plane radiation patterns, were demonstrated. In [8], a coax-feed wideband dual-polarized patch antenna with low cross polarization and high port isolation is presented, achieving a 10-dB return loss bandwidth of 1.70–2.73 GHz, and the isolation between the two ports remains more than 38 dB in the whole bandwidth. An antenna achieving bandwidth from 575 to 722 MHz (22.7%), the isolation between the two polarizations better than 35 dB was presented in [9]. With wide impedance bandwidth

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from 1.68 to 2.75 GHz, a high port-to-port isolation (better than 37 dB) within the operating frequency bandwidth was achieved in [14]. In the above papers, the proposed high ports isolation characteristics are very practical, and they exhibit good performance over the whole working bands, while their impedance bandwidths are not broad. However, none of these base station antennas cover the frequency bands 3.3 GHz–3.6 GHz and 4.8 GHz–5 GHz used in the 5G communication system in China.

In this paper, a novel broadband high-isolation dual-polarized antenna is proposed for 5G application. The novel simple L-shaped antenna element greatly increases the isolation between the two ports. Moreover, owing to the rectangular box-shaped reflector, the antenna's back radiation can be suppressed, and high gain can be achieved across the operating frequency range. Besides, due to the Γ -shaped feeding structure, the proposed antenna exhibits better performance in impedance bandwidth than that in the literature, and it can also obtain wide impedance bandwidth of 50.6% (3.1–5.2 GHz), a high port-to-port isolation higher than 45 dB, and a stable radiation pattern. Moreover, it is more suitable for 5G application.

This paper is organized as follows. In Section 2, the basic structure and operation principle of the proposed antenna are described. Simulated and measured results are presented in Section 3. Parameter study is discussed in Section 4. The comparison of different high-isolation antennas is discussed in Section 5, followed by the conclusions which are presented in Section 6.

2. ANTENNA DESCRIPTIONS

2.1. Antenna Structure

The geometry of the broadband high-Isolation dual-polarized magneto-electric antenna is shown in Figures 1–2. Figure 1(a) shows the perspective view of the proposed antenna. It consists of a rectangular box-shaped reflector, two pairs of novel L-shaped antenna elements, and a pair of orthogonal Γ -shaped feeding strips. Figure 1(d) is a schematic diagram of the evolution of an L-shaped antenna element. The use of L-shaped antenna elements greatly increases the isolation between Port 1 and Port 2. Compared to conventional magneto-electric dipole antenna elements, L-shaped antenna element reduces the coupling between the antenna elements. The rectangular box-shaped reflector with dimensions of 50 mm \times 50 mm \times 28.8 mm is used to achieve relatively stable gain and better radiation performance over the passband.

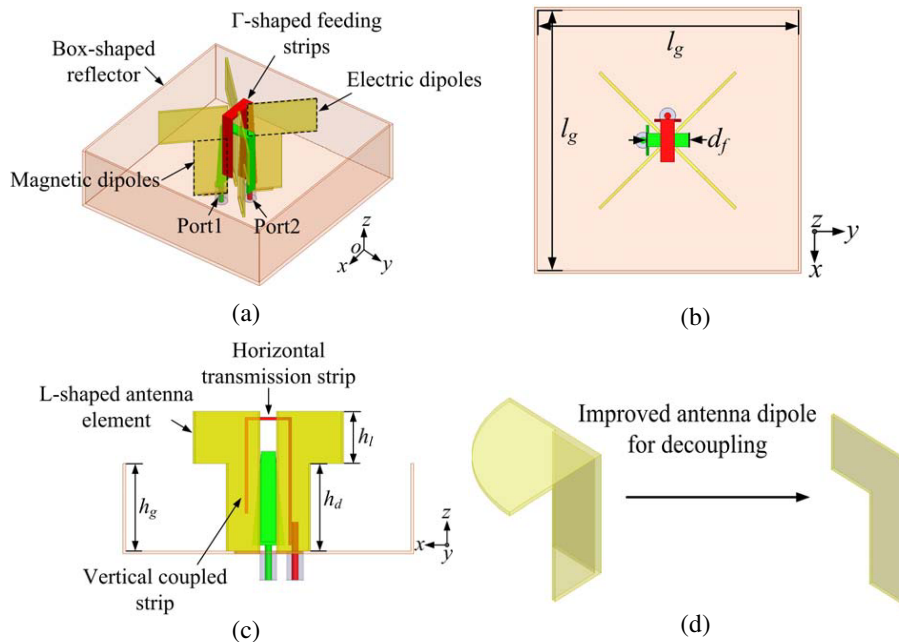


Figure 1. (a) Perspective view. (b) Top view. (c) Side view. (d) Schematic diagram of antenna element evolution.

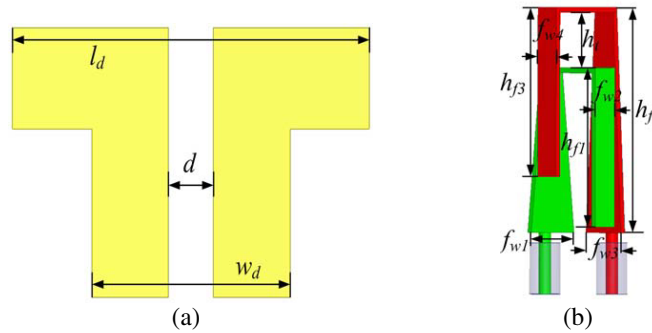


Figure 2. (a) Antenna elements of the proposed antenna. (b) Geometry of the orthogonal Γ -shaped feeding line.

The top and side views of the proposed antenna are depicted in Figure 1(b) and Figure 1(c). In order to describe the antenna element more clearly, Figure 2(a) shows a pair of proposed antenna element units. As shown in Figure 2(b), Γ -shaped feeding strips are used to excite the antenna. In fact, the feeding strip has two functions: one is a coupled strip, and the other is a transmission strip. Its horizontal part is responsible for coupling electrical energy to antenna. The vertical part incorporated with one of the vertical patches introduces some capacitance to compensate the inductance caused by the horizontal part. A trapezoid line is used for the transmission portion to increase the impedance bandwidth which is narrower at the top (f_{w2} and f_{w4} at each polarization) and wider at the bottom (f_{w1} and f_{w3} at each polarization). SMA connector located under the ground plane is connected to the bottom of the Γ -shaped strip line.

For dual polarizations, two Γ -shaped feeding strips are placed orthogonally at different heights to avoid mechanical interference. With the help of High Frequency Structure Simulator (HFSS) software, dimensions of the configurations are simulated and optimized, and the final optimal dimension values are listed in Table 1.

Table 1. Dimensions for the proposed high-isolation antenna.

Parameters	l_g	l_d	h_g	h_d	h_l	h_t	h_{f1}	h_{f2}
Values/mm	50	36	15.5	15	9	5.4	15.5	21.4
Parameters	h_{f3}	f_{w1}	f_{w2}	f_{w3}	f_{w4}	d	d_f	w_d
Values/mm	16.5	5.6	2.5	5	2.6	4.5	8	20

In fabrication of the prototype, the proposed antenna is made of copper, and the thickness of copper patch is 0.5 mm. The radius of the two SMA probes is 0.6 mm, and they protrude by 5 mm above the box-shaped ground plane.

2.2. Principle of Operation

It is well known that the radiation pattern of an electric dipole is like a figure “8” shape in the E -plane and “O” shape in the H -plane, whereas the radiation pattern of a magnetic dipole is like a figure “O” shape in the E -plane and “8” shape in the H -plane. If an electric dipole and a magnetic dipole are excited simultaneously with proper amplitudes and phases, the radiating power can be reinforced in the broadside direction but suppressed in the back side [8]. Therefore, a uniform unidirectional radiation pattern with good radiation performances can be achieved by combining an electric dipole and a magnetic dipole. In our design, since the L-shaped antenna element is simplified with a three-dimensional electromagnetic dipole antenna element, we use the theory of electromagnetic dipole to explain its principle.

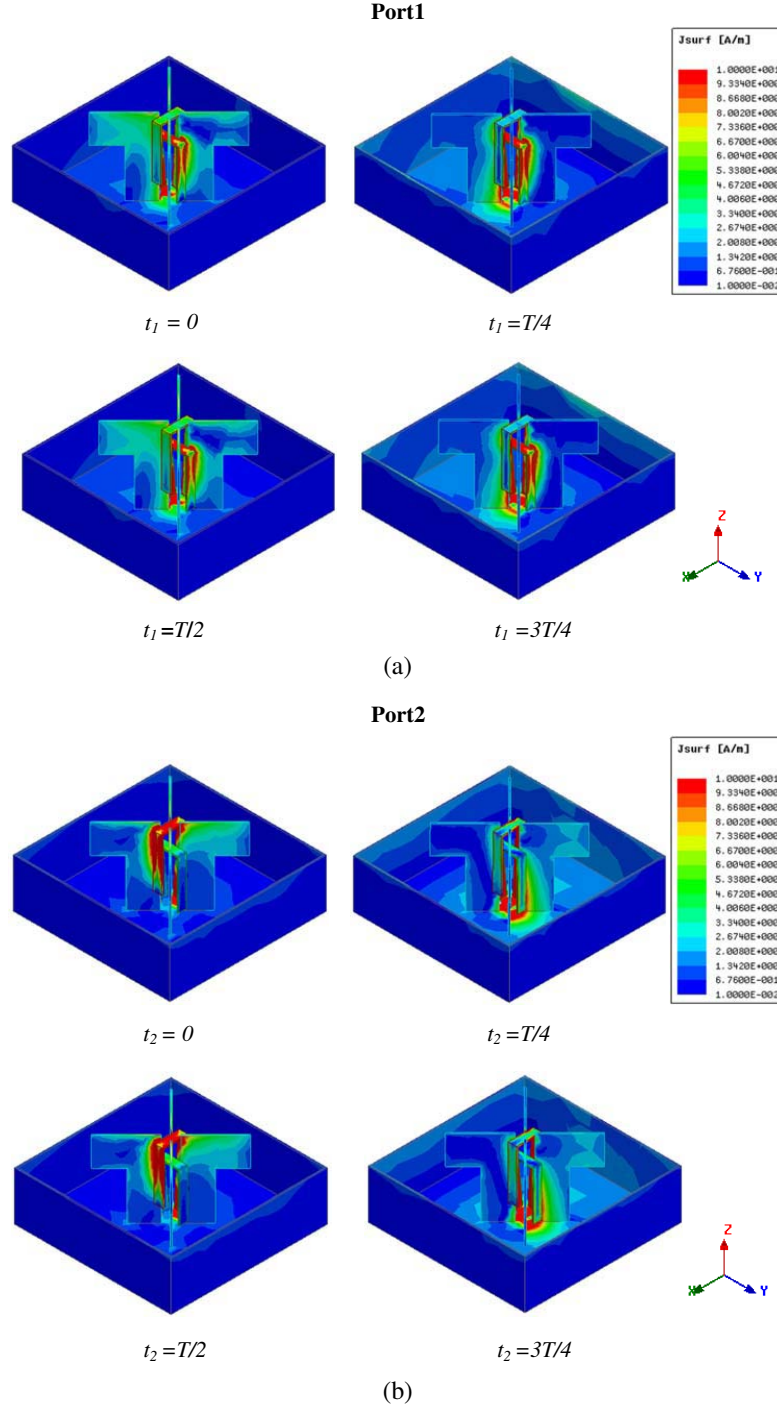


Figure 3. Current distributions of the high-isolation dual-polarized antenna at 4.2 GHz. (a) Port 1. (b) Port 2.

To better understand the working principle of the antenna, the current distributions of the proposed antenna with input from Port 1 and Port 2, at time t_1 and t_2 , are analyzed as shown in Figure 3, respectively. Definition T is the period of the variation of the electromagnetic fields caused by the proposed antenna, and at time $t_1 = t_2 = 0$, the currents are mainly distributed on the improved planar dipoles, whereas the currents on vertically oriented shorted patches are minimized. Therefore, it is clear that the electric dipole mode is mainly excited in the horizontal and vertical directions when Port 1 and

Port 2 are excited at time $t_1 = t_2 = 0$, respectively. At time $t_1 = t_2 = T/4$, the currents distributed on the improved planar dipoles are minimized, whereas the currents on vertically oriented shorted patches are strongest, suggesting that the magnetic dipole mode is mainly excited in the horizontal and vertical directions when Port 1 and Port 2 are excited at time $t_1 = t_2 = T/4$, respectively. At time $t_1 = t_2 = T/2$, the electric dipole mode is mainly excited again with opposite current direction to the mode at $t_1 = t_2 = 0$. At time $t_1 = t_2 = 3T/4$, the magnetic dipole mode is mainly excited again with opposite current direction to the mode at $t_1 = t_2 = T/4$.

Hence, two degenerate modes of similar magnitudes in strength are excited on the planar dipole (electric dipole) and the quarter-wave vertically oriented shorted patch antennas (magnetic dipole). The equivalent electric and magnetic currents are 90 degrees in phase difference and orthogonal to each other. It is expected that the antenna in this proposed form can achieve stable gain and low back radiation over the operating frequency band.

3. SIMULATED AND MEASURED PERFORMANCE

To verify the proposed design, an antenna prototype was constructed, as shown in Figure 4. Measured results of S -parameters, gains, isolation, and radiation patterns were obtained by Agilent N5247A network analyzer and a SATIMO antenna measurement system.

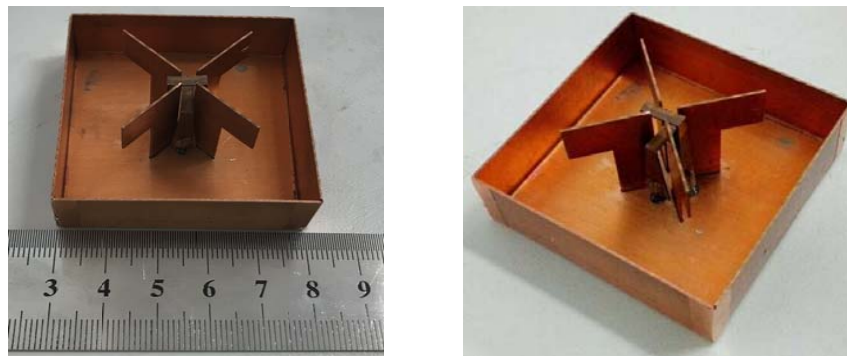


Figure 4. Prototype of the high-isolation 5G antenna.

Figure 5 depicts simulated and measured S -parameters and gains of the proposed high-isolation antenna. It can be seen that the antenna operates from 3.1 to 5.2 GHz with a bandwidth of 50.6% ($S_{11} < -10$ dB & $S_{22} < -10$ dB). The operating frequency ranges for the two ports are slightly different due to the unequal heights and dimensions of the two orthogonal strip lines. The common bandwidth of the two ports is 50.6% ranging from 3.1 to 5.2 GHz. Figure 5(c) shows the isolation between the two ports. The measured isolation between the two ports is better than 45 dB over the entire operating frequency band. Over the operating frequency range, the measured broadside gain is 8.7 ± 1.1 dBi.

The measured radiation patterns of the proposed high-isolation magneto-electric dipole antenna for Port 1 and Port 2 at frequencies 3.3, 4.8, and 5 GHz are plotted in Figure 6, where cross-pol and co-pol are the cross-polarization and co-polarization, respectively. It is shown that the antenna has a nearly symmetric and good unidirectional radiation pattern across the entire bandwidth.

Detailed measured results including the Half-Power beamwidth in both horizontal and vertical planes and the Cross-Polarization Level at two ports are summarized in Table 2. The Half-Power beamwidth in both horizontal and vertical planes for both ports becomes narrower as frequency increases. The cross-polarization levels for both H - and V -planes are less than -18 dB.

4. PARAMETRIC STUDY

For a better understanding of how the dimensions of the antenna affect its performances, some parameters of the antenna dipoles and rectangular box-shaped reflector are studied by simulation.

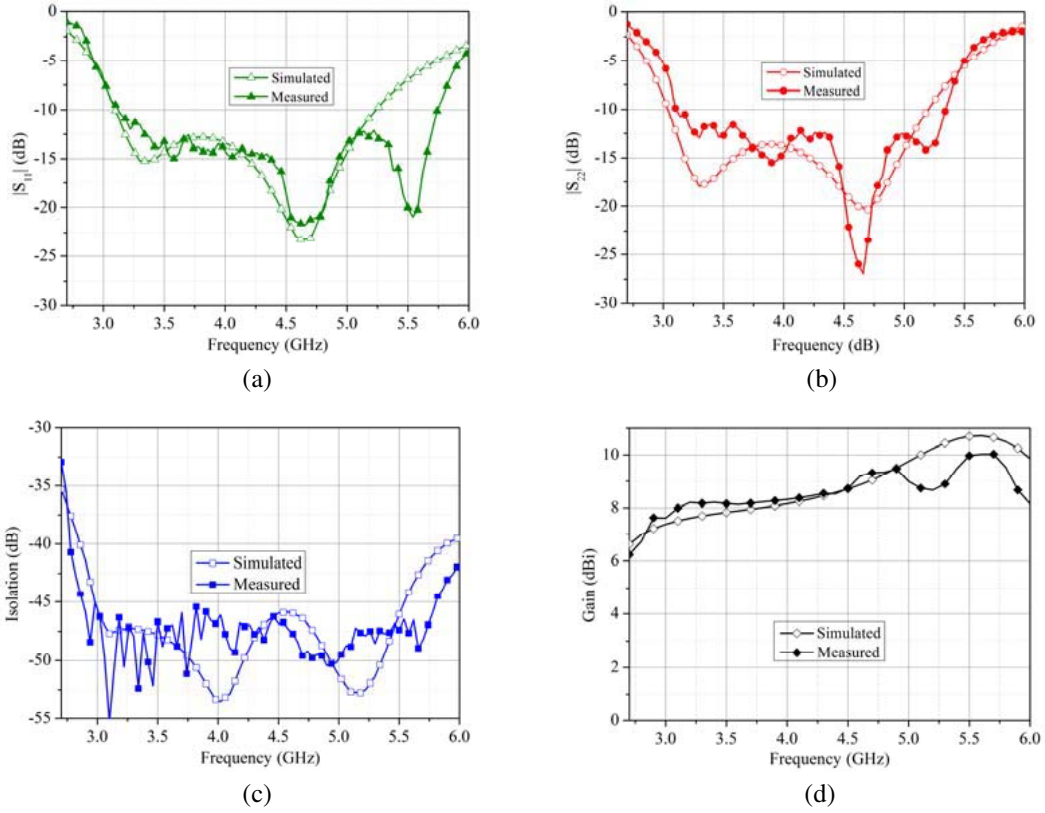


Figure 5. Simulated and measured: (a) S_{11} ; (b) S_{22} ; (c) isolation and (d) gain.

Table 2. Half-power beamwidth and cross-polarization level.

Frequency (GHz)	Port 1		Port 2		Cross-polarization Level (dB)
	Half-Power beamwidth		Half-Power beamwidth		
	H -plane	V -plane	H -plane	V -plane	
3.3	61.7°	88.2°	61.4°	87.4°	-18
4.8	61.4°	70.9°	61.2°	65.9°	-26
5.0	58.9°	62.1°	59.6°	57.1°	-28

For simplicity, only Port 1 is excited, because of the symmetry of the antenna. When one parameter is studied, the others are kept constant. The result provides a useful guideline for practical design.

4.1. Effects of Antenna Dipole

As we all know, the feeding strip in Port 1 has a great influence on S_{11} and a weak influence on S_{22} . The feeding strip in Port 2 has a great influence on S_{22} and a weak influence on S_{11} . Therefore, we only analyze the effect of the L-shaped antenna element in Port 1 on S_{11} .

First and foremost, the structural parameters of the antenna element unit proposed in this paper are analyzed. The proposed novel L-shaped antenna element unit can effectively reduce the isolation between the two ports of the dual-polarized antenna.

As can be seen from Figures 7(a), (b), the S -parameter and antenna ports isolation are highly sensitive to the value of l_d . With the increase of l_d , the frequency band matching of the antenna gradually becomes better, but it cannot be increased all the time, and the problem of isolation between

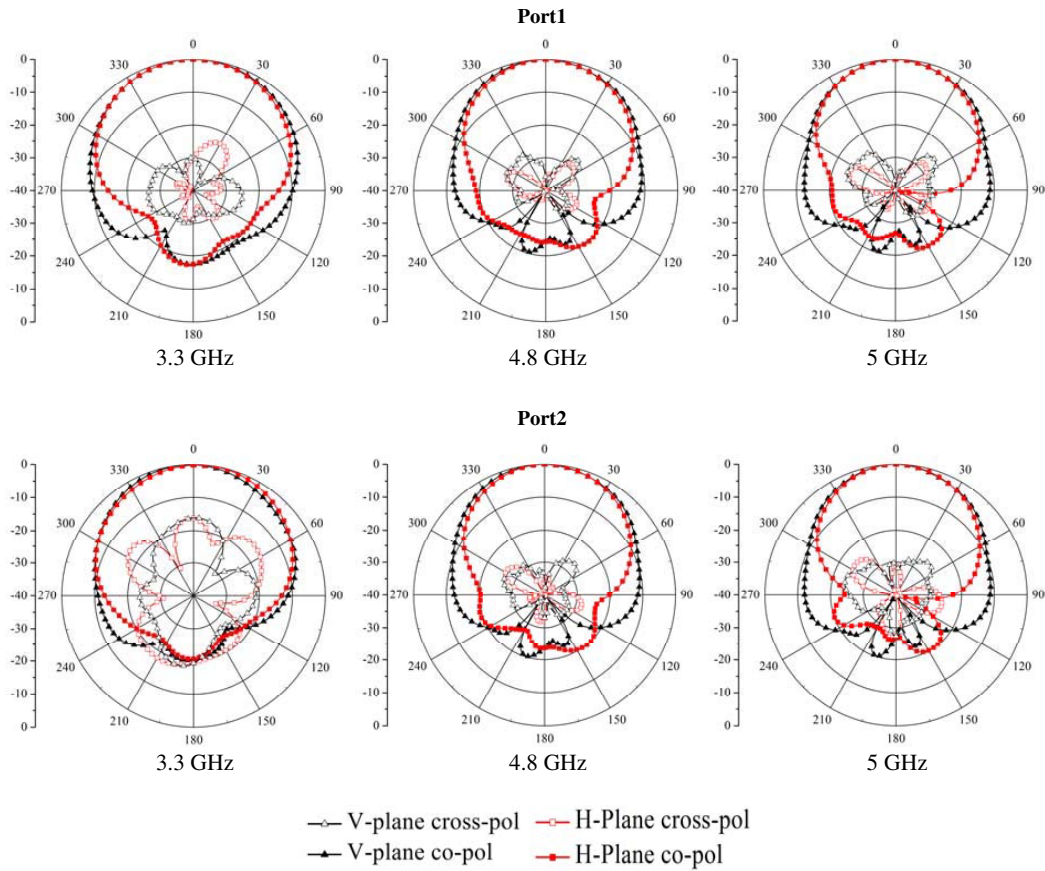


Figure 6. Measured radiation patterns of the high-isolation dual-polarized antenna at frequencies of 3.3, 4.8 and 5 GHz.

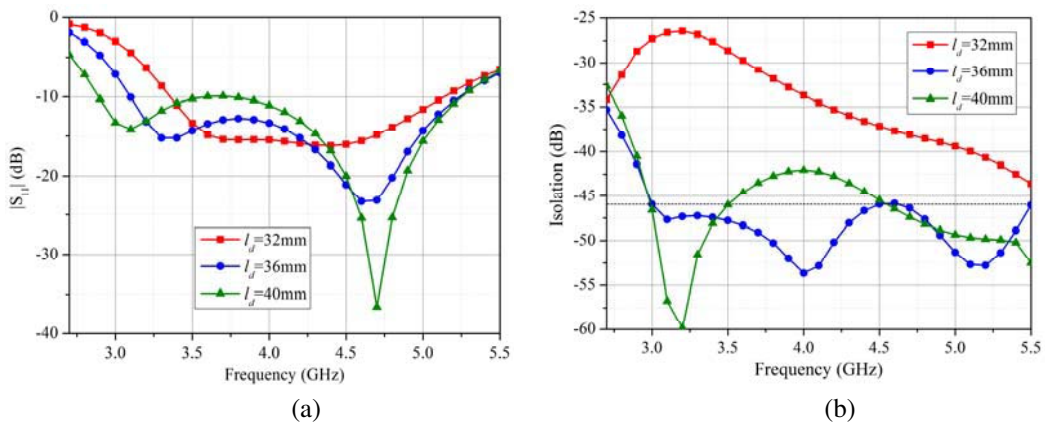


Figure 7. Effects of L-shaped Antenna element: (a) Effects of l_d on S_{11} and (b) effects of l_d on isolation.

two ports must be considered. Taken together, to achieve a good impedance matching and high isolation over a wide frequency band, $l_d = 36$ mm was selected.

The second important parameter is the length w_d of the L-shaped antenna element. It can be observed from Figures 8(a), (b) that antenna ports isolation is highly sensitive to the value of w_d . As can be seen from Figure 8(b), the change in w_d has a significant impact on the change in antenna ports isolation. Therefore, $w_d = 20$ mm was used.

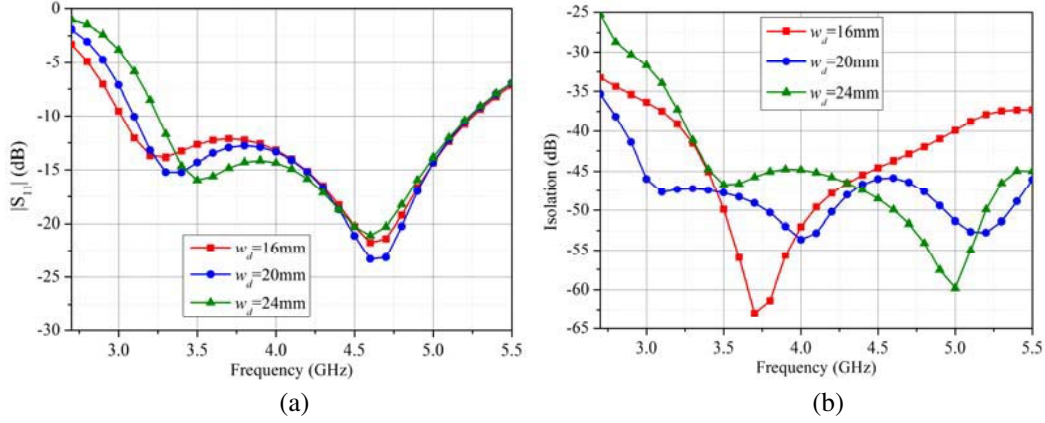


Figure 8. Effects of L-shaped antenna element: (a) Effects of w_d on S_{11} and (b) effects of w_d on isolation.

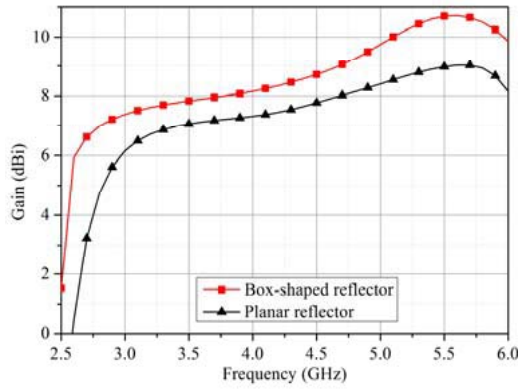


Figure 9. Effects of different reflectors on gain.

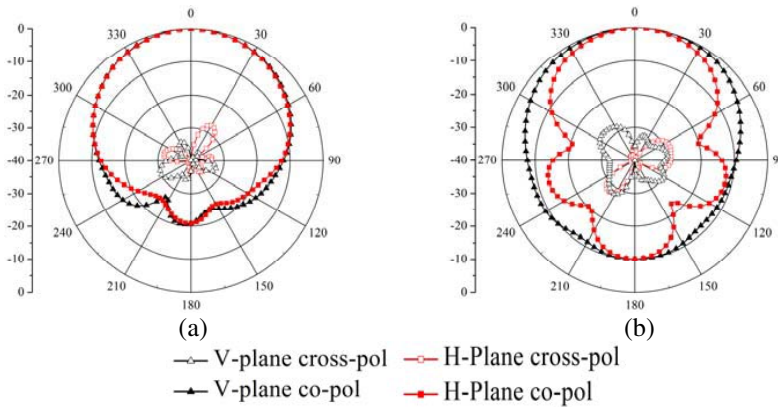


Figure 10. Simulated radiation patterns of the high-isolation antenna. (a) With box-shaped reflector at 3.6 GHz. (b) With planar reflector at 3.6 GHz.

4.2. Effects of the Reflectors

To achieve a stable and high gain, a rectangular box-shaped reflector is necessary for a unidirectional antenna. To understand the usefulness of such a reflector, an antenna with a rectangular box-shaped reflector and a planar reflector was analyzed. As shown in Figure 9, with a rectangular box-shaped reflector, the gain is much higher than the other. Figure 10 depicts the simulated radiation patterns

when Port 1 is excited at 3.6 GHz for the high-isolation antenna using the rectangular box-shaped reflector and planar reflector. It can be seen that back radiation was suppressed by the box-shaped reflector. In the other words, the rectangular box-shaped reflector is conducive to improving the antenna performances.

5. COMPARISON

The measured characteristics of the proposed antenna are compared with previous works in Table 3. The size of the antenna is related to the wavelength at the center frequency of the low frequency band. In the high-isolation antennas listed in Table 3, the proposed antenna is higher than the reference antennas in operating frequency bands. We can find that the proposed antenna in this paper has wide impedance bandwidth, dual polarizations, high isolation, and application at 5G.

Table 3. Comparison of proposed antenna and references.

Ref.	Bandwidth	Isolation	Polarization	Size (mm ³)
[8]	1.7–2.73 GHz	> 38 dB	Dual	160 × 160 × 28
[9]	575–722 MHz	> 35 dB	Dual	212 × 212 × 80
[13]	2.4–2.83 GHz	> 40 dB	Dual	82 × 82 × 11.8
[14]	1.68–2.75 GHz	> 37 dB	Dual	106 × 106 × 25
This Work	3.1–5.2 GHz	> 45 dB	Dual	50 × 50 × 24

6. CONCLUSION

A novel high-isolation dual-polarized magneto-electric antenna is proposed. The proposed antenna exhibits better performance in impedance bandwidth than the referenced antennas listed in Table 3, and it can obtain wide impedance bandwidths of 50.6% (3.1–5.2 GHz) with the reflection coefficients lower than 10 dB for both input ports. Due to its special L-shaped antenna element structure, ports isolation above 45 dB can be achieved. In addition, it is suitable for 5G application.

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