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Dual-Band Dual-Polarized Magneto-Electric Dipole Antenna with Dual-Layer Structure

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Abstract—In this paper, a dual-band dual-polarized magneto-electric (ME) dipole antenna with a dual-layer structure is proposed. The antenna consists of a dual-layer magneto-electric dipole, a Γ-shaped feeding line, and a rectangular box-shaped reflector. The dual-layer magneto-electric dipole is able to generate two resonant frequencies. Both simulated and measured results show that the antenna can obtain two wide impedance bandwidths of 47.5% (1.70–2.76 GHz) in lower frequency band and 30.2% (4.50–6.10 GHz) in higher frequency band with the reflection coefficients lower than −10 dB for both input ports. The isolation between ports is greater than 25 dB in the corresponding frequency band. The gains of the measured antenna are 8.5–9.7 dBi in the low frequency band and 7.5–8.5 dBi in the high frequency band, respectively.

1. INTRODUCTION

In the development of recent wireless communications, multiband and broadband antennas with higher gain for base-station communication are in urgent need. Compared to the traditional single band antenna, a multiband antenna can effectively decrease the number of antenna elements and covering different areas [1]. Recently, dual-polarized antennas have drawn much attention in modern mobile communication systems, because they can provide double independent transmission channels to enhance channel capability on a single antenna and also deal with multipath fading problems [2]. Meanwhile, wideband dual-band and low cross-polarization electrical characteristics with a compact size are huge problems for a wideband dual-band dual-polarized antenna.

In recent years, a lot of broadband antennas have been developed for base stations [3]. The commonly used antennas for base stations include patch antennas [4–7] and dipoles [8, 9]. A wideband unidirectional antenna composed of a shorted bowtie patch antenna and an electric dipole is available in [7]. A patch antenna usually has a narrower bandwidth than magnetic-electric dipole antenna. Various types of dual-polarized antennas have been proposed in [10–13]. Several studies have been focused on the development of dual-band antennas [14–19]. In [8], the proposed antennas obtain multiple bands by etching slots on monopole antennas. A antenna integrates lower and higher frequency band elements and then realizes dual-band dual-polarized electric characteristics ranging from 1.68 to 2.84 GHz and 5.31 to 5.95 GHz in [15]. As presented in [16], A U-shaped electric dipole antenna is employed to generate dual resonant frequencies, and the results show that the dual bands with bandwidths of 72% from 1.48 to 3.15 GHz and 21% from 4.67 to 5.78 GHz are achieved. However, only a single polarization is considered, which cannot increase polarization diversity.

In this paper, a dual-band dual-polarized magneto-electric antenna with dual-layer structure is presented. A metal double-layer magneto-electric dipole is deployed to generate the dual resonant frequencies. Besides, it can obtain two wide impedance bandwidths of 47.5% (1.70–2.76 GHz) in low

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frequency band and 30.2% (4.50–6.10 GHz) in high frequency band with the reflection coefficients lower than −10 dB for both input ports. Moreover, it is more suitable for 2G/3G/LTE/5G (4.80–5 GHz)/WiMAX/WLAN applications.

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 dual-band dual-polarized magneto-electric dipole is shown in Fig. 1. The antenna is designed to cover two frequency bands with center resonant frequencies at $f_L = 2.2$ GHz and $f_H = 5.5$ GHz, respectively. The two-layer structure of the antenna element excites the dual frequency bands of the antenna. For dual polarizations, two linear polarized magneto-electric dipole elements are located orthogonally. As shown in Fig. 1, the proposed antenna consists of a pair of dual-layer cross-ME-dipoles, a rectangular reflector, and a pair of orthogonal Γ-shaped feeding strips. The thickness of the copper patches is 0.5 mm. The lower-layer cross-ME-dipole comprises two pairs of symmetrical rectangular patches ($l_2 \times l_2$). They are connected to the ground plane by four identical vertical folded rectangular patches ($2w \times h_2$), which are called shorted walls and separated by a gap of d. The upper-

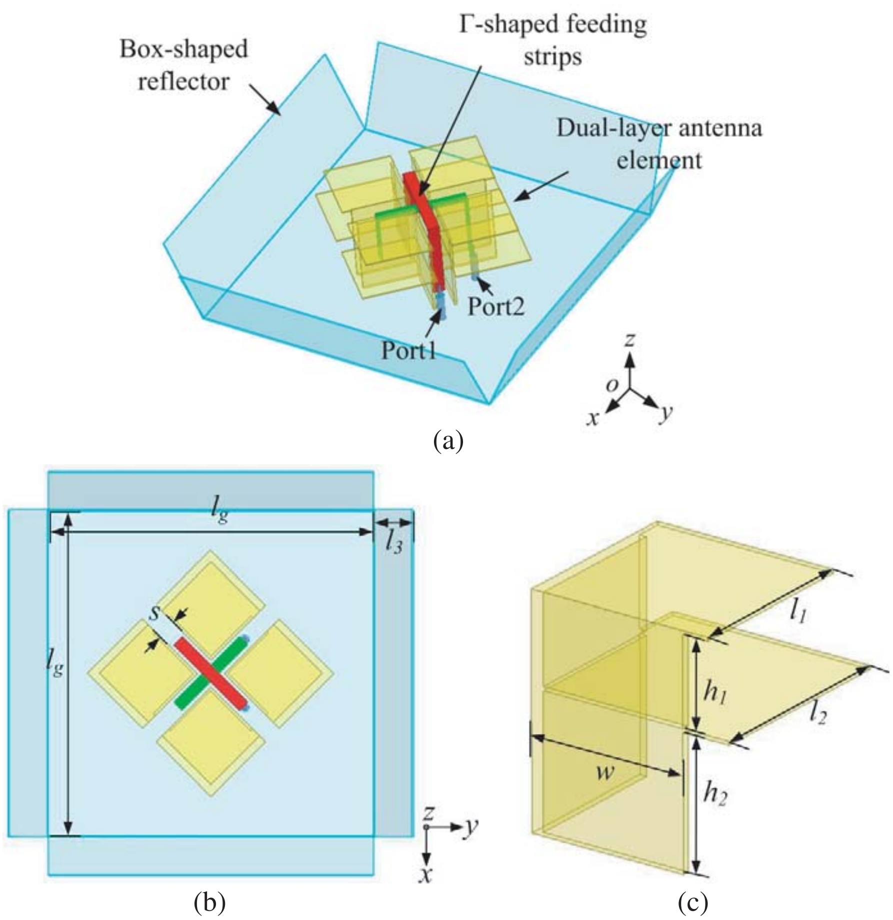

Figure 1. Perspective, top and side views of the dual-band dual-polarized antenna. (a) Perspective view; (b) Top view; (c) Side view.

layer cross-ME-dipole comprises two pairs of symmetrical rectangular patches ($l_1 \times l_1$). Similarly, the upper-layer and lower-layer cross-ME-dipole patches are joined through four identical vertical folded rectangular patches ($2w \times h_1$). The lower-layer cross-ME-dipole and the upper-layer one form a dual-layer cross-ME-dipole. They are set in the center of a box-shaped reflector.

As shown in Fig. 2, Γ-shaped feeding strips are used to excite the antenna. The feeding strips separate 1 mm ($(d - f_w)/2$) from the nearest vertical shorted-wall patches. 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. One Γ-shaped feeding line in the +45 degree direction excites +45 degree polarization, and another Γ-shaped feeding line in the −45 degree direction forms another −45 degree polarization, thereby forming ±45 degree dual polarizations. An SMA connector located under the ground plane is connected to the bottom of the Γ-shaped strip line.

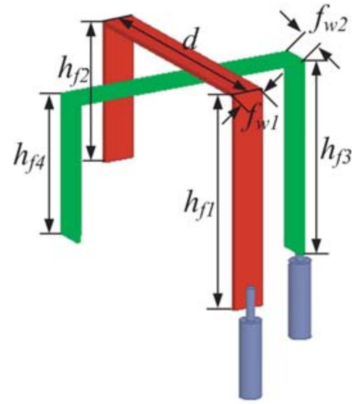

Figure 2. Geometry of the orthogonal Γ-shaped feeding line.

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, the 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 dual-band dual-polarized Magneto-electric antenna.

Parameters	L_g	L_1	L_2	h_1	h_2	w	s	d
Values/mm	120	25	30	12	18	25	7	33
Parameters	h_{f1}	h_{f2}	h_{f3}	h_{f4}	f_{w1}	f_{w2}	l_3	
Values/mm	26	22	23	22	4.3	4.3	13	

In fabrication of the prototype, the proposed antenna is made of copper. 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

In 2006, Luk proposed a new type of broadband electromagnetic dipole antenna based on previous studies [20]. This antenna element consists of a $\lambda/4$ height metal patch and a planar electric dipole metal patch (λ is the wavelength of the center frequency of the designed antenna operating frequency band). It is equivalent to the combination of magnetic dipole and electric dipole. In our design, as shown in Fig. 1, the antenna is a combination of four pairs of horizontal plane dipoles (electric dipoles) and four pairs of vertically oriented shorted patches antennas (magnetic dipoles). The high band is excited by the bottom layer, and the low band is excited by the high layer. Therefore, dual-band operation is realized by the two-layer magneto-electric dipole.

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 Fig. 3, respectively. Definition of T is the period of the variation of the electromagnetic fields caused by the proposed antenna. At time $t_1 = t_2 = 0$, the currents are mainly distributed on the planar dipoles, whereas the currents on

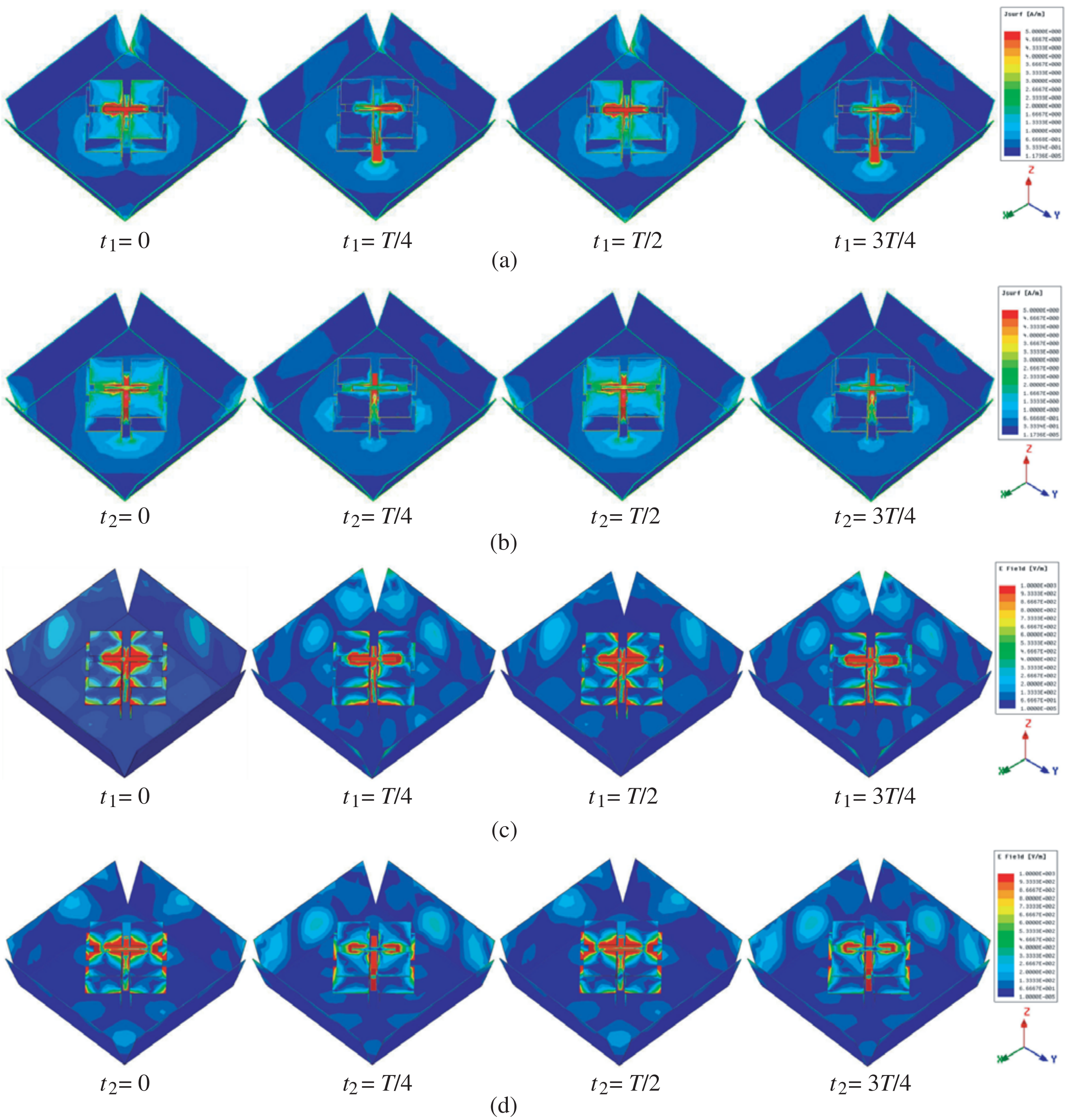

Figure 3. Current distributions of the dual-band dual-polarized antenna: 2.2 GHz (a) Port 1; (b) Port 2; 5.5 GHz (c) Port 1, (d) Port 2.

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 planar dipoles are minimized, whereas the currents on vertically oriented shorted patches are the 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. ANTENNA PERFORMANCE

3.1. Simulated and Measured Results

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

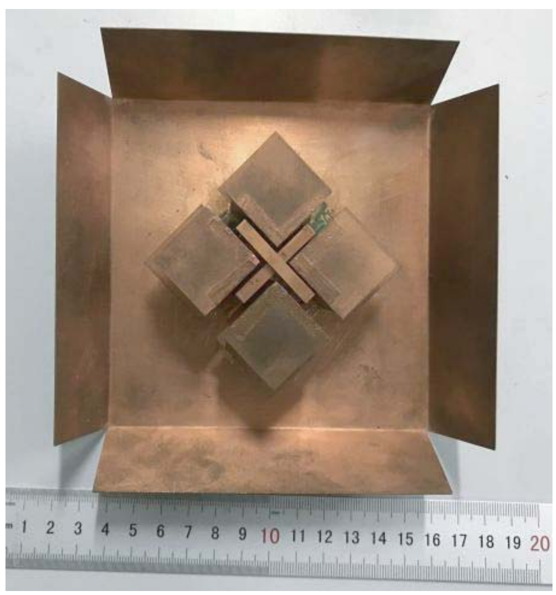

Figure 4. Prototype of the dual-band dual-polarized antenna.

Figure 5 depicts simulated and measured S-parameters gains and isolations of the proposed dual-band dual-polarized antenna. It can be seen that the antenna operates from 1.70 to 2.76 GHz with a bandwidth of 47.5% ($S_{11} < -10$ dB & $S_{22} < -10$ dB) and from 4.50 to 6.10 GHz with a bandwidth of 30.2% ($S_{11} < -10$ dB & $S_{22} < -10$ dB) for low frequency band and high frequency band, respectively. 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 bandwidths of the two ports are 47.5% ranging from 1.70 to 2.76 GHz at lower-band and 30.2% ranging from 4.50 to 6.10 GHz. The measured isolation between the two ports is better than 25 dB over the entire operating frequency band. Over the operating frequency range, the measured broadside gains for lower band and higher band are 9.1 ± 0.7 dBi and 8 ± 0.5 dBi, respectively.

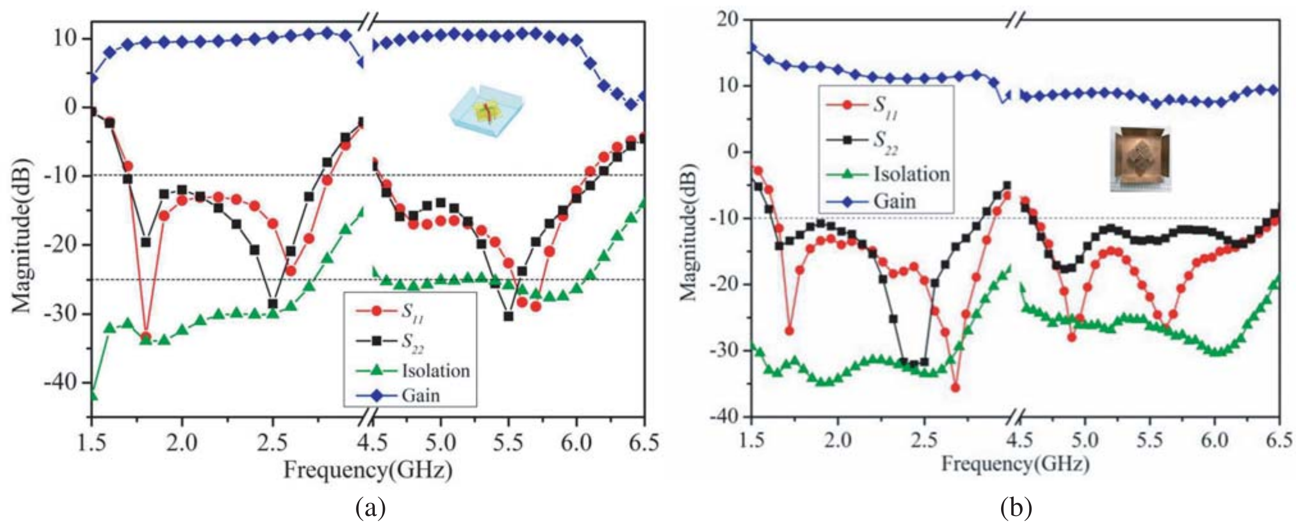

Figure 5. Simulated and measured results: (a) Simulated; (b) Measured.

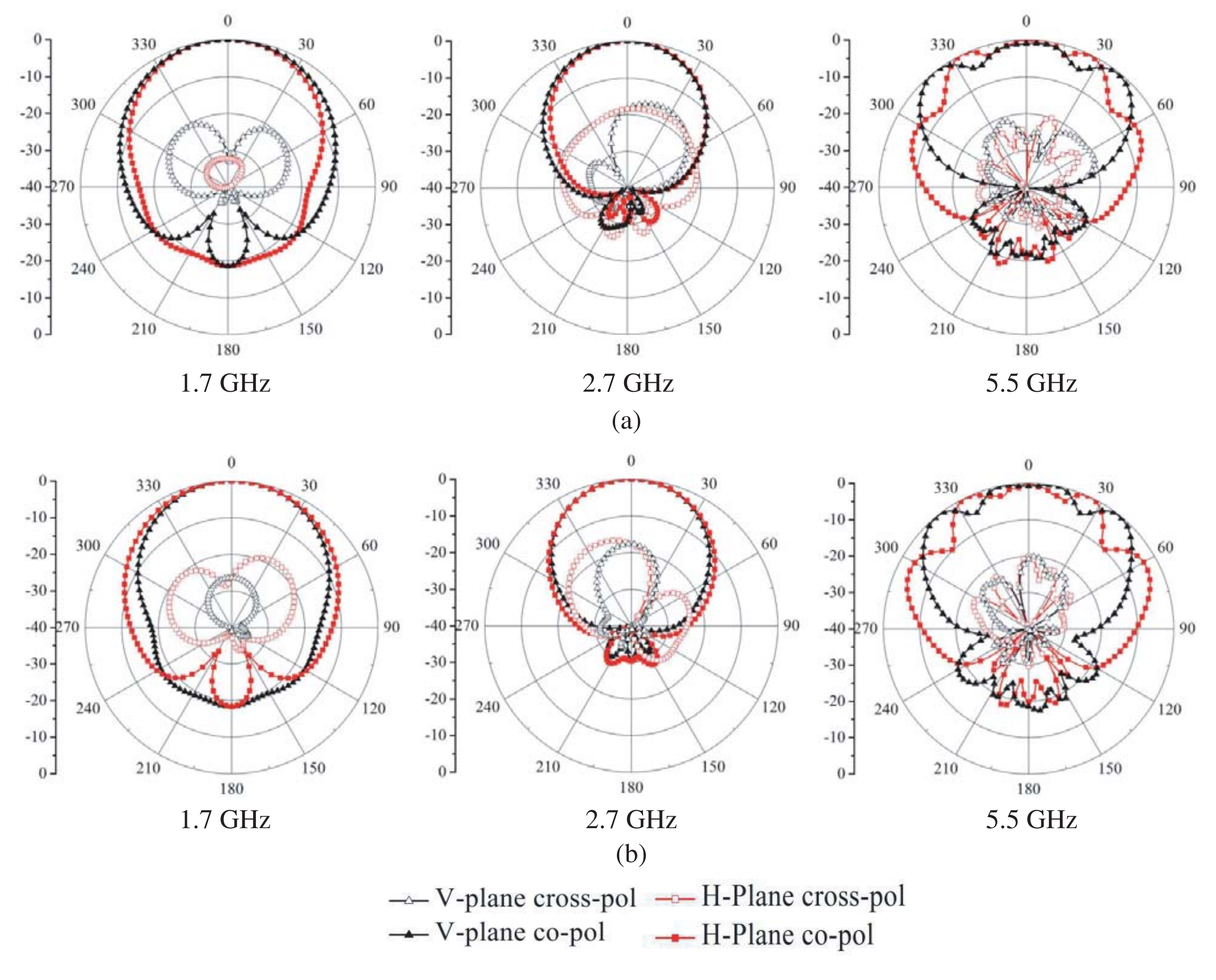

Figure 6. Radiation patterns of the antenna at frequencies of 2.2, 2.7 and 5.5 GHz. (a) Port 1; (b) Port 2.

The measured radiation patterns of the proposed dual-band dual-polarized magneto-electric dipole antenna for port 1 and port 2 at frequencies 2.2, 2.7, 5.5, and 5.8 GHz are plotted in Fig. 6. It is shown that the antenna has a nearly symmetric and good unidirectional radiation pattern across the entire bandwidth.

4. PARAMETRIC STUDY

For a better understanding of how the dimensions of the antenna affect its performances, some parameters of the dual-layer cross-ME-dipole and L-shaped feeding structure are studied by simulation.

4.1. Effect of Dual-Layer Cross-ME-Dipole

The first and the most important parameter is the height h_2 of the upper part of the antenna. It can be seen from Fig. 7 that with the increase of h_2, the low frequency band moves toward the low frequency, and the suppression depth also becomes deeper. The high-frequency part is basically unchanged. These characteristics can more verify that the center frequency of the electromagnetic dipole antenna is determined by $\lambda/4$ (λ is the wavelength at the center frequency of the operating frequency band). In order to ensure that the low frequency band is within 1.70–2.76 GHz, h_2 is chosen at 12 mm.

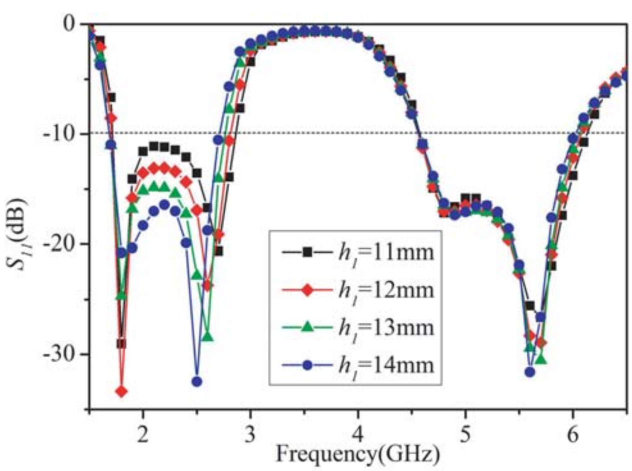

Figure 7. Effects of h_1 on S_{11}.

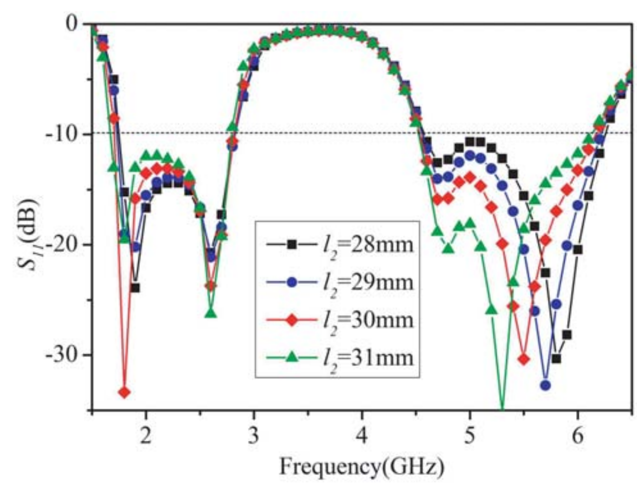

Figure 8. Effects of l_2 on S_{11}.

l_2 is the width of the electric dipole in the lower part of the antenna. Fig. 8 shows that the change of l_2 has a great effect on the high frequency band of the antenna. With the increase of l_2, the S_{11} suppression depth in the high frequency band becomes deeper. Considering the reasonable suppression depth of the high frequency band and the position of the center frequency, l_2 is selected here as 30 mm.

4.2. Effects of L-Shaped Feeding Structure

In order to better achieve the impedance matching of the antenna, we analyze the matching of the two feedings of the dual-polarized antenna. Fig. 9(a) shows the matching of the feeding length fh_2 of port 1 to S_{11}. As fh_2 increases, the bandwidth of the low frequency band becomes slightly narrower, and the suppression depth becomes smaller; the bandwidth of the high frequency band becomes wider, and the suppression depth becomes smaller. Comprehensive overall matching situation, f_{h2}, is selected as 22 mm. Fig. 9(b) shows the matching of the feeder length fh_4 of port 2 to S_{22}. As fh_4 increases, the bandwidth of the low frequency band becomes slightly narrower, and the suppression depth becomes smaller; the bandwidth of the high frequency band becomes wider, and the suppression depth becomes smaller. Comprehensive overall matching situation, f_{h4}, is selected as 22 mm. The high frequency band is very sensitive to changes in size.

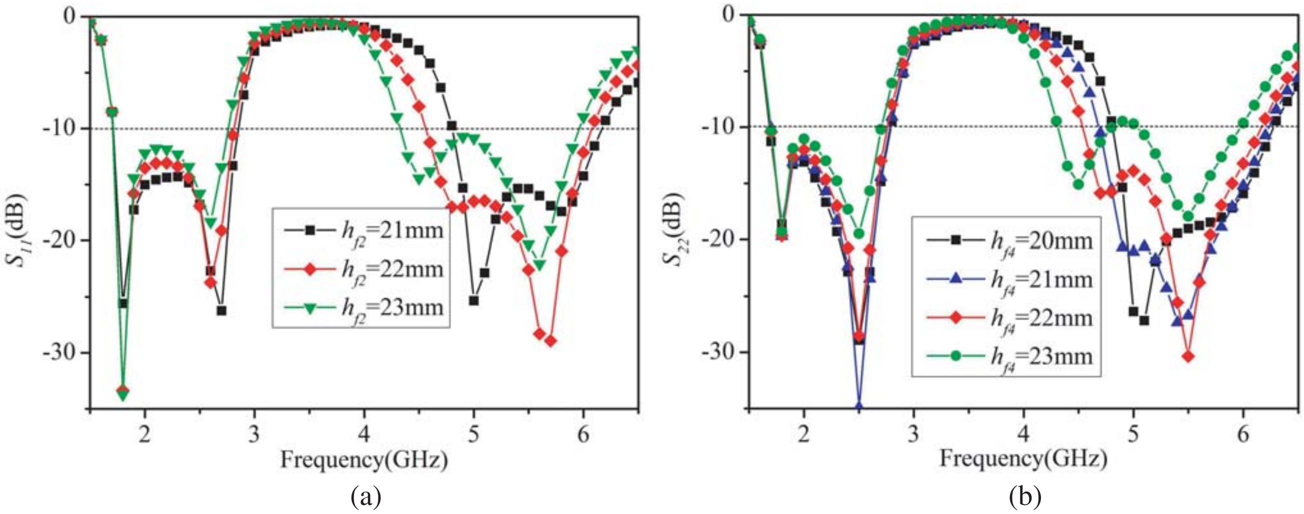

Figure 9. Effects of L-shaped feeding structure: (a) Effects of h_{f2} on S_{11}; (b) Effects ofh_{f4} on S_{22}.

5. COMPARISON

The measured characteristics of the proposed antenna are compared with previous works in Table 2. The size of the antenna is related to the wavelength at the center frequency of the low frequency band. Compared with the antenna in the reference, the proposed dual-polarized antenna effectively utilizes polarization diversity. Low frequency covers all 2G/3G/4G, and high frequency covers 5G (4.8–5 GHz), WIMAX, WLAN, and other applications. We can find that the proposed antenna in this paper has dual frequencies, dual polarizations, and wide impedance bandwidth.

Table 2. Comparison of proposed antenna and references.

Ref.	Lower Band (GHz)	Upper Band (GHz)	Isolation	Polarization	Size (λ_L)	Material	Antenna type
[15]	1.68–2.84 (51.3%)	5.31–5.95 (11.4%)	/	Single	$1.05 \times 1.05 \times 0.286$	All metal	Magneto-electric
[16]	1.48–3.15 (72%)	4.67–5.78 (21%)	/	Single	$0.926 \times 0.926 \times 0.185$	All metal	Magneto-electric
[17]	0.78–1.1 (34%)	1.58–2.62 (49.5)	/	Single	$0.689 \times 0.689 \times 0.179$	All metal	Magneto-electric
[2]	0.8–0.96 (18%)	1.7–2.7 (45%)	25& 25	Dual	$0.611 \times 0.611 \times 0.151$	All metal	Magneto-electric
[19]	2.4–2.48 (3.3%)	5.15–5.85 (12.7%)	30& 30	Dual	$0.813 \times 0.813 \times 0.244$	microstrip	Magneto-electric
[21]	5.04–5.35 (6%)	5.73–5.92 (3.4%)	28& 28	Dual	$1.5 \times 1.3 \times 0.244$	microstrip	SIW
[22]	6.43–6.58 (2.3%)	7.10–7.28 (2.5%)	30.3& 37.7	Dual	$0.698 \times 0.698 \times 0.034$	microstrip	SIW
[23]	5.15–5.28 (2.5%)	5.71–5.86 (2.6%)	33.2& 33.8	Dual	$0.444 \times 0.444 \times 0.027$	microstrip	HMSIW
This Work	1.7–2.76 (47.5%)	4.5–6.1 (30.2%)	28& 25	Dual	$0.892 \times 0.892 \times 0.234$	All metal	Magneto-electric

λ_L is the wavelength at the center frequency of the lower working band.

6. CONCLUSION

A dual-band dual-polarized magneto-electric antenna with a dual-layer cross-ME-dipole structure for base-station communications is proposed. The proposed antenna exhibits better performance in impedance bandwidth, and it can obtain two wide impedance bandwidths of 47.5% (1.70–2.76 GHz) in lower frequency band and 30.2% (4.50–6.10 GHz) in higher frequency band with the reflection coefficients lower than −10 dB for both input ports. In addition, it is more suitable for 2G/3G/LTE/5G (4.8–5 GHz)/WiMAX/WLAN applications.

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