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A Broadband Dual-Polarized Magneto-Electric Dipole Antenna for 2G/3G/LTE/WiMAX Applications

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Abstract—A novel broadband dual-polarized magneto-electric (ME) dipole antenna is proposed for 2G/3G/LTE/WiMAX applications. The proposed antenna has stair-shaped feeding strips to impart a wide impedance bandwidth to it and a rectangular box-shaped reflector to enhance its stability in radiation patterns and high gain over the operating frequencies. The measured results show that a common impedance bandwidth is 80% with standing-wave ratio (SWR) ≤ 1.5 from 1.68 to 3.92 GHz, and port-to-port isolation larger than 25 dB within the bandwidth. The measured antenna gains vary from 9.2 to 12 dBi and from 9.2 to 11.8 dBi for port 1 and port 2, respectively. The antenna has nearly symmetrical radiation patterns with low back-lobe radiation both in horizontal and vertical planes, and broadside radiation patterns with narrow beam can also be obtained.

1. INTRODUCTION

With the great development of modern mobile communication systems in China, there is an ever-growing demand for wideband antennas, which meet the expansion of services bands and number of mobile users. Over the last few years, dual-polarized antennas have been widely used in base stations because they can provide polarization diversity to reduce side effects of multipath fading and also to increase channel capacity [1]. Meanwhile, wide bandwidth, high isolation and low cross-polarization electrical characteristics with a compact size are the scabrous problems for the dual-polarized antenna. Patch antenna is a good choice for base station antennas, due to its attractive features such as light weight, low costs, and easy fabrication for dual-polarization implementation. The patch antenna type has already been studied a lot [2–7], but wide impedance bandwidth is very difficult to be achieved with these antennas.

To achieve equal radiation patterns in the E- and H-planes, the concept of exciting an electric dipole and a magnetic dipole simultaneously was firstly revealed by Clavin in 1954 [8]. Recently, a novel type of complementary antenna named magneto-electric (ME) dipole antenna was developed by Luk and Wong [9, 10]. This kind of antenna comprises a vertically oriented quarter-wave shorted patch and a planar dipole, which are equivalent to a combination of a magnetic dipole and an electric dipole. Several types of magneto-electric dipole antennas have been reported [11–14]. 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. Moreover, its gain and beamwidth are not noticeably changed within its bandwidth. As a basic element, the magneto-electric dipole antenna was employed in a dual-polarization antenna [15–19]. In [17], The antenna achieved 65.9% impedance bandwidth (SWR ≤ 2) and stable radiation pattern with 3-dB beamwidth $61.5^\circ \pm 3.5^\circ$ at H-plane and $62.5^\circ \pm 2.5^\circ$ at V-plane. A novel differentially-driven dual-polarized magneto-electric dipole antenna was proposed [18] in 2013, which achieved a wide impedance bandwidth of 68% (0.95 GHz to

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1.92 GHz) for SWR ≤ 2 and unidirectional radiation pattern with 3-dB beamwidth of 62% (1.09 to 2.08 GHz). In 2015, a new ±45° dual-polarized magneto-electric dipole antenna with Γ-shaped feeding structure was presented [19]. The antenna exhibits good performance over the whole working bands, but its impedance bandwidth is not broad enough to support WiMAX applications at 3.5 GHz.

In this paper, a novel dual-polarized magneto-electric dipole antenna for base station applications is presented. To the authors' knowledge, the dual-polarized antenna is the first excited by one stair-shaped feeding strip at each polarization. Besides, due to the special feeding structure, the proposed antenna exhibits better performance in impedance bandwidth. Broad impedance bandwidth is achieved with SWR less than 1.5 from 1.68 to 3.92 GHz, which is suitable to serve the frequency bands of 2G/3G/LTE/WiMAX communication systems. Moreover, owing to the rectangular box-shaped reflector, high and stable gain can be achieved across the operating frequency range.

This paper is organized as follows. In Section 2, the basic structure and operation principle of the proposed antenna are described. The experiment results of the antenna are given in Section 3. Parameter study is discussed in Section 4, followed by the conclusions which are presented in Section 5.

2. ANTENNA DESCRIPTIONS

2.1. Antenna Structure

The geometry of the dual-polarized magneto-electric dipole antenna is shown in Figs. 1–3. For a better description of the antenna, we define the xoz-plane as the horizontal plane (H-plane) and yoz-plane as the vertical plane (V-plane). For dual polarizations, two linear polarized magneto-electric dipole elements are located orthogonally. As can be seen from Fig. 1, the proposed antenna consists of a rectangular box-shaped reflector, two pairs of horizontal planar patches, two pairs of vertically oriented folded shorted patches, and a pair of stair-shaped feeding strips. The horizontal planar patch has the form of an isosceles trapezoid attached with a semicircle. The rectangular box-shaped reflector with dimensions of $130\,\text{mm}(1.21\lambda_0) \times 130\,\text{mm}(1.21\lambda_0) \times 26\,\text{mm}(0.24\lambda_0)$ is used to achieve relatively stable gain and better radiation performance over the passband.

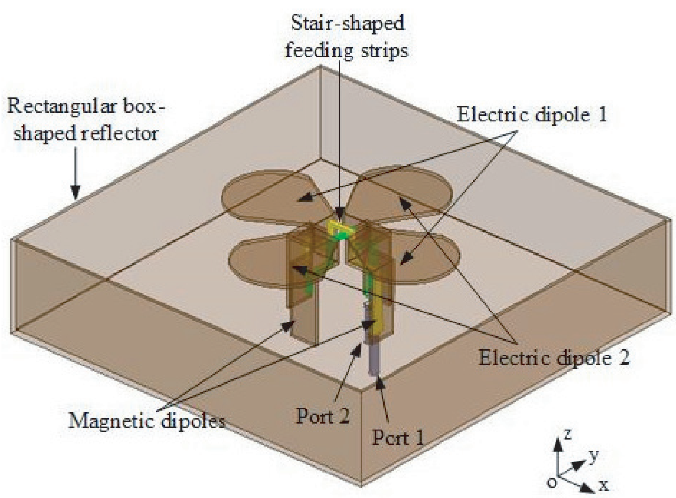
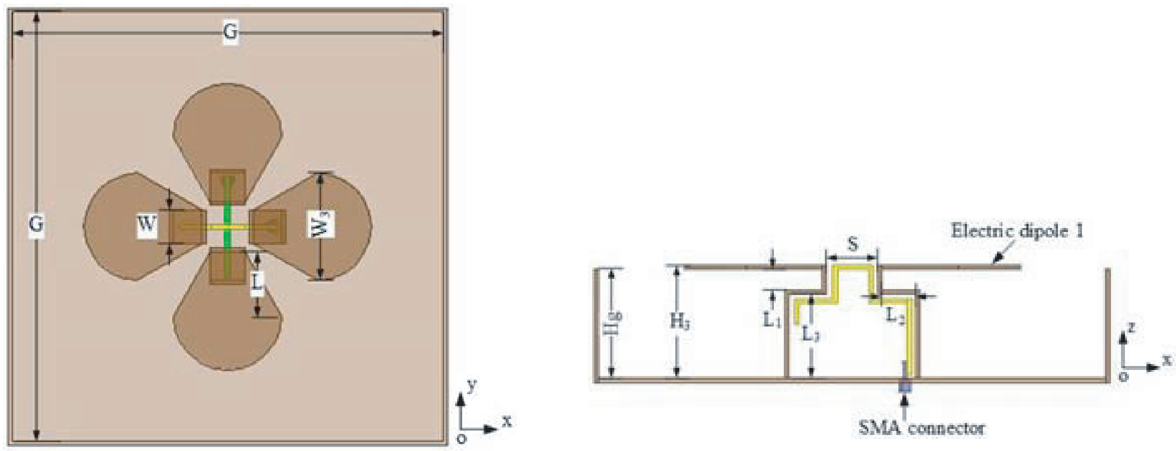


Figure 1. Perspective view of the dual-polarized antenna.

As depicted in Fig. 3, the stair-shaped feeding strip is used for exciting the antenna, which is placed between the vertically-oriented folded shorted patches of the same polarization. In fact, the feeding strip can be divided into two portions: a coupling strip and a transmission line. The coupling strip is stair-shaped which can be thought as the combination of two L-shaped strips with different lengths. Indeed, the stair-shaped feeding strip achieves more degree of freedom for impedance tuning than other feeding structure [9–19]. 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



(a) (b)

Figure 2. Top and side views of the dual-polarized antenna. (a) Top view. (b) Side view.

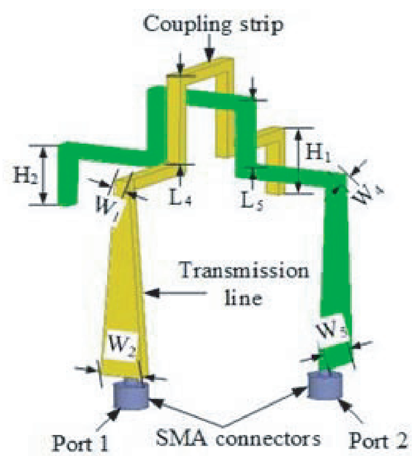


Figure 3. Geometry of the orthogonal stair-shaped feeding strips.

Table 1. Dimensions for the proposed dual-polarized antenna.

Parameters	L	L_1	L_2	L_3	L_4	L_5
Value/mm	18 ($0.17\lambda_0$)	5 ($0.05\lambda_0$)	9 ($0.08\lambda_0$)	20 ($0.19\lambda_0$)	8 ($0.07\lambda_0$)	6.1 ($0.06\lambda_0$)
Parameters	W	W_1	W_2	W_3	W_4	W_5
Value/mm	9.5 ($0.09\lambda_0$)	1.3 ($0.01\lambda_0$)	4.2 ($0.04\lambda_0$)	30 ($0.28\lambda_0$)	1.7 ($0.02\lambda_0$)	4 ($0.04\lambda_0$)
Parameters	H_1	H_2	H_3	S	G	Hg
Value/mm	6 ($0.06\lambda_0$)	5.5 ($0.05\lambda_0$)	27 ($0.25\lambda_0$)	12 ($0.11\lambda_0$)	130 ($1.21\lambda_0$)	26 ($0.24\lambda_0$)

λ_0 is the wavelength referring to the center frequency of the operating band.

the inductance caused by the horizontal part. The transmission line formed by folding a linear tapered metallic strip acts as an air microstrip with 1 mm separation from one of the vertical patches. The linear tapered line is used for the transmission portion to increase the impedance bandwidth which is narrower at the top (1.3 mm and 1.7 mm at each polarization) and wider at the bottom (4.2 mm and 4 mm at each polarization). SubMiniature version A (SMA) connector located under the ground plane is connected to the bottom of the stair-shaped strip line.

For dual polarizations, two stair-shaped feeding strips are placed orthogonally at different heights to avoid mechanical interference. By using 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.

In fabrication of the prototype, the proposed antenna is made of copper, and the thickness of copper patch is 1 mm. The radius of the two SMA probes is 0.6 mm, and they protrude by 4 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 as depicted in Fig. 1, the antenna is a combination of two pairs of horizontal planar dipoles (electric dipole) and two pairs of vertically oriented folded shorted patch antennas (magnetic dipole).

For further understanding the antenna operation principle better, the current distributions of the proposed antenna with input from the two ports, i.e., port 1 and port 2, at time t_1 and t_2, respectively, are analyzed as shown in Fig. 4. At time $t_1 = t_2 = 0$, the currents are mainly distributed on the planar dipoles, whereas the currents on vertically oriented folded 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 $t_1 = t_2 = T/4$, where T is

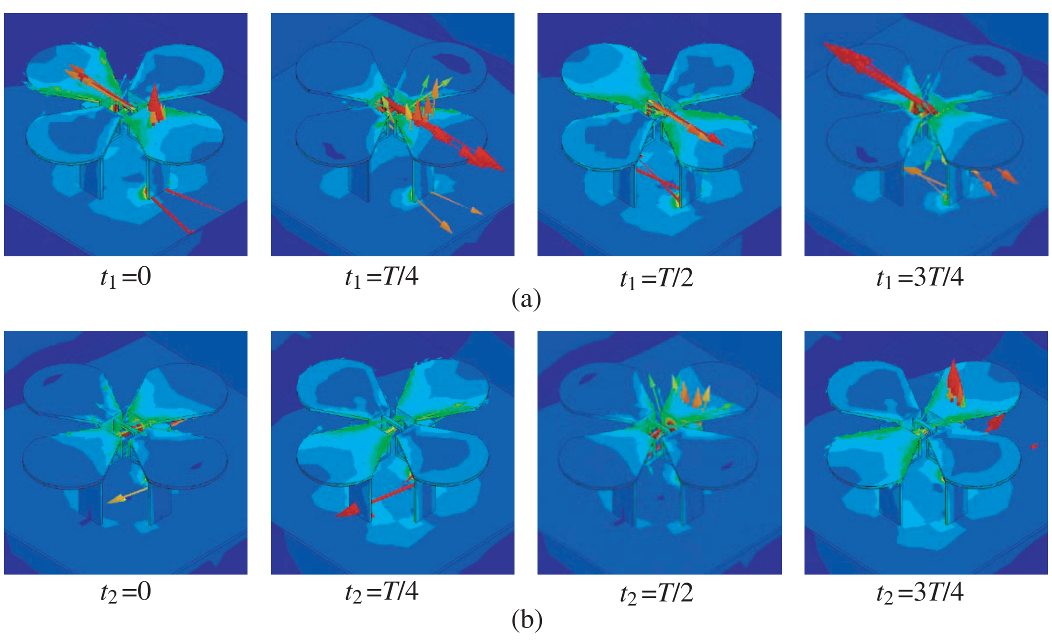


Figure 4. Current distributions of the dual-polarized antenna. (a) Port 1. (b) Port 2.

the period of the variation of the electromagnetic fields caused by the proposed antenna, the currents distributed on the planar dipoles are minimized, whereas the currents on vertically oriented folded shorted patches are predominant, 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 magnitude in strength are excited on the planar dipole (electric dipole) and the quarter-wave vertically oriented folded shorted patch antennas (magnetic dipole). The equivalent electric and magnetic currents are 90° 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

To verify the proposed design, an antenna prototype was constructed, as shown in Fig. 5. Measured results of SWRs, gains, isolation and radiation patterns were obtained by Agilent N5247A network analyzer and a SATIMO antenna measurement system.

Figure 6 depicts simulated and measured SWRs and gains of the proposed dual-polarized antenna. It can be clearly seen that the antenna operates from 1.68 to 4.2 GHz with a bandwidth of 85.7% (SWR $\leq$ 1.5) and from 1.68 to 3.92 GHz with a bandwidth of 80% (SWR $\leq$ 1.5) for ports 1 and 2, 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 bandwidth of the two ports is 80% ranging from 1.68 to 3.92 GHz. Over the operating frequency range, the measured broadside gains for port 1 and port 2 are 10.6 ± 1.4 dBi and 10.5 ± 1.3 dBi, respectively. Hence, the gains are relatively stable and high enough for 2G/3G/LTE/WiMAX base-station communications. Fig. 7 shows the isolation between the two ports. The measured isolation between the two ports is better than 25 dB over the entire operating frequency band.

The measured radiation patterns of the proposed dual-polarized magneto-electric dipole antenna for port 1 and port 2 at frequencies of 2.2, 2.7 and 3.5 GHz are plotted in Fig. 8, which show that the antenna has a nearly symmetric and good unidirectional radiation pattern across the entire bandwidth. Detailed measured results including the 3-dB beamwidth in both horizontal and vertical planes and the front-to-back ratio (FBR) at two ports are summarized in Table 2. The 3-dB beamwidth in both horizontal and vertical planes for both ports becomes narrower as frequency increases, due to the effect of the rectangular box-shaped reflector. Besides, the 3-dB beamwidth is influenced to high-order mode at higher frequencies. The measured FBR of the two ports is above 20 dB in most parts of the operating frequency band. The cross-polarization levels for both H- and V-planes are less than -12 dB.

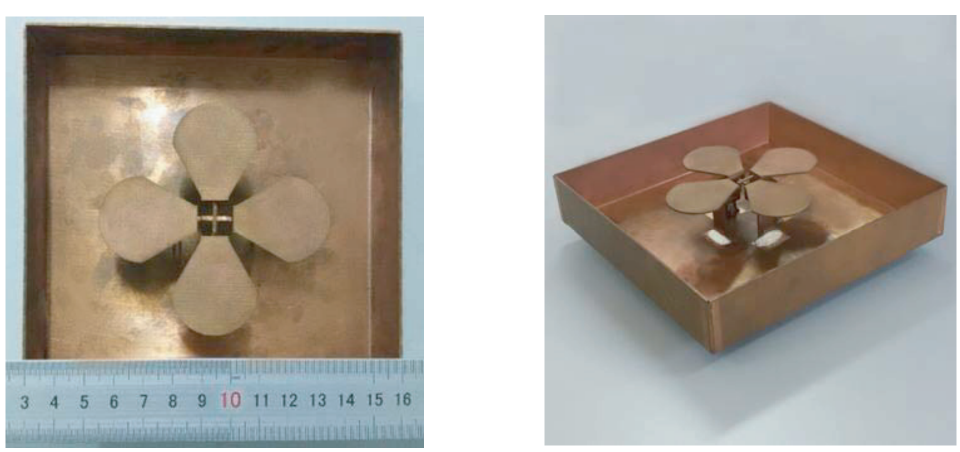


Figure 5. Prototype of the dual-polarized antenna.

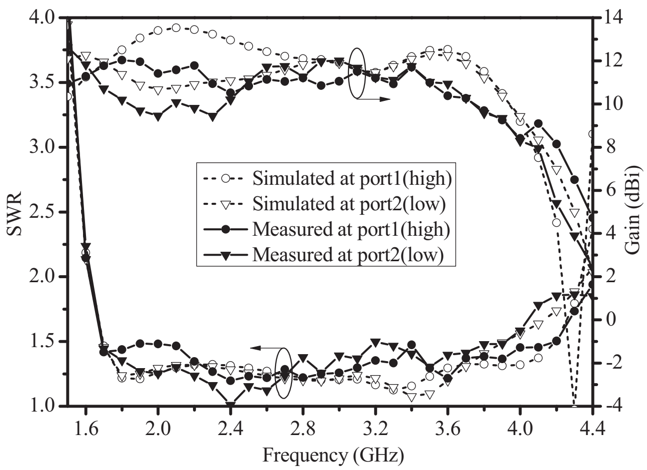


Figure 6. Simulated and measured SWRs and gains of the dual-polarized antenna.

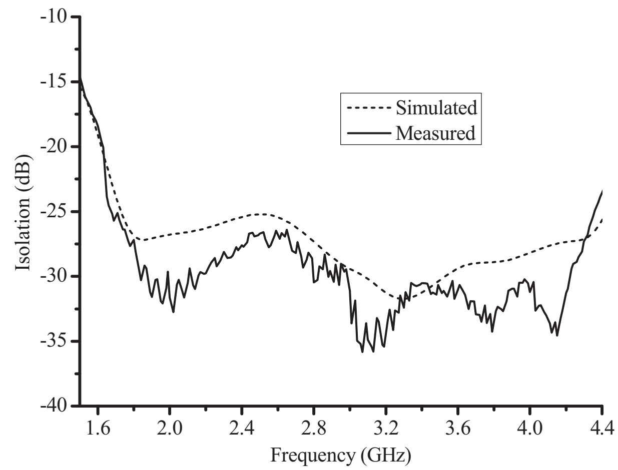


Figure 7. Simulated and measured isolation of the dual-polarized antenna.

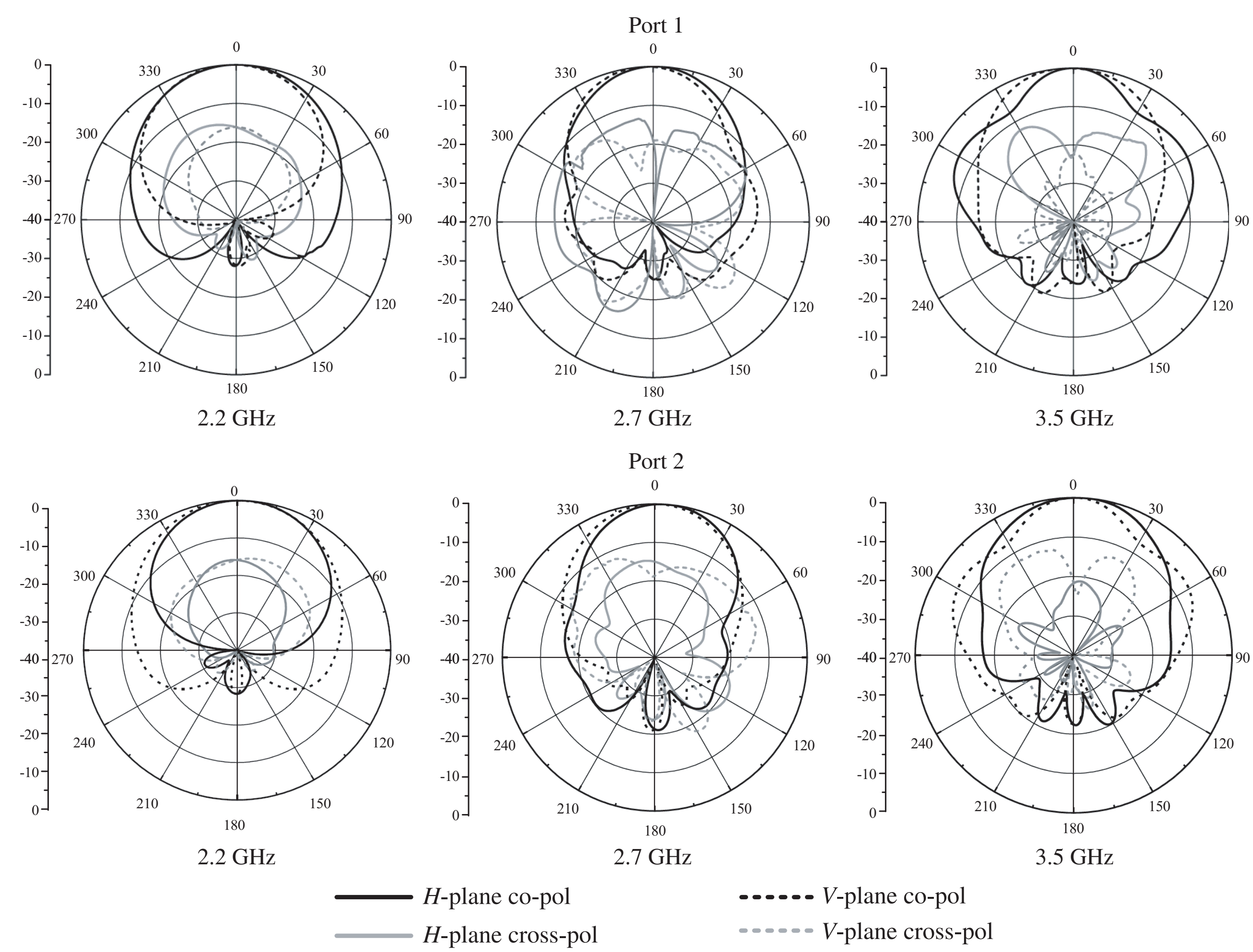


Figure 8. Measured radiation patterns of the dual-polarized antenna at frequencies of 2.2, 2.7 and 3.5 GHz.

Table 2. Summary of the measured radiation patterns at different frequencies.

Frequency (GHz)	Port 1			Port 2		
	3-dB beamwidth		FBR (dB)	3-dB beamwidth		FBR (dB)
	H-plane	V-plane		H-plane	V-plane	
1.8	70.9°	61.7°	22.7	56.5°	66.7°	21.1
2.0	67.4°	58.5°	30.9	57.3°	65.9°	26.4
2.2	61.3°	55.3°	28.1	55.7°	62.6°	28.6
2.5	57.2°	51.0°	25.7	48.8°	53.4°	24.6
2.7	49.1°	48.6°	20.9	44.1°	46.8°	22.2
3.0	42.6°	42.0°	18.5	42.0°	41.5°	19.5
3.5	33.5°	51.5°	21.1	51.1°	32.9°	25.0

4. PARAMETRIC STURY

For a better understanding of how the dimensions of the antenna affect its performances, some parameters of the magneto-electric (ME) dipoles and the rectangular box-shaped reflector are studied by simulation. 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 results provide a useful guideline for practical design.

4.1. Effects of the ME Dipoles

The first and the most important parameter was the length L of the horizontal portion of the planar dipole. It can be observed from Fig. 9 that both SWR and antenna gain are highly sensitive to the value of L. If L is increased so that the electric dipole is enlarged, the first resonance is shifted to a lower frequency. Thus, it can be concluded that the first resonance is mainly affected by the electric dipole, and when the length of the electric dipole becomes longer, the resonant frequency obviously should move to a lower frequency according to the antenna theory. Therefore, to achieve a good impedance matching and stable gain over a wide frequency band, $L = 18\,\text{mm}$ was selected.

The second parameter studied was the width W of the planar dipole and folded shorted patches. Fig. 10 shows the simulated results of the SWR and gain versus W. It can be seen that the SWR bandwidth is very sensitive to this parameter. The antenna gain at lower frequency is highly influenced

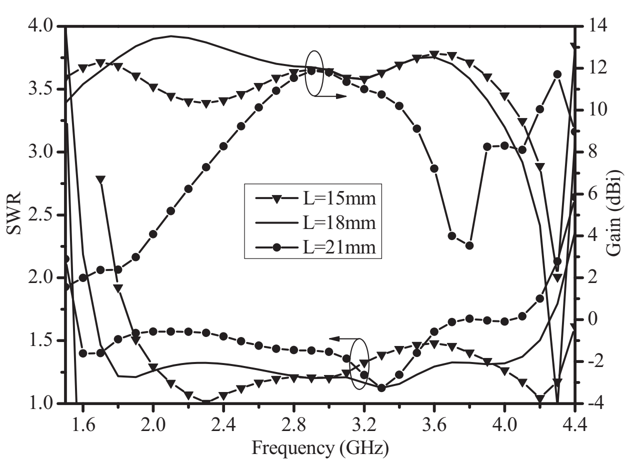


Figure 9. Effects of L on SWR and gain.

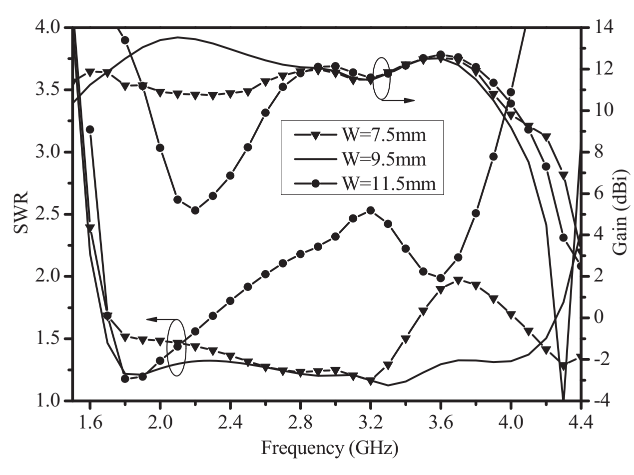


Figure 10. Effects of W on SWR and gain.

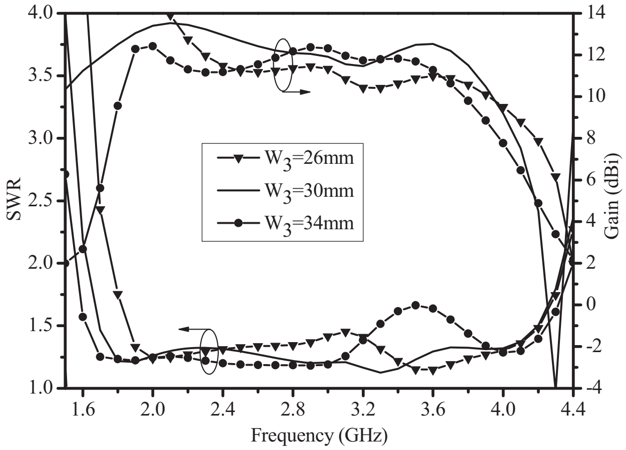


Figure 11. Effects of W_3 on SWR and gain.

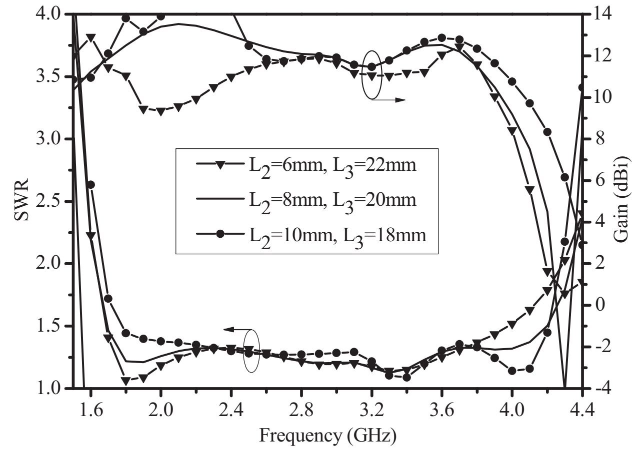


Figure 12. Effects of L_2 while keeping $L_2 + L_3 =$ 28 mm.

by the variation of W. For the proposed prototype, $W = 9.5$ mm was chosen to achieve wide impedance bandwidth and stable gain.

The third parameter studied was W_3. The effects of W_3 on SWR and gain are shown in Fig. 11. As W_3 increases, the lower resonant frequency is shifted to a lower frequency because the length of the electric dipole is increased, while the fluctuation of the antenna gain changes at lower frequencies with W_3. $W_3 = 30$ mm was chosen for stable antenna gain and good impedance matching over a wide frequency band.

The fourth parameter studied was the length L_2 of the horizontal portion of the folded shorted patch. It was found that the SWR and gain are sensitive to the value of L_2. To observe the influence of L_2 more clearly, $L_2 + L_3$ was set at 28 mm as the optimized value. It can be seen from Fig. 12 that a larger L_2 produces larger impedance bandwidth to cover higher frequencies, at the expense of the impedance matching at lower frequencies. Therefore, to achieve a good impedance matching over a wide frequency band, $L_2 = 8$ mm was selected.

4.2. Effects of the Rectangular Box-Shaped Reflector

To achieve stable radiation patterns, a rectangular box-shaped reflector is necessary for a unidirectional antenna. To understand the usefulness of such a reflector, the antenna with a rectangular box-shaped

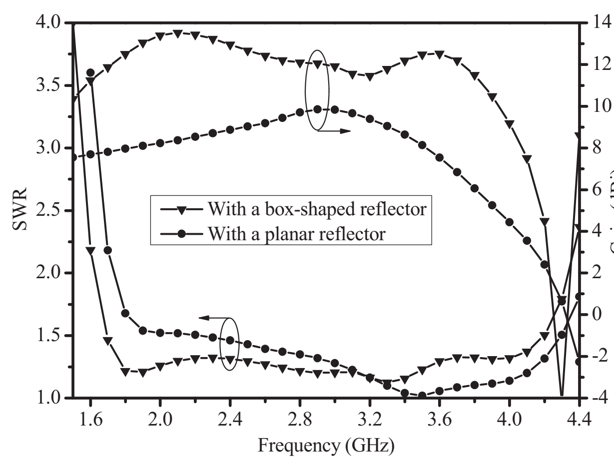


Figure 13. Effects of reflectors on SWR and gain at port 1.

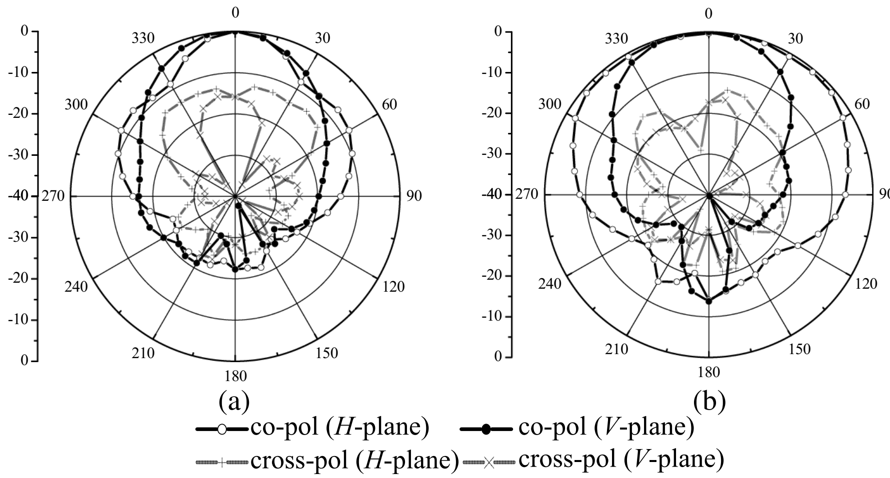


Figure 14. Simulated radiation patterns of the dual-polarized antenna. (a) With rectangular box-shaped reflector at 3.5 GHz. (b) With planar reflector at 3.5 GHz.

reflector and a planar reflector was analyzed. As shown in Fig. 13, with a rectangular box-shaped reflector, the SWR is more stable, and the gain is much higher than the other. Consequently, the impedance bandwidth is much wider. Fig. 14 depicts the simulated radiation patterns when port 1 is excited at 3.5 GHz for the dual-polarized antenna with and without metallic wall. The metallic wall suppresses both 3-dB beamwidth and back radiation. In short, the rectangular box-shaped reflector is conducive to improving the antenna performances.

5. CONCLUSION

A novel broadband dual-polarized magneto-electric dipole antenna with stair-shaped feeding strips proposed for base-station communication is designed, fabricated, and measured. According to the measured results, the antenna achieves a wide impedance bandwidth of 80% (1.68–3.92 GHz) for SWR ≤ 1.5 with a high port-to-port isolation better than 25 dB. Other electric characteristics, such as stable and high gain, high front-to-back ratio, and symmetrical H- and V-plane radiation patterns are also obtained. Because of these excellent features, the proposed antenna is a promising candidate for modern 2G/3G/LTE/WiMAX base-station communication systems.

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