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A NOVEL DUAL-POLARIZED DIPOLE ANTENNA WITH COMPACT SIZE FOR WIRELESS COMMUNICATION

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Abstract—A novel dual-polarized dipole antenna with compact size is presented for wireless communication applications. The proposed antenna is composed of a dual-polarized cross dipole, a small-sized tapered reflector, a square patch director, and an octagon ring as a parasitic element. Low VSWRs (< 1.5) are achieved in aimed operating band of 2500–2690 MHz at both ports, which can cover the LTE2600 frequency band. High port isolation (> 38 dB) and symmetric broadside radiation patterns are also achieved. Two dual-polarized reference antennas are also developed. Contrast results show that the proposed antenna can obtain improved radiation patterns compared with the reference antennas. Moreover, the proposed antenna is very compact in size ($0.52\lambda_0 \times 0.52\lambda_0 \times 0.32\lambda_0$, λ_0 refers to the center frequency of operating band), which achieves about 20% size reduction than Ref 2. Experimental results are also carried out to verify the simulation analysis.

1. INTRODUCTION

With the great development of wireless communication systems, the dual-polarized antennas, especially ±45° slant polarized antennas, have been widely used to combat multipath fading and to increase capacity [1]. The patch antenna is a good choice to achieve dual polarization, due to their low profile, light weight, low cost, and flexible structure. By using probes [2, 3], coupled apertures [4, 5], or both [6, 7] to feed the patch antenna, good performance of high isolation can be obtained. However, they have the weakness of asymmetry radiation patterns. Besides, the ground with larger size is needed to obtain high gain. The DRAs (Dielectric Resonator Antennas) are also used

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to achieve dual-polarized radiation [8], but complex feeding mechanics are required to achieve low cross polarization.

With quarter-wave coaxial balun or integrated microstrip balun [9], many types of dipole antennas with dual polarization have been widely investigated and developed in modern BTS (base transceiver station) communication. The dual-polarized cross bow tie dipole antenna can be found in [10], which provides a high isolation of more than 30 dB. The fourpoint antenna [11], the cross folded dipole [12] and the magneto-electric dipole [13] with wide bandwidth are also presented to achieve dual polarization. However, large-sized reflectors are required to be replaced below the dipoles to achieve good radiation patterns and high gain.

There is a growing need for compact antenna configuration, as it is an important task to achieve system integration in wireless communications. However, it is not easy to obtain miniaturization of the dual-polarized antenna at the same time keeping good radiation characteristics. Very few designs with miniaturized operations have been reported for application in mobile communication systems.

In this paper, a novel dual-polarized dipole antenna operating at LTE2600 is proposed, which has a compact size of only $0.52\lambda_0 \times 0.52\lambda_0 \times 0.32\lambda_0$ (λ_0 refers to the center frequency of operating band). A director and a parasitic element are added below and above the original cross dipole respectively to make up the bad effect caused by the small-sized reflector. Good matching and high port isolation are achieved across the aimed operating band of 2500–2690 MHz. The proposed antenna obtains symmetrical radiation patterns. The measured peak gain is about 8.5 dB, and the 3-dB beam widths are about 70°. Two reference antennas named Ref 1 and Ref 2 are developed to make comparisons. The reflector of Ref 1 is of the same size with the proposed antenna, while a larger size reflector is used in the case of Ref 2. Contrast results show that the gain of the proposed antenna is about 1 dB and 0.44 dB higher than Ref 1 and Ref 2, respectively. Correspondingly, the decreased HPBW (half power beam width) in the horizontal plane is about 7.6° and 3.7°. More importantly, the overall volume of the proposed antenna is only 80% of Ref 2.

2. PROPOSED ANTENNA DESIGN

The dual-polarized dipole antenna is aimed to operate in the frequency band of 2500–2690 MHz for potential application in LTE BTS communication. High isolation and compact size are also desired. The structure of the proposed antenna is central symmetric, composed of a cross dipole, a small-sized reflector, a director, and a parasitic element. The configuration is shown in Figs. 1–2. The software of high frequency structure simulation (HFSS) was used to analyze the antenna.

The cross dipole shown in Fig. 1(b) consists of two pairs of radiating arms and an integrated quarter-wave coaxial balun. The bow-tie arms are bent along Z-axis to make the antenna compact. The two pairs of radiating arms provide orthogonally polarized radiators, configured for ±45° polarization diversity. The cross dipole is fed by two Γ-shaped probes with different height to avoid structure conflict. The probe depicted in Fig. 2(a) consists of a vertical portion and a horizontal portion. One end of the horizontal portion is electrically connected to the second dipole arm, and one end of the vertical portion is connected to the feed cable beneath the reflector. The quater-wave coaxial balun is formed by the feed probe and its outside conductor. It is integrated with the radiating arms. On one hand, the balun provides a balanced feed for dipole antenna, which can be found in [9, 10]. On the other hand, it acts as a quarter-wave impedance transformer. By changing the ratio between inner and outer diameter of cable, the characteristic impedance is easily to be adjusted. The input impedance of the dipole antenna can be converted to $50\,\Omega$ for good matching.

A reflector shown in Fig. 1(c) is placed below the cross dipole to obtain broadside radiation patterns. The distance between the dipole and the reflector is approximately one quarter wavelength. The designed reflector is only $0.52\lambda_0 \times 0.52\lambda_0$ in size. It is much smaller than those of the antennas proposed in [11, 13], which are $1.5\lambda_L \times 1.5\lambda_L$ (λ_L refers to lower end of the operating band) and $1.28\lambda_0 \times 1.28\lambda_0$, respectively. The tapered reflector shown in Fig. 1(c) is the initial choice because we found that a narrower beam can be obtained compared with a box-shaped reflector. It has to be mentioned that the effect is not obvious. A box-shaped reflector is also a good choice.

The key part of the design is the introduction of the square patch director and the parasitic element simultaneously, which are shown in Fig. 2(b). A square patch director is placed above the dipole, and the angle between the patch side and the X-axis is 45°. The side length of the square patch is about $0.3\lambda_0$. Considering the whole antenna volume, the distance between the radiating arms and the patch director is chosen to be about $0.09\lambda_0$. An octagon ring acting as a parasitic element is positioned between the arms and the reflector but much closer to the arms. The energy coupled to the parasitic element is strongly impacted by the spacing between the parasitic element and the radiating arms, which will have a great influence on the antenna input impedance. Even though only the octagon ring is presented,

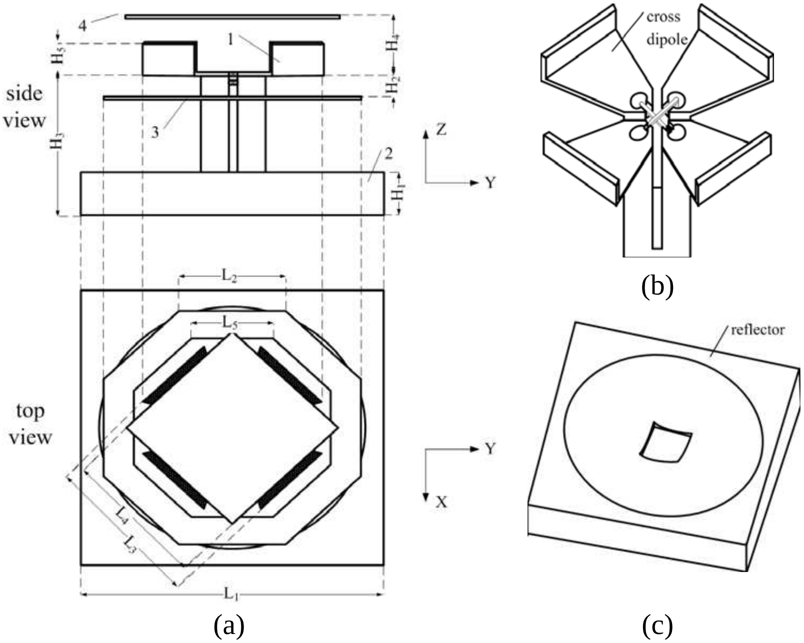


Figure 1. (a) Side view and top view of the proposed antenna (1. Cross dipole. 2. Reflector. 3. Parasitic element. 4. Director). (b) Geometry of the cross dipole. (c) Geometry of the reflector. $L_1 = 60\,\text{mm}$, $L_2 = 20.4\,\text{mm}$, $L_3 = 34.6\,\text{mm}$, $L_4 = 34\,\text{mm}$, $L_5 = 14.5\,\text{mm}$, $H_1 = 10\,\text{mm}$, $H_2 = 5\,\text{mm}$, $H_3 = 27\,\text{mm}$, $H_4 = 10\,\text{mm}$, $H_5 = 5\,\text{mm}$.

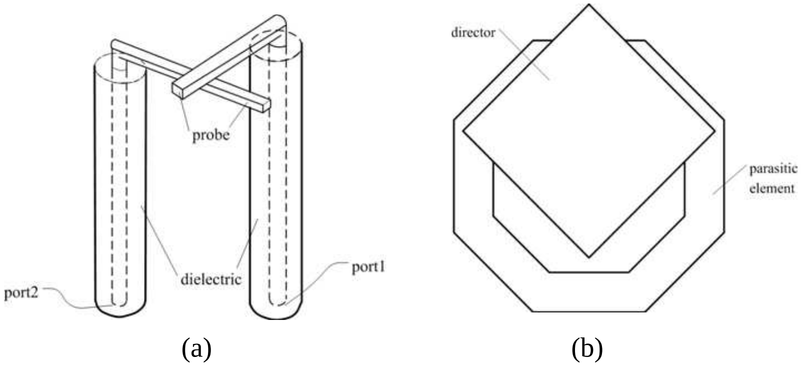


Figure 2. (a) Geometry of the Γ-shaped probes. (b) Geometry of the parasitic element and the director.

the parasitic element of other geometry like circular ring can also get acceptable performance. It is demonstrated that the introduction of both the parasitic element and the director can effectively improve the antenna gain and narrow the radiation pattern.

3. SIMULATED AND MEASURED RESULTS

In order to verify the simulated results, the antenna is fabricated and tested. The cross dipole is cast in aluminum, which is shown in Fig. 3. A POM support ($\varepsilon_r = 3.4$) is implemented to fix the suspending patch director and the octagon ring. The overall dimension of the proposed antenna is only 60 mm × 60 mm × 37 mm ($0.52\lambda_0 \times 0.52\lambda_0 \times 0.32\lambda_0$). The measurement was carried out using Agilent E8362B vector network analyzer and anechoic chamber.

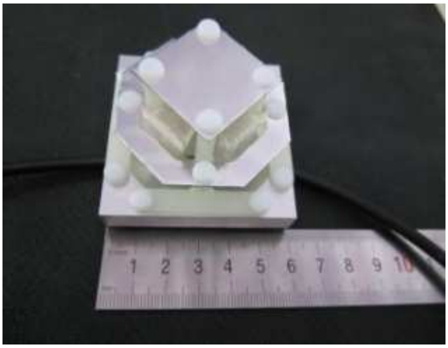


Figure 3. Photograph of the proposed antenna.

The simulated and measured VSWRs are depicted in Fig. 4. It can be seen clearly that low VSWRs less than 1.5 can be obtained in the aimed frequency band of 2500–2690 MHz. The VSWRs at port 1 and port 2 are slightly different due to the small difference in the heights of the two feed probes. The measured band is wider than simulated band. The difference is mainly caused by the manufacturing errors. High isolation between input ports is required for polarization diversity antenna. Fig. 5 shows the isolation between two ports. Both simulated and measured results of isolation are higher than 38 dB over the whole frequency band, which can satisfy the commercial standard.

The proposed antenna radiates towards the broadside with symmetrical radiation patterns. The radiation patterns in the vertical plane are similar with that in the horizontal plane due to the symmetry of the antenna structure. The radiation patterns of port 1 in the

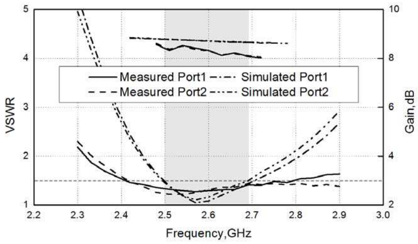


Figure 4. Simulated and measured results of VSWRs and antenna gain.

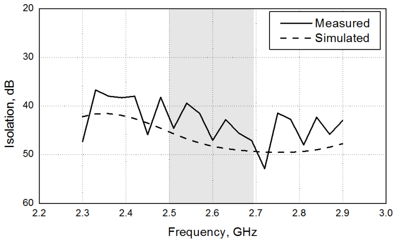
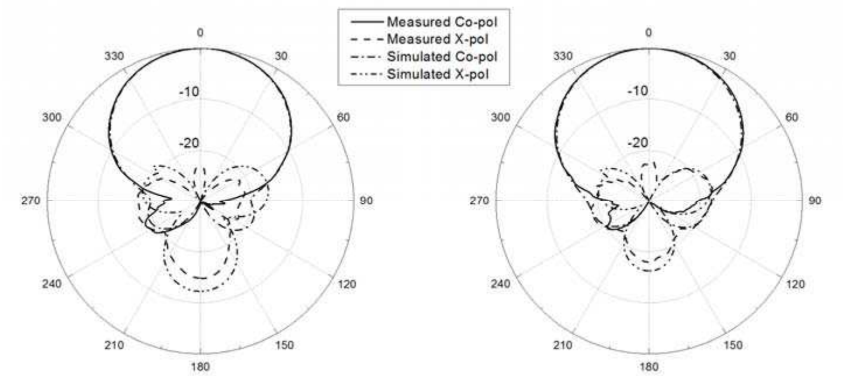


Figure 5. Simulated and measured isolations.



(a) (b)

Figure 6. Simulated and measured radiated patterns of port 1 in the horizontal plane. (a) At 2500 MHz. (b) At 2690 MHz.

horizontal plane at 2500 MHz and 2690 MHz are plotted in Fig. 6. Low cross polarization less than −25 dB in the broadside direction is achieved. The back-lobe radiation is relatively large (−15 dB) due to the small-sized reflector. The simulated HPBWs in both planes vary in 65° ± 5° and the measured results are about 70°. The difference could be attributed to fabrication tolerance and measurement errors. The HPBWs at different frequencies are summarized in Table 1. Stable antenna gain of over 8 dB is obtained as shown in Fig. 4. The average of measured gain is 0.5 dB lower than the simulated gain, and the measured peak gain is about 8.5 dB. From these results, it can be concluded that good symmetrical broadside radiation patterns with high gain can be achieved.

Table 1. HPBWs of the proposed antenna at different frequencies.

Frequency (MHz)	**Simulated**			
	Port 1		Port 2	
	H-plane	V-plane	H-plane	V-plane
2500	67.27°	67.26°	67.57°	67.38°
2690	67.94°	67.50°	69.21°	67.62°
	Measured			
	Port 1		Port 2	
	H-plane	V-plane	H-plane	V-plane
2500	71°	71°	70°	68°
2690	69°	71.5°	70.5°	69.5°

4. REFERENCE ANTENNA AND CONTRAST

To make comparisons, two dual-polarized dipole antennas named Ref 1 and Ref 2 are developed. Similar with the dipole presented in [10], the two reference antennas are used widely to form arrays in modern BTS communication. The geometries of Ref 1 and Ref 2 are shown in Fig. 7 and Fig. 8, respectively. Ref 1 consists of the same bow-tie arms with the proposed antenna, while Ref 2 consists of two pairs of square-ring

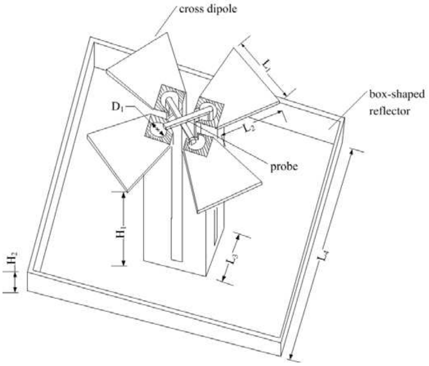


Figure 7. Geometry of the Ref 1. $L_1 = 20\,\mathrm{mm}$, $L_2 = 16.5\,\mathrm{mm}$, $L_3 = 17\,\mathrm{mm}$, $L_4 = 60\,\mathrm{mm}$, $L_5 = 2\,\mathrm{mm}$, $H_1 = 27\,\mathrm{mm}$, $H_2 = 10\,\mathrm{mm}$, $D_1 = 3.5\,\mathrm{mm}$.

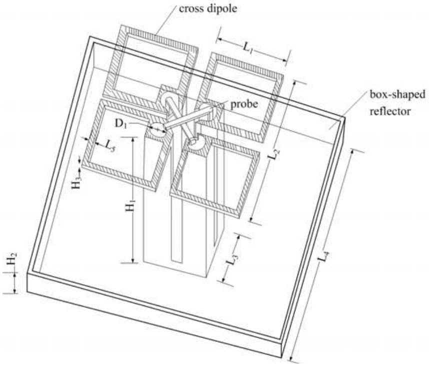


Figure 8. Geometry of the Ref 2. $L_1 = 17\,\mathrm{mm}$, $L_2 = 39.5\,\mathrm{mm}$, $L_3 = 17\,\mathrm{mm}$, $L_4 = 80\,\mathrm{mm}$, $L_5 = 2\,\mathrm{mm}$, $H_1 = 27\,\mathrm{mm}$, $H_2 = 10\,\mathrm{mm}$, $H_3 = 2\,\mathrm{mm}$, $D_1 = 3.5\,\mathrm{mm}$.

arms. The two dipoles are backed by the box-shaped reflectors with different sizes respectively. The reflector of Ref 1 has the same size with the proposed antenna, which is 60 mm × 60 mm ($0.52\lambda_0 \times 0.52\lambda_0$). And Ref 2 has a larger size reflector of 80 mm × 80 mm ($0.72\lambda_0 \times 0.72\lambda_0$). All the parameters are optimized to operate at around 2600 MHz and to obtain good impedance matching.

The radiation performances of the reference antenna is simulated and compared with the proposed antenna. The results of the VSWR on the port 1 are showed in Fig. 9. Due to the special configuration of radiation arms and a larger reflector, Ref 2 achieves the widest impedance band in them. The impedance band of Ref 1 is similar with that of the proposed antenna, for the reason that the same type of dipole and the same size reflector are used in both the two antennas.

Due to the symmetric structure, the reference antennas have the same radiation patterns in both the vertical and horizontal planes. The patterns also remain the same on both ports. Comparisons of radiation patterns at 2600 MHz are shown in Fig. 10. Compared with Ref 1, much narrower beam and higher front-to-back ratio can be obtained by the proposed antenna. Compared with Ref 2, the beam is narrower, but the back lobe is larger. Detailed comparison study including the impedance bandwidth (BW), port isolation, antenna gain, cross polarization discrimination (XPD), front-to-back ratio (F/B) and half power beam width (HPBW) in horizontal plane are tabulated in Table 2. The peak gain of the proposed antenna is 1 dB and 0.44 dB higher than that of Ref 1 and Ref 2, respectively. Correspondingly, the HPBW in the horizontal plane decreases by 7.6° and 3.7°. The novel

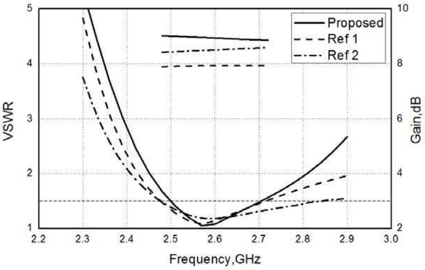


Figure 9. Comparisons of impedance band and antenna gain.

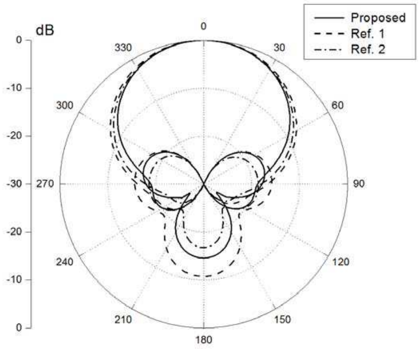


Figure 10. Comparison of radiation patterns.

Table 2. Comparison of radiation characteristics of port 1 at 2600 MHz.

	Proposed	**Ref 1**	**Ref 2**
BW (MHz)	220	240	331
Isolation (dB)	48	43	43.7
Gain (dB)	8.93	7.92	8.49
XPD (dB)	−43.35	−41.88	−46.5
F/B (dB)	−14.7	−10.8	−16.9
HPBW	67.6°	75.2°	71.3°
Dimension (mm^3)	$60 \times 60 \times 37$	$60 \times 60 \times 28$	$80 \times 80 \times 28$
Increase in Volume over Pro Ant	0	−24%	+20%

design also results in a better front-to-back ratio, which is 3.9 dB higher than Ref 1. But it is 2.2 dB lower than Ref 2, for the reason that the reflector size of Ref 2 is 78% larger than that of the proposed antenna. Considering the 20% volume reduction than Ref 2, the improvement of radiation patterns is very attractive. It provides a new idea to design compact dual-polarization antennas.

The measured performances of the design in this paper comparing with the state-of-the-art literature reference [12, 13] are shown in Table 3. Different cross dipole types with lager antenna apertures and much larger reflector are used in [12, 13]. It can be understood easily

Table 3. The performances of the proposed design comparing with References [12, 13].

<table>
<tr><td>Design</td><td colspan="2">Overall Antenna Volume (λ_0^3)</td><td>Increasein Volume over Pro Ant</td><td>SWR</td><td>Impedance BW (MHz)</td></tr>
<tr><td>Ref. [12]</td><td colspan="2">$0.98 * 0.98 * 0.35$</td><td>280%</td><td>< 1.4</td><td>1710–2170</td></tr>
<tr><td>Ref. [13]</td><td colspan="2">$1.28 * 1.28 * 0.23$</td><td>335%</td><td>< 2.0</td><td>1718–3409</td></tr>
<tr><td>Proposed</td><td colspan="2">$0.52 * 0.52 * 0.32$</td><td>0</td><td>< 1.5</td><td>2420–2780</td></tr>
<tr><td>Design</td><td>Isolation (dB)</td><td>Gain (dB)</td><td>HPBW</td><td>XPD (dB)</td><td>F/B (dB)</td></tr>
<tr><td>Ref. [12]</td><td>> 25</td><td>\</td><td>65° ± 5°</td><td>\</td><td>> 28</td></tr>
<tr><td rowspan="2">Ref. [13]</td><td rowspan="2">> 36</td><td rowspan="2">9.5</td><td>60° ± 5°</td><td>−23</td><td>> 18</td></tr>
<tr><td colspan="3">in the band of 2109–3306 MHz</td></tr>
<tr><td>Proposed</td><td>> 38</td><td>8.5</td><td>about 70°</td><td>−25</td><td>> 14.7</td></tr>
</table>

that the antennas in [12, 13] will result in a wider impedance band and a better radiation patterns than the proposed one. However, they are too large in size. When the overall antenna volume deceases, the radiation performance will deteriorate rapidly. Considering the trade-off, the proposed novel structure has obtained an accepted radiation characteristics when keeping a compact size.

5. CONCLUSION

A novel dual-polarized dipole antenna is simulated, fabricated, and tested. The key design is to introduce a parasitic element and a director. The antenna has good VSWRs (< 1.5) and high isolation ($> 38\,\mathrm{dB}$) in the frequency band of 2500–2690 MHz. Symmetrical radiation patterns with HPBWs of about 70° are achieved. Reference antennas with reflector of the same size and larger size are also developed. Comparison results show that the radiation patterns and the antenna gain can be improved a lot in the case of small-sized reflector by the novel structure. The proposed antenna can be applied in LTE2600 communication systems.

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