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Broadband, Wide Beam Circularly Polarized Antenna with a Novel Matching Structure for Satellite Communications

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Abstract—A wide beam, circularly polarized (CP) antenna is presented for satellite communications. The antenna consists of two crossed bent dipoles, two baluns and two pairs of rectangular patches and a feeding network. The two dipoles are fed by the two baluns, respectively. The arms of the dipoles are bent to save the horizontal space and to broaden the beamwidth. The rectangular patches which are connected to the arms of the dipoles form the matching structure of the proposed antenna. The impedance bandwidth of the antenna is broadened by adjusting the length of the rectangular patches. A broadband 90° power divider is used to feed the proposed antenna and to realize circular polarization. The antenna has a −10-dB impedance bandwidths of 77% (1.73–3.89 GHz). The proposed antenna exhibits a measured 2-dB AR bandwidth of 76.3%, from 1.71 GHz to 3.8 GHz. The 3-dB beamwidth is greater than 88° over the whole working band. Results show that the proposed antenna is suitable for the application of satellite communications.

1. INTRODUCTION

Circular polarization (CP) and wide beam are required for an antenna for satellite communications [1]. Moreover, wide beamwidth is also required to ensure the signal quality at any place on the earth [2]. CP antennas are divided in two types in general. 1) single-fed antenna [3–5] and 2) dual-fed antenna [2, 6–8]. There is no external feed network for a single-fed antenna. But the usable impedance and axial ratio bandwidths are usually narrow [1]. For a dual-fed CP antenna, the circular polarization is generated by exciting two orthogonal resonant modes with a feeding network which provides equal amplitude and 90° phase difference. The feeding network is often realized by a hybrid or Wilkinson power divider.

In [6], a dual-fed, bidirectional radiated circularly polarized square-ring antenna is presented. The antenna has abroad impedance bandwidth ($|S_{11}| < -10$ dB) of about 45.2% and a 3 dB axial-ratio bandwidth of about 8.7%. In [7], a CP antenna which consists two bowtie patch and two electric dipoles is proposed. The antenna achieves an impedance bandwidth (SWR < 1.6) of 41% and a 3-dB ratio bandwidth of 33%. In [8], a structural modification of turnstile antenna with cylindrical parasitic elements is introduced. The antenna has a 5-dB AR bandwidth of 12.3% and a stable peak gain of 7.6 dBi.

In this paper, a broadband, wide-beam CP antenna is presented. The antenna is a crossed-dipole fed by a broadband 90° power divider. The axial-ratio bandwidth of the proposed antenna is larger than that of the antennas in [2–8]. The 3-dB beamwidth is larger than 88° over the whole working frequency band. The bandwidth of the proposed antenna is broadened by a novel matching structure. The matching structure is part of the antenna structure rather than additional lumped elements. The concept of the matching structure is discussed in detail in the following paper.

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2. ANTENNA DESIGN CONCEPT AND STRUCTURE

The geometry of the proposed antenna is shown in Fig. 1. Detailed dimensions are given in Table 1. The proposed antenna consists of two crossed dipoles, two pairs of coaxial cables, a ground plane and two pairs of rectangular patches. The arms of each dipole are bent toward the ground plane to save the horizontal space and widen the beamwidth. Each dipole is fed by a balun. The balun is formed by the four coaxial cables.

The outer conductors of the four coaxial cables are replaced by copper tubes with the same radius to strengthen the antenna structure. And the four arms are fixed as well as connected to the top end of these copper tubes respectively. Significantly, the inner conductor of the coaxial cable1 and 3 (where the arm1 and arm3 is connected to) are connected to the outer conductors of the coaxial cable2 and 4 (the copper tube2 and 4) respectively. Moreover, the bottom end of the four copper tubes are connected to the ground plane so as to be shorted together. The whole structure forms a balun. This balun integrates with the antenna well. Coaxial line1 and 3 are connected to SMA connectors which are underneath the ground plane and fed by a feeding network which provides equal amplitude and 90° phase difference across a wide bandwidth to realize circular polarization. Details of the feeding network will be illustrate later.

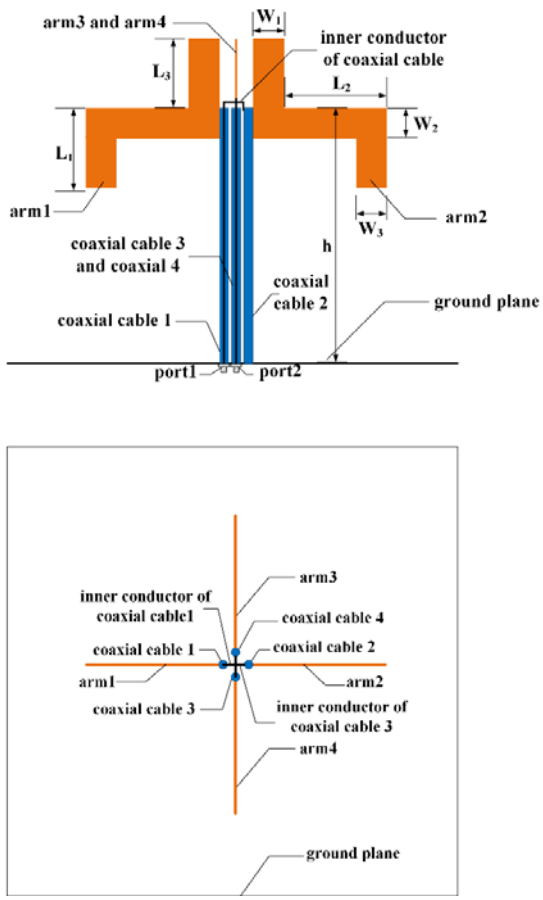


Figure 1. Geometry of the proposed antenna, side view and top view.

Table 1. Detailed dimensions of the proposed antenna (unit:mm).

Name	L_1	L_2	L_3	W_1	W_2	W_3	h
Value	12	15	18	5	5	5	38

The impedance bandwidth of the proposed antenna is broadened by the rectangular patches, which are attached to one end of the four arms of the dipoles. Based on the transmission line theory, it is pretty clear that a short transmission line (less than $\lambda/4$) which is terminated with an open circuit is capacitive and has a negative reactance $\text{Zin} = -jZ_0 \cot \beta l$, where Z_0 is the characteristic impedance of the transmission line, β is the phase constant and l is the length of the transmission line. Thus the rectangular patches of the proposed antenna act as capacitors which are in parallel with the input impedances of the bent dipoles. The impedance of the antenna on Smith Chart while varying the parameter h_3 when port 1 is excited and port 2 is terminated with a $50\,\Omega$ resistor is illustrated in Fig. 2. It can be seen that the imaginary part of the impedance is increased with the increase of h_3. When the length of the rectangular patch (h_3) is very small, the absolute value of its reactance is very large. Such a shunt capacitor is can be viewed as open circuit thus it has little influence on the input impedance of port 1. As h_3 increases, the absolute value of its reactance decreases and the influence of the rectangular patches on the impedance of the antenna becomes more and more apparent. The optimum value of h_3 occurs at 18 mm.

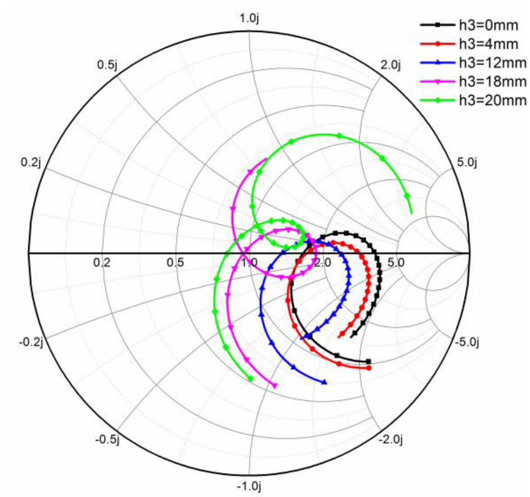


Figure 2. The impedance of the port 1 with different h_3.

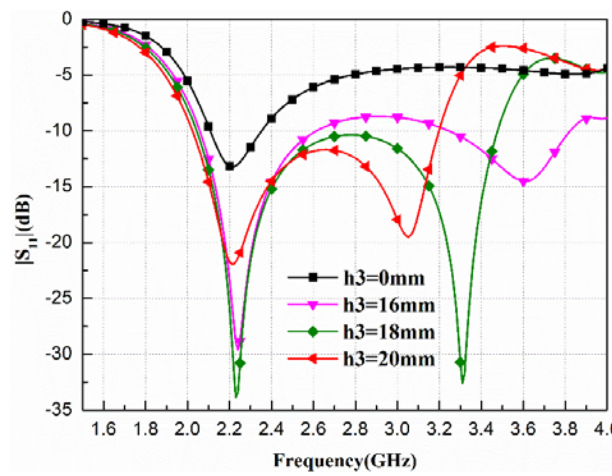
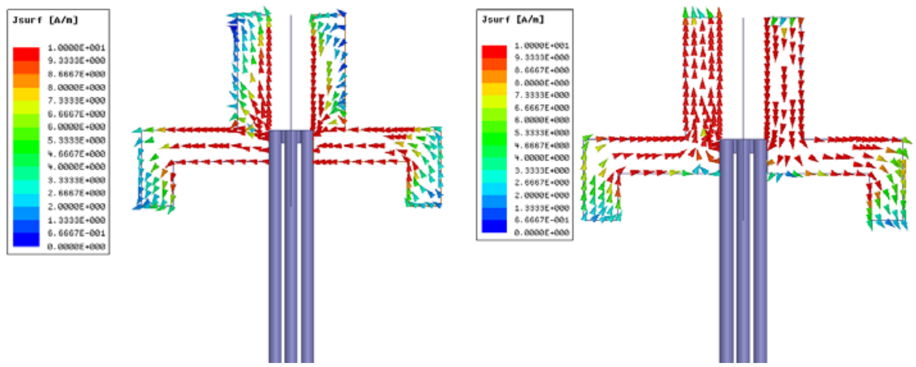


Figure 3. The $|S_{11}|$ of port 1 with different h_3.

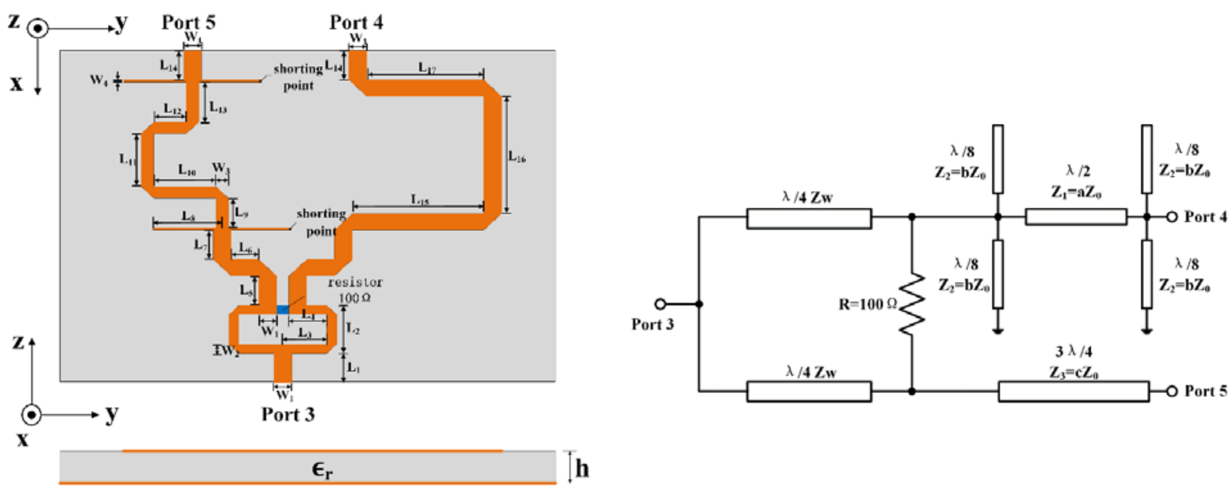
The variation of $|S_{11}|$ with different h_3 is shown in Fig. 3. It can be seen that the antenna resonant at $f_1 = 2.2$ GHz when there is no rectangular patches. The variation of h_3 only changes the depth of the resonance of the resonant frequency f_1. Moreover, another resonant frequency f_2 occurs with the increase of h_3. And the second resonant frequency f_2 decreases with the increase of h_3. The optimum value of h_3 is 18 mm. The rectangular patch has a greater effect on higher frequency band than lower one. This is mainly due to the fact that for a given value of h_3, the electric length of the rectangular patch is very small on the lower frequency band and it is quite large on the higher frequency band. Similar to the analysis of the effect of the value of h_3 on the antenna for a given frequency, the rectangular patch changes the input impedance of the antenna very little when it is very small. Thus the rectangular patch affects the lower resonant frequency f_1 very little.

In order to verify the aforementioned analysis, the current distributions on the rectangular patches at 2.2 GHz and 3.3 GHz are simulated and shown in Fig. 4. It can be seen that the current on the rectangular patch at 3.3 GHz is much bigger than that at 2.2 GHz. This indicates that the rectangular patches play a greater role at higher frequency than lower frequency. Moreover, the current distributions on the two rectangular patches which are connected to the arm 1 and arm 2 have same magnitudes and opposite directions. The distance between two patches is very small thus the electric fields caused by the current on the rectangular patch are cancelled. The rectangular patches broaden the impedance bandwidth of the proposed antenna without degrading the radiation performance of the proposed antenna. And it can be seen from the current magnitude and direction that the rectangular patches can be viewed as a short transmission line which is terminated by an open circuit. Port 2 of the proposed antenna has a similar performance due to the symmetry of the antenna structure.



(a) (b)

Figure 4. The current distributions on the antenna at (a) 2.2 GHz and (b) 3.3 GHz when port 1 is excited.



(a) (b)

Figure 5. (a) The structure and (b) schematic diagram of the feeding network.

Up to now, we have designed a broadband linearly polarized crossed-dipole. A broadband, equal-split power divider with 90° phase difference is needed for the realization of circularly polarization. The broadband power divider we used in this paper is based on the feeding network in [9]. For the completeness and a better understanding of the paper, the feeding network used for the proposed antenna is introduced briefly. The structure and schematic diagram feeding network is shown in Fig. 5. Detailed dimensions of the feeding network are shown in Table 2. Fig. 6 shows the simulated results including magnitude and phase responses. It can be seen that small reflection (below -10 dB), small amplitude imbalance (less than ± 0.12 dB) and small phase variation (less than $\pm 5°$) are obtained. The power divider is able to provide 90° phase difference output signals at port 4 and port 5 within 1.6 GHz-4 GHz band. Port 4 and port 5 of the feeding network are connected to port 1 and port 2 of the antenna, respectively.

The wide beam of the proposed antenna is mainly caused by two reasons. The first one is the folded part of the dipole acts as a director which leads the radiation pattern has a trend to the horizontal direction. The second one is that a horizontal dipole above a ground plane can be viewed as a two-element dipole array with equal amplitude and out-of-phase feeding. Thus the total radiation pattern can be calculated by the radiation pattern of a single dipole multiplied by the array factor. The proposed antenna has a height larger than a quarter wavelength when the frequency is larger than 1.9 GHz. Thus the maximum direction of the array factor is deviated from broadside at higher frequencies. Although the

Table 2. Detailed dimensions of the proposed antenna (unit:mm).

Name	W_1	W_2	W_3	W_4	L_1	L_2	L_3	W_1	L_4	L_5	L_6
Value	2.84	1.61	2.015	0.446	5	8.22	6.89	2.84	5.97	5	4.32
Name	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}	L_{13}	L_{14}	L_{15}	L_{16}	L_{17}
Value	5	10.85	5	9.719	9	5.0814	6.757	5	14.32	20	18.32

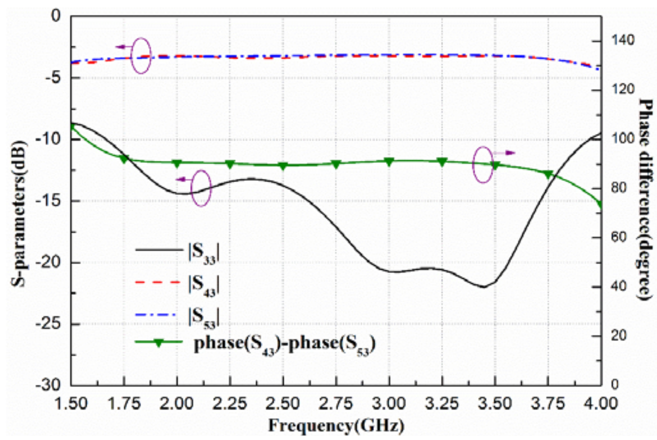


Figure 6. Simulated performance of the feeding network.

maximum direction of the total radiation pattern is still at broadside because of the radiation pattern of a single dipole, the antenna beamwidth is broadened. It should be noticed that the impedance matching of a dipole over a ground plane will become poor as the distance increases. However, the rectangular patches of the proposed antenna is a broadband matching structure which can match the proposed antenna at higher frequencies.

3. RESULTS AND DISCUSSION

The proposed antenna has been designed, fabricated, and measured. Fig. 7 shows the prototype of the proposed antenna and the feeding network.

Figure 8 shows the simulated and measured S-parameters of the proposed antenna. The simulated results are obtained by Ansoft HFSS ver.12, and the measured results are tested by an Agilent E5071C network analyzer. The measured results agree with the simulated results well with an acceptable difference. The differences between simulated and measured results are mainly caused by the fabrication errors. As can be observed from Fig. 8, the proposed antenna exhibits measured 10 dB impedance ($|S_{11}| < -10$ dB) bandwidth of about 77%, from 1.73 GHz to 3.89 GHz. It has a relatively broad impedance bandwidth compared with traditional dipoles. It should be noticed that the $|S_{11}|$ curve is different form the curve in Fig. 3 which is mainly caused by the performance of the feeding network.

Figure 9 shows the simulated and measured ARs and gains. The proposed antenna exhibits a measured 2-dB AR bandwidth of 76.3%, from 1.71 GHz to 3.8 GHz and a measured 3-dB AR bandwidth of 87.8%, from 1.56 to 4 GHz. The measured antenna gain varies between 2 dBi to 5.5 dBi. The antenna gain is small at higher frequencies. This is mainly owning to that the distance between the arms and the ground plane is large than $\lambda_h/4$, where λ_h is the wavelength at higher frequency and the beamwidth of the antenna is increased with increases of frequency.

The simulated 3 dB beamwidths of the proposed antenna at different frequencies are shown in Table 3. It can be seen that the beamwidth of the proposed antenna is larger than 88°. The radiation patterns of the proposed antenna at 2.2 GHz and 3.3 GHz on the $\phi = 45°$ and $\phi = 135°$ planes are shown in Fig. 10. It can be seen that the proposed antenna has a broadside radiation pattern. The crosspolarization level of less than −20 dB. The measured beamwidths of the radiation patterns at 2.2 GHz and 3.3 GHz are 90° and 167°, respectively. The proposed antenna is a broadband, wide beam CP antenna with a novel matching structure. Results show that proposed antenna is suitable for satellite communications.

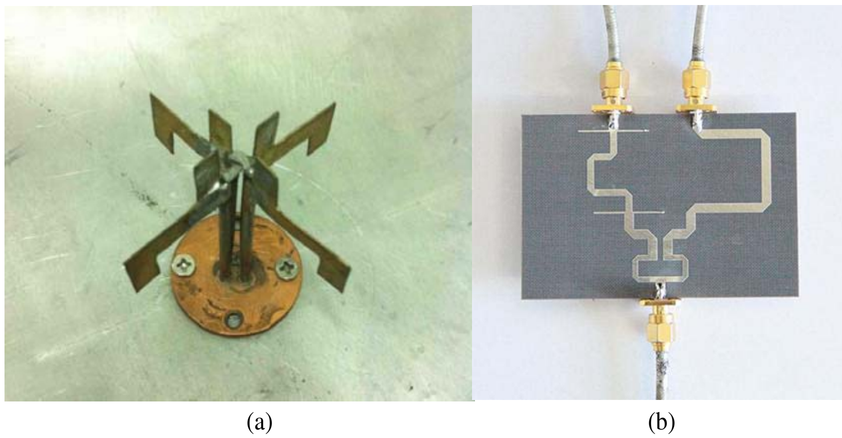


Figure 7. The prototype of (a) the proposed antenna and (b) the feeding network.

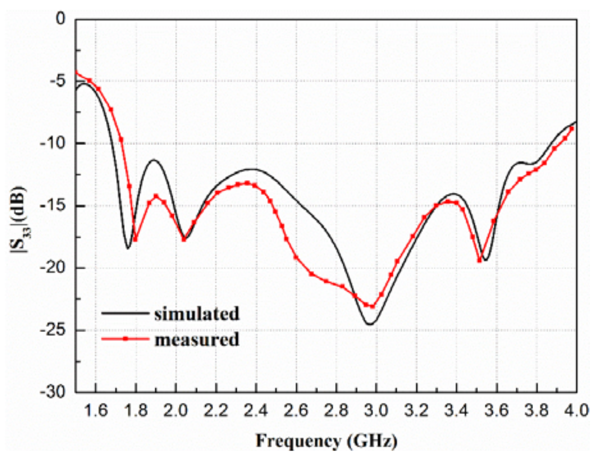


Figure 8. Simulated and measured $|S_{33}|$ of the proposed antenna.

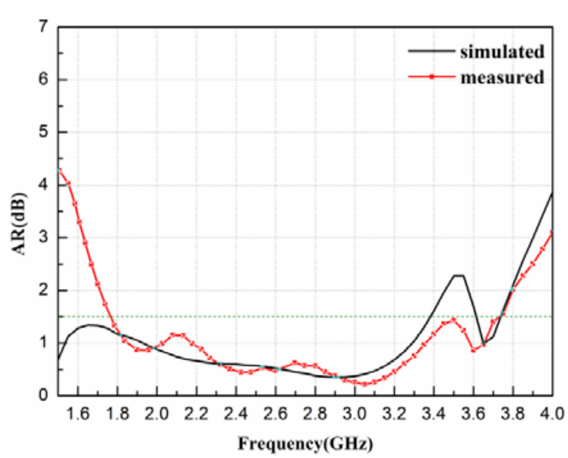


Figure 9. Simulated and measured ARs and Gains of the proposed antenna.

Table 3. Beamwidth the proposed antenna at different frequencies (unit:mm).

Frequency (GHz)	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8
Beamwidth (degree)	88	90	92	104	123	139	148	164	169	171	172

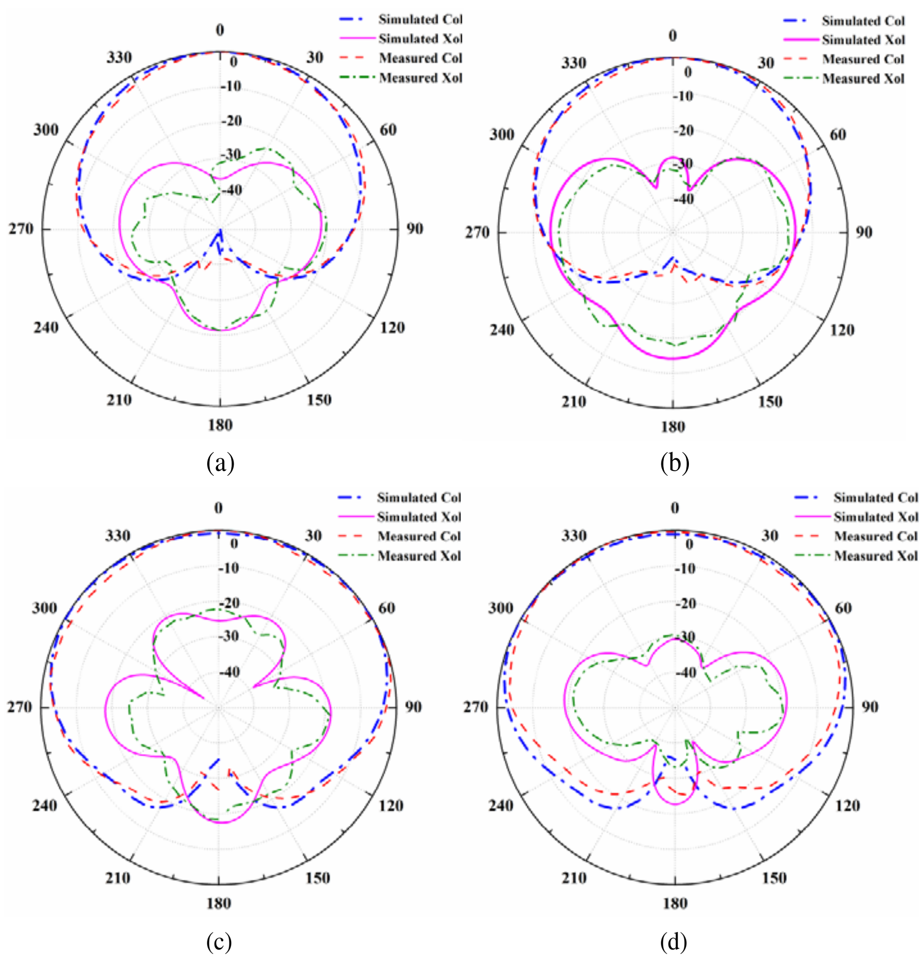


Figure 10. The radiation patterns of the proposed antenna, (a) 2.2 GHz, $\phi = 45°$ plane, (b) 2.2 GHz, $\phi = 135°$ plane, (c) 3.3 GHz $\phi = 45°$ plane and (d) 3.3 GHz $\phi = 135°$ plane.

4. CONCLUSION

A broadband, wide-beam CP antenna with a novel matching structure is proposed. The proposed antenna consists of two crossed dipoles, a ground plane, two baluns and two pairs of rectangular patches. The rectangular patches can be viewed as shunt capacitors which introduce another resonant frequency on higher frequency band. And it does not change the original resonant frequency of the dipoles, nor does it affect the radiation performance of the proposed antenna. Impedance matching is realized by tuning the length of the rectangular patches. A broadband, equal-split power divider with 90° phase difference is used to feed the proposed antenna and realize circular polarization. The antenna has a −10-dB impedance bandwidths of 77% (1.73–3.89 GHz). The proposed antenna exhibits a measured 2-dB AR bandwidth of 76.3%, from 1.71 GHz to 3.8 GHz. The 3-dB beamwidth is greater than 88° over the whole working band. Results show that the proposed antenna is suitable for the application of satellite communications.

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