

# A Compact Ultrawideband Circularly Polarized Antenna Array With Shared Partial Patches

Wei He , Yejun He , Senior Member, IEEE, Yin Li , Sai-Wai Wong , Senior Member, IEEE, and Lei Zhu , Fellow, IEEE

**Abstract**—In this letter, a compact ultrawideband circularly polarized (CP) antenna array is proposed. The antenna array consists of four cross dipoles with asymmetric elliptical arms and a wideband 1-to-4 feeding network. By employing the ellipses of different sizes as the arms of the cross dipole, the operating bandwidth of the antenna array element can be enhanced. Rotating four of these elements in sequence can obtain an antenna array with symmetrical radiation patterns. The size of the antenna array can be reduced by shortening the distance between adjacent elements and exchanging the upper and lower layers patches of the second and fourth elements to partially overlap between adjacent elements. In addition, the axial ratio (AR) bandwidth can be further expanded because of the sequential rotation topology and the wideband feeding network with a 90° phase difference between adjacent elements. A prototype is fabricated to verify the design principle. The measured and simulation results show that the proposed antenna array has great CP characteristics. The measured impedance bandwidth for  $|S_{11}| < -10$  dB and 3 dB AR bandwidth are about 104.4% and 111.8%, respectively. The peak gain is 13.2 dBic at 4.5 GHz. The overall size of the antenna array is only  $0.88 \lambda \times 0.88 \lambda \times 0.14 \lambda$  (all refers to the wavelength of the lowest operating frequency in free space).

**Index Terms**—Circularly polarized (CP) antenna, cross dipole, ultrawideband antenna.

## I. INTRODUCTION

IN RECENT years, more and more ultrawideband (UWB) antennas have been widely used in indoor and outdoor positioning, radar imaging, wireless data collection, and other wireless communication systems [1]. As multifunctional systems and miniaturized systems become more and more popular, the demand for UWB antennas with compact and circular polarization (CP) is also increasing.

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A variety of different wideband and UWB CP antennas have been reported. A CP dielectric resonator antenna loaded with the partially reflective surface could achieve a wide axial ratio (AR) bandwidth of 54.9%, while it has a higher profile ( $0.6\lambda$ ) [2]. A compact CP spiral antenna was proposed in [3], and its AR bandwidth covered the frequency range of 2–6 GHz. By using a pair of curved tapered slots with a meshed reflector to obtain an UWB antenna and employing double Y-shaped slots with a multilayer patch to achieve an UWB high gain antenna were described in [4] and [5], respectively. In [6], an L-shaped radiator monopole antenna with defect ground was illustrated, the AR bandwidth was about 115.2%; an UWB CP antenna consisting of an asymmetric-fed radiator and a frame structure lower ground with an U-shaped slot was shown in [7], the AR bandwidth of about 110.5%; and in [8], a geometrically simple compact UWB CP antenna was proposed, it exhibits an AR bandwidth of about 82%, but these antennas were with bidirectional radiations. An UWB CP asymmetric- $S$  antenna with the AR bandwidth of about 84.8% was presented in [9], its overall size was  $1.07 \lambda \times 1.07 \lambda \times 0.36 \lambda$ . In addition, a cross dipole antenna with ellipse arms that could reach a 3 dB AR bandwidth of about 96.6% from 1 to 2.87 GHz was illustrated in [10], and adding four rotated elliptical slots to the elliptical arms could obtain 4.1:1 AR bandwidth [11]. The antennas mentioned previously are all different types of UWB CP antennas realized by a single feed, but the use of multifeed technology can achieve a compact UWB CP antenna. A compact UWB CP antenna based on crossed tapered slot radiation elements was mentioned in [12], its 3 dB axial ratio bandwidth is 105.5%, but it has a complicated 3-D structure. In [13], a multimode patch antenna with a four-feed network was illustrated, the AR bandwidth of which was 85%. Nevertheless, the gain of which is only 6 dBic. In [14], four broadband CP monopole elements with a sequentially rotated feeding network are used to excite the UWB CP radiation, but this antenna has a complicated gradient artificial magnetic conductor with a metal cone. A  $2 \times 2$  sequentially rotated symmetric metasurface antenna with a slot linear polarized antenna array could achieve a 3 dB AR bandwidth of about 83.2% [15], but this antenna could not maintain a stable and symmetrical radiation pattern in the operating frequency bandwidth. In a word, the antennas mentioned previously are either thick in profile, large in size, or have narrow bandwidth.

In this letter, we proposed a compact UWB CP antenna array with shared partial patches. The proposed antenna array consists of two-layer printed circuit boards (PCBs). Four cross dipoles

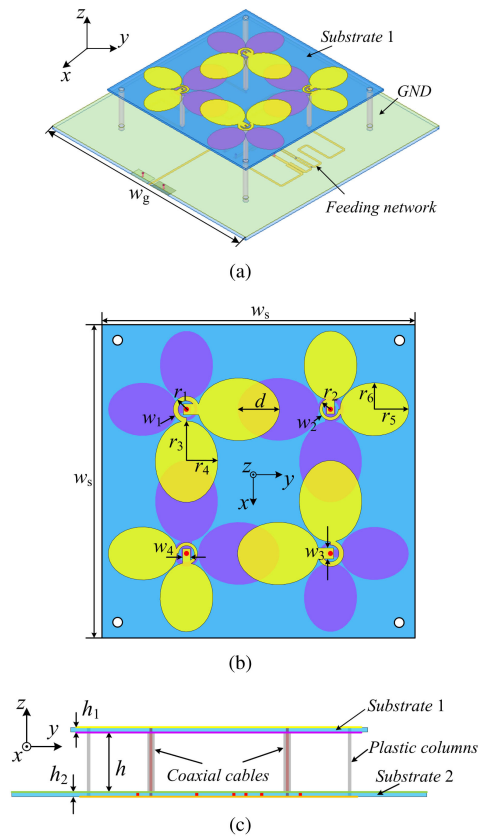


Fig. 1. Configuration of the proposed antenna array. (a) 3-D view. (b) Top view of  $2 \times 2$  antenna arrangement. (c) Side view.

with asymmetric elliptical arms are printed on the two sides of the top PCB, and a wideband 1-to-4 feeding network is printed on the bottom PCB. Using ellipses of different sizes as the arms of the cross dipole, the operating bandwidth of the antenna array element can be enhanced. By shortening the distance between adjacent elements and exchanging the upper and lower layers patches of the second and fourth elements to partially overlap between adjacent elements can reduce the size of the antenna array. In addition, the sequential rotation topology and the wideband feeding network can further enhance the AR bandwidth. The simulated and measured results verify the good performance of the proposed antenna array.

## II. ANTENNA DESIGN AND ANALYSIS

Fig. 1 shows the configuration of the proposed antenna array, which consists of  $2 \times 2$  sequentially rotated cross dipoles with asymmetric elliptical arms, a feeding network, two layers of substrate, four supporting plastic columns, and four feeding coaxial cables. The top layer substrate ( $\epsilon_1 = 2.2$  and  $\tan \delta_1 = 0.0009$ ) has a size of  $w_s \times w_s$  and a thickness of  $h_1$  (0.508 mm). Four cross dipoles with asymmetric elliptical arms are printed on the two sides of the substrate. By using the ellipses of different sizes as the arms of the cross dipole, the operating bandwidth of the antenna array element can be enhanced. As shown in Fig. 1(b), the size of the proposed antenna array can be reduced by exchanging the upper and lower patches of adjacent antenna array elements and overlapping partial patches of the

TABLE I  
ANTENNA PARAMETERS (mm)

$w_1$	$w_2$	$w_3$	$w_4$	$w_s$	$w_g$	$d$	$h$
1.5	1	3.5	2.5	100	140	13.4	22
$r_1$	$r_2$	$r_3$	$r_4$	$r_5$	$r_6$	$h_1$	$h_2$
4.2	3.5	13	10	11	8.5	0.508	0.508

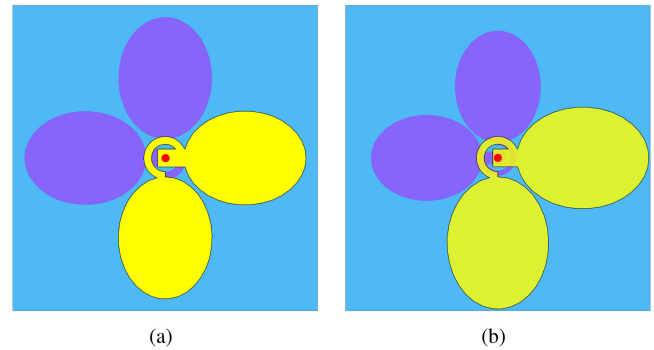


Fig. 2. (a) Reference antenna. (b) Proposed antenna element.

adjacent antenna array elements simultaneously. The width of the overlapped part is  $d$  (13.4 mm). In addition, this special topology structure shown in Fig. 1 can enable the antenna array to obtain a stable and symmetrical radiation pattern. More importantly, compared with the conventional array, this topology structure makes the distance between antenna elements only 46 mm, much less than the half of the free-space wavelength at 1.9 GHz (78.9 mm). Furthermore, when a wideband feeding network with a  $90^\circ$  phase difference between adjacent elements is added, the operating bandwidth of the proposed antenna array can be greatly expanded. The optimized design parameters are as follows in Table I.

To illustrate the advantages of the proposed design method, the cross dipole with symmetric elliptical arms and the conventional array composed of those are compared with the proposed antenna element and array. The geometries of the cross dipole with symmetric elliptical arms (reference antenna) and asymmetric elliptical arms (proposed antenna element) are shown in Fig. 2. As shown, one half of the proposed antenna element is slightly smaller than the cross dipole with symmetric elliptical, while the other half is slightly larger than the cross dipole with symmetric elliptical. The performance comparison of the two antennas for  $|S_{11}|$ , and AR and gain are shown in Fig. 3(a) and (b), respectively. It can be seen that the impedance bandwidth of the two antenna is almost consistent, while the 3 dB AR bandwidth of the proposed antenna element is much wider. This is because slightly reducing the half of the cross dipole with symmetrical elliptical arms will extend the operating frequency to a higher frequency, while slightly increasing the size of the other half will extend the operating frequency to a lower frequency. In short, selecting the size of the asymmetric elliptical arms of the cross dipole properly can obtain a wider operating bandwidth.

As shown in Fig. 4(a), the feeding network is printed on the bottom layer substrate. The bottom layer substrate ( $\epsilon_2 = 3.55$

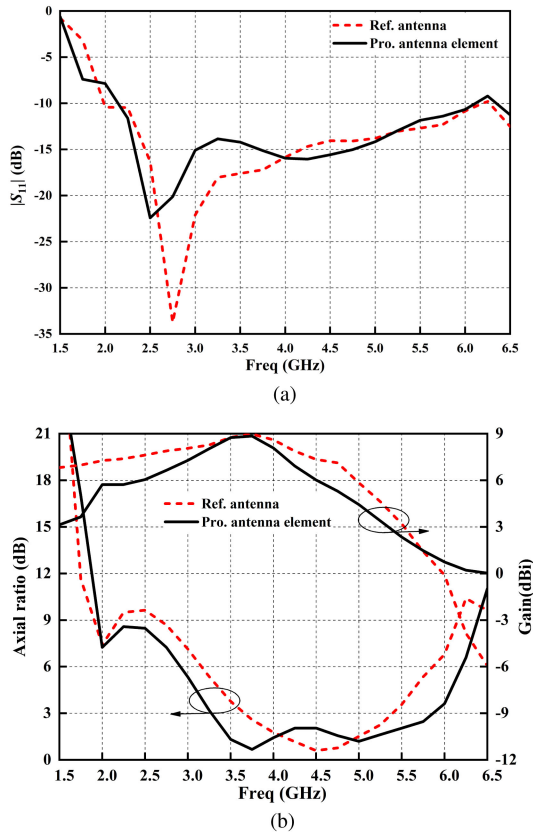


Fig. 3.  $|S_{11}|$  and AR of the reference antenna and the proposed antenna element. (a)  $|S_{11}|$ . (b) AR and gain.

and  $\tan \delta_1 = 0.0027$ ) has a size of  $w_g \times w_g$  and a thickness of  $h_2$  (0.508 mm). This feeding network has an UWB power divider and a stable phase difference performance and consists of a  $180^\circ$  out-of-phase balun and two  $90^\circ$  baluns, which is designed in [16]. The simulation results of this feeding network are illustrated in Fig. 4(b). The impedance bandwidth of the feeding network with  $|S_{11}| < -10$  dB is from 1.82 to 6.21 GHz (109.3%), and the phase difference between Port 2, Port 3, Port 4, and Port 5 is maintained at about  $90^\circ$  within the bandwidth of 1.82–6.21 GHz. The magnitude unbalance of the insertion loss is less than 1.5 dB.

### III. RESULTS AND DISCUSSIONS

To prove the correctness of the previous analysis, the proposed compact UWB CP antenna array was fabricated and measured. The photos of the fabricated antenna are shown in Fig. 5. The simulated and measured results of the proposed antenna array in terms of S-parameters, AR, and gain performance are shown in Figs. 6 and 7, respectively. As shown in Fig. 6, the measured impedance bandwidth of  $|S_{11}| < -10$  dB is about 104.4% (3.18:1, 1.96–6.24 GHz), which is in a good agreement with the simulated result. As illustrated in Fig. 7, the measured 3 dB AR bandwidth can cover the frequency range from 1.75 to 6.19 GHz, reaching 111.8% (3.53:1), which is slightly different from the simulated result. In addition, the measured gain is positive in the operating bandwidth, a slight fluctuation compared with the

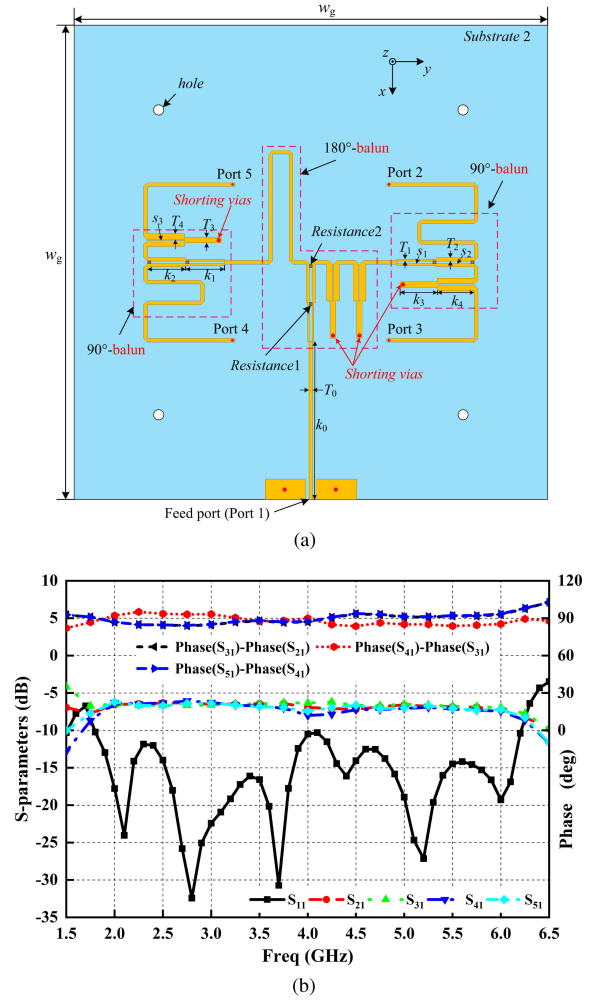


Fig. 4. Feeding network of the proposed antenna array. (a) Schematic of the feeding network. (b) Simulation performance of the feeding network. ( $w_g = 140$  mm,  $k_0 = 46.65$ ,  $k_1 = 11.5$ ,  $k_2 = 11.3$ ,  $k_3 = 10.9$ ,  $k_4 = 11$ ,  $T_0 = 1.1$ ,  $T_1 = 0.53$ ,  $T_2 = 0.96$ ,  $T_3 = 1.74$ ,  $T_4 = 1.65$ ,  $s_1 = 0.8$ ,  $s_2 = 0.8$ ,  $s_3 = 0.3$  mm,  $Resistance1 = 62 \Omega$ , and  $Resistance2 = 562 \Omega$ .)

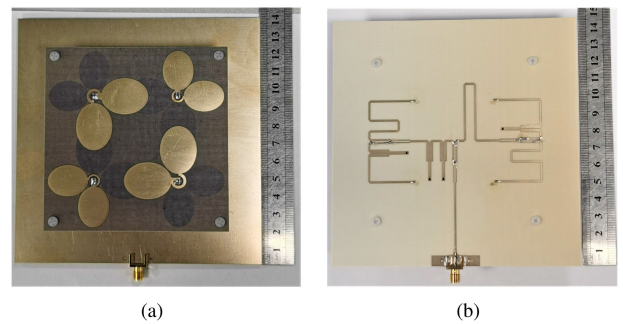


Fig. 5. Prototype of the proposed antenna. (a) Top view. (b) Bottom view.

simulated gain, and the peak gain is 13.2 dBi at 4.25 GHz. The measured and simulated results of the radiation pattern in the  $xoz$  and  $yo z$  planes at 2.5, 3.5, 4.5, and 5.5 GHz are plotted in Fig. 8(a)–(d), respectively. The antenna yields a stable left-hand CP radiation pattern in both  $xoz$  and  $yo z$  planes at all frequencies. The performance comparison between the proposed

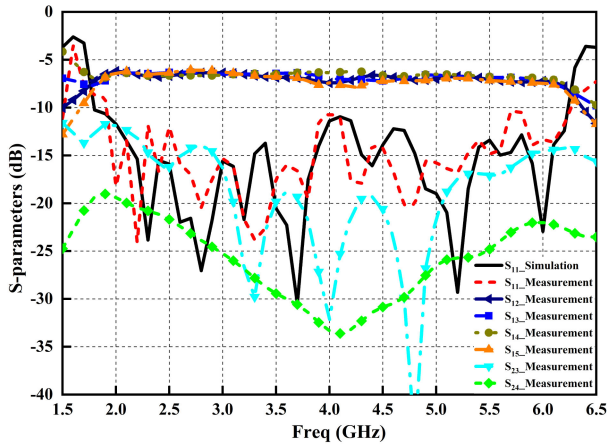


Fig. 6. Simulated and measured S-parameters of the proposed antenna.

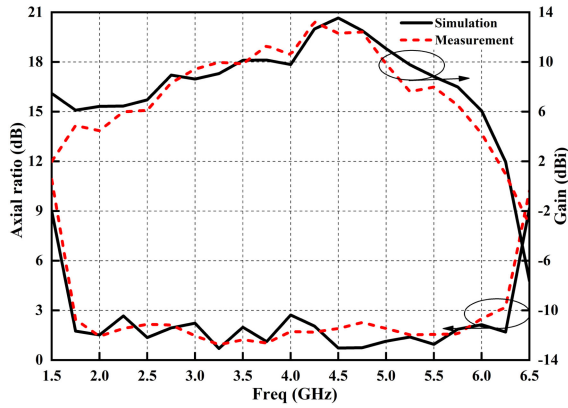


Fig. 7. Simulated and measured AR and gain of the proposed antenna.

TABLE II  
COMPARISON BETWEEN THE PROPOSED ANTENNA AND OTHER UWBCP ANTENNA

Ref.	Antenna Size ( $\lambda^3/\text{mm}^3$ )	Impedance bandwidth	AR bandwidth	Peak gain (dBic)
[12]	$0.33\lambda \times 0.33\lambda \times 0.3\lambda$ $53 \times 53 \times 47$	108% 1.85-6.22 GHz	107% 1.82-6.2 GHz	8
[13]	$0.62\lambda \times 0.62\lambda \times 0.1\lambda$ $85 \times 85 \times 8.5$	85% 2.2-5.5 GHz	85% 2.2-5.5 GHz	6
[14]	$1.17\lambda \times 1.17\lambda \times 0.1\lambda$ $200 \times 200 \times 17.5$	132.8% 1.17-5.79 GHz	92.5% 1.75-4.76 GHz	12.6
[15]	$0.8\lambda \times 0.8\lambda \times 0.05\lambda$ $77 \times 77 \times 4.38$	97.2% 2.75-7.95 GHz	83.2% 3.3-7.75 GHz	10.8
[16]	$1.13\lambda \times 1.13\lambda \times 0.15\lambda$ $85 \times 85 \times 11.6$	98% 2.5-9.2 GHz	96.3% 2.15-6 GHz	9.5
<b>This work</b>	$0.88\lambda \times 0.88\lambda \times 0.14\lambda$ $140 \times 140 \times 23$	<b>104.4%</b> <b>1.96-6.24 GHz</b>	<b>111.8%</b> <b>1.75-6.19 GHz</b>	<b>13.2</b>

antenna array and other UWBCP arrays is shown in Table II. It can be shown that the proposed antenna not only has a compact size but also has a wider 3 dB AR bandwidth.

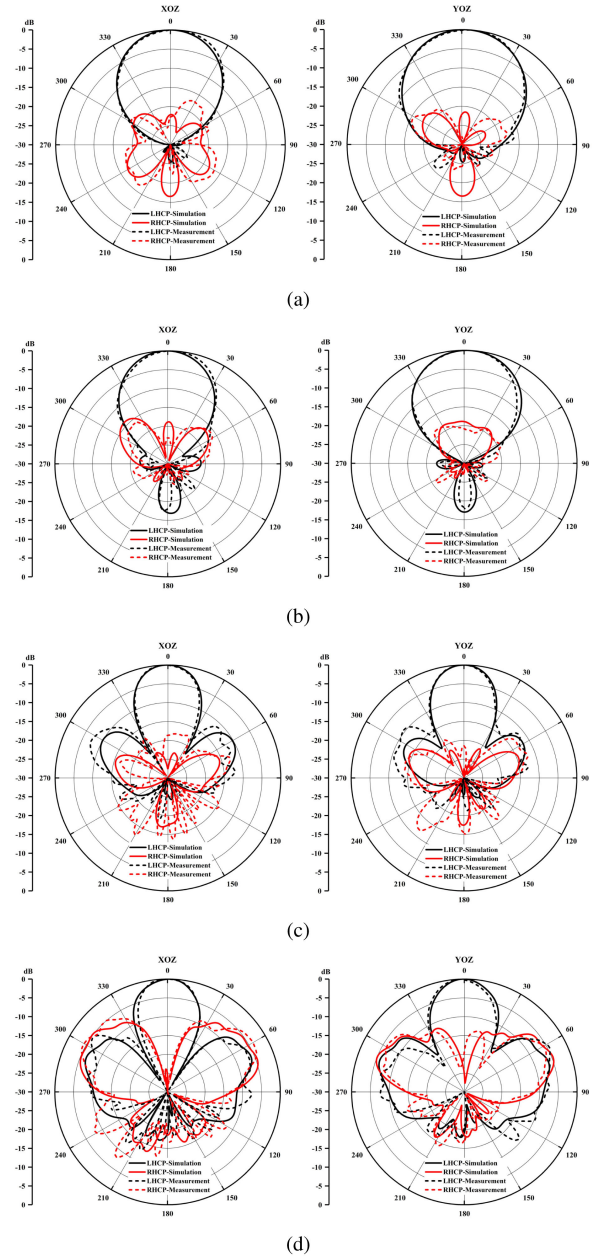


Fig. 8. Simulated and measured radiation pattern of the proposed antenna in *xoz* and *yoz* planes. (a) 2.5 GHz. (b) 3.5 GHz. (c) 4.5 GHz. (d) 5.5 GHz.

#### IV. CONCLUSION

In this letter, a compact UWBCP array with shared partial patches is proposed. By using an asymmetric ellipse to replace the arms of the conventional cross dipole, the operating bandwidth can be enhanced. Rotating four of these elements in a sequence and exchanging the upper and lower patches of adjacent antenna array elements and making the adjacent antenna array elements partially overlapped can reduce the size of the proposed antenna array. The overall size of the antenna array is only  $0.88\lambda \times 0.88\lambda \times 0.14\lambda$ . In addition, the impedance bandwidth of 104.4% and AR bandwidth of 111.8% are mentioned. The good performance of this antenna array makes it a potential candidate for many UWBCP applications.

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