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# A Compact Circularly-Polarized Array Based on Superdirective Elements

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**Abstract**—In this paper, a new strategy for designing compact Circularly-Polarized (CP) arrays is proposed. This approach consists of using small parasitic superdirective arrays as unit elements. An array is designed for 866MHz RFID band and a parametric analysis on the inter-element distance is performed to highlight the trade-offs between the antenna- dimensions, -directivity and radiation efficiency. For total dimensions of  $220 \times 220 \times 25.8\text{mm}^3$  ( $0.58\lambda \times 0.58\lambda \times 0.075\lambda$ ), the array has a CP directivity of 10.3dBic and a radiation efficiency of 38.5%.

**Keywords**—Superdirective arrays, parasitic elements, circular polarization.

## I. INTRODUCTION

Novel wireless technologies require increasingly compact antennas. However, conventional arrays lead to a significant increase in their size. Meanwhile, in superdirective arrays the unit-elements are put very closely together and their excitation coefficients are controlled to achieve the maximum directivity (in the end-fire direction) predicted by Uzkov [1]. Recently, there has been a renewed interest in superdirective arrays and in particular electrically small ones [2]-[11]. In this paper, we propose a new strategy for designing compact Circularly-Polarized (CP) arrays by using small superdirective arrays as unit-elements. The constraints including the maximum directivity, the efficiency, the antenna dimensions are studied. Results are validated through the realization and measurement of a  $2 \times 2$  array.<sup>1</sup>

## II. ARRAY GEOMETRY AND PARAMETRIC STUDY

In [10] a design methodology for superdirective arrays was detailed. It was shown that, by exciting one element and loading the others, the same excitation coefficients, and hence the same directivity radiation pattern, as in the fully driven array can be achieved. This method was used in [11] to design a two-element array for 866MHz RFID band. The unit-element used in the array is a short-circuited half loop antenna [8]. In the array, one element was excited while the other was loaded with a capacitor of  $3.3\text{pF}$ . The antenna had a size factor of  $ka = 1.1$  and it had a simulated (HFSS [12]) total directivity of 7dBic and radiation efficiency of 43.4%. Four elements of this array are integrated in  $2 \times 2$  planar CP array (using the classical sequential rotation method) as shown in Fig. 1(a). The four elements are excited with phases of  $0, 90^\circ, 180^\circ$  and  $270^\circ$  to achieve a Left-Hand

Circular-Polarization (LHCP). It should be noticed that these excitations can be reversed to achieve Right-Hand Circular-Polarization (RHCP). The spacing between the elements  $d$  (calculated as a straight line between the excitation ports as shown in Fig. 1(a)) is changed from  $10.1\text{cm}$  to  $27.6\text{cm}$ . Fig. 1(b) shows the antenna maximum LHCP directivity and the efficiency as a function of the distance. It can be noticed that as the distance increases the coupling effect decreases and the achieved directivity increases till it reaches its maximum value around  $0.5\lambda$  where it starts decreasing again. We can also note that as the distance increases the radiation efficiency decreases and it reaches its minimum when the maximum directivity occurs. Fig. 1(c) shows the antenna Half Power BeamWidth (HPBW) and CP aperture for an Axial Ratio ( $AR$ )  $< 3\text{dB}$ . As it can be noticed, CP aperture is always higher than the the HPBW. Moreover, AR is lower than 1dB in the entire HPBW.

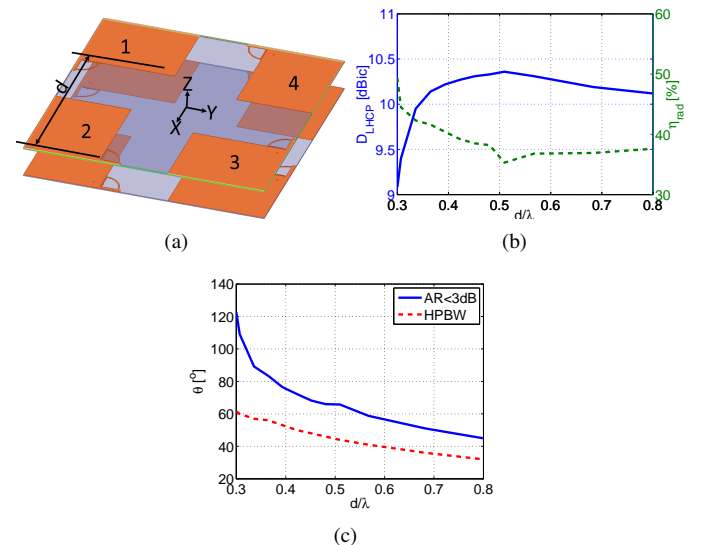


Fig. 1. Planar CP array simulated parameters as a function of the separation. (a) Geometry, (b) LHCP directivity and radiation efficiency and (c) HPBW and CP aperture.

## III. SIMULATION AND EXPERIMENTAL RESULTS

A prototype of the antenna was fabricated and measured for a distance of  $15.6\text{cm} \approx 0.45\lambda$  (Fig. 2(a)). Two ZX10-2-20+ power dividers ( $0, 180^\circ$ ) [13], a hybrid coupler ( $0, 90^\circ$ ) from KDI/triangle [14], and four 30cm-long UFL cables [15] are used for the feeding system. Fig. 2(b) shows the antenna input reflection coefficient magnitude in dB. The antenna has a

<sup>1</sup>This work was done with the funding of the French National Research Agency as part of the project "SOCRATE" and the support of the "Images et Reseaux" cluster of Brittany region, France.

simulated/measured resonance frequency of 866/879.8MHz (a frequency shift of 1.6%). The antenna with the feeding system is well matched in all the observed band. This is mainly due to the losses in the feeding system. The antenna measured LHCP directivity given in Fig. 2(c) shows it increases till it reaches its maximum value of 10dBic at the resonance frequency then it starts decreasing again. The measured AR is also minimal around the resonance frequency. The antenna has a measured CP bandwidth ( $AR < 3dB$ ) of 21MHz. Fig. 3(a) shows the antenna 3D LHCP directivity radiation pattern. It can be observed that the measured result is in a good agreement with the simulated one. The antenna has a simulated/ measured directivity of 10.3/10dBic in broadside direction ( $\phi=0^\circ$ ). The antenna cross-polar (RHCP) 3D directivity radiation pattern is given in Fig. 3(b). The measured result is in acceptable agreement with the simulated one. The antenna 2D main- and cross-polar -directivity radiation patterns are given in Fig. 4. It can be noticed that the measured results in the main-polar are in a good agreement with the simulated ones. The simulated/ measured HPBW in E ( $XoZ$ ) and H ( $YoZ$ ) planes are respectively 48/45° and 40.3/50.6° and FBR is 40.3/19.8dB. The small difference in the cross-polar levels is mainly due to the measurement environment (the feeding system and the support). The antenna has a simulated radiation efficiency of 38.5% and reveals a measured one of about 40% after compensating the losses in the feeding system.

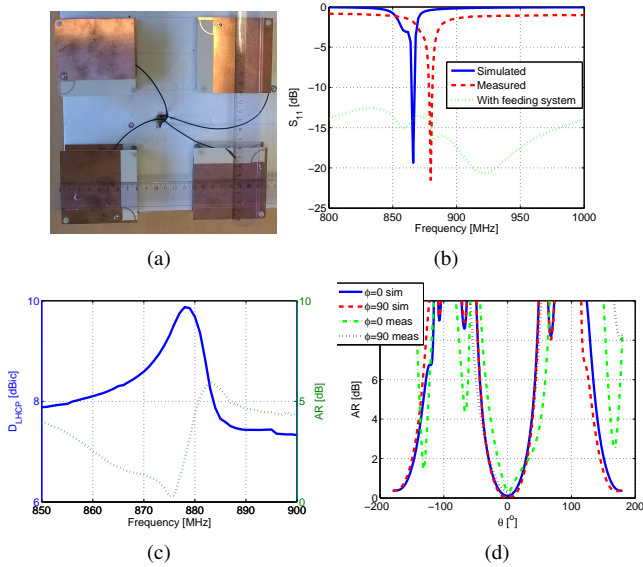


Fig. 2. Planar CP array with  $d = 15.6cm$ . (a) Fabricated prototype, (c) input reflection coefficient magnitude in dB, (d) measured LHCP directivity and AR as a function of the frequency and (e) AR.

#### IV. CONCLUSION

In this paper, a new design approach for compact CP arrays was presented. This approach consisted of using small parasitic superdirective arrays as unit elements. An array of total dimensions of  $0.58\lambda \times 0.58\lambda \times 0.075\lambda$  having a LHCP directivity of 10.3dBic and a radiation efficiency of 38.5% was designed for RFID applications. The experimental results were in a good agreement with the simulated ones.

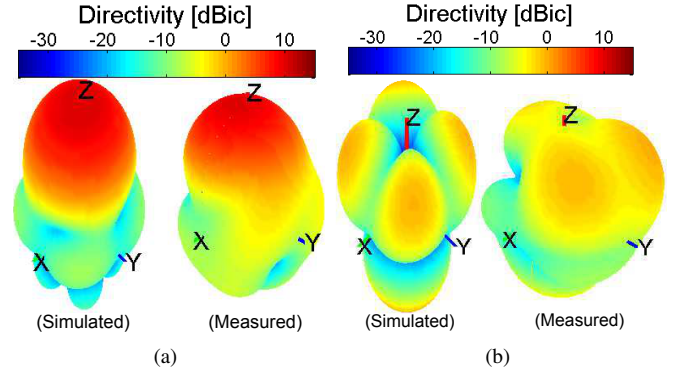


Fig. 3. Planar CP array 3D directivity radiation pattern for  $d=15.6cm$ . (a) Co-polar and (b) cross-polar.

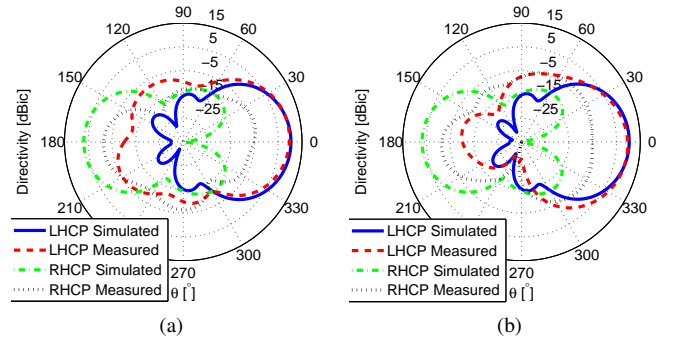


Fig. 4. Planar CP array 2D LHCP and RHCP directivity radiation pattern for  $d=15.6cm$ . (a) E plane and (b) H plane.

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