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HIGH GAIN AND BROADBAND CIRCULARLY POLARIZED SQUARE SLOT ANTENNA ARRAY

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Abstract—A high-gain and low-cost circularly polarized antenna array is proposed, which consists of four sequentially rotated circularly polarized square slot antennas (CPSSA). A novel feeding network is applied to the four-element array antenna, which results in increasing the axial ratio (AR) bandwidth. The measured impedance bandwidth for VSWR < 2 is around 3.48 GHz (3.75 GHz$\sim$7.23 GHz) exhibiting a 2.8 GHz (3.8 GHz$\sim$6.6 GHz) 3 dB axial-ratio bandwidth (ARBW) and 9.05 dBic peak gain. The simulated and measured results are in good agreement with each other to verify the design.

1. INTRODUCTION

In modern communication systems, circularly polarized (CP) microstrip antennas are more attractive for many applications, such as fixed and mobile satellite systems, the remote control and telemetry, radar and wireless communication systems due to their very thin profile, light weight and low manufacturing cost [1, 2]. Furthermore, CP antennas are excellent choice over linearly polarized (LP) antennas owing to their flexibility in orientation angle between transmitter and receiver antennas [3]. However microstrip antennas suffer from their inherent drawbacks such as narrow bandwidth (generally less than 5 percent) and relatively high-fed line losses [3, 4]. The microstrip antenna arrays are used in order to overcome the aforementioned disadvantages. They exhibit low efficiency (typically less than 50 percent) due to ohmic/dielectric losses and parasitic radiation in the feeding network, as well as surface wave excitations in the dielectric substrate [5, 6]. An array with circular polarization and low voltage-standing wave ratio over a wide frequency band can be designed using

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sequential rotation technique [7–14]. The circularly polarized square slot antenna array (CPSSAA) proposed in this work has a feed network that comprises a 180° ring hybrid coupler linked to two branch-line hybrid couplers. The presented array employs a pair of branch line couplers to feed CPSSA elements, which improves the performance of the array considerably. The measured impedance bandwidth for VSWR < 2 is around 3.48 GHz (3.75 GHz∼7.23 GHz) exhibiting a 2.8 GHz (3.8 GHz∼6.6 GHz) 3 dB axial-ratio bandwidth (ARBW) and average 6.7 dBic gain over the 3 dB ARBW. Details of the 2×2 sequentially rotated planar CPSSA array configuration are given as follows.

2. ANTENNA ELEMENT CONFIGURATION AND DESIGN

The geometry of the proposed CPSSA, depicted in Fig. 1, consists of a ground-loop conductor with side length $G = 25$ mm, and square aperture with a side length of $L = 18$ mm. The ground-loop envelops a rectangular radiating patch of length $L_f = 8$ mm and width $W_f = 3.1$ mm. A pair of inverted L-shaped conductor strips of side length $0.3L$ is located at opposite diagonal corners of the ground-loop, one of which is adjacent to the patch. Circularly polarized operation of the antenna is chiefly related to the width of the two inverted L-shaped conductor strips. By embedding two identical L-shaped metallic strips, right-handed and left-handed circularly polarized (RHCP and LHCP) radiation in z directions with a wideband axial-ratio have been generated. The proposed element was printed on a FR4 substrate

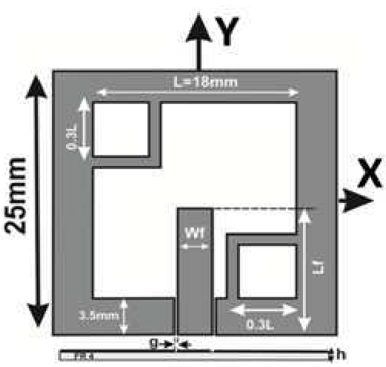

Figure 1. Configuration of the proposed CPSSA structure. Dimensions of the structures parameters are: $G = 25$, $L = 18$, $W_f = 3.1$, $L_f = 8$, $g = 0.3$, $h = 0.8$. (Units in mm).

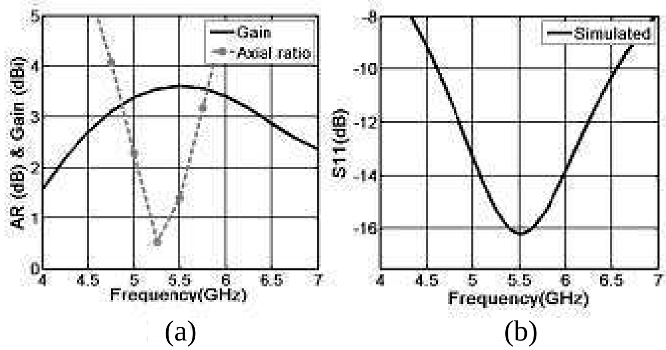

Figure 2. Simulated frequency response of a single element CPSSA: (a) CP axial-ratio (AR) and gain, and (b) return-loss.

with $\epsilon_r = 4.4$, $\tan\delta = 0.024$ and height of $h = 0.8$ mm. The CPSSA was optimized at 5.5 GHz as shown in Fig. 2 to have an impedance bandwidth of 2 GHz [1]. However, using circularly polarized elements gives substantial improvement in network performance. It is depicted from Fig. 2 that the array elements of this network have inherently appropriate axial ratio.

3. BROADBAND CIRCULAR POLARIZATION ANTENNA ARRAY

A 2×2 planar array antenna has been established by using the proposed CPSSA element. Each element is separated by a distance of $0.65\lambda_0$

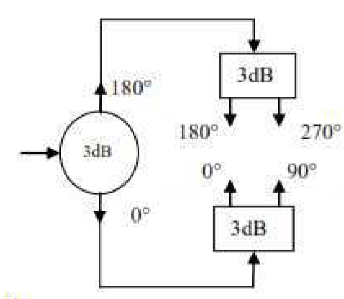

Figure 3. The diagram of the proposed feed network.

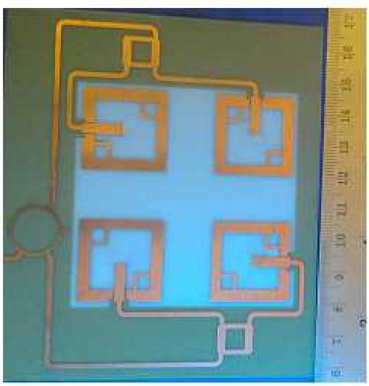

Figure 4. Photograph of the fabricated 2 × 2 CPSSA array.

(wavelength in free space) and is excited through a microstrip-feed network incorporating a 180° ring hybrid coupler, two 90° hybrid (branch-line) couplers and delayed lines placed on the topside of the antenna in order to perform the impedance matching and phase controlling functions. In Fig. 3, the diagram of the proposed feed network is shown.

The outputs of the 180° ring hybrid are equal in magnitude

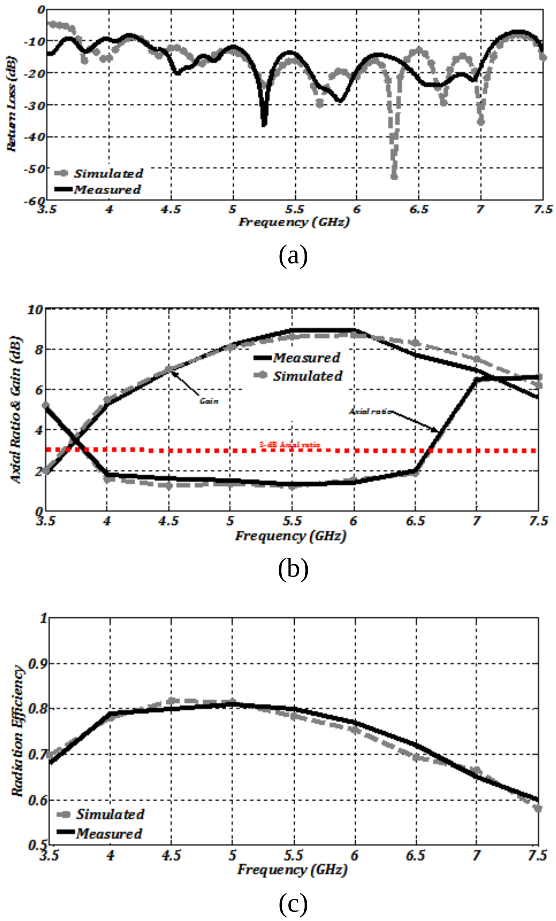

Figure 5. Measured and simulated results of the proposed antenna array, (a) S_{11}, and (b) axial-ratio and gain, (c) radiation efficiency. (Black solid line denotes simulated and gray dash line denotes measured results).

and 180° out of phase. Two supplementary branch-line hybrid couplers have been used for dividing the output power of the ring coupler into two paths with equal amplitude and 90°, phase difference. Consequently the relative phases at four feed points are 0°, 90°, 180° and 270°, respectively.

The array network configuration was designed in *Agilent*™ Advance Design System (ADS) environment. Hence, the CPSSA elements are excited by respective similar signals and the signal to be radiated is thus circularly polarized. Each element is fed through the microstrip circuit of couplers and delay lines. Via pins are used to enhance the transition between microstrip line to CPW feed line. Distances between via pins in input of each element are optimized by using S-parameters and input impedance.

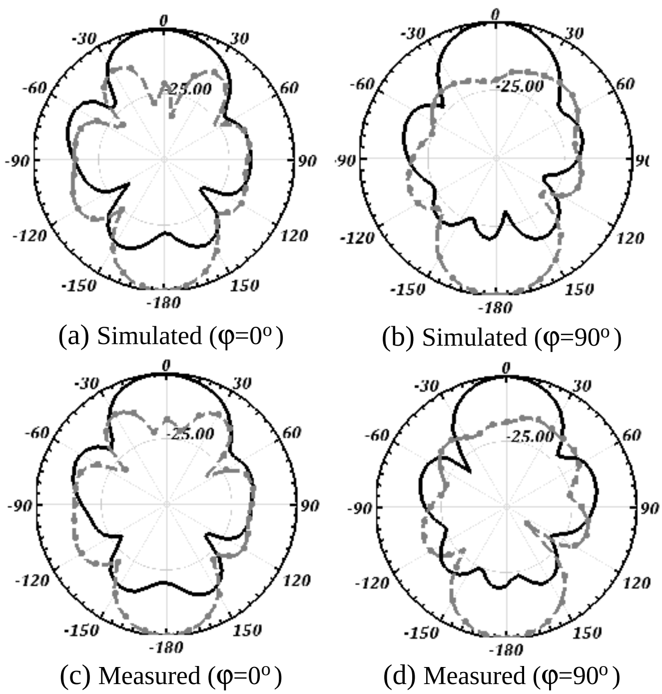

Figure 6. The proposed antenna array with normalized RHCP and LHCP at 5.5 GHz: (a) simulated $\varphi = 0°$, (b) simulated $\varphi = 90°$, (c) measured $\varphi = 0°$, and (d) measured $\varphi = 90°$. (Black solid line denotes RHCP and gray dash circle line denotes LHCP).

4. RESULTS AND DISCUSSION

The fabricated array antenna and its simulation and measurement results are presented in Fig. 4 and Figs. 5(a), (b), (c), respectively.

The S_{11} and axial-ratio of the proposed antenna array were measured using the Agilent 8722ES network analyzer. There were slight differences between the measured and simulated results. The antenna array delivers a measured impedance bandwidth of 63.4 percent from 3.75 GHz to 7.23 GHz for VSWR < 2 and a measured 3 dB axial-ratio bandwidth of 53.8 percent from 3.8 GHz to 6.6 GHz, respectively. Measured peak gain of CPSSAA is 9.05 dBic at 5.5 GHz and minimum of axial ratio of the proposed antenna array is 1.2 dB at 5.5 GHz. Fig. 5(b) shows a gain dropping after 7 GHz. It is depicted

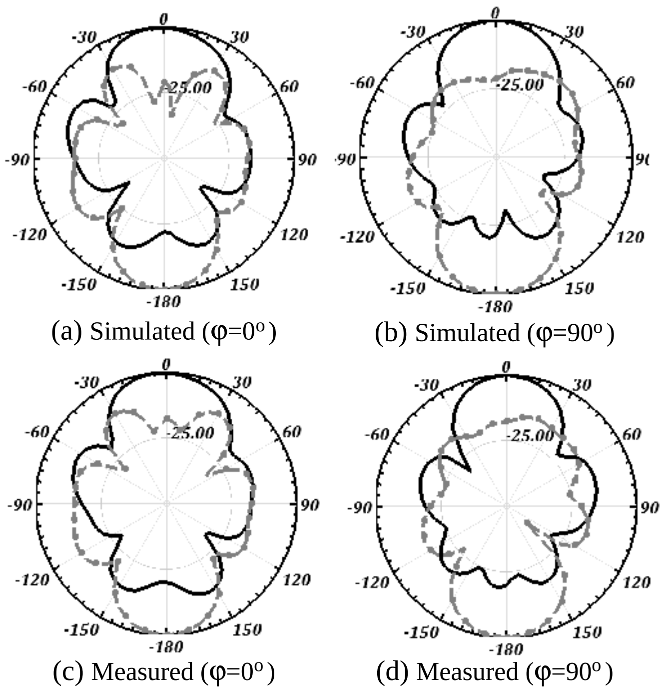

Figure 7. The proposed antenna array with normalized RHCP and LHCP at 4.5 GHz and 6 GHz: (a) measured $\varphi = 0°$, $f = 4.5$ GHz, (b) measured $\varphi = 90°$, $f = 4.5$ GHz, (c) measured $\varphi = 0°$, $f = 6$ GHz and (d) measured $\varphi = 90°$, $f = 6$ GHz (Black solid line denotes RHCP and gray dash circle line denotes LHCP.

from the Fig. 5(c) increasing frequency leads to decreasing the radiation efficiency. It is because of the loss tangent of substrate rises with increasing the frequency. So one can conclude that gain dropping related to decreasing of the radiation efficiency.

The measured and simulated results of the normalized radiation patterns of the array at 5.5 GHz are presented in Fig. 6. The RHCP and LHCP radiation patterns of the array were obtained at $\varphi = 0°$ and $\varphi = 90°$. Fig. 7 illustrates measured radiation patterns in two other frequencies. The measured patterns were both in good agreement with the theoretical curves. Comparison of the proposed CPSSA array with the previous CPSSA array structures with sequential feed network and arc feed-line presented in Table 1. It shows that there are significant increases in impedance bandwidth and axial-ratio bandwidth.

Table 1. Comparison of the proposed feed network structure with other array antennas.

Ref.	[1]	[12]	[13]	This work
Feed Network	Asymmetric CPW	Aperture Coupled	Asymmetric CPW	Asymmetric CPW
BW (freq. range) (GHz)	2.80 (4.0–6.8)	0.80 (1.6–2.4)	0.80 (1.1–1.9)	3.48 (3.75–7.23)
ARBW (freq. range) (GHz)	1.90 (5.1–7.0)	0.60 (1.7–2.3)	0.80 (1.1–1.9)	2.8 (3.8–6.6)
Peak Gain (dBic)	7.5	∼15	∼8	9.05
Substrate	FR4	RT/Duroid 5880	FR4	FR4

5. CONCLUSION

A circularly polarized square slot antenna array (CPSSAA) using a two-section cascaded coupler feeding system for generating broadband circular polarization performance is presented. The feeding network of the array comprises a 180° ring hybrid coupler connected to two branch line couplers generating circular polarization. The proposed antenna array architecture presents a number of well-behaved attributes including the flexibility of mixed type of feeding, low parasitic radiation from the feeding network, high polarization purity and a very high gain.

This is extremely important for mobile communications systems where small size, light weight, low profile and low cost are often claimed in portable or compact sized equipment. Our design, however, is also able to address these drawbacks since we have used a commercially available substrate such as FR4, which suffer from a higher loss but remarkably low cost. The trade-off between axial ratio and impedance bandwidth has been satisfactorily controlled as well. The spacing between two elements is 35.45 mm in two dimensions. The whole size of this broadband array is $120 \times 95 \times 0.8$ mm. The measured 3 dB AR bandwidth of the array is 64.5 percent, in the AR bandwidth the return loss is below 10 dB. The 3 dB gain bandwidth is about 38.1 percent with the peak gain 10.1 dBi.

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