Broadband Circularly Polarized Slot Antenna Array Using Sequentially Rotated Technique for *C*-Band Applications

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***Abstract*—This paper presents the investigation results on a novel circularly polarized square slot antenna (CPSSA) array designed to operate at a frequency of 5.5 GHz. In order to realize the proposed antenna array, four miniature circular polarized square slot antennas are used with L-shape grounded strips located at the slots opposite corners. The antenna is fed by symmetric coplanar waveguide. The CPSSA element achieves a bandwidth of 18% for an axial ratio ≤ 3 dB. The CPSSA's performance is further enhanced with the construction of a novel 2×2 antenna array that is designed using sequentially rotated feed technique. The 3 dB axial ratio of the array extends over 2 GHz with an impedance bandwidth of 33.33%. The CPSSA array was design operates over the frequency range between 4 and 6.87 GHz (52.8%) for VSWR<2 (1.71:1). Acceptable agreement between the simulation and measured results validates proposed design.**

***Index Terms*—Microstrip array, slot antenna, sequentially rotated feed technique, symmetrical coplanar waveguide feed.**

I. Introduction

In recent years microstrip antenna arrays have become a popular choice for applications in modern wireless communication systems such as satellite, radar tracking and mobile communication systems. This is attributed to their light weight, low-profile and ease of fabrication. Unlike linearly polarized (LP) antennas, circular polarized (CP) antennas are ideal for addressing challenges associated with mobility, adverse weather conditions, and non-line-of-site applications [1]-[9]. CP delivers better connectivity with both fixed and mobile devices and ultimately leads to a superior user experience. Despite these advantages, microstrip arrays suffer from narrow bandwidth (generally less than 5%) and relatively high feed line losses. Amongst the various established techniques to design an antenna array, sequential rotation feed technique is found to be effective for CP antenna arrays in terms of improving the array's main beam, bandwidth and polarization purity of the array. The use of LP elements in sequential rotation feed technique leads to a gain reduction exceeding 4 dB and high cross-polarization level compared to CP elements [9]. In the last few years, various designs of broadband CP slot antennas have been proposed to overcome the narrow impedance and axial ratio (AR) bandwidth problems, which include: (i) embedding inverted-L grounded strips in the slot, (ii) inserting spiral slot in ground-plane, and (iii) utilizing arc-shaped grounded metallic strip [1]-[8].

In this letter, a novel broadband circularly polarized antenna array is presented that is composed of four circularly polarized square slot antennas (CPSSA). The antenna unit-cells are sequentially rotated to form the array. The individual antennas are constituted from a ground-plane conductor with a square aperture, and excited with a rectangular patch. The design principle of the proposed sequential rotation technique has been described in details by P.S. Hall in ref. [8]. In order to overcome the high cross-polarization level that is normally encountered in the sequential rotation technique, CPSSA element includes two L-shape grounded strips located at two opposite corners of the slot. Due to the wide bandwidth and relatively simple technique for realizing CP radiation from a coplanar waveguide slot antenna [1], [2], the use of the sequentially rotation feed [8] with these elements has received much attention and employed in the proposed design. The proposed CPSSA array uses via pins to improve the transition between microstrip-line to CPW feed [9], [10]. The configuration of the proposed miniaturized element is simple and is six fold smaller than previously published design [3]. A 2×2 planar antenna array was designed by using the proposed CPSSA element. Inter element spacing of 0.7λ is selected in both azimuth and elevation planes to achieve better performance. The operation frequency of proposed design is between 4.5-7 GHz. A prototype of proposed CPSSA array has been fabricated and its performance measured to verify the design methodology. In the proposed array instead of using linearly polarized elements [9], [11], the work is done by using circularly polarized antenna elements with significant improvement in the antenna's axial ratio bandwidth.

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II. Antenna Elements Configuration and Design

The geometry of the proposed circularly polarized square slot antenna, depicted in Fig. 1, basically consists of a ground-plane conductor with side length G = 25 mm, and square aperture with a side length of L = 18 mm and located at the center of the ground conductor. The ground-plane envelops a rectangular radiating patch of length L_f = 8 mm and width W_f = 3.1 mm. The CPW is symmetrically positioned in the antenna structure and the feeding network is fed with a SMA connector attached at the back side of the board. A pair of inverted L-shaped conductor strips of side length 0.3L is located at opposite diagonal corners of the ground-plane, with one of them adjacent to the patch. Circularly polarized operation of the antenna is chiefly related to the width of the two inverted L-shaped conductor strips.

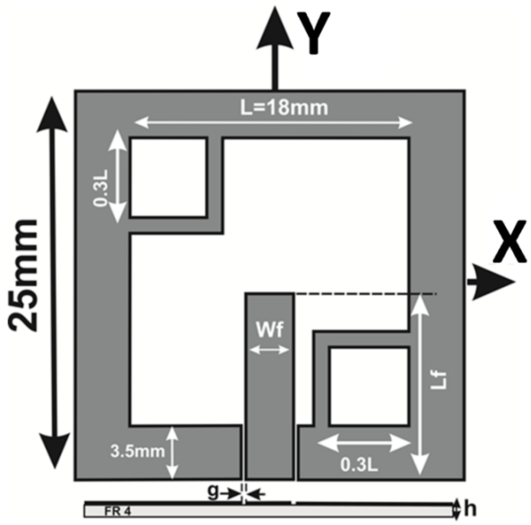

Fig. 1. Configuration of the proposed CPSSA structure. Dimensions of the structure's parameters are: G=25, L=18, W_f=3.1, L_f=8, g=0.3, h=0.8. (Units in mm).

By embedding two identical L-shaped metallic strips of side length ~0.3L [1], right- and left-handed circularly polarized (RHCP and LHCP) radiation is generated in ±z directions with wideband axial ratio, i.e. AR < 3 dB [1]-[4], [6]. The proposed element was printed on a FR4 substrate with ε_r = 4.4, tanδ = 0.024 and height of h = 0.8 mm. The CPSSA was optimized at 5.5 GHz to have an impedance bandwidth of 2 GHz. The magnitude and 3 dB bandwidth of the axial ratio of polarization at 5 GHz is 1.4 dB and 18%, respectively. The configuration of the CPSSA was optimized using Ansoft's HFSS commercial software. Detailed design principle of the miniature circularly polarized square slot antenna using L-shaped metallic strips is summarized in [1]. The proposed circularly polarized square slot antenna has an area of 625 mm^2 $(25\ \mathrm{mm} \times 25\ \mathrm{mm})$, which is less than the previously published square slot antennas as summarized in Table I & II along with other salient parameters.

III. Broadband Circular Polariation Antenna Array

The feed network of the proposed circularly polarized square slot antenna array consists of seven quarter-wave transformers sections that are curved and linked together in a consecutive sequence to form a four-port network, as shown in Fig. 2 along with its the transmission-line equivalent circuit. In the design of the proposed feed network some assumptions were made, namely the input impedance of the individual CPSSA elements and characteristic impedance of the main input feed-line are 50 Ω. As shown in Fig. 2, in this feed network, P_0 and $P_{m(m=1,2,3,4)}$ stands for the input power and the power flowing into the mth port of the CPSSA, respectively. $P_{in}^{j(j=1,2,3)}$ stands for the total power flowing in the downstream direction. $Z_{m(m=1,2,3,4)}$, $Z_{inm(m=1,2,3,4)}$ and $Z_{in}^{j(j=1,2,3)}$ stands for the characteristic impedances of the quarter-wavelength line sections, the impedance looking into the four output ports, and the impedance looking in the downstream at the junction ports, respectively.

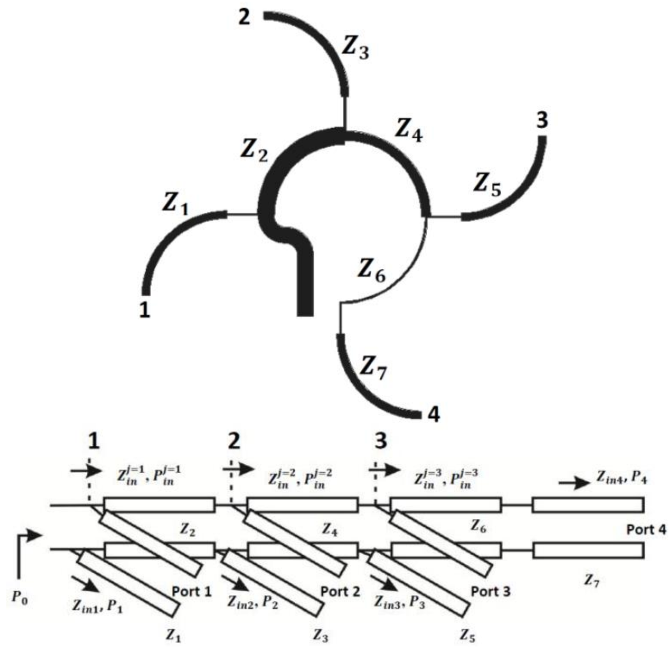

Fig. 2. Feed network and equivalent circuit of the circularly polarized square slot.

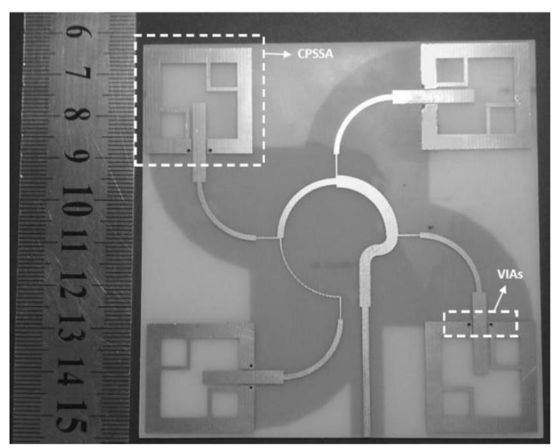

Fig. 3. Photograph of the fabricated 2 × 2 CPSSA array.

The proposed CPSSA was employed in the design of an array based on sequentially rotated CPSSA. This configuration will be referred here as sequentially rotated antenna (SRA). The photograph of fabricated SRA is shown in Fig. 3. The feeding system to the CPSS antennas in SRA employ a microstrip-line to a CPW transition with cylindrical via pins in the ground-plane. The configuration of the array network was designed by using Agilent™ Advanced Design System (ADS) commercial software. As shown in Fig. 2, to minimize the discontinuity to the array feed, all feed-line λ/4 transformers were designed in a curved shape.

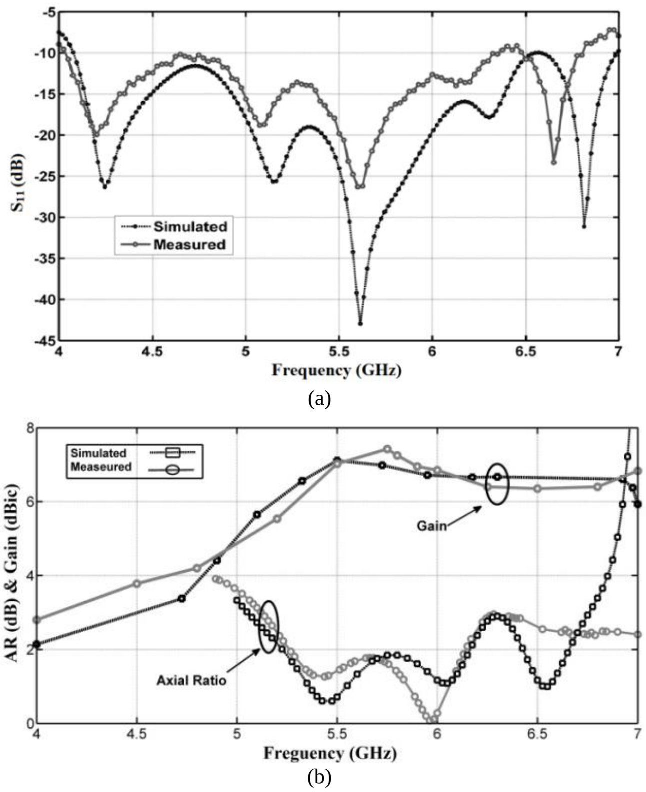

Fig. 4. Measured and simulated results of the proposed antenna array, (a) S_{11}, and (b) Axial ratio and gain.

III. Results And Discussion

The S_{11} and axial ratio of the proposed antenna array were measured using the Agilent™ 8722ES network analyzer. The measured impedance bandwidth for S_{11}<-10 dB was 51.91%, from 4012 to 6825 MHz, as shown in Fig. 4(a). The array's simulated and measured axial ratio is shown in Fig. 4(b). The measured AR bandwidth of the CPSSA array is 1686 MHz between 5111 MHz to 6797 MHz. A standard linearly polarized horn antenna was used to measure the total gain characteristics of proposed design. The measured and simulated results of the normalized radiation patterns of the array at 5.3 GHz are presented in Fig. 5. The minimum point of axial ratio curve is at 5.92 GHz with a magnitude of 0.43 dB. The RHCP and LHCP radiation patterns of the array were obtained at φ=0° and φ=90°. The proposed CPSS antenna array has a peak gain of 7.2 dBi at 5.63 GHz. The antenna gain varied between 6.2-7.2 dBic across the frequency band between 5111 MHz to 6797 MHz. The antenna array's size is 92 mm×92 mm. The design when compared with the previous CPSSA array structures with sequentially feed network [12] and arc line feed [9] show increased impedance bandwidth and axial ratio bandwidth, i.e. the impedance and AR bandwidth are, respectively, three and two fold wider than the of previous designs.

TABLE I
Summary of CPPS Antenna Size And Measured Charactersistics. The Impedance Bandwidth Is For A Frequency Range Where The VSWR ≤ 2; ARBW Is The 3 dB Axial Ratio Bandwidth.

Ref.	Size [mm]	Substrate	Impedance BW.	ARBW	Peak Gain
[3]	70 × 70 × 1.6	FR4	1.75-2.6 (0.875)	1.7-2.1	3.7
[4]	70 × 70 × 1.6	FR4	1.5-1.7 (0.204)	1.5-1.8	3.5
[5]	70 × 70 × 1.6	FR4	1.6-2.4 (0.864)	1.8-2.0	3.5
[6]	60 × 60 × 0.76	FR4	1.7-2.5 (0.819)	1.8-2.5	3.5
[7]	60 × 60 × 0.74	FR4	1.6-3.0 (1.455)	2.3-3.0	4
Proposed Element	25 × 25 × 0.8	FR4	4.6 - 6.5 (1.960)	4.9-5.7	3.6

TABLE II
Summary of Feed And Measured Charactersistics of Array Antennas. The Impedance Bandwidth (BW) Is The Frequency Range Where The VSWR ≤ 2; ARBW Is The 3 dB Axial Ratio Bandwidth.

Ref.	Element Feed	Substrate	Impedance BW.	ARBW	Gain
[9]	Symmetrical Coplanar Waveguide Feed	FR4	1.1-1.9 (0.8)	1.1-1.9	~ 8
[12]	Aperture-Coupled Feed	RT/Duroid 5880	1.6-2.4 (0.8)	1.7-2.3	~15
Proposed Array	Symmetrical Coplanar Waveguide Feed	FR4	4.0-6.8 (2.8)	5.1-6.7	7.2

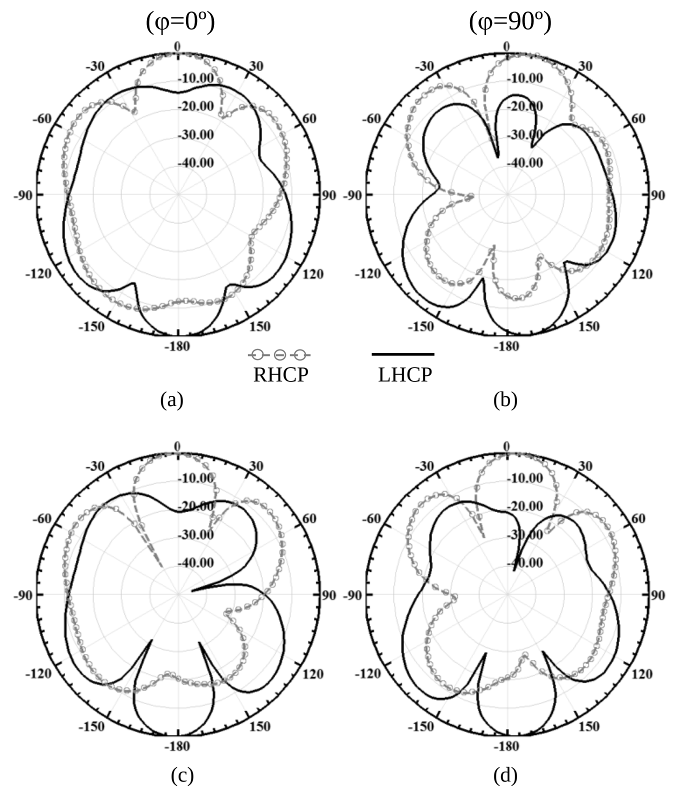

Fig. 5. The proposed antenna array with normalized RHCP and LHCP at 5.92 GHz, where the solid-line is normalized right- and left-hand LHCP. (a) Simulated φ =0°, (b) Measured φ =90°, (c) Measured φ =0°, and (d) Measured φ =0°.

IV. Conclusion

Four-element antenna array comprising of sequentially rotated circularly polarized square slot antennas (CPSSA) with microstrip-line to CPW feed network has been presented. The attributes of the proposed CPSSA array include: a relatively simple structure, low fabrication cost, and broadband operation across 4-7 GHz. The measured results show the impedance bandwidth is greater than 52% for VSWR<2, and axial ratio < 3 dB is 33.33%. The broadband circularly polarized slot antenna array used a sequentially rotated antenna feed network and via pins for enhancing the transition between microstrip-line to CPW feed-line. The measured maximum antenna gain was 7.2 dBi.

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