Broadband CPW-Fed Circularly Polarized Square Slot Antenna with Arc-Shaped and Inverted-L Grounded Strips

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Abstract **─** This paper presents a new wideband circularly polarized square slot antenna (CPSSA) with a coplanar waveguide (CPW) feed. The proposed antenna is composed of two arc-shaped and inverted-L grounded strips around opposite and mirror corners of the square slot. In this antenna the impedance bandwidth and the axial ratio bandwidth (ARBW) are increased compared to the previous CPSSA structures. For the optimized antenna prototype, the measured 3 dB axial ratio bandwidth is 76 % (3 GHz - 6.7 GHz) and the measured VSWR < 2 impedance bandwidth is as large as 108 % (3 GHz - 10.1 GHz). Throughout this paper, the improvement process of the axial ratio (AR) and S_{11} properties are presented and discussed in detail.

Index Terms **─** Axial ratio (AR), broadband, circularly polarized (CP), and square slot antenna.

I. INTRODUCTION

In the past few years, circularly polarized (CP) antennas have become more popular due to their importance in wireless communications, radar, radio frequency identifier (RFID), and sensor systems. For deploying a transmitter and a receiver without causing a polarization mismatch between them, circular polarization (CP) is becoming popular in wireless communications to enhance system performance, providing better mobility, and weather penetration, more than the linearly polarized (LP) antennas [1, 2] and also reduction in multi-path reflections. In addition, the channel capacity of a communication link can be doubled in a frequency reuse system by using circular polarization [3]. To create circular polarization, the antenna must radiate from two orthogonal modes with equal amplitude that are in phase quadrature. For generating CP radiation, various structures and designs of broadband CP antennas have been produced. A microstrip slot antenna may be a good choice as it is low profile, low cost, lightweight, and can be easily integrated with monolithic microwave integrated circuits (MMICs) [4].To improve the operating bandwidth and not increase the antenna size, using the printed slot antenna is a possible method. Since the printed slot antenna is a dual of the microstrip antenna, it is also possible that by introducing some perturbations to the slot antenna, CP radiation of slot antenna can be achieved [5]. Some of the techniques that are used to design these kinds of antennas with broad CP bandwidth include the following: embedding two inverted-L grounded strips around two opposite corners of the slot [1], embedding T-shaped grounded metallic strip, which is perpendicular to the axial direction of the CPW feed-line [2], using an asymmetric CPW fed from a corner of the slot with an additional pair of grounded strips implanted in the slot [6], corrugated slot antenna with meander line loaded [7], utilizing the embedded arc-shaped grounded metallic strip for circular and linear polarization [8], and embedding a lightning-shaped feed line and inverted-L grounded strips [9].

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This paper presents a novel design of a CPW-fed circularly polarized square slot antenna. According to measured results, the impedance bandwidth is about 108 %, entirely covering the 3 dB AR bandwidth, which is about 76 %. This antenna is suitable for IEEE 802.11a, (5150–5350 MHz / 5725–5825 MHz) and for IEEE 802.16, (3200–3800 MHz / 5200–5800 MHz).

II. ANTENNA DESIGN

Figure 1 shows the configuration of the proposed CPW-fed circularly polarized square slot antenna (CPSSA).

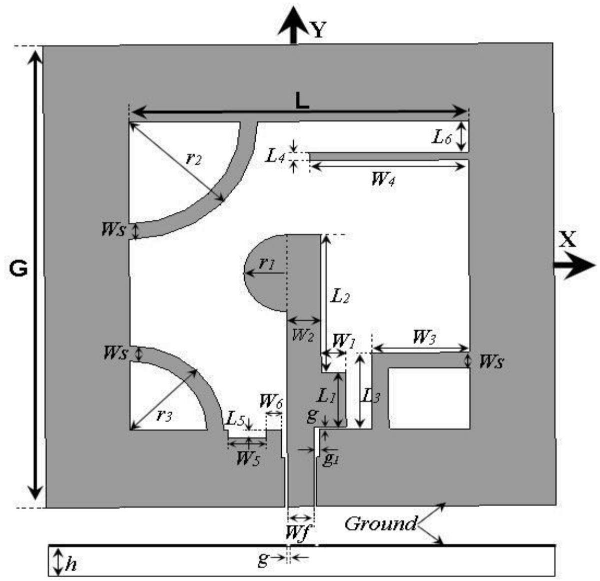


Fig. 1. Geometry of the proposed CP square slot antenna with G = 60, L = 40, h = 0.8, W_f = 3.1, g = 0.3, g_1 = 0.7, r_1 = 5, r_2 = 15.2, r_3 = 11, Ws = 2, L_1 = 7, W_1 = 2.9, L_2 = 18, W_2 = 4.05, L_3 = 9.9, W_3 = 11.6, L_4 = 1, W_4 = 18.75, L_5 = 1.1, W_5 = 4.5, L_6 = 4.1, and W_6 = 1.75 (All units are in millimeters).

The proposed CPSSA is printed on a commercially cheap FR4-epoxy substrate with ε_r = 4.4, tan (δ) = 0.024, and dimensions of 60 × 60 × 0.8 mm^3. The feed line of the proposed antenna is CPW and is connected to a 50 Ω SMA connector. The gap between the feed line and the ground is 0.3 mm, which is widened at the end to improve the impedance bandwidth. The length and width of the feed line are, respectively, 35.3 mm and 3.1 mm, which is connected to a semi-circular patch. A tuning vertical stub has been embedded in the feeding structure. The CP operation of the proposed antenna is greatly related to the two arc-shaped and an inverted-L grounded strips in opposite and mirror corners placed around the corners of the square slot. The structure of the inverted-L grounded metal strips was first proposed in [1]. For increasing ARBW a tuning horizontal grounded strip at the top right corner and a tuning slit at the left side of the feed line on the ground plane have been employed. The structure shown in Fig. 1 will generate right-hand and left-hand circularly polarized (RHCP and LHCP) radiations in the +z and -z directions, respectively.

III. RESULTS AND DISCUSSION

The performance of the CPSSA at parametric studies has been investigated to find the optimized parameters using the Ansoft high frequency structure simulator software (HFSS, ver.12) based on the finite element method (FEM). An Agilent 8722ES vector network analyzer has been used to measure the return loss (S_{11}). In the simulation setup perfect electric conductor (PEC) and an ideal excitation port are assumed. For simplification in the antenna design G = 60 mm, L = 40 mm, h = 0.8 mm were preselected. For describing the design process, five prototypes of the proposed antenna are defined as follows (Fig. 2): Ant. I includes only a feed line connected to semi-circular patch and ground plane; Ant. II contains two arc-shaped grounded strips around left side corners and inverted-L grounded strip at the bottom right side corner. In Ant. III a vertical tuning stub ($L_1 \times W_1$) is embedded in the feed structure and the gap between the signal strip and the ground plane is widened at the end. Ant. IV has a horizontal grounded strip ($L_4 \times W_4$) at top right corner and Ant. V has a tuning slit ($L_5 \times W_5$) that has been cut and removed from the ground plane at the left side of the feed line.

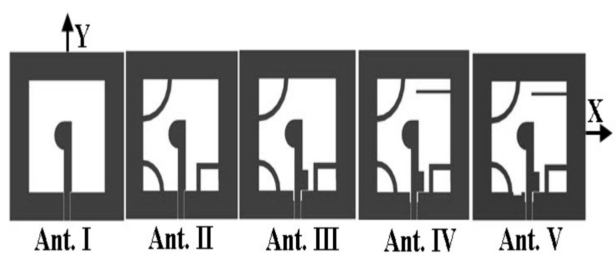
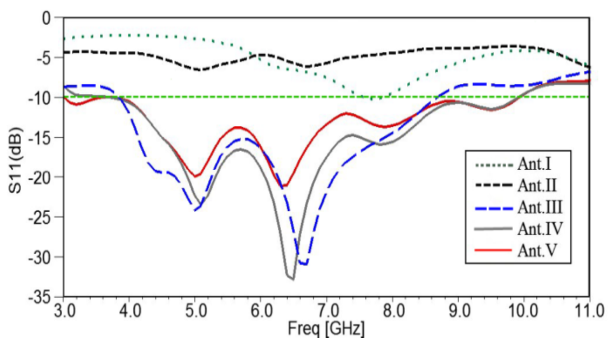
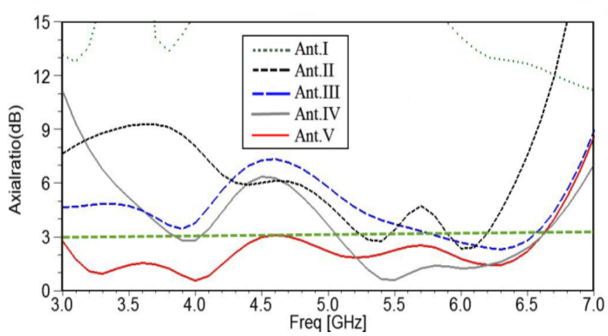


Fig. 2. Five improved prototypes of the proposed CPSS antenna.

Figure 3 (a) and (b) present the simulated frequency responses of 10 dB return loss and 3 dB axial ratio variations for the five designed prototypes of the proposed antenna. From Fig. 3 (b), it can be observed that Ant. I has a linear polarization. By embedding two arc-shaped and an inverted-L grounded strip around the corners of the square slot, the AR is greatly improved, which reaches 3 % (5.27 GHz–5.44 GHz) and 4 % (5.92 GHz–6.17 GHz) (Ant. II). Nevertheless, in this case the AR is not guaranteed by -10 dB return loss.



(a)



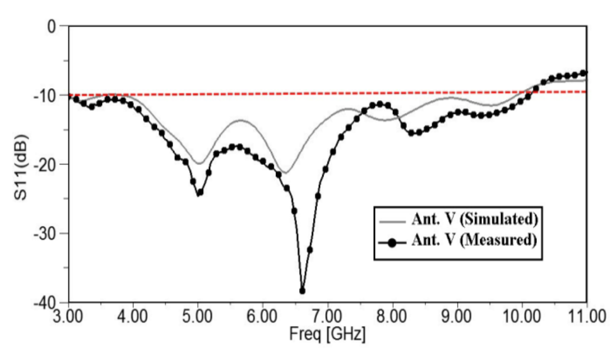
(b)

Fig. 3. Simulated (a) S_{11} and (b) AR for antennas I-V (for CPSS antennas with optimized values of the design parameters shown in Fig. 1).

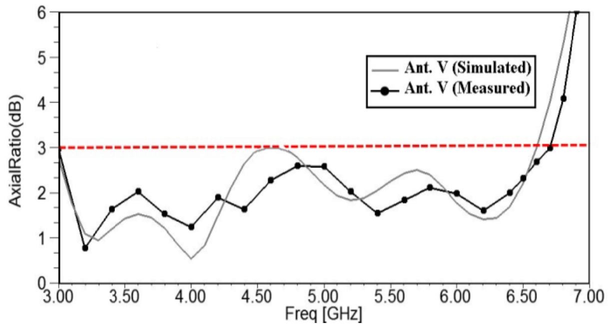
To improve the impedance matching, a vertical tuning stub is added to the feed structure and the gap of CPW feed is formed to a step shape. As shown in Fig. 3 (b), these structures (the embedding of vertical tuning stub to the feed line and widening the gap between the feed line and the ground plane) have great effect on the impedance bandwidth of Ant. II (called Ant. III). The 3 dB ARBW achieved for Ant. III is about 11 % (5.84 GHz – 6.53 GHz). By adding a horizontal strip at the top right corner of the ground plane the AR bandwidth will reach 26 % (5.07 GHz – 6.6 GHz), (Ant. IV). At last, by embedding the rectangular slit at the left side of the feed, not only AR bandwidth is increased to 75 % (3 GHz – 6.6 GHz) but also the impedance bandwidth can be increased to cover the whole CP bandwidth. The simulated results in Fig. 3 (a) indicate that including the horizontal strip and the rectangular slit, greatly influence the ARBW.

Figure 4 (a) and (b) indicate the measured and simulated return loss and AR characteristics for the proposed antenna. Close correspondence between the simulated and measured results is observed and the little difference between them is attributed to factors such as SMA connector effects, fabrication imperfections, and inappropriate quality of the microwave substrate. As also indicated in Fig. 4, the measured impedance bandwidth of the proposed antenna is from 3 GHz up to 10.1 GHz (3.33:1, 108 %) for VSWR < 2 and the measured 3 dB ARBW is extended from 3 GHz to 6.7 GHz (2.2:1, 76 %) that is about 3700 MHz. Considering the AR and the impedance bandwidth, it is clear that this proposed antenna is suitable for IEEE 802.11a, (5150–5350 MHz / 5725–5825 MHz) and for IEEE 802.16, (3200–3800 MHz / 5200–5800 MHz).

In Table 1 the impedance bandwidth and AR bandwidth of the proposed antenna (designed based on the ideas, which are presented in [1, 2, 6-11]) has been compared with prototypes in [1, 9, 10]. It is observed that the proposed antenna has wider AR bandwidth than the other ones. All these antennas were fabricated on an FR4 substrate with a loss tangent of tan (δ) = 0.024, permittivity of ε_r = 4.4. A photograph of the realized CPSSA antenna is shown in Fig. 5.



(a)



(b)

Fig. 4. Measured and simulated diagrams of (a) the return loss and (b) the axial ratio of the proposed antenna.

Table 1: Summary of the measured characteristics of some CPSS antennas, where f_c refers to the center frequency of the 3 dB AR bandwidth.

Ref.	Impedance Band (MHz)	f_c (MHz)	3 dB ARBW (MHz, %)
Ref. [1]	1600-3055	2665	2300-3030, 27.4%
Ref. [9]	2023-3421	2754	2075-3415, 48.8%
Ref. [10]	2674-13124	5969	4995-6945, 32.2%
Proposed antenna	3000-10100	4850	3000-6712, 76%

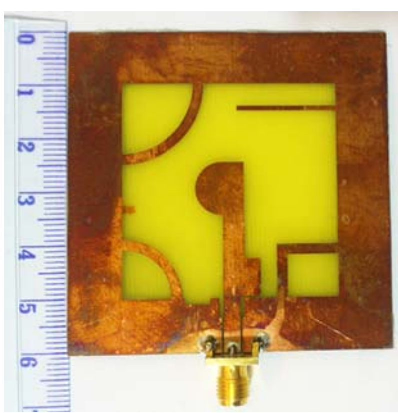


Fig. 5. Photograph of the realized CPSS antenna with standard SMA connector.

Figure 6 shows the surface current distributions of the proposed antenna at 4 GHz at the minimum point of the simulated AR for four different time instants, i.e., ωt = 0˚, 90˚, 180˚, and 270˚. It is observed that the current distribution in 180˚ and 270˚ are equal in magnitude and opposite in phase to that of 0˚ and 90˚. The proposed CP slot antenna is able to generate RHCP in the +z direction, whereas LHCP is produced in the –z direction.

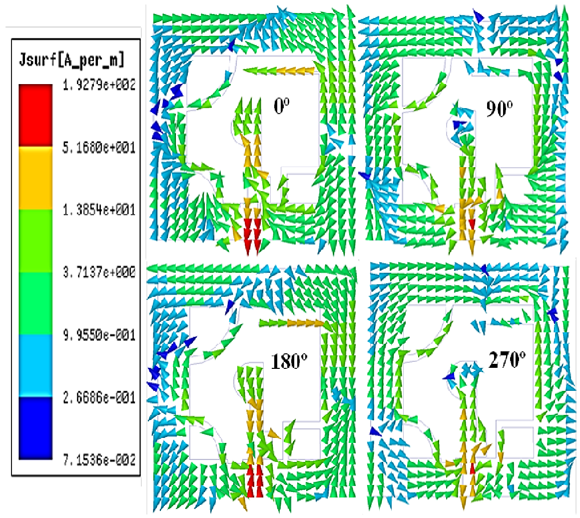


Fig. 6. Distribution of the surface current on the feed and ground of the proposed antenna at 4 GHz in 0˚, 90˚, 180˚, and 270˚ phases.

The simulated and measured gain in +z direction is plotted in Fig. 7. For measuring the gain of the fabricated antenna, one LP antenna is used in two orientations, the partial gains, G_{TV} and G_{TH} are combined to yield the total gain as in [11],

$$G_T = 10 \log (G_{TV} + G_{TH}) . \qquad (1)$$

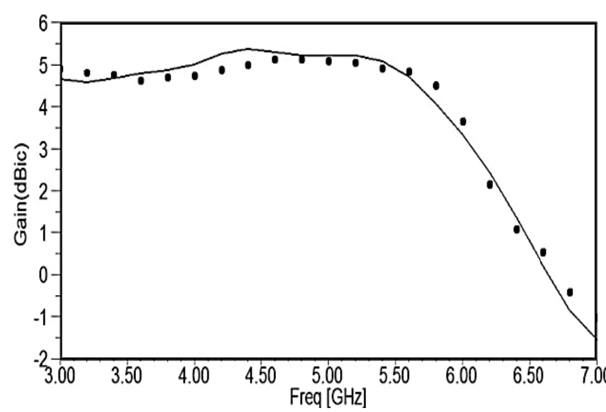


Fig. 7. Measured and simulated antenna gains in the +Z-direction.

Figure 8 shows the normalized radiation patterns of the proposed antenna simulated and measured at two sample frequencies of 4.2 GHz and 6.5 GHz. The results include RHCP and LHCP in the XZ and YZ planes.

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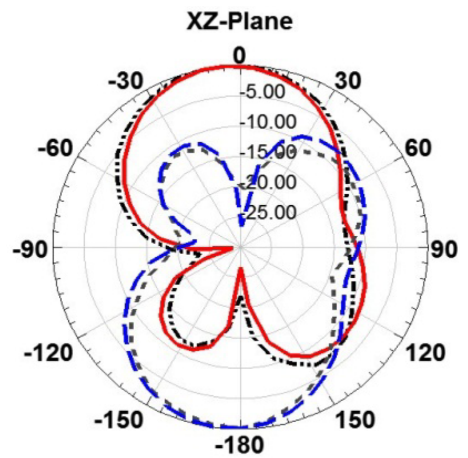
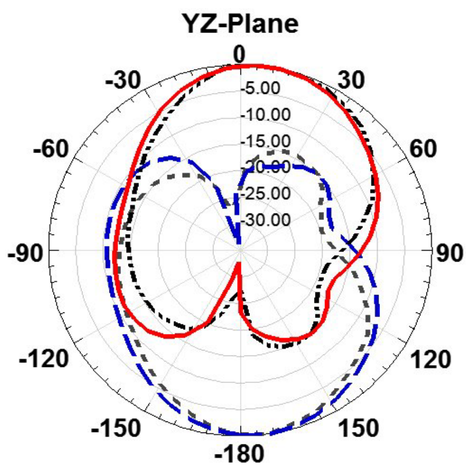
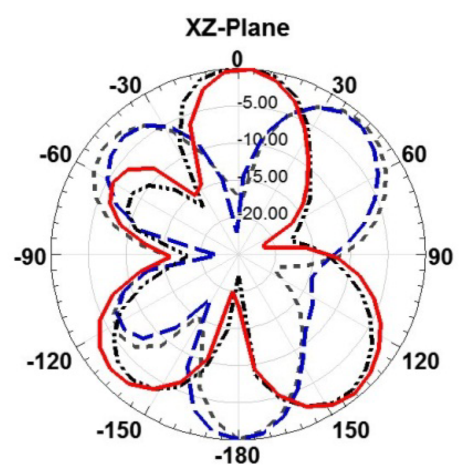
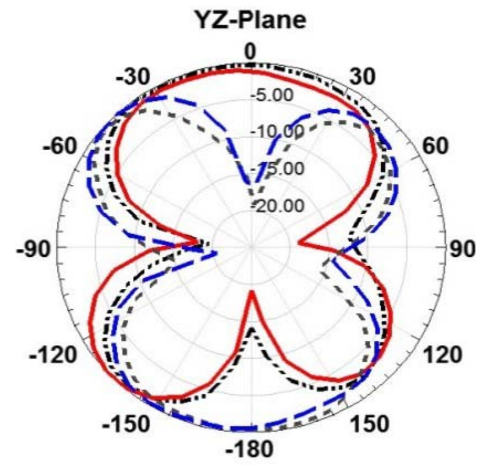




(a)





(b)

Simulated RHCP. Measured RHCP.
Simulated LHCP. Measured LHCP.

Fig. 8. Simulated and measured radiation patterns of the proposed antenna at (a) 4.2 GHz and (b) 6.5 GHz.

IV. CONCLUSION

A new wideband CPW-fed CPSSA has been proposed and implemented. By employing two arc-shaped and an inverted-L grounded strips CP radiation can be realized. The vertical tuning stub and step-shape gap between the feed line and the ground plane improved the impedance bandwidth. The horizontal grounded strip and the rectangular slit that are embedded in the left side of the feed line have effectively widened the 3 dB AR bandwidth apart from broadening impedance bandwidth. Experimental results show that the present proposed antenna has an impedance bandwidth of about 7 GHz (108 %) and a 3 dB AR bandwidth of about 3.7 GHz (76 %), which are greater than those obtained for similar designs. This antenna is suitable for IEEE 802.11a, (5150–5350 MHz / 5725–5825 MHz) and for IEEE 802.16, (3200–3800 MHz / 5200–5800 MHz).

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