Circularly Polarized Square Slot Antenna Using Crooked T-Shape Technique

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Abstract **─** This paper presents the investigation results on a novel circularly polarized square slot antenna (CPSSA) designed to operate at a frequency of 5.5 GHz. In order to realize the proposed antenna, miniature circular polarized square slot antenna is used with L-shape and crooked T-shape grounded strips located at the slots opposite corners to reduce cross-polarization. The antenna is fed by coplanar waveguide. The 3 dB axial-ratio of the CPSSA extends to approximately 2 GHz. The CPSSA was designed to operate over the frequency range between 3 and 11.1 GHz corresponding to an impedance bandwidth of 115% for VSWR<2. Acceptable agreement between the simulation and measured results validates the proposed design.

Index Terms **─** Circularly polarized, coplanar waveguide feed, planar antenna, slot antenna.

I. INTRODUCTION

Recently, circularly polarized planar patch antennas have gain more attention in the field of wireless communication. CPW-fed print slot antennas have many advantages, such as low profile, lightweight, ease of integration and wider impedance bandwidth; moreover, circularly polarized is much superior to linearly polarized duo to its agility of choosing polarization at the receiving locations and have good performance of anti-interference in bad weather [1-15]. For generating circular polarization (CP) radiation using a single feed, many microstrip antenna designs have been reported [1-9]. The obtained CP bandwidth (3-dB axial-ratio bandwidth), however, is usually narrow and less than 2%. When the same microwave substrate is used, corresponding printed slot antennas usually have a much wider CP bandwidth than single-feed circularly polarized microstrip antennas [2].

To benefit from broadband and low profiles, various shapes and designs of broadband circularly polarized slot antennas have been developed to overcome both the narrow impedance and axial-ratio bandwidths (ARBWs) by applying different techniques on patch and ground structures [2-4]. In [9], by embedding two inverted-L-shaped grounded strips around two opposite corners of slot, circular polarization is obtained. The idea of embedding a T-shaped grounded metallic strip that is perpendicular to the axial direction of the CPW feed line is used in [4], and a corrugated slot antenna with a meander line is presented in [10]. In [11], a square slot antenna with a lightning-shaped feed line and inverted-L grounded strips is presented. To produce the circular polarization, the arc-shaped grounded metallic strip is utilized in [12-13].

In this letter, a novel design of a CPW-fed

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circularly polarized square slot antenna composed of a square ground plane, an inverted-L-shape strips, two crooked T-strips and a vertical stub is presented. In this design, 3-dB AR bandwidth can reach as large as 2000 MHz (5-7 GHz) which is about 33.3%, to cover the WLAN/WiMAX band. The proposed design also has the VSWR≤2 impedance bandwidth of 8100 MHz (3-11.1 GHz) which is about 115%. Details of the proposed antenna design and experimental results of the broadband operation are presented. The proposed of this article is designed an ultra-wide band antenna with utilizing of novel methodology which can be provided broadband circular polarization. The simultaneous use of the crooked T-shape and L-shape techniques has readied the above conditions.

II. ANTENNA CONFIGURATION

The geometrical layout and photograph of the proposed CPW-fed broadband CPSS antenna is shown in Fig. 1. The proposed antenna is printed on a square microwave substrate FR4, with a side length of 25 mm, a thickness of 0.8 mm and a dielectric constant of relative permittivity ε_r=4.4. The antenna is fed by a 50 Ω CPW feeding line, where the signal strip and gaps have widths of 3.1 and 0.3 mm, respectively.

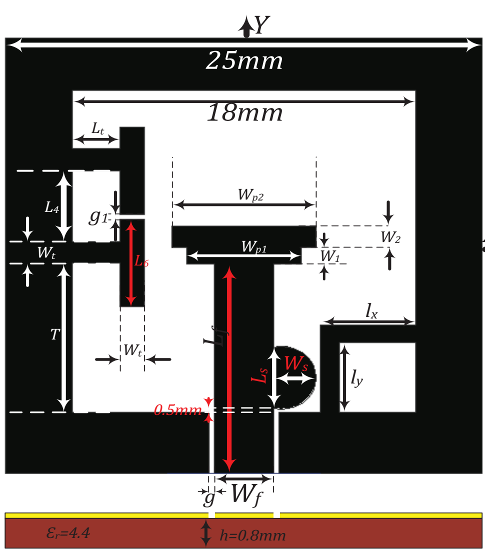

Fig. 1. Configuration of the proposed CPSSA structure. Dimensions of the structure's parameters are: W_f=3.1, L_f=8, g=0.3, h=0.8, W_t=1.25, W_{p1}=6, W_{p2}=7.6, L_s=3.5, W_s=3.5, g_1=0.4, L_4=4, W_1=1, W_2=1.2, L_t=2.5, l_x=5, l_y=4, L_6=4.5 (units in mm).

III. EXPERIMENTAL RESULTS AND DISCUSSION

The simulated CPSSA structures have been fabricated using conventional printed circuit board (PCB) techniques. In each step of the design procedure, the full-wave analyses of the proposed antenna were performed using Ansoft HFSS (ver.11) based on the finite element method (FEM) to find optimized parameters of the antenna structure [13].

As indicated in Fig. 2, five improved designs of the proposed CPSS antenna are presented. The antenna design is started by applying a simple strip feed line (step 1) and then improved through adding the vertical tuning stub formed by extending the feed section to the right (+y-direction) by a width of W_s=3.5mm and a length of L_s=3.5mm (step 2). Our simulations show that width (W_s) of the tuning stub has great effect on improving the impedance matching in the 3 dB AR band. A further improvement is achieved by adding two embedded rectangular strip patches with W_{p1}, W_{p2}, W_1 and W_2 dimensions (step 3). -10 dB impedance matching curves of the antenna are presented in Fig. 3. As it is observed from Fig. 3, by employing a simple strip as the feed line, a great impedance mismatch is experienced (step 1) and consequently, any bandwidth of the antenna under -10 dB is available.

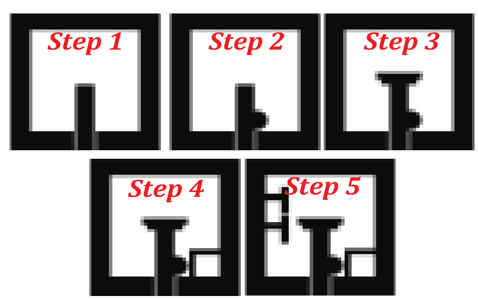

Fig. 2. Five improved prototypes of the antenna.

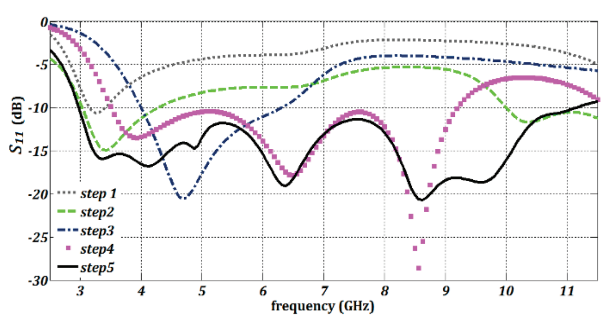

Fig. 3. Improved S_{11} of the antenna (step 1~5).

By adding the vertical tuning stub and two embedded rectangular strip patches on the feed line, antenna operates between 4~6.3 GHz. The simulation results show that embedding rectangular strip patches on the feed line (step 1 - step 5) and adjusting the parameters, an improvement on the impedance bandwidth as well as CP characteristic can be accomplished for the proposed antenna. To obtain CP operation by exciting two orthogonal polarizations, the design is improved by adding an inverted-L strip to the right bottom corner of the structure. This structure is presented as step 4 in Fig. 2. According to simulation results for step 4, we have found that choosing ly and lx of the inverted-L strips equal to 5 mm (0.275L), not only increases the ARBW but also improves impedance bandwidth. S_{11} variations of step 4 is presented in Fig. 3.

Considering the CP characteristic of the antenna, the changing regulation of the right hand side feed is similar to that of left hand side one. Through Fig. 4, it can be observed that by adding an inverted-L strip to the antenna structure, a small improvement in the axial ratio of the antenna is created and antenna operates CP about 2.6% (7.4~7.6 GHz). To further improve the CP characteristic of the antenna, two crooked T-shape strips are sequentially added to the structure (step 5). As it is seen from Fig. 3, adding two crooked T-shape strips to step 5 make the antenna operate UWB; and it can be seen in Fig. 4, that the ARBW of the antenna is increased to 5~7 GHz for step 5.

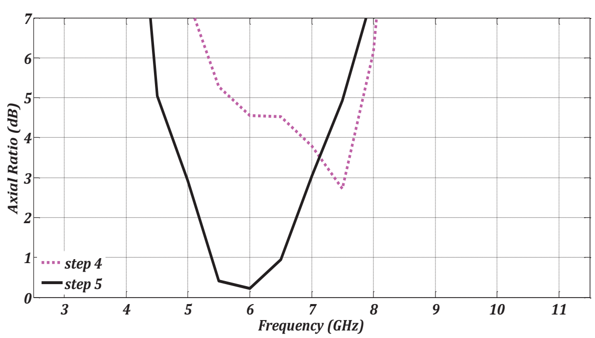

Fig. 4. Improved axial ratio of the antenna (step 4~5).

Through extensive simulations, it was found that length of the crooked T-shape strips (L_6) should be selected as 0.25L, and the distance between them (L_4) should be 0.22L, to attain the 33.3% ARBW. Changing the length or distance between these strips will degrade the axial ratio and subsequently CP characteristic of the antenna seriously. Considering Fig. 5, it is understood that increasing the distance of L_4 will decrease axial ratio bandwidth. The simulation results of surface current distribution for antenna in step 5 are shown in Fig. 6. As indicated in Fig. 6, the current distribution of proposed antenna at counterclockwise. It is observed that the surface current distribution in 180˚ and 270˚ are equaling magnitude and opposite in phase of 0˚ and 90˚. If the current rotates in the clockwise (CW) direction, the antenna can radiate the right-hand circular polarization (RHCP).

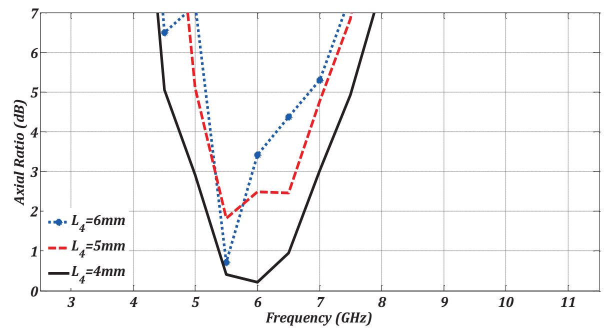

Fig. 5. Axial ratio for different value of L_4.

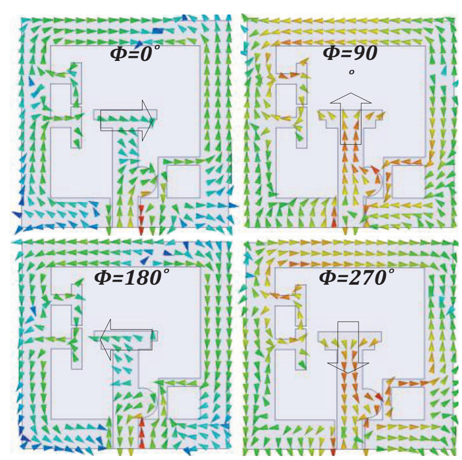

Fig. 6. Distribution of the surface current on the feed and ground of the CPSS antenna at 5.5 GHz in 0˚, 90˚, 180˚ and 270˚ phase.

An Agilent 8722ES vector network analyzer was used to measure S_{11} and impedance bandwidth for simplification in the antenna design. The simulated and measured S_{11} of the proposed antenna is shown in Fig. 7. As seen in Fig. 7, the simulated and measured impedance bandwidth of antenna are 115% (from 3 GHz to 11.1 GHz) and 119% (from 2.9 GHz to 11.5 GHz), respectively. The difference between measured and simulated impedance bandwidth are originating from different substrate specifications and fabricated problems.

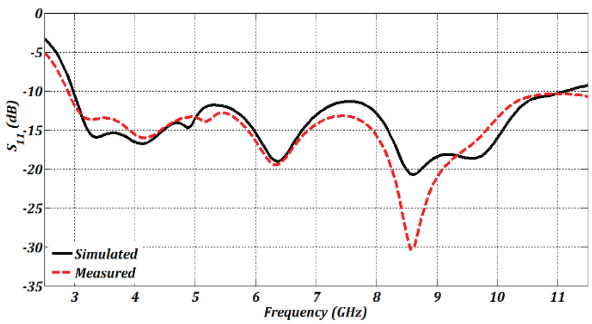

Fig. 7. Measured and simulated S_{11}.

Figure 8 indicated the close correspondence between the measured and simulated curves of gain and AR for the proposed antenna with optimized values presented in Fig. 1. As plotted in Fig. 8, the simulated ARBW of the suggested antenna is from 5000 MHz to 7000 MHz (33.3%), and the measured ARBW of antenna is from 5050 to 7100 (33.7%). Also, the measured peak gain of antenna is 4.25 dBic at 10 GHz. The average measured gain of the antenna is about 3.5 dBic.

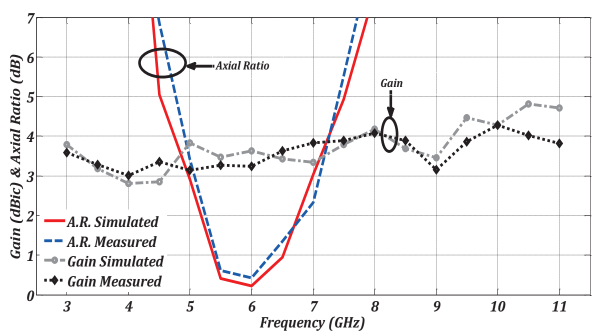

Fig. 8. Measured and simulated gain and axial ratio of the CPSSA.

The measured results of the normalized radiation patterns of the CPSS antenna are presented in Fig. 9. The radiation pattern is left-hand circular polarization (LHCP) for z>0 and RHCP for z<0, as can be deduced from surface current distributions in Fig. 6. The proposed antenna has a compact size of 25 mm × 25 mm. When compared with the previous CPSSA structures presented in Table 1, our proposed antenna shows significantly increased impedance bandwidth and axial-ratio bandwidth; i.e., the impedance and AR bandwidths are, respectively, more than three and two fold wider than the previous designs. Dielectric substrate used is FR4 with ε_r=4.4, tanδ=0.024. The impedance bandwidth is for a frequency range where the VSWR≤2; and ARBW is the 3-dB axial-ratio bandwidth.

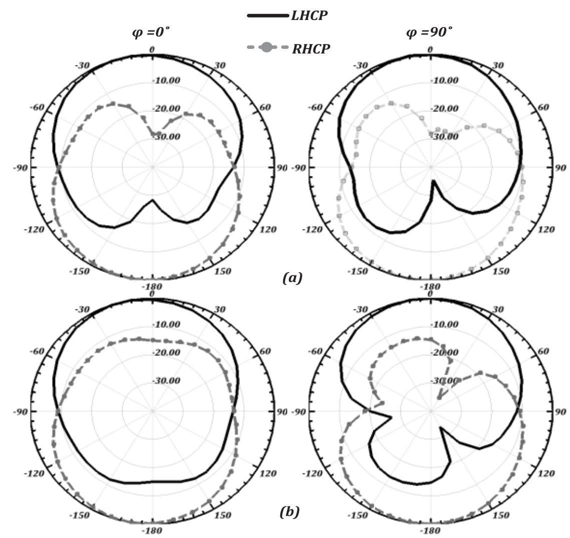

Fig. 9. Measured normalized radiation patterns of the CPSS proposed antenna at: (a) 5.5 GHz, and (b) 6 GHz.

Table 1: Comparison of the proposed CPSS antenna size and measured characteristics with other references

Ref.	Size (mm^3)	BW (GHz)	ARBW (freq. range) (GHz)	Peak Gain (dBic)
[3]	70×70×1.60	0.85 (1.75-2.6)	0.4 (1.7-2.1)	3.7
[4]	70×70×1.60	0.20 (1.5-1.7)	0.3 (1.5-1.8)	3.5
[5]	70×70×1.60	0.80 (1.6-2.4)	0.2 (1.8-2.0)	3.5
[14]	25×25×0.80	1.90 (4.6-6.5)	0.8 (4.9-5.7)	3.6
[15]	25×25×0.8	7.8 (3.1-10.9)	2 (4.5-6.5)	3.2
This work	25×25×0.80	8.6 (2.9-11.5)	2 (5-7)	4.25

The suggested antenna with optimal structure, as shown in Fig. 10, was fabricated and tested in the Antenna Measurement Laboratory at Iran Telecommunication Research Center (ITRC).

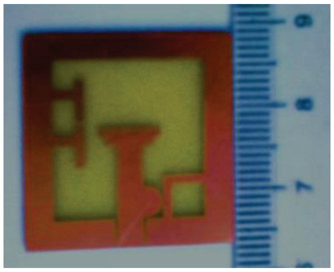

Fig. 10. Photograph of fabricated Antenna.

IV. CONCLUSION

This paper presents circularly polarized square slot antenna (CPSSA) fed by coplanar waveguide (CPW) with a crescent shaped patch. All of the important parameters that are determinant in antenna characteristics were depicted one by one while keeping the others fixed. The attributes of the proposed CPSSA include a relatively simple structure, low fabrication cost, and UWB operation across 3-11.1 GHz. The measured results show the impedance bandwidth is 115% for VSWR<2, and axial-ratio < 3 dB is 33.3%. An antenna gain of around 3.5 dBic has been obtained.

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