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A CORNER-FED SQUARE RING ANTENNA WITH AN L-SHAPED SLOT ON GROUND PLANE FOR GPS APPLICATION

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Abstract—This paper proposes a square ring patch antenna for GPS L_1 band application. The square ring patch located on the center of an FR4 substrate was truncated a square to guide two resonant modes. The dimensions of the truncated square located on the center of the patch controls the antenna's frequency band. Larger truncated square creates longer resonant path that decreases the resonant band. To achieve the CP radiation patterns, the corner-fed method and a truncated L-shaped slot on the ground plane are applied. After the size of the truncated L-shaped slot is optimized, the currents of E_θ and E_φ are around 90° shifts that make the antenna's AR lower than 3 dB. By switching the positions of the feed point and the L-shaped slot, both RHCP and LHCP can be obtained individually. Beside the CP operation, the proposed design also has advantages of planar structure, simple design, low cost, and good performances.

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1. INTRODUCTION

Recently, positional information derived from global positioning system (GPS) receivers has been employed in a number of applications ranging from land navigation, vehicle tracking [1, 2], personal communication [3], and emergency assistance [4]. To effectively reduce multipath interference and receive the GPS signals, circularly polarized (CP) radiation provides higher receiving power and better accuracy. In principle, the antennas for CP wave have to excite two perpendicular electric fields with equal magnitudes. Many types of antennas, such as loop [5, 6], fractal [7], slot [8, 9], and patch [10–12] for CP applications have been proposed previously. In [5], an L-shaped slot is embedded in the ground plane for CP characteristics and improving its impedance. The CP radiation proposed in [6] is achieved by two traveling wave modes. The Koch fractal antenna with corner-truncated structure used in [7] achieves the right-handed circular polarization (RHCP) radiation. In [8], CP radiation is obtained by truncating one of the corners of the antenna element. By introducing asymmetry ring slot structure and feeding the ring slot using a microstrip line at 45°, circular polarization radiation is introduced in [9]. In [10], CP operation is obtained by selecting an optimal size of the truncated corners. To produce broadside right-hand CP radiation in [11], the square-ring patch is with truncated corners of equal side length. In [12], the patch have four slots at the edges and a cross slot at the center to carry out the CP patterns. Based on the CP mechanisms described above, the popular and effective methods for CP radiation can be accomplished through truncated corner, asymmetry antenna structure or feeding point, and embedded slits in the ground plane, which all excite two perpendicular surface currents with equal magnitudes. In this design, a square ring patch antenna, which is an extended study of [13], is proposed for GPS L_1 band application. The square ring containing a truncated slot is used to extend the antenna's current path and decrease the resonances. The concept of decreasing resonant mode can be reviewed back to last century as in [14], which cut a rectangular slot to reduce antenna dimensions in about 33%. In [15], the resonant mode of the first iteration order (S_1) successfully decreases the operating frequency from 1.8 to 1.5 GHz by a truncated slot. To the CP radiation, the proposed design is achieved by fed at corner of the patch and a truncated L-shaped slot on ground plan. When the feeding point is placed at the right bottom corner and the L-shaped slot is truncated at the left bottom corner, right-handed circular polarization (RHCP) is produced. In addition, left-handed circular polarization (LHCP) can be formed by switching the locations of the feeding point and the L-shaped slot. The operating bandwidth based on the -10 dB S_{11} (1.55–1.59 GHz) and the 3 dB axial ratio (1.565–1.579 GHz) are all cover the GPS L_1 band at 1.575 GHz.

2. ANTENNA DESIGN

The geometry of the proposed GPS antenna, which is fabricated on an FR4 substrate with relative permittivity constant of 4.4, loss tangent of 0.0245, and thickness of 1.6 mm, is shown in Figure 1. On front side of the substrate, a square ring patch antenna, which uses to excite the GPS L_1 band and has a dimension $40 \times 40\,\text{mm}^2$, is printed on the center of the substrate. A $13 \times 13\,\text{mm}^2$ truncated square in center of the patch is etched to guide two perpendicular surface currents. The feeding point (point A) is located at the right bottom side of the patch for exciting the patch. The distances of point A to the edge of the substrate in X-axis and Y-axis are both 13.5 mm (D_1). The antenna's ground plane is fabricated on the back side of the substrate with dimension of $56 \times 56\,\text{mm}^2$. An L-shaped slot, which is beneath the left bottom side of the square ring patch, is etched on the ground plane for improving the antenna's axial ratio (AR). By optimizing the dimensions of the L-shaped slot, the AR within the L_1 band is lower than 3 dB. Note that the L-shaped slot to the edge of the substrate in X-axis is 9.5 mm (D_3) and in Y-axis is 11 mm (D_2). The right-handed circular polarization

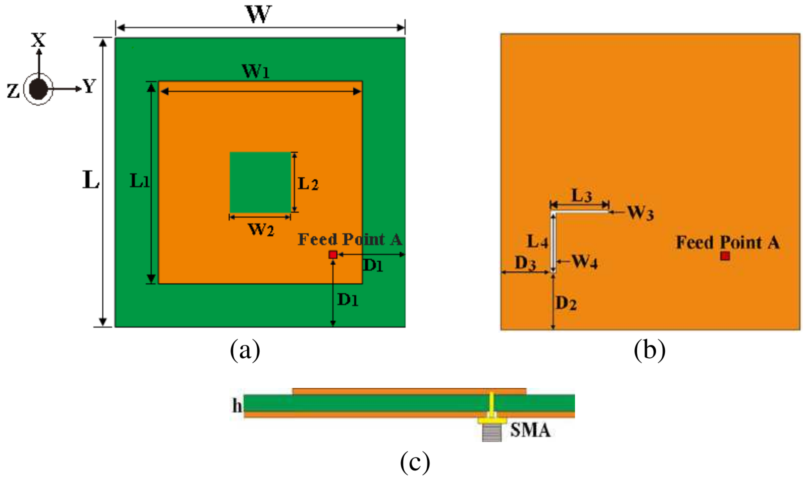


Figure 1. Geometry of the proposed GPS antenna, (a) front side, (b) back side, and (c) side view.

Table 1. Detailed parameters of the proposed antenna.

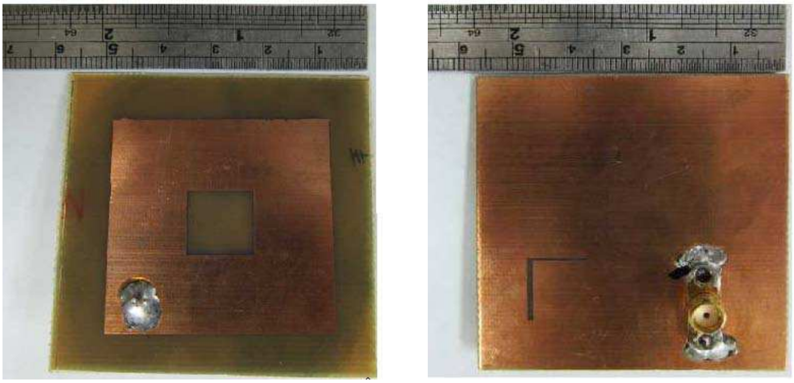
L	56	L_1	40	L_2	13	L_3	11.5	L_4	11.5
W	56	W_1	40	W_2	13	W_3	0.5	W_4	1
D_1	13.5	D_2	11	D_3	9.5	h	1.6	unit: mm	

(RHCP) radiation can be obtained by placing the feeding point at the right bottom corner and the L-shaped slot at the left bottom corner. On the other hand, left-handed circular polarization (LHCP) radiation is accomplished by switching the feeding point and the L-shaped slot to the opposite positions. The overall dimensions of $56 \times 56\,\text{mm}^2$ have advantages of planar and simple structures. The detailed parameters are listed in Table 1.

3. PARAMETRIC STUDY AND EXPERIMENTAL RESULTS

Based on the optimal dimensions listed in Table 1, a prototype of the proposed antenna was fabricated and measured. Figures 2(a) and 2(b) show photographs of the fabricated antenna on front and back sides, respectively. The measured and simulated S_{11} of the proposed antenna illustrated in Figure 3 were in good agreement, and the measured result based on the $-10\,\text{dB}$ S_{11} is from 1.55 to 1.59 GHz for GPS L_1 band application. The simulated results of this article were conducted using ANSYS HFSS simulation software. In Figure 4, the simulated S_{11} for different widths of W_2 and L_2 are plotted. The results indicate that larger truncated square ($W_2 \times L_2$) creates longer resonant path and shifts the resonant mode to lower band. When W_2 and L_2 are equal to 13 mm, the resonance meets the GPS L_1 band and the S_{11} reaches $-13.2\,\text{dB}$.

To demonstrate the 3 dB axial ratio (AR), the measured and simulated results shown in Figure 5 cover the GPS L_1 band and have good agreements. As mentioned above, the L-shaped slot controls the two perpendicular surface currents to process better AR. In Figures 6(a), 6(b), 6(c), and 6(d), the parameters of the L-shaped slot (L_3, W_3, L_4, and W_4) are adjusted to optimize the antenna's AR. From the results, when L_3, W_3, L_4, and W_4 are selected as 11.5 mm, 0.5 mm, 11.5 mm, and 1 mm, respectively, the currents of E_θ and E_φ have around 90° shifts that realize the optimal AR. To verify the radiation patterns of RHCP and LHCP, the time-varying



(a) (b)

Figure 2. Photographs of the fabricated antenna on (a) front side and (b) back side.

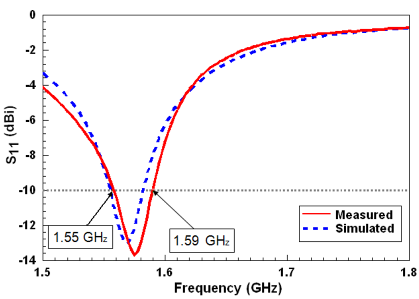


Figure 3. Measured and simulated S_{11} of the proposed antenna.

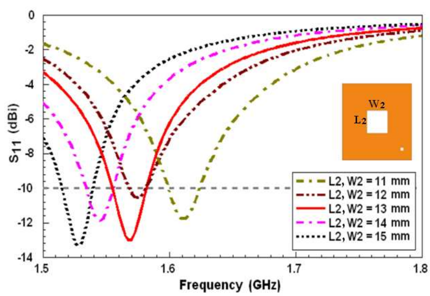


Figure 4. Simulated S_{11} for different lengths of W_2 and L_2.

surface current distributions for placing the feeding point at the right bottom corner and the L-shaped slot at the left bottom corner is shown in Figure 7(a). Figure 7(b) plots the time-varying surface current distributions of the feeding point placing at the left bottom corner and the L-shaped slot placing at the right bottom corner. The results indicate that the surface current distributions shift about 90° at each time period of T/4. Form the rotated and radiated directions, the results confirm that Figures 7(a) and 7(b) obtain RHCP and LHCP, respectively. Figure 8 shows measured and simulated Smith chart of the proposed antenna. The impedance locus having a small loop in the center indicates that two modes are excited at closer frequencies for CP operation.

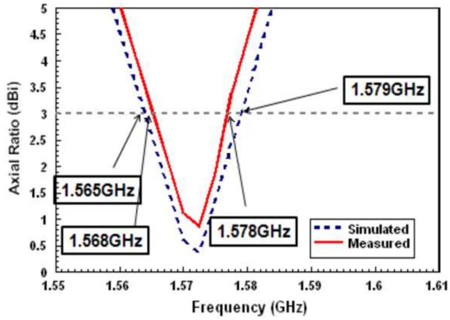


Figure 5. Measured and simulated AR of the proposed antenna.

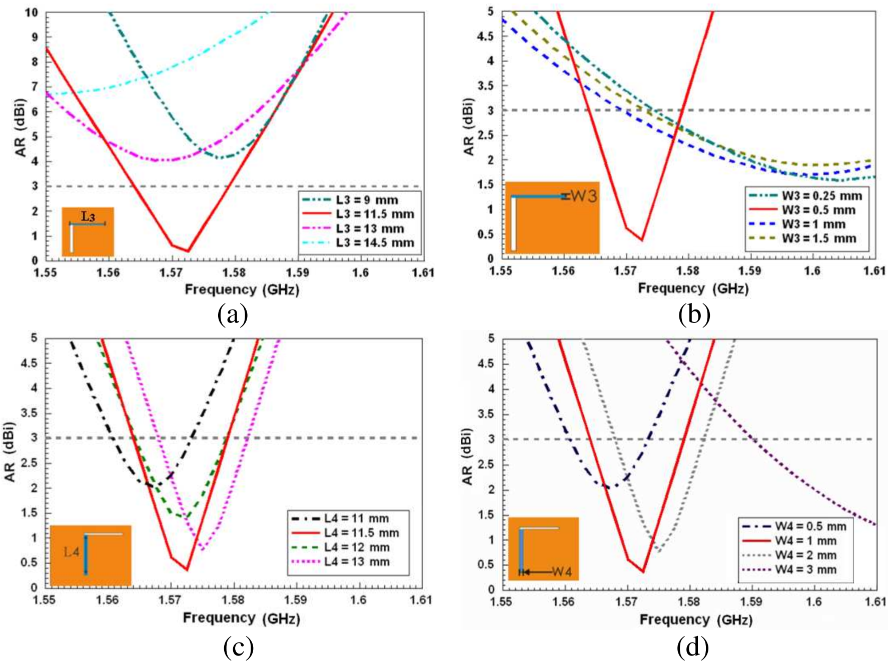


Figure 6. Simulated AR for varying parameters of the L-shaped slot (a) L_3, (b) W_3, (c) L_4, and (d) W_4.

The measured radiation patterns of the proposed antenna at 1.575 GHz are presented in Figure 9. Due to the L-shaped slot truncated on the ground plane, the patterns do not have higher directivity in $+Z$ direction. In addition, because the electric field on the vertical and horizontal segment is comparable, the magnitudes

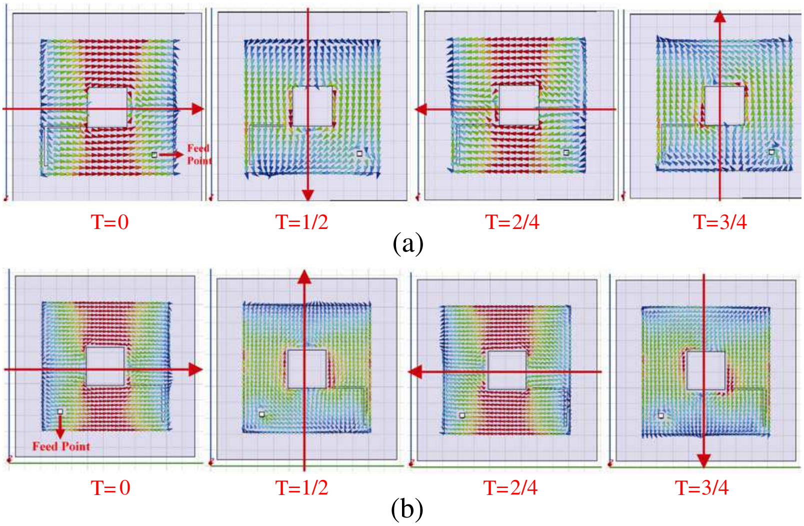


Figure 7. Time-varying surface current distributions of the proposed antenna for (a) RHCP and (b) LHCP.

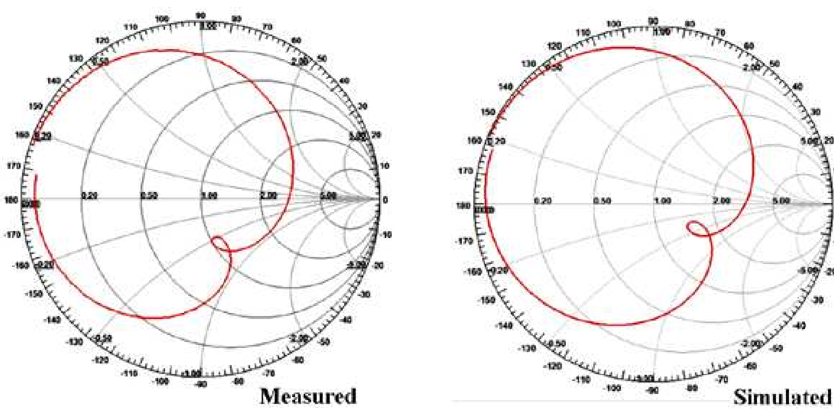


Figure 8. Measured and simulated Smith chart of the proposed antenna.

of the cross-polarized patterns are similar to that of the co-polarized patterns. Figures 10(a) and 10(b) present the measured and simulated antenna gain and efficiency of the proposed antenna at GPS L_1 band. At 1.575 GHz, the measured and simulated gains are around 1.9 and 1.95 dBi, while efficiency is about 26 and 31%, respectively. The results are similar to that of conventional microstrip antennas.

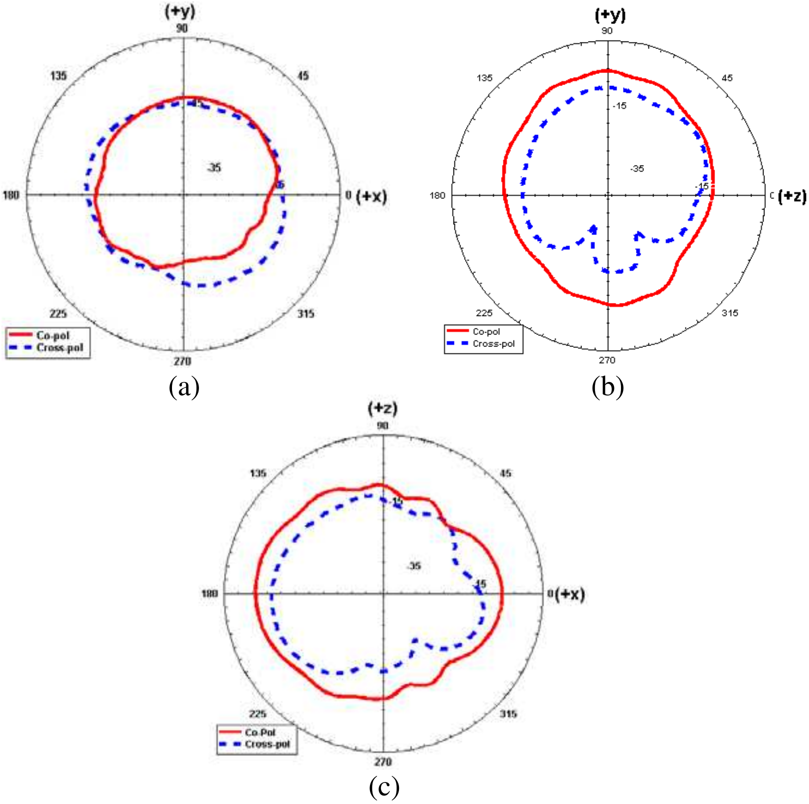


Figure 9. Measured radiation patterns of (a) X-Y, (b) Y-Z, and (c) X-Z plane at 1.575 GHz.

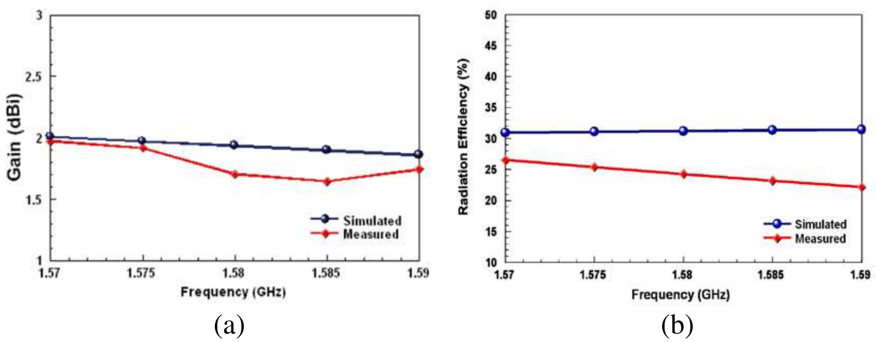


Figure 10. (a) Measured and simulated antenna gain and (b) measured and simulated radiation efficiency of the proposed antenna at 1.55 to 1.6 GHz.

4. CONCLUSIONS

A planar and simple square ring patch antenna for GPS L_1 band application is proposed and verified. The GPS L_1 resonant mode can be easily controlled by the size of truncated slot. Based on the -10 dB value of the measured S_{11}, the resonant band is from 1.55 to 1.59 GHz that covers the GPS L_1 band application. By optimizing the dimensions of the L-shaped slot, the AR below 3 dB is from 1.565 to 1.579 GHz that also meets the requirement of GPS L_1 band. Both the RHCP and LHCP can be obtained through switching the feed point and the truncated L-shaped slot. Beside the advantages of applicable resonant band, AR, and CP, the proposed antenna has a compact dimension of $56 \times 56\,\mathrm{mm}^2$ with a simple structure, low cost, and good performances.

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