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A Fan-Shaped Circularly Polarized Patch Antenna for UMTS Band

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Abstract—A simple microstrip circular disc antenna to excite circularly polarized radiation is presented. In a single-probe fed circular disc sector patch, the corners are further truncated to obtain circular polarization characteristics. The truncation helps to reduce the ground plane dimensions making the antenna more compact with overall dimensions of 50 mm × 50 mm × 1.6 mm. The lengths of truncation necessary to achieve circular polarization are mathematically expressed. The simulated and experimental results are compared and are found to be in good agreement. Axial ratio bandwidth of 1.3% is obtained. The overall size reduction is 55% in comparison with the original disc sector antenna. The antenna resonates in the UMTS 1900–2170 MHz band and can be employed for Mobile Communication applications.

1. INTRODUCTION

Circular polarization (CP) is suited for antennas used in mobile communication, due to their insensitivity to transmitter and receiver orientation [1]. CP operation can use single-feed and double-feed schemes. Single feed systems have the advantage of requiring no external polarizers or power divider networks as compared to double feed systems [2]. A widely used technique to achieve CP in single feed systems is to modify the antenna structure itself. This includes truncating the patch corners, using slits or protruding stubs close to the boundary of the patch and embedding a diagonal slot in the patch centre [3]. The technique of truncating the patch corners to obtain CP in single feed systems has been widely used in an equilateral triangular patch [4]. It has also been demonstrated that by using a specific fraction of the circular patch, i.e., a disk-sector microstrip patch with a fixed flare angle, CP radiation can be achieved using a single probe feed [5]. It is well known that the disc sector patch antenna has the advantage of being physically smaller at a fixed frequency, as compared to square or circular microstrip antennas. However, very few designs for achieving CP operation using disc sector shaped microstrip antennas are found in the literature, which motivated this study. In this work, the coaxial-probe fed circular disc sector patch in [5] hereinafter called the reference antenna, is truncated at its corners to attain a fan-shaped patch and subsequent circular polarization. It is seen that by suitably trimming the two corners, two orthogonal modes with equal amplitude and 90° phase difference can be excited. The length of truncation was parametrically varied and the optimum value was determined. The reference antenna required a very large ground plane and larger patch area. By making these corner truncations here, the ground plane size and the patch area can be decreased.

2. ANTENNA DESIGN AND SIMULATED RESULTS

Figure 1(a) shows the geometry of the proposed antenna. The substrate used is FR4 with $\varepsilon_r = 4.4$ and thickness $h = 1.6$ mm. The patch is printed on the top side of the substrate, and a ground plane of size

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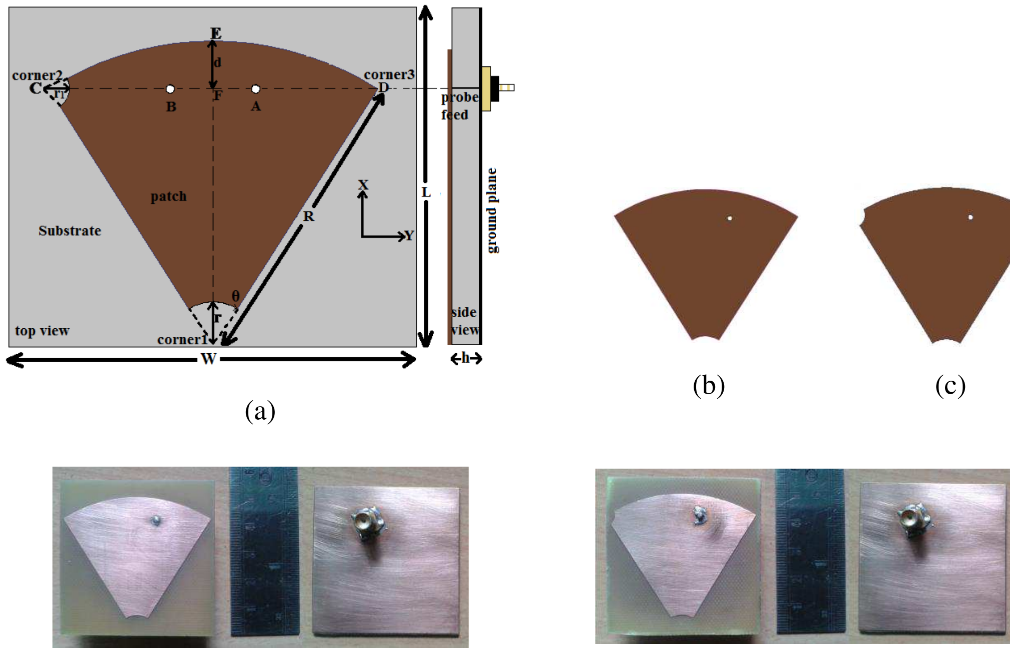


(a) (b) (c)

(d) (e)

Figure 1. Geometry of the proposed antennas. (a) Top view and side view of the proposed antenna structure. (b) Top view of the fan-shaped patch in Antenna 1. (c) Top view of the patch in Antenna 2. (d) Photograph of Antenna 1. (e) Photograph of Antenna 2.

$W \times L\,\text{mm}^2$ covers the bottom side. A sectoral portion of radius r mm truncated from the tip (corner 1) of the circular disc sector patch with radius R mm forms the basic patch shape and is denoted as Antenna 1. An additional truncation of radius r_1 mm from corner 2 gives rise to an alternate structure which is denoted as Antenna 2. The top view of the two patch structures are depicted in Figures 1(b) & 1(c). Both the structures are found to radiate circularly polarized waves with the excitation applied at the feed point A or B as in Figure 1(a). The coaxial-probe feed point A (x_p, y_p) is chosen along the locus of $50\,\Omega$ characteristic impedance and is adjusted for perfect matching to obtain the coordinates as $x_p = 37.4$ and $y_p = 6.2$. Conversely, point B, the mirror image of A with respect to the center of the disc, is the feed point to obtain the opposite sense of circular polarization. By truncating the sectoral portion r mm from corner 1, it is found that the ground plane size could be reduced to $50\,\text{mm} \times 50\,\text{mm}$ which is equal to 55% reduction in the overall antenna size in comparison with the reference antenna. Simulations are performed using Ansoft HFSS software.

In Antenna 1, with the feed applied at A, $R = 45\,\text{mm}$, $\theta = 65^\circ$ and $W = L = 50\,\text{mm}$, the parameter r is varied starting from 3 mm. It is observed that circularly polarized radiation is obtained when r becomes approximately equal to the length 'd' which is the perpendicular distance from the radial point E to the chord CD joining the corners 2 & 3 of the sector as in Figure 1(a). The value of d is measured in this case as 7 mm. The achievement of CP radiation at $r = 7\,\text{mm}$ is confirmed from the simulated axial ratio graphs shown in Figure 2, where the necessary criterion of axial ratio $< 3\,\text{dB}$ is satisfied. Fine adjustments are applied to r to get the best impedance matching. The best simulated results in terms of return loss and axial ratio are obtained when $r = 6.6\,\text{mm}$ and are shown in Figure 3(a) & Figure 3(b). This small difference might be due to the effect of the fringing fields at the truncated corner. Two near-degenerate orthogonal modes are excited here, which makes CP operation possible. The patch size reduction for $r = 6.6\,\text{mm}$ is 2.15%. The mathematical equations for the length of truncation r in terms of the radius and wavelength are deduced and expressed as follows.

$$R = 0.47\lambda_g, \quad r = 0.073\lambda_g, \quad R = 6.43r. \tag{1}$$

where λ_g is the guided wavelength corresponding to the lower operating frequency of the band.

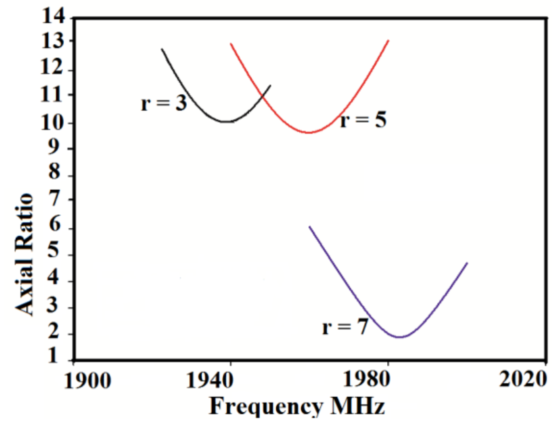


Figure 2. Simulated axial ratio characteristics of Antenna 1 for variation of the parameter r.

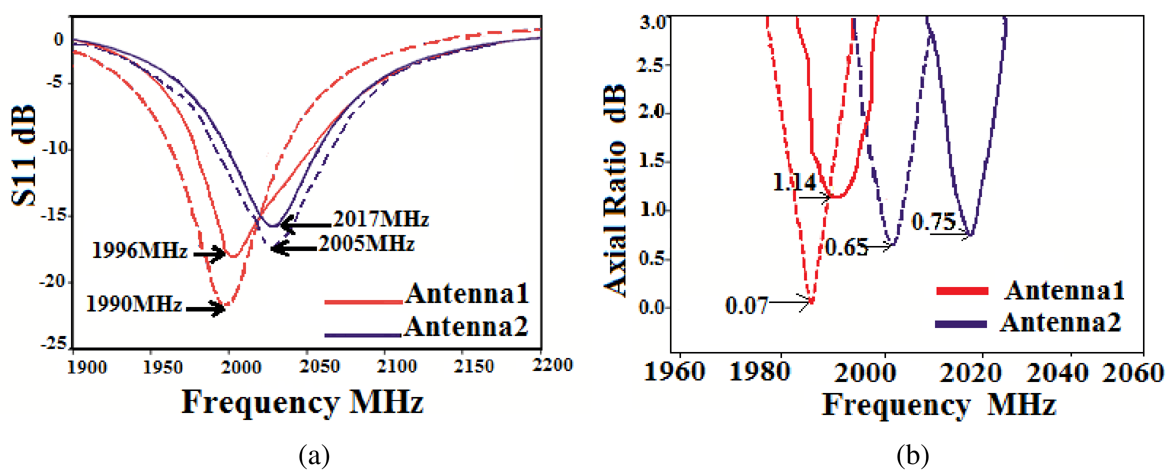


Figure 3. Simulated (dotted line) and measured (solid line) characteristics of Antenna 1 & Antenna 2 with $r = 6.6\,\text{mm}$, $r_1 = 3\,\text{mm}$. (a) S_{11} (10 dB return loss). (b) Axial ratio.

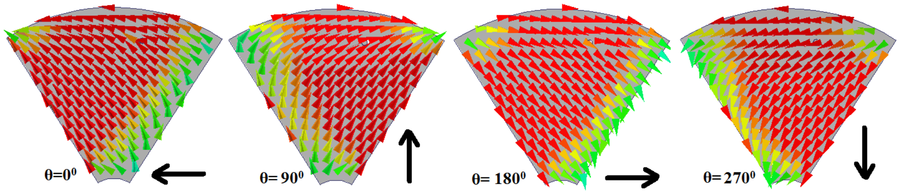
Keeping all other dimensions and the feed point the same as in Antenna 1, corner 2 is also truncated with a sectoral cut of radius $r_1 = 3\,\text{mm}$ to form Antenna 2. It is observed that CP radiation is still achieved but with a small reduction in total bandwidth (BW). Also the resonance frequency of Antenna 2 shifts towards the higher end of the band, which is expected, due to the reduction in patch size of 2.755%. The simulated return loss and axial ratio results for Antenna 2 are shown in Figures 3(a) and 3(b). Similar to Equation (1) the relations for r_1 can be expressed as

$$R = 0.47\lambda_g, \quad r_1 = 0.031\lambda_g, \quad R = 15.16r_1. \tag{2}$$

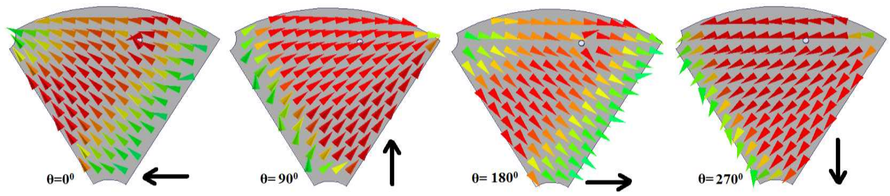
The mathematical relation between the two truncations is now expressed as

$$r = 2.35r_1 \tag{3}$$

The simulated current distributions on the patch in Antenna 1 and Antenna 2 are illustrated in Figure 4. It is obvious from the distributions that the dominant surface currents at 0° and 90° are equal in magnitude and opposite to those at 180° and 270° respectively. Thus the criterion of spatial and temporal quadrature for CP is satisfied [6]. As the direction of view chosen as $+Z$-axis, the rotation of current is clockwise and the sense of polarization is concluded as left hand circular polarization (LHCP). If the feed is applied at point B, it gives good right hand circular polarization (RHCP). The simulated Smith Chart in Figure 5 exhibits a dip at the two respective centre frequencies of Antenna 1 and Antenna 2 confirming the excitation of two resonant modes at two frequencies very close to each



(a)



(b)

Figure 4. Simulated current distribution on the patch at four different phase angles in (a) Antenna 1 at 1990 MHz; (b) Antenna 2 at 2005 MHz.

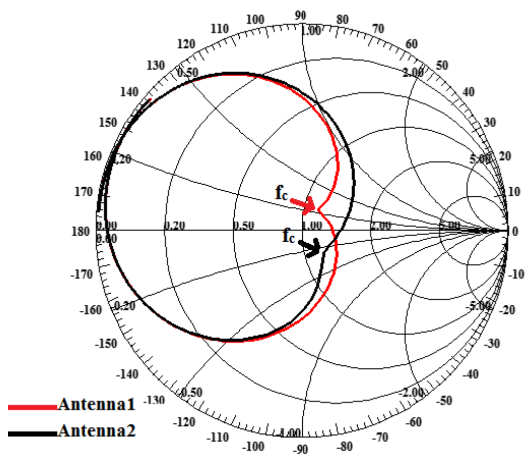


Figure 5. Smith chart of Antenna 1 and Antenna 2 (Simulated).

other, producing circular polarization [7]. This effect is in turn due to the slight difference in length of the excited patch surface currents in the x and y directions.

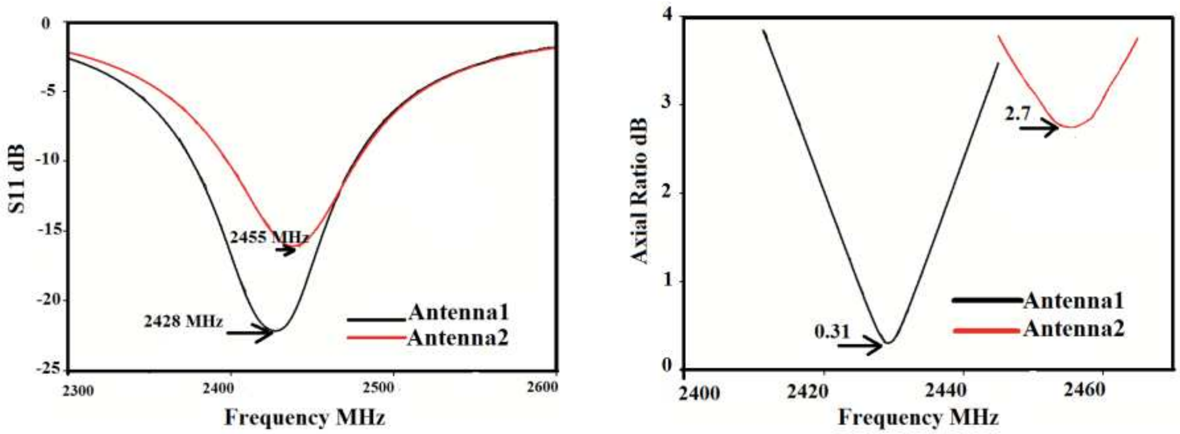
Truncations according to Equations (1) and (2) were applied to fan-shaped patches of different radii R and were found to yield CP characteristics. The calculated values of r and r_1 for two different frequencies are presented in Table 1. Simulations alone were performed for a frequency of 2.4 GHz also, with the calculated values of r and r_1 as in Table 1. Hence the validity of Equations (1)–(3) for all frequencies is asserted. The simulated results in terms of return loss and axial ratio are shown in Figure 6 for the Antenna 1 and Antenna 2 structures at frequency 2.4 GHz.

3. EXPERIMENTAL RESULTS

Prototypes of the two proposed structures Antenna 1 and Antenna 2 for the UMTS band were fabricated and tested using the PNA E8362B Vector Network Analyzer. Figures 1(d) & 1(e) show the photograph of the antennas in top and bottom views. The measured return loss for both the structures agree with the simulated ones as illustrated in Figure 3(a). Axial ratio (AR) and Axial Ratio Bandwidth (ARBW)

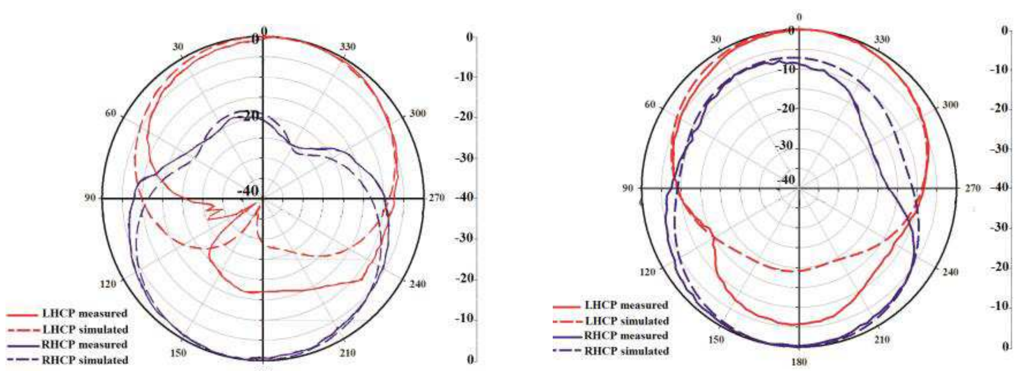
Table 1. Lengths of corner truncations at different frequencies.

Frequency (GHz)	r (mm)		r_1 (mm)	R (mm)
	Calculated ($= d$)	Optimised		
1.9	7	6.6	3	45
2.4	5.6	5.1	2.36	36.5



(a) (b)

Figure 6. Simulated characteristics at frequency 2.4 GHz. (a) Return loss. (b) Axial ratio.



(a) (b)

Figure 7. Simulated and measured radiation patterns in two orthogonal planes for Antenna 1 at $f_c = 1996$ MHz. (a) YZ plane. (b) XZ plane.

less than 3 dB have also been measured for the two structures. The measured minimum AR values are 1.14 and 0.75 respectively for Antenna 1 and Antenna 2 as shown in Figure 3(b). CP centre frequency f_c is defined as the frequency with minimum AR value. Table 2 shows the measured bandwidth and centre frequency values of the proposed structures in comparison with the reference antenna. The measured values of the proposed structures are very close to those of the reference antenna. The radiation patterns in two orthogonal planes at the respective f_c values in Table 2 were also measured for the two structures for both feed positions A and B. The simulated and measured radiation patterns at the two respective CP centre frequencies of the two structures are compared in Figure 7 and Figure 8, respectively. It is observed that the simulated and measured radiation patterns are in good agreement. The gain was measured for the two structures at their respective ARBWs and the gain plot is shown in Figure 9. The maximum gain obtained is 1.4 dBi for Antenna1 and 1.04 dBi for Antenna 2.

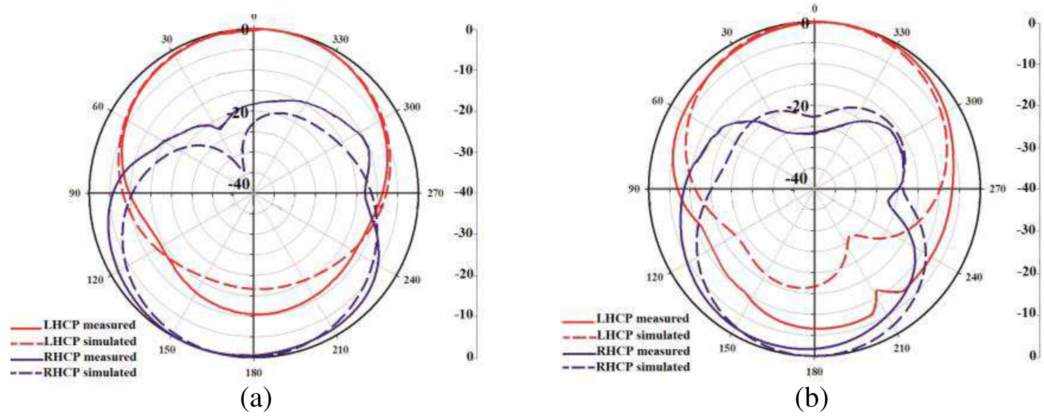


Figure 8. Simulated and measured radiation patterns in two orthogonal planes for Antenna 2 at $f_c = 2017\,\text{MHz}$.

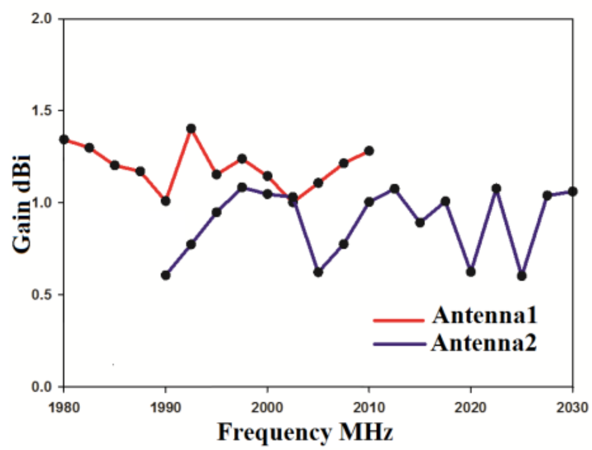


Figure 9. Measured gain plot of Antenna 1 and Antenna 2.

Table 2. Comparison of Measured values of the proposed antennas with the reference antenna.

	Antenna 1	Antenna 2	reference antenna
BW (MHz)	80	60	76
ARBW (MHz)	26 (1.3%)	20 (1%)	25 (1.3%)
f_c (MHz)	1996	2017	1944

4. CONCLUSION

A novel single-feed circularly polarised fan-shaped microstrip antenna has been proposed and experimentally investigated. By suitably truncating a small portion from the two corners of the sectoral patch, the excitation of two near-degenerate orthogonal modes for CP radiation is controlled. No external perturbation elements need to be introduced inside the patch. The size reduction for ground plane obtained is 55% while patch size is reduced by 2.755%. The structures can be made further compact by introducing suitably shaped slots on the patch. The CP bandwidth and centre frequencies remain within the UMTS band, which makes the antenna suitable for applications in that band.

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