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OPTIMIZATION OF THREE-DIMENTIONAL (3-D) GROUND STRUCTURE FOR IMPROVED CIRCULARLY POLARIZED MICROSTRIP ANTENNA BEAMWIDTH

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Abstract—A novel circularly polarised (CP), single-fed widebeam microstrip antenna is presented. The antenna consists of a corner-truncated square patch and a three dimensional circular ground structure. Simulated and measured results show that, owing to the ground structure, the 3 dB beamwidth of the CP radiation can reach more than 165°, which is about 85° greater than that of a corresponding regular microstrip antenna. It is also shown that experimental results were in good agreement with the simulated performance. Details of the proposed 3-D circular ground structure are described, and the effects of various dimensions of the proposed ground structure on the beamwidth enhancement of CP radiation are studied.

1. INTRODUCTION

For practical applications, microstrip antennas have a finite ground plane. Many theoretical studies of the finite ground plane effects on the microstrip antenna radiation characteristics have also been reported [1–12]. The available studies mainly work on linearly polarized microstrip antennas with a finite planar or two-dimensional ground plane [1–10]. A microstrip antenna with a three-dimensional (3-D) ground plane has also been analyzed [11, 12], but the improvement of the radiation beam width is not obvious. In this paper, we present a study of the beamwidth enhancement of a regular circularly polarized microstrip antenna mounted on a 3-D circular ground structure (see Figure 1). With the proposed ground structure, a regular circularly polarized microstrip antenna can have a 3 dB beamwidth of CP radiation larger

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than 165°, about 85° greater than a corresponding regular microstrip antenna and about 55° greater than the antenna investigated by [12]. With increased 3 dB beamwidth of CP radiation obtained, the microstrip antenna can have an increased coverage angle for practical applications. The effects of various dimensions of the proposed circular ground structure on the beamwidth enhancement and the antenna gain are analyzed by using Ansoft HFSS.

2. PROPOSED THREE-DIMENSIONAL GROUND STRUCTURE

Figure 1 shows the geometry of a regular circularly polarized microstrip antenna mounted on the proposed 3-D circular ground structure. The side lengths of the square patch and truncated corners are L and Δd, respectively, and the square patch is printed on a circular grounded microwave substrate of thickness h and of radius of r, relative permittivity ε_r. For the proposed ground structure, there are three sections within it: the upper circular substrate ground plane section with a radius of r_1, the middle truncated cone section with a upper radius of r_2, a lower radius of r_3 and a height of h_1, and the lower cavity ground section with a radius of r_4 and a flange of height h_2. The middle truncated cone section is hollow inside and is centered between the lower and upper ground sections. Through the hollow middle ground section, a coax feedline is used to feed the microstrip antenna. It is found that, with the regular microstrip antenna mounted on the proposed ground structure, the 3 dB beamwidth of the CP radiation

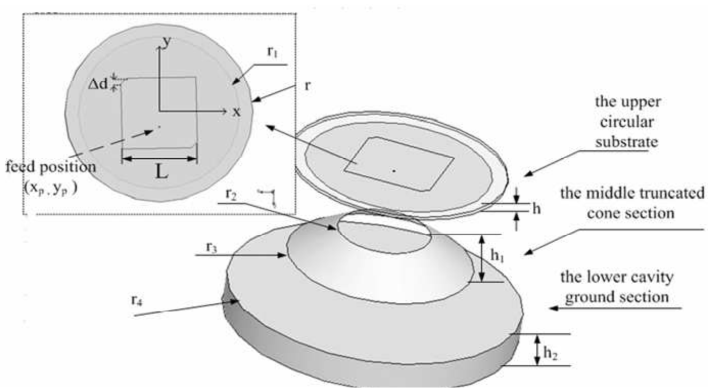

Figure 1. Geometry of a regular circularly polarized microstrip antenna mounted on the proposed 3-D circular ground structure.

can be significantly increased. Simulated results for various dimensions (r_1, r_2, r_3, r_4) of the ground structure on the beamwidth enhancement are given in the following section.

3. RESULTS AND DISCUSSION

In this study, the proposed antenna made of substrates ($h = 2.0$ mm $\varepsilon_r = 2.55$ loss tangent $= 0.001$) was first used. The side length of the corner-truncated square patch was selected to be $L = 56.3$ mm, and the truncated corners had a side length of $\Delta d = 4.65$ mm. With the feed position at $(xp, yp) = (0, -11\text{ mm})$, left-hand CP radiation was obtained with a CP bandwidth of about 1.3% referenced to the center frequency at 1616 MHz (the center frequency is defined to be the frequency with minimum axial ratio). At the center frequency, the 3 dB beamwidths in the x-z and y-z planes are 77° and 75°, respectively, and the antenna gain is 7.8 dBi for the case with the radius of the grounded substrate being 70 mm($r = r_1$). By mounting this regular microstrip antenna on the proposed ground structure with various dimensions of r_1, large variations in the 3 dB beamwidth of radiation are observed. Results of the simulated radiation patterns are plotted in Figure 2 for $r_1 = 40$ mm $\sim$ 65 mm, and the corresponding simulated data are given in Table 1 for comparison. First note that the external ground structure has negligible effects on the center frequency of the antenna, and it is seen that, with $r_1 = 60$ mm, the 3 dB beamwidth of CP radiation can reach 167° and 168° in the x-z and y-z planes,

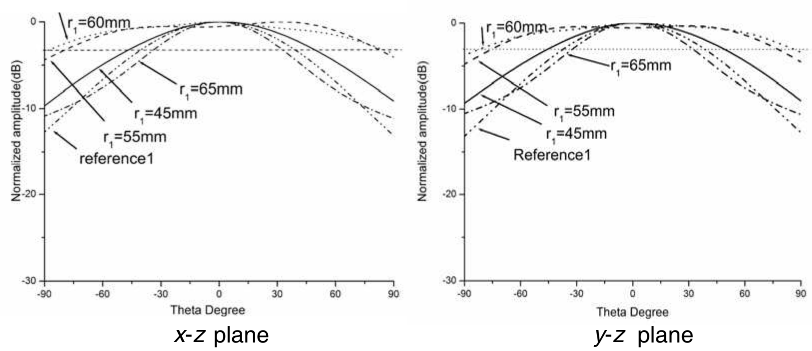

Figure 2. Simulated radiation patterns as a functions of r_1: $r = 70$ mm, $r_2 = 30$ mm, $r_3 = 60$ mm, $h_1 = 20$ mm, $r_4 = 95$ mm, $h_2 = 20$ mm, $r = 70$ mm, $L = 56.15$ mm, $\Delta d = 4.65$ mm, $(xp, yp) = (0, -11\text{ mm})$, $h = 2.0$ mm.

Table 1. Radiation characteristics as a function of r_1 for a regular circularly polarized microstrip antenna with the proposed 3-D circular ground structure; Reference [1] is the regular microstrip antenna without the proposed ground structure; Reference [2] is the regular microstrip antenna mounting on a square 3-D ground structure [12]; Antenna parameters are given in Figure 2.

Radius of substrate ground r_1 (mm)	Center frequency (MHz)	x-z planes 3 dB beamwidth (degree)	y-z planes 3 dB beamwidth (degree)	Antenna gain (dB)
40	1623	92	94	6.0
55	1621	156	152	2.92
60	1616	167	168	2.71
65	1612	63	64	8.0
Reference [1]	1616	77	75	7.8
Reference [2]	2323	112	112	4.5

respectively. However, the antenna gain is decreased from 7.8 to 2.7 dBi. This is largely due to the beamwidth broadening, which causes the decrease in the antenna's directivity and thus results in the decrease in the antenna gain. Also note that the ripples seen within the 3 dB beamwidth of the radiation patterns are mainly owing to the finite dimension r_1 of the circular ground plane.

Figure 3 and Table 2 show the results for the effects of various dimensions of r_2 on the beamwidth enhancement. In this case, r_1 is fixed to be 60 mm, with other parameters the same as in Figure 2. From the obtained results, it is determined that the optimal dimension of r_2 should be about 30 mm. Also note that, when using other dimensions of r_1, such as 55 mm, similar results are observed. It is observed that, to have more symmetric and wider beamwidth radiation patterns, the optimal dimension of r_3 should be about 60 mm (see the results given in Table 3 and Figure 4). The height of the truncated cone and flange height of cavity ground (h_1 and h_2, respectively) have a strong effect on antenna polarization axial ratio and VSWR. For convenience, h_1 was chosen to be equal to h_2 and was fixed to be 20 mm, that is $h_1 = h_2 = 20$ mm. Table 4 gives the results for various radii (r_4) of the lower cavity ground section. It is shown that the optimal dimension of r_4 should be about 95 mm.

Finally, to check the correctness of the proposed circular ground structure on beamwidth enhancement of CP radiation, a prototype of regular circularly polarized microstrip antenna was also constructed, and was mounted on the proposed circular ground structure with the same dimensions as in Figure 2. Figure 6 presents the measured radiation patterns for the cases with and without the proposed

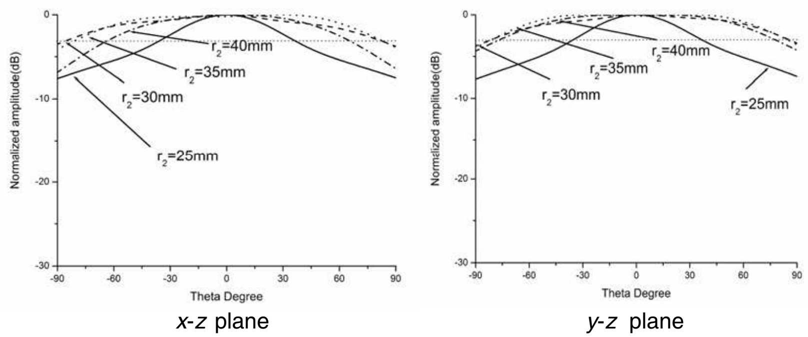

Figure 3. Simulated radiation patterns as a functions of r_2 : $r_1 :=$ 60 mm, other parameters are the same as in Figure 2.

Table 2. Radiation characteristics as a function of r_2, $r_1 = 60$ mm; Other parameters are given in Figure 2.

upper radius of truncated cone r_2 (mm)	Center frequency (MHz)	x-z planes 3 dB beamwidth (degree)	y-z planes 3 dB beamwidth (degree)	Antenna gain (dB)
25	1611	71	72	6.0
30	1616	167	168	2.71
35	1621	162	167	2.94
40	1612	128	155	3.10

Table 3. Radiation characteristics as a function of r_3, $r_1 = 60$ mm; Other parameters are given in Figure 2.

Lower radius of cone r_3 (mm)	Center frequency (MHz)	x-z planes 3 dB beamwidth (degree)	y-z planes 3 dB beamwidth (degree)	Antenna gain (dB)
50	1614	67	67	7.0
60	1616	167	168	2.71
70	1612	166	151	2.91

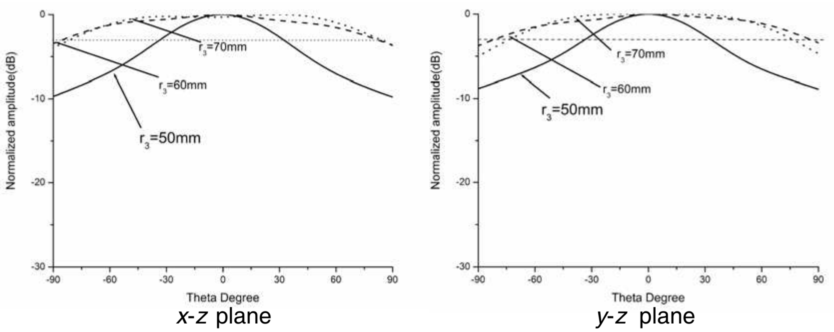

Figure 4. Simulated radiation patterns as a functions of r_3 : $r_1 :=$ 60 mm, other parameters are the same as in Figure 2.

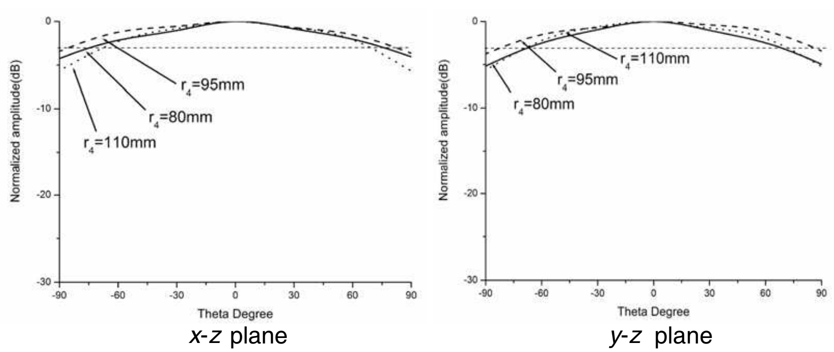

Figure 5. Simulated radiation patterns as a functions of r_4 : $r_1 :=$ 60 mm, other parameters are the same as in Figure 2.

Table 4. Radiation characteristics as a function of r_4, $r_1 = 60$ mm; Other parameters are given in Figure 2.

Radius of cavity ground r_4 (mm)	Center frequency (MHz)	x-z planes 3 dB beamwidth (degree)	y-z planes 3 dB beamwidth (degree)	Antenna gain (dB)
80	1614 MHz	151	125	3.6
95	1616 MHz	167	168	2.71
110	1613 MHz	137	140	3.43

circular ground structure ($r_1 = 60$ mm and 70 mm, respectively; other parameters are the same as in Figure 2). Figure 7 shows photographs of the fabricated antenna. Symmetric and wide beamwidth radiation patterns for the prototype antenna are obtained. The axial ratio in x-z and y-z planes are both less than 6 dB between $-80°$ and $80°$. Measured results were in good agreement with the simulated performance. The 3 dB beamwidths in the x-z and y-z planes are $167°$ and $167°$, respectively, which is about $85°$ greater than a corresponding regular microstrip antenna. About a $55°$ increase in the 3 dB beamwidth of CP radiation is obtained by comparing the antenna mounting on a 3-D square ground structure [12].

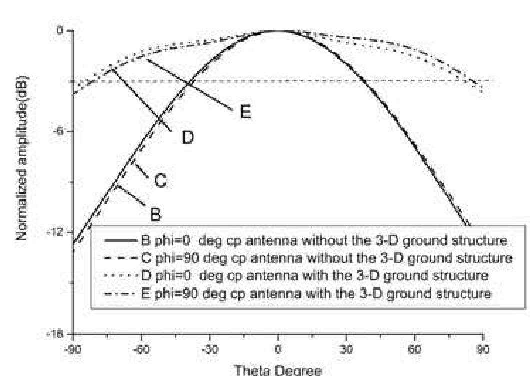

Figure 6. Measured radiation patterns for a regular microstrip antenna and the regular microstrip antenna with the proposed circular ground structure.

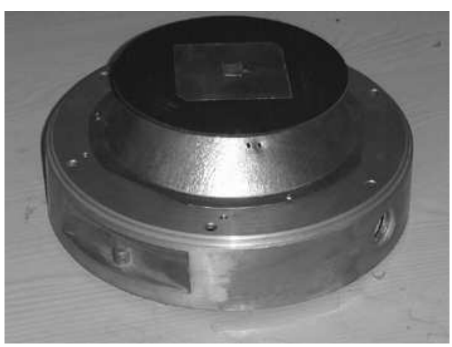

Figure 7. Photograph of the proposed antenna with the proposed circular ground structure.

4. CONCLUSION

A three-dimensional circular ground structure for beamwidth enhancement of a regular circularly polarized microstrip antenna has been demonstrated. The effects of various dimensions of the proposed circular ground structure on the beamwidth enhancement of CP radiation have been analyzed. The decrease in the antenna gain due to the beamwidth enhancement is also measured and presented. Experimental results were in good agreement with the simulated performance. Results indicate that the proposed circular ground structure can effectively enhance the 3 dB beamwidth of CP radiation of a regular microstrip antenna.

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