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THE EFFECT OF GROUND PLANE ON THE PERFORMANCE OF A SQUARE LOOP CPW-FED PRINTED ANTENNA

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Abstract—The effect of shaping the ground plane on the performance of a square loop coplanar waveguide (CPW)-fed printed antenna is reported in this paper. Experimental results are presented on the reflection coefficient and radiation pattern of the investigated antennas. Simulation results are presented on the current distribution, input impedance and gain. It is observed based on the results that shaping the ground plane significantly affects the reflection coefficients, input impedances and current distributions.

1. INTRODUCTION

Printed antennas have been a popular research topic since the last decade. This is due to their major advantages such as low profile, ease of manufacture, low cost and light weight. As the printed antenna performance is well known to be dependent on the ground plane, this aspect has been actively researched [1–8]. Radiation from the ground plane is inevitable as the electric currents are distributed on both the radiator and on the ground plane. Chen, See and Qing reported in [1] that by cutting a notch from the radiator, it would be possible to reduce the ground-plane effect on the performance of a small printed UWB antenna. In another effort, a microstrip-fed printed rectangular monopole antenna has been examined by introducing asymmetrical feed-line and a windowed ground plane, with the intention to reduce the ground-plane-dependent effects [2]. Antennas with windowed ground

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plane [2, 9–12] and modified ground [13–19] have been designed for various purposes. A half cut disc CPW-fed printed antenna, with a portion of the ground plane cut, has been investigated in [13]. Another antenna with V-shaped ground has been designed for RFID readers [14].

In this paper, a study is conducted to investigate the performance of square loop CPW-fed printed antenna when its ground plane is gradually cut. The objective being so, no optimization or size reduction was attempted. Characteristics of the antenna with gradually cut ground plane that include reflection coefficient, current distribution, input impedance, radiation pattern and gain are studied and discussed.

2. ANTENNA DESIGN

Figure 1 shows the initial design of the square loop CPW-fed printed antenna. The antenna is printed on a Rogers 4350B dielectric substrate of thickness 1.524 mm and relative permittivity of 3.48. A CPW transmission line with a signal strip width (F) of 3.6 mm and gap width between the ground plane and signal strip (g) of 0.3 mm is used to feed the antenna. It is seen through simulation that this dimension results in a 50 Ω input impedance. The prototype of the antenna is fabricated using photolithographic printing circuit technology following the parameters given in Table 1. The ground plane of the antenna has been studied for various angles θ of 44.8° (degrees), 61.5°, 76.9° to 90° as shown in Figure 2.

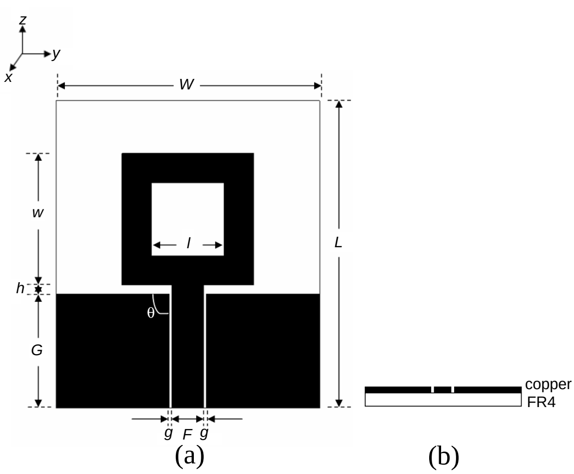

Figure 1. Structure of the orignal antenna (Antenna 1): (a) Top view and (b) side view.

Table 1. Dimensions of Antenna 1.

Parameter	W	L	G	h	w	l	F	g	θ
Value (mm)	30	35	13	1	15	8.3	3.6	0.3	90 degrees

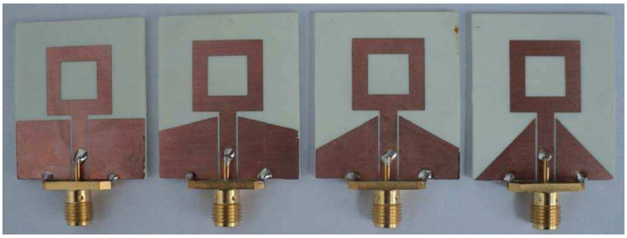

Figure 2. Prototypes of Antenna 1 to Antenna 4 (from left to right).

3. RESULTS AND DISCUSSIONS

3.1. Current Distributions

In order to understand the radiation behavior, the current distribution of the two designs (Antennas 1 and 4) at the resonating frequencies was simulated by using commercial software package CST Microwave Studio, as illustrated in Figures 3 and 4. It is obvious from Figure 3 that at both operating frequencies, there is a reasonably strong distribution of currents at the top and side edges of the ground plane. This observation, incidentally, provides support to the fact that the ground plane affects the antenna performance. Based on the current distribution, the top edges of the ground plane are cut, whereas the side edges are retained in their original form in order to maintain the $50\,\Omega$ input impedance. For comparison, Figure 4 shows the surface current distribution of Antenna 4, in which the top edges of the ground plane have been cut. It can also be observed that current is essentially distributed at the side edges of the ground plane and only insignificantly at the slanted edges at 3.38 GHz. The current distribution at 6.68 GHz of Antenna 4 shows that very minimum currents are concentrated at the slanted edges. The top edges of the ground plane contribute significantly at high frequency mode. It is therefore the reflection coefficient of the higher resonant frequency worsens (Figure 5) with the removal of top edges of the antenna ground plane. It emerges from the current distribution study that the ground plane acts as an active part of the antenna [8].

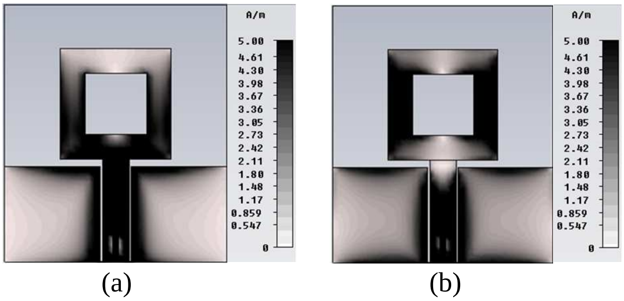

Figure 3. Simulated surface current distributions of Antenna 1 at (a) 4.48 GHz and (b) 6.58 GHz.

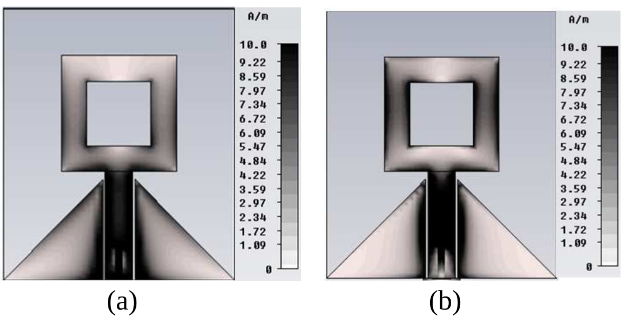

Figure 4. Simulated surface current distributions of Antenna 4 at (a) 3.38 GHz and (b) 6.68 GHz.

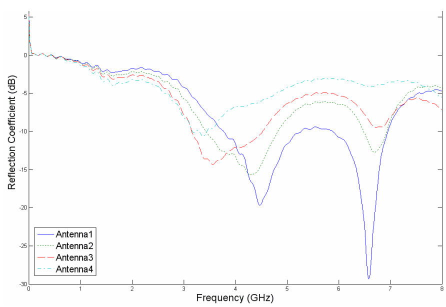

Figure 5. Measured reflection coefficients against frequency.

3.2. Reflection Coefficients

The reflection coefficient magnitude of the antenna configurations was measured using an Agilent 8757D Scalar Network Analyzer. The

Table 2. Resonant frequencies comparison between the four antennas.

Antenna	**1st**		**2nd**	
	Resonant frequency (GHz)	Reflection coefficient magnitude (dB)	Resonant frequency (GHz)	Reflection coefficient magnitude (dB)
Antenna 1	4.48	−19.68	6.58	−29.32
Antenna 2	4.28	−15.71	6.68	−12.74
Antenna 3	3.56	−14.31	6.72	−9.454
Antenna 4	3.38	−10.67	-	-

measured results show that for the original design (Antenna 1 in Figure 2), the antenna resonates at two frequencies – 4.48 GHz and 6.58 GHz. When the ground plane is slightly shaped (Antenna 2 in Figure 2), the first resonant frequency decreases to 4.28 GHz and the second resonant frequency slightly increases by 0.1 GHz, with reflection coefficient worsening. When the ground plane is further removed (Antenna 3 in Figure 2), the first resonant frequency decreases to 3.56 GHz and second resonant frequency does not increase much but to 6.72 GHz. Antenna 4 is the antenna where a large portion of the ground plane is removed as shown in Figure 2. The antenna resonates at only one frequency (reflection coefficient ≤ -9.5 dB), which is at 3.38 GHz. It can be seen that the bandwidth is lost for a small ground plane. The operating bandwidth of the square loop CPW-fed printed antenna decreasing with decreasing ground-plane size proves that impedance matching is very sensitive to the ground plane. Table 2 shows a comparison of the resonant frequencies between the four antennas (Antenna 1 to Antenna 4). It could be observed from the current distributions that at the radiating frequencies, the currents are concentrated at the top edges and side edges of the ground plane, besides the radiating square loop. When the top edges are removed, the impedance changes. Thus, top edge of the ground plane is clearly critical to the resonant modes.

3.3. Input Impedances

The input impedances of Antennas 1 and 4 have been obtained through simulation. As shown in Figure 6, Antenna 1 has flatter input resistance at lower frequency band compared to Antenna 4. It could be observed, as should be expected, that the two resonant frequencies of Antennas 1 and 4 occur when the reactance of the antenna is zero.

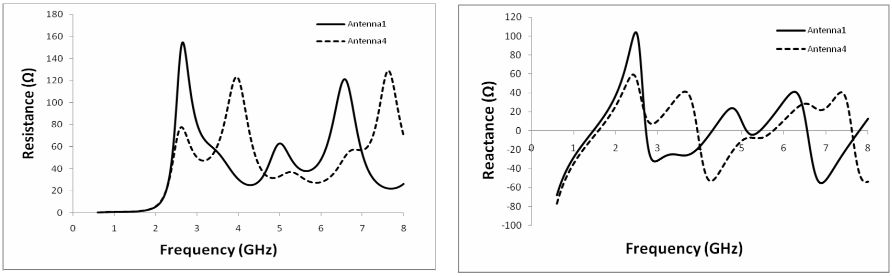

Figure 6. Resistance and reactance of the input impedances for Antennas 1 and 4.

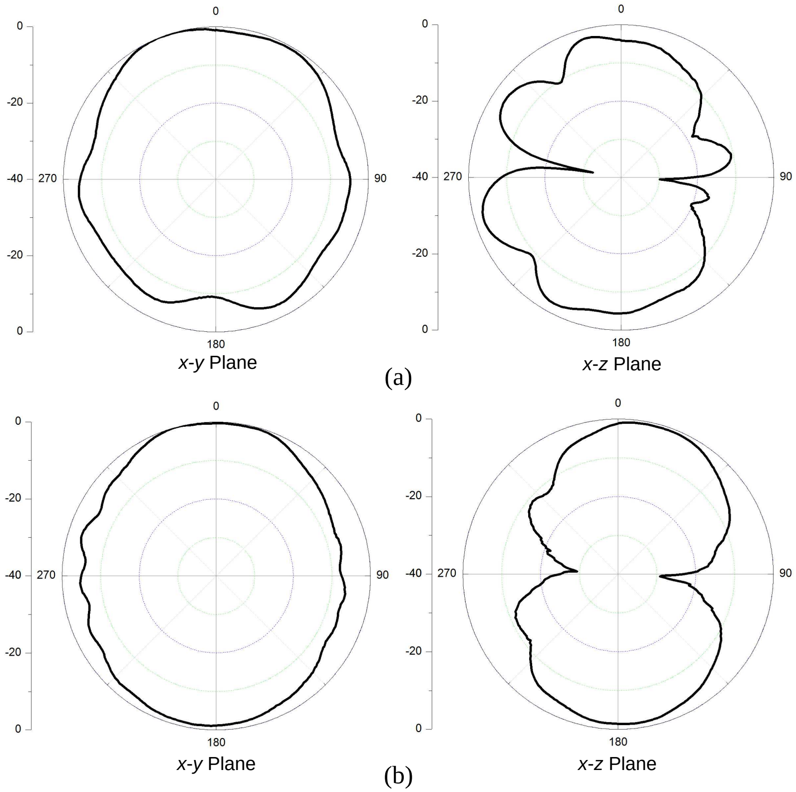

Figure 7. Measured radiation patterns of Antenna 1 at (a) 4.48 GHz and (b) 6.58 GHz.

3.4. Radiation Patterns

The measured radiation patterns of Antenna 1 at 4.48 GHz and 6.58 GHz and Antenna 4 at 3.38 GHz are illustrated in Figures 7 and 8,

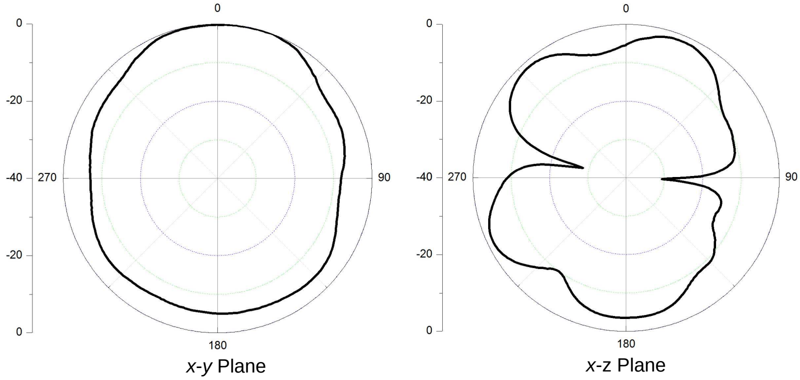

Figure 8. Measured radiation patterns of Antenna 4 at 3.38 GHz.

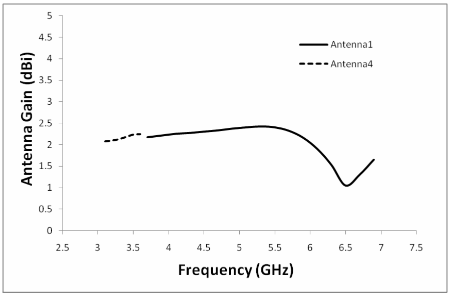

Figure 9. Simulated boresight gain of Antennas 1 and 4.

respectively. It is noticed that the x-y plane pattern for both antennas in all the cases is close to omni-directional. The antennas exhibit a traditional dipole antenna pattern at x-z plane, but with slight distortion. From these results, it could be concluded that for both designs of Antennas 1 and 4, they have a bidirectional pattern in the x-z plane and an omni-directional pattern in the x-y plane.

3.5. Gains

Figure 9 show the simulated on-axis gains of Antennas 1 and 4 respectively. Antenna 1 exhibits gain from 1.05 dBi to 2.42 dBi, with gain variations of less than 1.5 dBi in the operating bandwidth. The average gain of Antenna 4 is observed to be 2.16 dBi, with a peak gain of 2.24 dBi. It can be concluded that there is very little gain variation between Antennas 1 and 4.

4. CONCLUSIONS

In this paper, the ground plane effect has been studied on a simple square loop CPW-fed printed antenna. The edges of the ground plane where the currents are concentrated have been gradually shaped and the antenna characteristics have been studied. The study has shown that the ground plane is a dominant factor in establishing the antenna's impedance matching. Similar radiation patterns and gains have been obtained for both antennas, implying thereby that these characteristics are less sensitive to ground-plane shaping.

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