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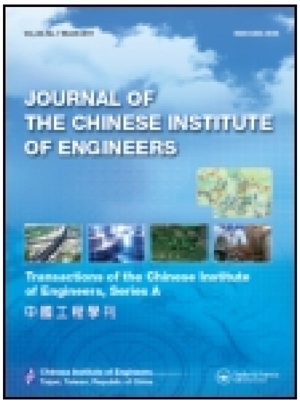

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A novel design of a cpw-fed single square-loop antenna for circular polarization

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A NOVEL DESIGN OF A CPW-FED SINGLE SQUARE-LOOP ANTENNA FOR CIRCULAR POLARIZATION

I-Chung Deng*, Ren-Jie Lin, Qing-Xiang Ke, Jia-Min Huang and Kow-Ming Chang

ABSTRACT

The experimental and simulated results for the proposed antenna are investigated in this article. Moreover, a novel broadband design of a circularly polarized (CP) single square slot antenna fed by a single coplanar waveguide is presented. By appropriately choosing the circumference of the square-loop, the length of the protruded strip, and the gap, this proposed antenna thus owns good CP radiation and good impedance match simultaneously at the frequency of 2.45 GHz. This proposed antenna has the fundamental resonant frequency of 2.5 GHz with the minimum return loss of -39.9 dB. Furthermore, its impedance bandwidth is 460 MHz or 18.4% and 3-dB axial-ratio (AR) bandwidth is 360 MHz or 14.4% at 2.5 GHz.

Key Words: circularly polarized, square slot antenna, coplanar waveguide, axial ratio.

I. INTRODUCTION

Advantageously, circularly polarized (CP) antennas radiate nearly constant radiation even though the angle of the antenna changes. Recently, the signal-feed coplanar waveguide (CPW) antenna for producing CP radiation with a compact antenna size has received much attention. CPW antennas are preferable for monolithic microwave integrated circuits (MMIC) since no backside processing is required for integrating with devices (Kormanyos *et al*., 1994). In order to obtain circularly polarized (CP) radiation by a single feed, many microstrip antenna designs have been reported (Wong, 2002). However, the CP bandwidth of the conventional microstrip antenna determined by 3-dB axial-ratio (AR) is usually narrow and sometimes even less than 2%. From previous works, Wong *et al*. (2002) have proposed microstrip-line-fed ring slot antennas with 3-dB AR bandwidths of only about 4.3% and 3.5% for square and annular ring slot antennas, respectively. Although a few CP slot antennas have been designed for CPW-feed, the sizes of these antennas are over 70×70 mm^2 (Sze *et al*., 2003; Chen *et al*., 2006). In this paper, a compact CPW-fed square slot antenna with the size of 42×51 mm^2 is designed. In order to generate a CP wave, the square-loop is slit into two arms through a narrow gap. Furthermore, the length of the two arms can be used to adjust two standing-wave currents. The CP wave is radiated when two standing-wave current distributions are at equal amplitude and at quarter-wave length difference (Lin *et al*., 2005; Elliott, 2003). This new slot antenna resembles the presented antenna geometry of these literatures (Morishita *et al*., 1998; shi *et al*., 2001; Chang *et al*., 2006) which include two rhombic or rectangular loop wire antennas. Frankly speaking, the presented antennas in these papers have several disadvantages such as larger structure, more difficult fabrication, and narrower AR bandwidth than our proposed ones. Our proposed antenna excludes these drawbacks and shows better circularly polarized radiation performance.

II. ANTENNA CONFIGURATIONS

The geometry of the proposed antenna is shown in Fig. 1. It is realized on an inexpensive FR4 dielectric material with a thickness (h) of 1.6 mm, a relative permittivity (ε_r) of 4.4, and a loss tangent of

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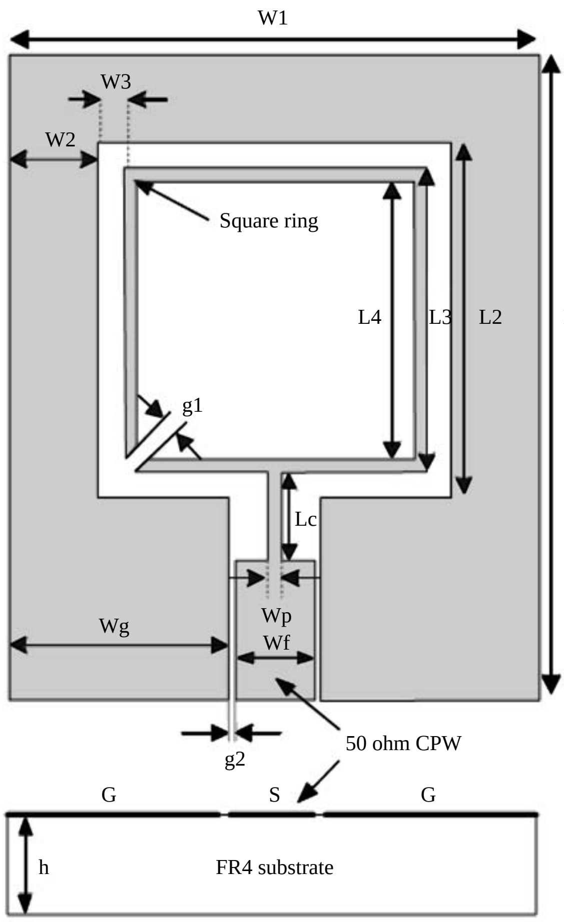

Fig. 1 Geometry of the proposed CPW-fed CP square slot antenna

0.0245. The square slot of the side length of L_2 is printed on the grounded substrate, and a 50 Ohm CPW transmission line with a protruding signal strip is used to feed it. Furthermore, the 50 Ohm CPW feed has a signal strip of width W_f = 6.3 mm and a slit distance g_2 = 0.5 mm between the signal strip and the ground plane. A signal strip, Lc in length and Wp in width, is connected to the center of the square-loop bottom. The most important design feature for the proposed CP slot antenna is the square-loop circumference, which the resonant frequency mainly depends on. It is designed to have about (1.12~1.15) λ_{eff} (effective wavelength of the operational frequency within the coplanar waveguide structure) on the desirable substrate. The left hand circular polarization (LHCP) radiation can be excited by using a gap (g1) at the lower left or lower right corner of the square-loop. However, in this condition, good CP radiation and good impedance match of the proposed antenna cannot be achieved at the same frequency. By varying the length of the protruding strip (Lc), both good CP radiation (the minimum AR value less than 1.5 dB) and good impedance match (return loss less than -30 dB) can be consequently obtained at the same frequency.

From the above observations, we conclude that, in this proposed antenna, good CP radiation and a good impedance match can be obtained simultaneously at the frequency of 2.45 GHz on the FR4 substrate by appropriately choosing the circumference of the square-loop (1.15 λ_{eff}), the length of the protruding strip (7 mm), and the gap (1.3 mm).

III. RESULTS AND DISCUSSIONS

The goal of this study is to develop a new square-slot antenna with good CP radiation and good impedance match at the same frequency of 2.45 GHz on FR4 substrate. In order to easily evaluate the circumference of the square-loop related to the desirable operational frequency, several simulations on three different substrates which have relative permittivity and thickness of (4.4 and 1.6 mm), (4.4 and 20 mm), and (9 and 1.6 mm) have been done by IE3D simulator, and the geometric parameters of these slot antennas are listed and marked as Case 1 to 3 in Table 1. All of the simulated return loss and simulated CP axial ratio are optimum, and they have minimum values at the same operational frequency of 2.45 GHz. When the minimum AR value is less than 1.5dB at the angle of (0, 0) and the return loss is less than -30 dB, under this condition, it is the most preferable. In order to simplify the comparisons between these cases, the dimensions of W_2, g_1 and the square-loop line width are fixed to be 7 mm, 1.3 mm and 1 mm, respectively. In table I, these λ_{eff} on different substrates, at the frequency of 2.45 GHz, are calculated by the LineGauge software included in the IE3D simulator. It can be seen that the circumferences of these square-loops are about 1.15 λ_{eff}, 1.12 λ_{eff}, and 1.12 λ_{eff} for these three different substrates, separately. Although the length of 1.12 λ_{eff} can also achieve good CP radiation and 3dB AR bandwidth in case 1, the performances are optimum by using 1.15 λ_{eff} as the circumference of the square-loop in this case. Table I also shows that the design rule of the circumference of the square-loop = 1.12~1.15 λ_{eff} not only satisfies different substrates but also suits other resonant frequencies (not shown here).

Figures 2(a) and 2(b) show the simulated results of the return loss and the ratio axial against frequency at different protruding signal strip lengths (L_C), respectively. With the increase of L_C, the frequency with minimum return loss slightly increases when the length of Lc ranges from 5~7 mm and 8~9 mm. However, there are large variations in frequency within the range of 7 mm to 8 mm. The 3-dB AR bandwidth and the frequency of the minimum AR

Table 1 Design parameters of the proposed antenna geometry on three different substrates and at three different frequencies

	Substrate parameters		(Unit : mm)								3db AR bandwidth
	ε_r	h	W1	W3	4*L3	Wp	Wf	Lc	λ_{eff}	$4{*}L3/\lambda_{\text{eff}}$	
					Design for 2.45 GHz						
Case 1	4.4	1.6	42	2	96	1	6.3	7	82.88	1.15	360 MHz
Case 2	4.4	20	37	1	84	1.4	4.0	4.7	74.68	1.12	420 MHz
Case 3	9.0	1.6	38	4	64	0.8	14.2	7.5	56.96	1.12	150 MHz
					Design for 4 GHz						
Case 4	4.4	1.6	30.2	2	57.6	1	6.3	6	50.76	1.13	540 MHz
					Design for 1.8 GHz						
Case 5	4.4	1.6	49.5	2	126	1	6.3	2	112.8	1.12	320 MHz

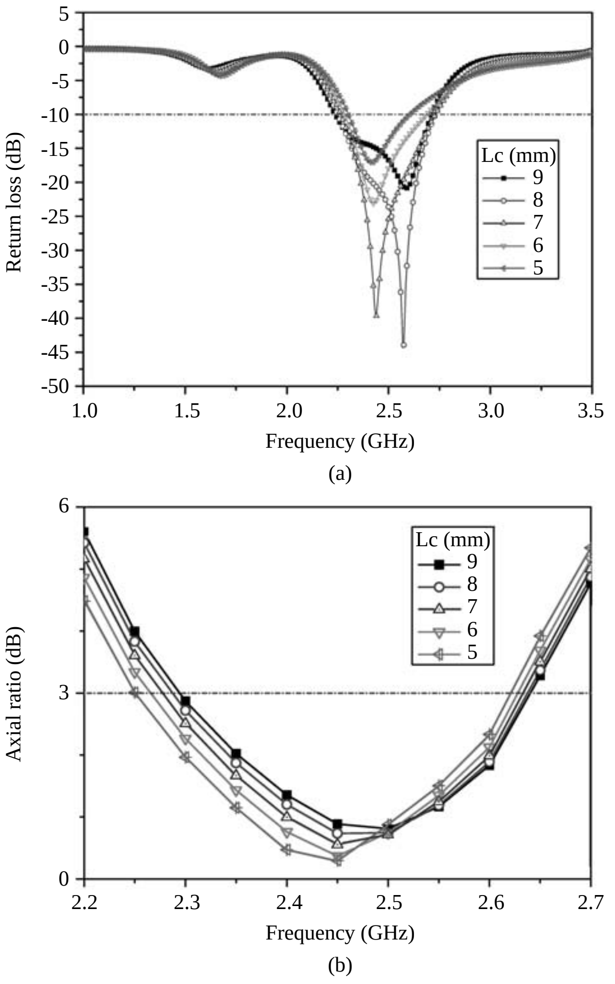

Fig. 2 Simulated (a) return loss and (b) axial ratio against frequency for the proposed slot antenna with different protruded strip lengths (Lc)

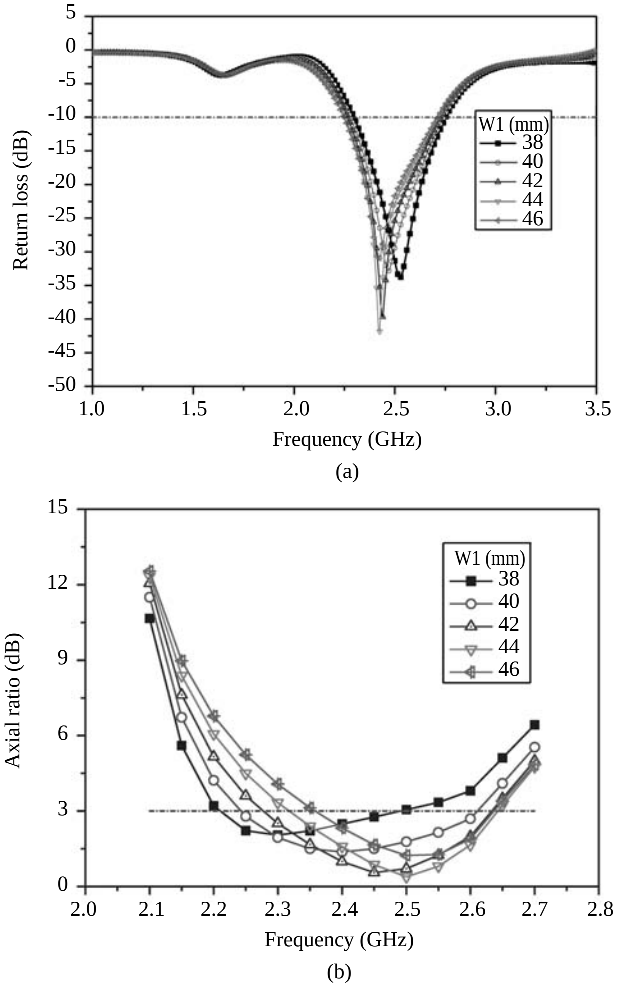

Fig. 3 Simulated (a) return loss and (b) axial ratio against frequency for the proposed slot antenna with different grounded plane widths (W1)

value slightly change with various length of L_C. Therefore, the protruded strip length mainly affects the behavior of the return loss.

In addition, the axial ratio could be also affected by the grounded plane width. The grounded plane effect has been simulated with various W_1. The return loss and the axial ratio against frequency with different W_1 are demonstrated in Figs. 3(a) and 3(b),

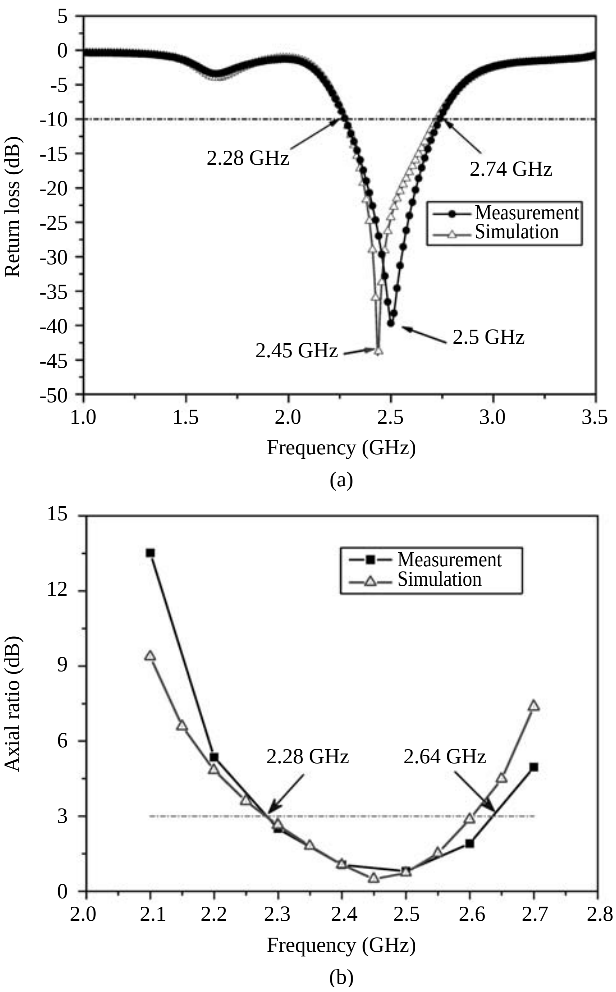

Fig. 4 Measured and simulated (a) return loss and (b) axial ratio against frequency for the optimum proposed slot antenna

respectively. From the simulation results, it can be seen that W_1 has the major influence on the axial ratio and has less effect on the return loss. The resonant frequency slightly increases as W_1 decreases. Contrastively, Fig. 3(b) shows that the frequency of minimum AR value increases as W_1 increases. Both AR bandwidths of the proposed antennas with W_1 of 40 mm and of 42 mm (W_2 = 6 mm and 7 mm) are the widest in the simulated results, but the antenna with W_1 of 42 mm has better AR response than that with W_1 of 40 mm.

In order to endow the antenna geometric parameters with the best antenna performance at the operational frequency of 2.45 GHz, many simulated results and optimum procedures have been done. Accordingly, Figs. 4(a) and 4(b) show the measured and simulated results of the return loss and the axial ratio against frequency, respectively. The fundamental resonant frequency is about 2.45 GHz and 2.5 GHz for the simulated and the measured results, respectively. The difference between the simulation and the measurement results is due to the tolerance of the fabrication and the measurement. From the measured results in Fig 4(a), the proposed antenna has a fundamental resonant frequency of 2.5GHz with a minimum return loss of -39.9dB, and the impedance bandwidth of 460 MHz or 18.4% (from 2.28 GHz to 2.74 GHz). In addition, Fig. 4(b) presents the measured bandwidth of 3dB axial-ratio (AR) of 360 MHz or 14.4% (from 2.28 GHz to 2.64 GHz), and the bandwidth of 1-dB axial-ratio is about 100 MHz and the frequency is from 2.42 GHz to 2.52 GHz. The minimum AR value occurs at the frequency of 2.5 GHz and is about 0.8dB.

Figure 5 reveals CP radiation patterns against the elevation angle with different azimuthal angles of phi = 0 and 90 degrees at the frequency of 2.45 GHz by simulation. In order to generate a CP wave, the square-loop is slit into two arms through a narrow gap (g1). Moreover, both arms can produce two orthogonal standing-wave current distributions. By adequately adjusting the lengths of the two arms, these currents can have equal amplitudes and a 90° time phase shift. When the vertical current leads the horizontal one, a good LHCP radiation can be obtained. On the other hand, an RHCP radiation can be thus obtained when the horizontal current leads the vertical one. Fig. 5 demonstrates good LHCP radiations in both azimuthal directions for the upper half free space. As known, the slot antenna is a bi-directional radiator. Therefore, if we examine this antenna from the upper half free space, an LHCP radiation can be observed. While we inspect it from the lower half, an RHCP radiation can be thus found.

The measurement of the polarization patterns in this study employs the rotating source method (Toh *et al.*, 2003). The measured results of the polarization patterns at 2.5 GHz are shown in Fig. 6. The ripples in the polarization patterns are a consequence of the beam ellipticity, which occur when a finite cross-polar component exists. The depth of the ripples defines the AR value. They present good circular polarization and also obtain good axial-ratio values over a wide angle range. The elevation-angle ranges, when AR values are less than 3dB, are -45 to 35 degrees at 2.5 GHz.

The measured and the simulated antenna gains against the frequency are shown in Fig. 7. The 3 dBi gain bandwidth of the measured result is about 340 MHz (from 2.26 GHz to 2.6 GHz) or 13.6% referred to the frequency of 2.5 GHz. The maximum gain of 3.74 dBi occurs at the frequency of 2.4 GHz, and the gain at the frequency of 2.5 GHz is about 3.47 dBi.

IV. CONCLUSIONS

A new design of CPW-fed CP square slot antenna has been investigated and successfully

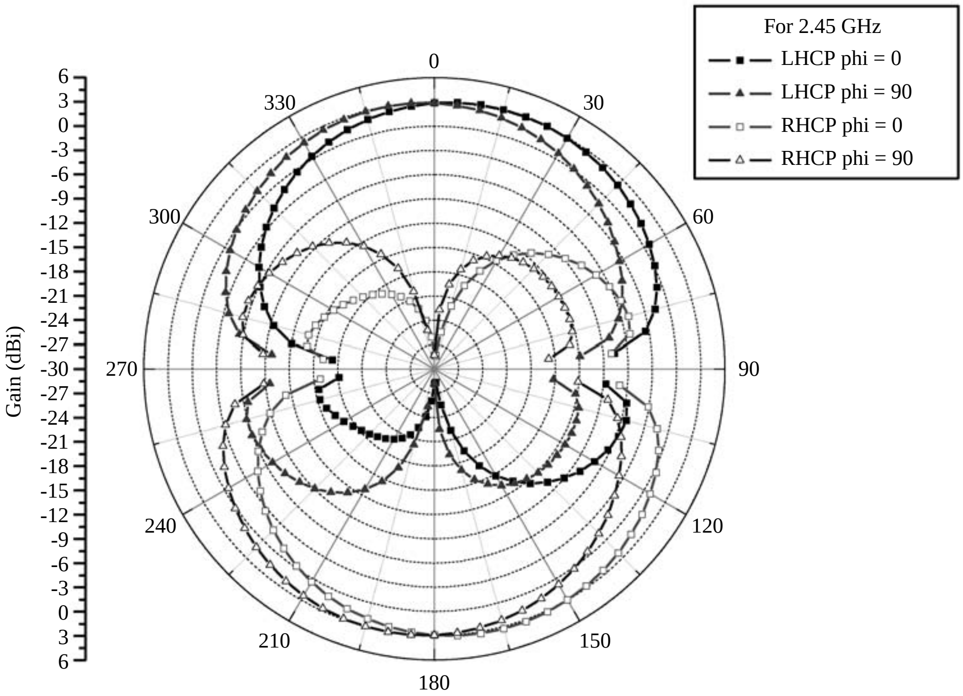

Fig. 5 Simulated CP radiation patterns for the optimum proposed slot antenna at the frequency of 2.45 GHz

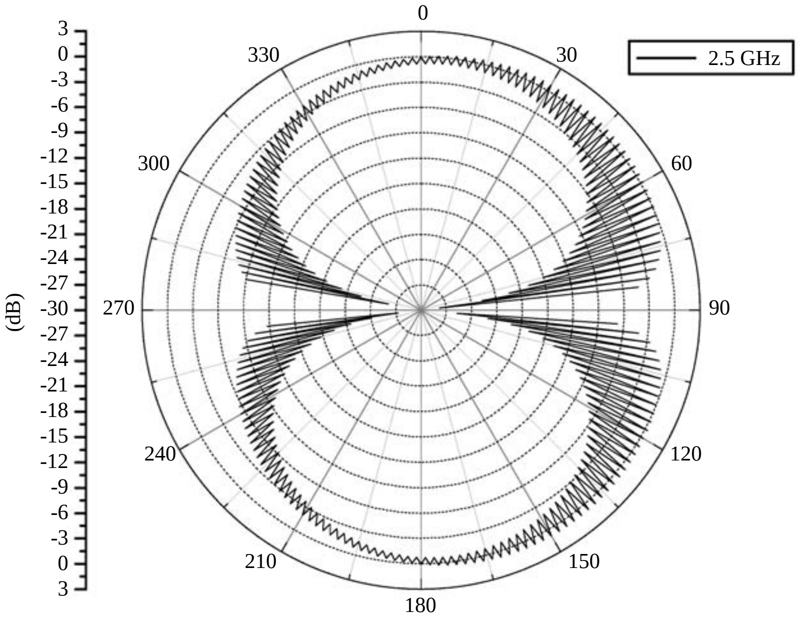

Fig. 6 Measured radiation patterns at the frequency of 2.5 GHz by the rotating source method

implemented. The proposed antenna has several advantages such as a return loss of -39.9dB at the fundamental resonant frequency of 2.5 GHz, impedance bandwidth of 460 MHz, 3-dB AR bandwidth of 360 MHz, and good broadside CP radiation patterns at least covering the range of 80 degrees in elevation. Based on the above, we conclude that the proposed antenna has excellent performance and is highly recommended for future wireless communication applications.

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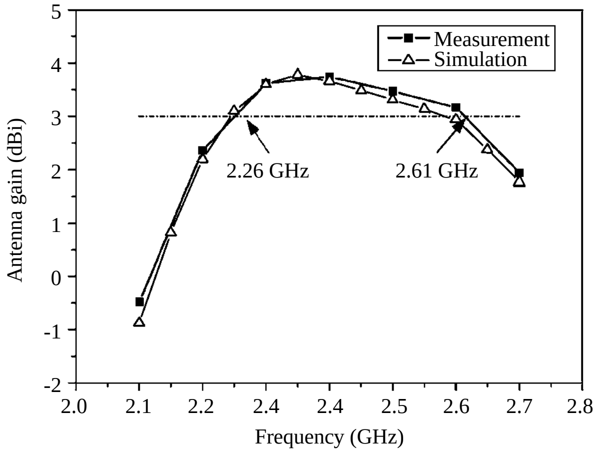

Fig. 7 Measured and simulated antenna gain against frequency for the proposed antenna

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