Circularly Polarized Square Slot Antenna With a Pair of Inverted-L Grounded Strips

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***Abstract*—This paper presents a new wideband circularly polarized square slot antenna (CPSSA) with a coplanar waveguide (CPW) feed. The proposed antenna features two inverted-L grounded strips around two opposite corners of the slot and a widened tuning stub protruded into the slot from the signal strip of the CPW. Broadside circular-polarization (CP) radiation can be easily obtained using a simple design procedure. For the optimized antenna prototype, the measured bandwidth with an axial ratio (AR) of less than 3 dB is larger than 25% and the measured VSWR $\leq$ 2 impedance bandwidth is as large as 52%.**

***Index Terms*—Circular polarization (CP), coplanar waveguide (CPW) feeding, slot antennas.**

I. Introduction

Due to their attractive features such as wide impedance bandwidth, single metallic layer, low profile, and easy integration with active devices or MMICs, printed wide slot antennas (PWSA) with a coplanar waveguide (CPW) feed have received increasing attention in circular polarization (CP) applications. Among those CP PWSAs, the ones having a simple slot shape and a 3-dB axial-ratio (AR) bandwidth of more than 15% have been designed by embedding into the square slots appropriate perturbation structures [1]–[5]. These perturbation structures can redistribute the magnetic currents in the slots so that two orthogonal resonant modes with an equal amplitude and a 90° phase difference can be excited. The perturbation structure can be constructed by loading in the square slot a criss-cross patch [1] or a grounded T-shaped metallic strip that is perpendicular to the axial direction of the feeding CPW [2], by protruding into the square slot a meandered [3] or inverted-L [4] conducting strip connected to the signal strip of the CPW, or by extending across the square slot a slotline-loaded inductively coupled conducting strip [5]. The fractional CP bandwidths (FCPBWs) of these antennas, however, cannot be larger than 25% (here, the CP band refers to the band with both $\mathrm{AR} \leq 3$ dB and $\mathrm{VSWR} \leq 2$). The reason is that the perturbation structures and the feeding structures extended from the CPW may both affect the field distributions in the aperture, giving rise to difficulty in obtaining a frequency band within which not only is the AR less than 3 dB but the input impedance is also well matched.

Manuscript received October 27, 2007; revised December 7, 2007. This work was supported by the National Science Council of the Republic of China (on Taiwan) under Grant NSC 92-2213-E-014-007.

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Digital Object Identifier 10.1109/LAWP.2008.921341

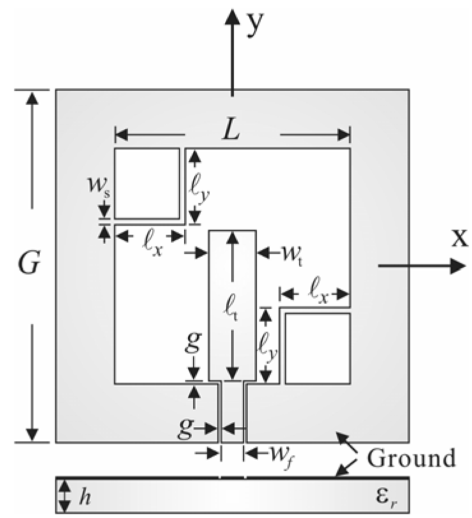

Fig. 1. Configuration of the proposed CPW-fed square slot antenna loaded by a pair of inverted-L grounded strips.

In this letter, we propose the design of a new CP square slot antenna (CPSSA), in which both the perturbation and feeding structures are simple. The achieved FCPBW is up to 27% and the VSWR $\leq$ 2 impedance band, which can completely cover the entire 3-dB AR band, is as large as 77%.

II. Antenna Design

Fig. 1 shows the geometry of the proposed CPW-fed CPSSA, which is printed on a square microwave substrate with a side length of G, a height of h, a dielectric constant of ε_{r}, and a loss tangent of $\tan\delta$. Etched at the center of the top-side ground plane is an $L \times L$ square slot, which is fed by a 50-Ω CPW having a signal strip of width w_{f} and two identical gaps of width g. The signal strip of the CPW is protruded into the slot by a length of $\ell_{\mathrm{t}} + g$ with its last ℓ_{t}-long section widened to have a width of w_{t}. Since the parameters ℓ_{t} and w_{t} may greatly influence the impedance matching of the antenna, we refer to the protruded metal strip as a tuning stub.

The CP operation of the proposed antenna is mainly attributed to the two grounded inverted-L metallic strips placed around two opposite corners of the square slot. Each of the w_s-wide metallic strips has a length of ℓ_x and ℓ_y, respectively, in the directions perpendicular and parallel to CPW. The structure shown in Fig. 1 will generate right- and left-hand circularly polarized (RHCP and LHCP) radiations in the $+z$ and $-z$ directions, respectively. Opposite-handed CP radiations can be generated if the two inverted-L strips are placed around the other two corners of the square slot.

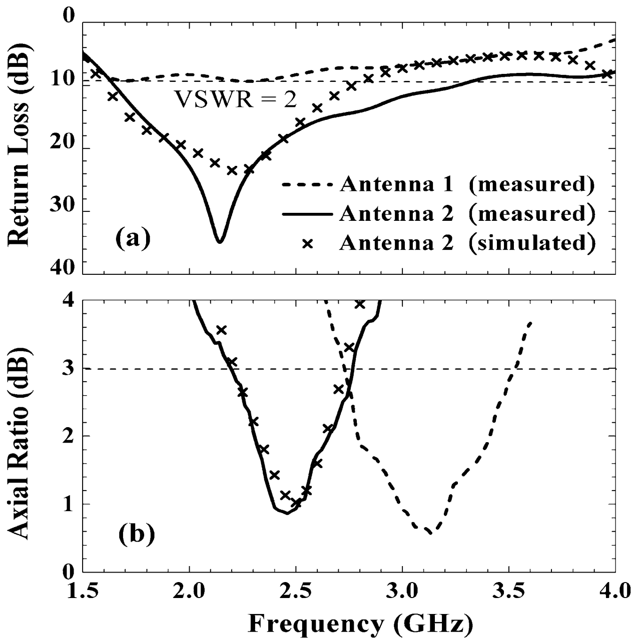

Fig. 2. Measured (a) return losses and (b) axial ratios for Antennas 1 and 2, with dimensions given in Table I. Also shown above are simulated data for Antenna 2.

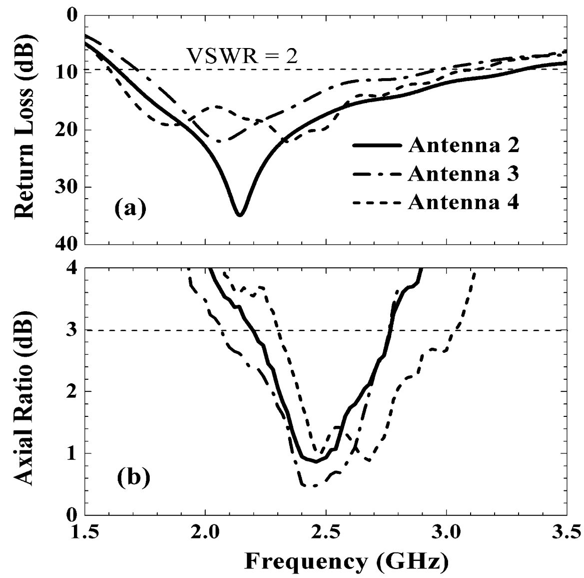

Fig. 3. Measured (a) return losses and (b) axial ratios for Antennas 2, 3, and 4, with dimensions given in Table I.

Although the inverted-L grounded metallic strips can lead the antenna to a wideband CP operation, the antenna's $\mathrm{VSWR} \leq 2$ impedance band may not completely cover the 3-dB AR band even if the protruded length of the conventional tuning stub (i.e., the one not widened at all) is optimized. Through extensive simulations and experiments, we have found that if part of the tuning stub is widened, impedance matching in the 3-dB AR band can be greatly improved, thus causing the 3-dB AR band completely enclosed by the impedance band. The protruded tuning stub, when properly widened, can not only enhance the coupling among the feed line, inverted-L strips, and the slot, but also further perturb the magnetic current distribution in the slot so that the 3-dB AR band would be shifted to around a lower frequency location, yet preserving the large 3-dB AR bandwidth (ARBW).

III. Experimental Results and Discussion

The proposed antenna shown in Fig. 1 was implemented on a commercially cheap FR4 substrate with $\varepsilon_r = 4.4, \tan\delta = 0.019$, and $h = 0.74$ mm, leading to $w_f = 3.1$ mm and g = 0.3 mm for the 50-Ω CPW. For simplification in the antenna design, $G = 60$ mm, $L = 40$ mm, and $w_s = 1$ mm were preselected. In each step of the design procedure, the commercial full-wave electromagnetic simulator Ansoft HFSS was utilized to find optimized structural parameters.

Because the success of the proposed CP antenna design mainly relies on whether the input impedance can be well matched in the entire wide 3-dB AR band, we will first focus on how the widened tuning stub affects both the 3-dB AR band and the impedance matching of the antenna. If ℓ_x and ℓ_y of the inverted-L strips are both set equal to 15 mm ($= 0.375$ L) and the tuning stub is not widened, i.e., $w_t = w_f$, a fractional 3-dB ARBW of 25.7% (relative to the center frequency of 3128 MHz) can be obtained with the tuning stub optimized to have $\ell_t = 24.5$ mm ≈ 0.6 L (called Antenna 1), as indicated by the measured results shown in Fig. 2. However, this antenna does not meet the impedance-matching criterion of $\mathrm{VSWR} \leq 2$ in the measured frequency band of 1.5–4 GHz. In the remaining designs, the same tuning-stub length will be adopted. When the tuning stub is widened to have $w_t = 8$ mm ≈ 0.2 L (denoted by Antenna 2), the 3-dB ARBW decreases from 805 MHz for Antenna 1 to 650 MHz. However, because the center frequency of the 3-dB AR band is lowered to 2445 MHz, Antenna 2 has a fractional 3-dB ARBW of 26.6%, which is slightly larger than that of Antenna 1. In addition, the VSWR ≤ 2 impedance band ranges from 1465 to 3290 MHz (with a fractional impedance bandwidth of 76.7% relative to the center frequency of 2378 MHz), which is large enough to completely cover the 3-dB AR band. Also presented in Fig. 2 are for Antenna 2 the simulated results, which agree reasonable well with the measured data.

Next, consider the effects of ℓ_x and ℓ_y of the inverted-L strips on the 3-dB ARBW. Refer to the antennas obtained by increasing ℓ_y and decreasing ℓ_x, respectively, of Antenna 2 by an amount of 0.5 mm as Antennas 3 and 4. As demonstrated in Fig. 3, the 3-dB AR bands of these two antennas are still completely enclosed by their corresponding $\mathrm{VSWR} \leq 2$ impedance bands. Nevertheless, the increase in ℓ_y for Antenna 3 and decrease in ℓ_x for Antenna 4, respectively, have resulted in lower and higher CP-band center frequencies, as compared with that of Antenna 2. The FCPBW of the former is slightly increased to 28.7%, and that of the latter, 27.4%. Furthermore, Antenna 3 has a $\mathrm{VSWR} \leq 2$ impedance band of 1720–2940 MHz (with a center frequency of 2330 MHz and a fractional impedance bandwidth of 52%), whereas Antenna 4 possesses a $\mathrm{VSWR} \leq 2$ impedance band of 1600–3055 MHz (with a roughly the same center frequency of 2328 MHz but a larger fractional impedance bandwidth of 62.5%). The fractional impedance bandwidths of these antennas are both smaller

TABLE I
STRUCTURAL PARAMETERS, MEASURED 3-dB ARBWS, AND MEASURED $\mathrm{VSWR} \le 2$ IMPEDANCE BANDS OF ANTENNAS 1–4; $\varepsilon_r = 4.4, \tan\delta = 0.019, h = 0.74\mathrm{mm}, G = 60\mathrm{mm}, L = 40\mathrm{mm}, w_f = 3.1\mathrm{mm}, g = 0.3\mathrm{mm}, g = 0.3\mathrm{mm}, w_s = 1\mathrm{mm}$, AND $\ell_t = 24.5\mathrm{mm}$. f_c REFERS TO THE CENTER FREQUENCY OF THE 3-dB AR BAND

	ℓ_y mm	ℓ_x mm	w_t mm	f_c MHz	3dB ARBW MHz, %	Impedance Band (MHz)
Antenna 1	15.0 (0.375L)	15.0 (0.375L)	3.1	3128	805, 25.7 (2725—3530)	———
Antenna 2	15.0	15.0	8.0	2445	650, 26.6 (2120—2770)	1465—3290
Antenna 3	15.5 (~0.388L)	15.0	8.0	2413	695, 28.8 (2065—2760)	1720—2940
Antenna 4	15.0	14.5 (~0.363L)	8.0	2665	730, 27.4 (2300—3030)	1600—3055

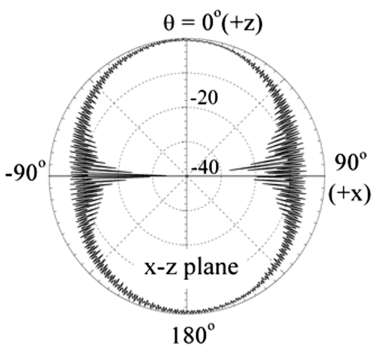

Fig. 4. Measured radiation pattern for Antenna 2 at 2445 MHz.

than that of Antenna 2. The structural parameters and measured results of Antennas 1–4 are summarized in Table I.

From the measured results presented above, it can be concluded that if the inverted-L metallic strips of the proposed antennas are designed with $\ell_x \approx \ell_y \approx 0.375$ L (Antennas 1–4), the 3-dB ARBW achieved can be larger than 25%. If, in addition, the widened tuning stub is designed to have the size of $\ell_t \approx 0.6$ L and $w_t \approx 0.2$ L (Antennas 2–4), the center frequency of the 3-dB AR band can be shifted to around a lower frequency location than that of the antenna where the tuning stub is not widened at all. Also note that the 3-dB AR bands are completely enclosed by their corresponding $\mathrm{VSWR} \le 2$ impedance bands with a fractional bandwidth of larger than 52%. The FCPBW achieved may be as large as 28.8%, which is about 1.5 times that of the antennas presented in [1]–[5].

Fig. 4 shows for Antenna 2 at 2445 MHz the measured far-field radiation pattern, which has lower ARs around the broadside directions (i.e., $\pm z$ directions). The $\mathrm{AR} \le 3$ dB CP beams occupy a spatial range of $\pm 30^\circ$ with respect to the broadside directions. Fig. 5 shows for Antenna 2 in its CP band the measured and simulated antenna gains, which are confined within 3–4 dBic.

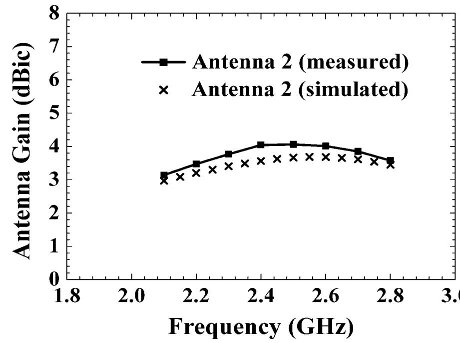

Fig. 5. Measured antenna gain within CP operating band for Antenna 2.

IV. CONCLUSION

A new wideband CPW-fed CPSSA has been proposed and successfully implemented. The antenna structure is simple, yet the measured FCPBW can be enhanced to 28.8% with a fractional impedance bandwidth of greater than 52%. In addition, excellent CP radiation patterns have been observed in the broadside directions, with RHCP and LHCP in the $+z$ and $-z$ directions, respectively. The antenna gain in the CP band was measured, and was found to have a maximum value of 4 dBic and a variation of less than 1 dB.

REFERENCES

[1] C. C. Chou, K. H. Lin, and H. L. Su, "Broadband circularly polarised cross-patch-loaded square slot antenna," *Electron Lett.*, vol. 43, no. 9, pp. 485–486, Apr. 2007.
[2] J. Y. Sze, K. L. Wong, and C. C. Huang, "Coplanar waveguide-fed square slot antenna for broadband circularly polarized radiation," *IEEE Trans. Antennas Propag.*, vol. 51, no. 8, pp. 2141–2144, Aug. 2003.
[3] K. M. Chang, R. J. Lin, I. C. Deng, J. B. Chen, K. Q. Xiang, and C. J. Rong, "A novel design of a CPW-fed square slot antenna with broadband circular polarization," *Microw. Opt. Technol. Lett.*, vol. 48, no. 12, pp. 2456–2459, Dec. 2006.
[4] Y. B. Chen, X. F. Liu, Y. C. Jiao, and F. S. Zhang, "CPW-fed broadband circularly polarised square slot antenna," *Electron Lett.*, vol. 42, no. 19, pp. 1074–1075, Sep. 2006.
[5] I. C. Deng, R. J. Lin, K. M. Chang, and J. B. Chen, "Study of a circularly polarized CPW-fed inductive square slot antenna," *Microw. Opt. Technol. Lett.*, vol. 48, no. 8, pp. 1665–1667, Aug. 2006.

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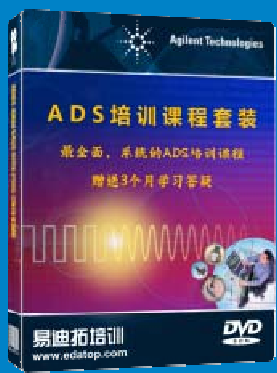

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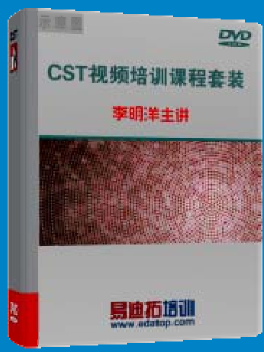

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