Communications

Printed Ring Slot Antenna for Circular Polarization

Kin-Lu Wong, Chien-Chin Huang, and Wen-Shan Chen

***Abstract*—A new design of a microstrip-line-fed circularly polarized printed ring slot antenna is proposed. Circular polarization (CP) radiation of the proposed design is achieved by introducing proper asymmetry in the ring slot structure and feeding the ring slot using a microstrip line at 45° from the introduced asymmetry. The asymmetry introduced in the proposed design is a meandered-slot section and the proposed CP design can be applied to printed square and annular ring slot antennas. Prototypes of the proposed design have been implemented. Experimental results show that good CP radiation performances are obtained and the 3 dB axial-ratio CP bandwidths obtained for the square and annular ring slot antennas are about 4.3% and 3.5%, respectively.**

***Index Terms*—Circular polarization (CP), printed-ring-slot antenna.**

I. Introduction

With the introduction of some asymmetry in the structure [1] to a single-feed ring microstrip antenna, it is possible to excite two orthogonal degenerate resonant modes for circular polarization radiation (CP). Since the printed-ring-slot antenna is a dual of the ring-microstrip antenna, it is also possible that by introducing some asymmetry to the ring-slot structure, CP radiation of printed-ring-slot antennas can be obtained. Also, since printed-slot antennas usually have a wider-impedance bandwidth than microstrip antennas, the obtained CP bandwidth for a printed-ring-slot antenna can be expected to be greater than that of a ring-microstrip antenna operated in the fundamental mode. This makes the design of circularly polarized printed-ring-slot antennas attractive. However, relatively fewer CP designs using a printed-ring-slot antenna have been available in the open literature. The related designs that have been reported are associated with the method of introducing some symmetric perturbation elements in the annular ring slot structure, such as the use of a pair of notches placed at 45° and 225° from the feed point for achieving CP radiation in the fundamental mode [2] or four notches placed midway between E- and H-planes at 22.5° and 112.5° from the feed point for CP radiation in a higher-order mode [3].

In this paper, we propose a new design of a circularly polarized printed-ring-slot antenna using the method of introducing asymmetry in the slot structure. The proposed asymmetry has a simple structure of a meandered slot section. Some prototypes of the proposed CP design applied to square- and annular-ring-slot antennas have been implemented and experimental results are presented and discussed.

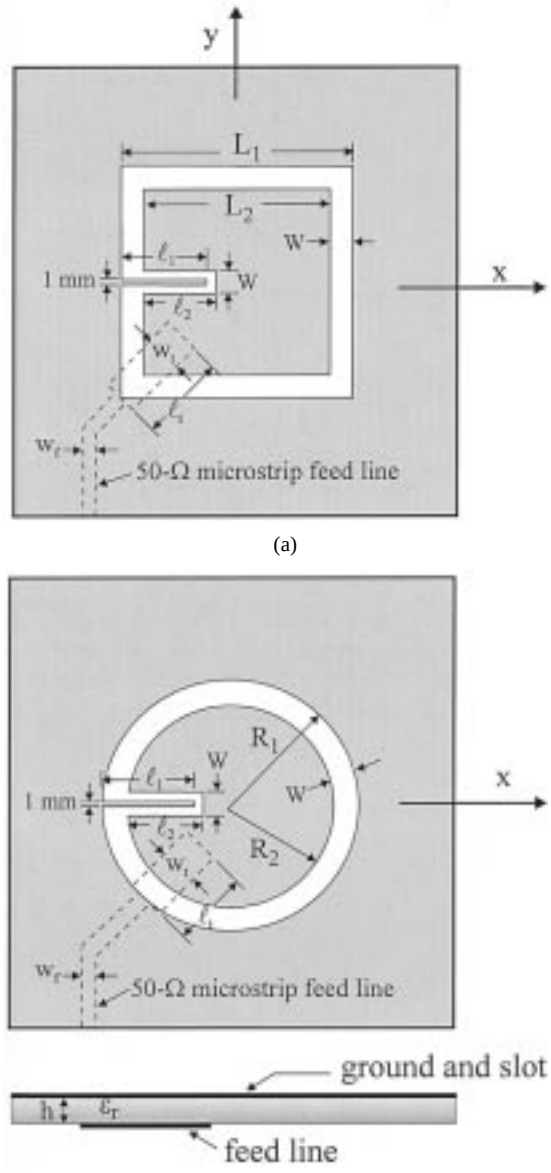

Fig. 1. Configurations of the proposed circularly polarized printed ring slot antenna. (a) Printed square ring slot antenna (antenna A). (b) Printed annular-ring-slot antenna (antenna B).

II. Antenna Designs

Fig. 1(a) and (b) show, respectively, the proposed printed square- and annular-ring-slot antennas with a meandered slot section for CP radiation. Both antennas are printed on a microwave substrate of thickness h and relative permittivity ϵ_r. For the square-ring-slot antenna, the outer- and inner-linear dimensions are L_1 and L_2, respectively, and the slot width is W. The meandered slot section is placed at the center of one of the slot edges and has a protruded rectangular slot of length ℓ_2 and width W (the width is the same as that of the square ring slot) and a metallic strip of narrow width 1 mm and length ℓ_1, which is centered in the rectangular slot. Also note that the length ℓ_1 is related to ℓ_2 with the expression of $\ell_1 = \ell_2 + 0.5W + 0.5$ mm in the proposed design, which results in a uniform slot width [$= 0.5(W - 1$ mm$)$] along the meandered slot section. A 50-Ω microstrip feed line with a widened tuning stub of length ℓ_t and width w_t is used to feed the ring slot along the diagonal direction; w_t is chosen to be about two times w_f in this study (w_f is the width of the 50-Ω microstrip line). With the widened tuning stub [4], the coupling between the microstrip feed line and the

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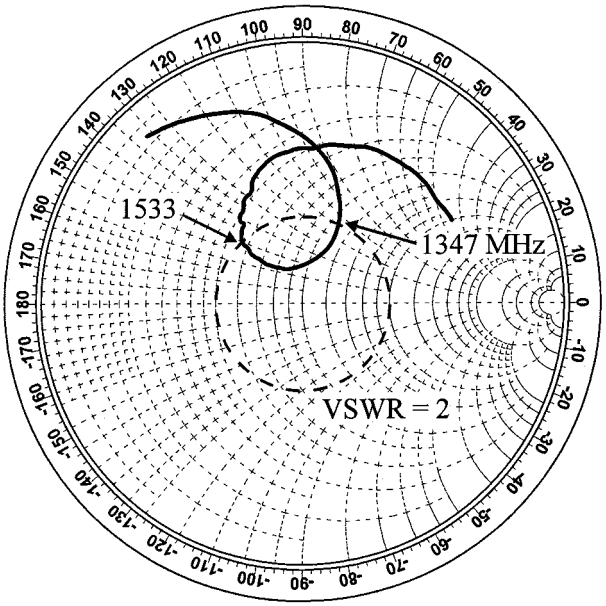

Fig. 2. Measured input impedance on Smith chart for antenna A; $L_1 = 40$ mm, $L_2 = 32$ mm, $W = 4$ mm, $\ell_1 = 15$ mm, $\ell_2 = 12.5$ mm, $\ell_t = 10$ mm, $w_t = 6$ mm, $w_f = 3.1$ mm, $h = 1.6$ mm, $\epsilon r = 4.4$, ground-plane size = 80 × 80 mm.

ring slot can be enhanced and good impedance matching for achieving CP radiation in the proposed design can be easily achieved.

For the design shown in Fig. 1(b), the annular-ring-slot antenna has an outer radius R_1, an inner radius R_2, and a slot width W. The meandered slot section and the microstrip feed line with a widened tuning stub are with the same variables as those in the square-ring-slot antenna in Fig. 1(a). For conventional square- and annular-ring-slot antennas, the fundamental resonant mode occurs at the frequency whose wavelength in the ring slot approximately corresponds to the mean circumference of the ring slot. That is, we have

$$f_a \approx \frac{c}{2(L_1+L_2)} \times \left(\frac{1+\varepsilon_r}{2\varepsilon_r}\right)^{1/2} \quad (1)$$

$$f_b \approx \frac{c}{\pi(R_1+R_2)} \times \left(\frac{1+\varepsilon_r}{2\varepsilon_r}\right)^{1/2} \quad (2)$$

where c is the speed of light in free space; f_a and f_b are, respectively, the fundamental resonant frequencies of the conventional square- and annular-ring-slot antennas; $2(L_1+L_2)$ and $\pi(R_1+R_2)$ are the mean circumferences of the square- and annular-ring-slot antennas, respectively; the second term in (1) and (2) is the correction factor considering the presence of different dielectric media on the two sides of the slot antenna [5]. In this study, the differences between the measured data and calculated results from (1) and (2) are within 5%.

With the introduced meandered slot section, the symmetry of the ring-slot antenna is perturbed and the fundamental resonant mode can be split into two orthogonal degenerate resonant modes for CP radiation. The optimal value of ℓ_2 in this study, is found from many experiments to be about 40% of L_2 (the square ring slot's inner linear dimension) or $2R_2$ (the annular ring slot's inner diameter). Also note that the design arrangements shown in Fig. 1(a) and (b) radiate a right-hand circularly polarized (RHCP) wave and when the microstrip feed line excites the ring-slot antenna along the other diagonal direction (i.e., 90° from the feed line shown in the figure), left-hand circularly polarized (LHCP) radiation can be obtained.

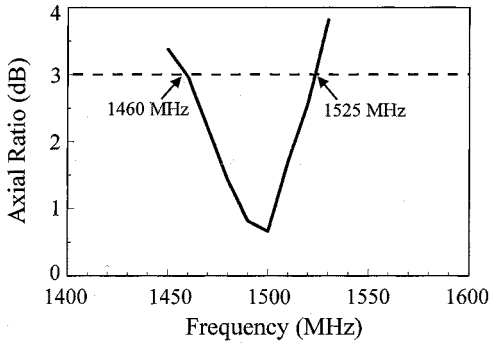

Fig. 3. Measured axial ratio in broadside direction for antenna A; parameters are given in Fig. 2.

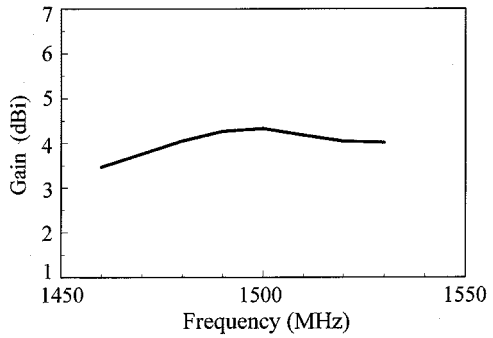

Fig. 4. Measured antenna gain of RHCP in broadside direction for antenna A; parameters are given in Fig. 2.

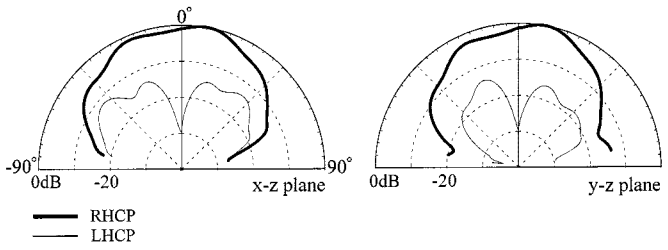

Fig. 5. Measured radiation patterns in two principal planes at 1500 MHz for antenna A; parameters are given in Fig. 2.

III. Experimental Results and Conclusion

Measured input impedance of a prototype for the proposed square-ring-slot antenna is presented in Fig. 2 and Fig. 3 shows the measured axial ratio. The 3-dB axial-ratio CP bandwidth is observed to be 65 MHz or about 4.3% with respect to the center frequency at 1500 MHz (the center frequency is defined here to be the frequency with minimum axial ratio in the CP bandwidth.). It should also be noted that the center frequency is smaller than the fundamental resonant frequency (about 1.7 GHz) of a corresponding conventional ring-slot antenna without the meandered slot section. The measured antenna gain and the radiation patterns at 1.5 GHz are shown in Figs. 4 and 5, respectively. The antenna gain within the CP bandwidth is about 3.5 to 4.3 dBi. Also, a slight asymmetry in the radiation patterns is observed, which is probably owing to the introduced asymmetry (the meandered slot section) in the ring-slot structure.

The proposed design is also applicable to an annular-ring-slot antenna. Fig. 6 shows the measured axial ratio of a constructed prototype. The 3-dB axial-ratio bandwidth is 60 MHz or about 3.5% referenced to the center frequency at 1720 MHz. The obtained center frequency is

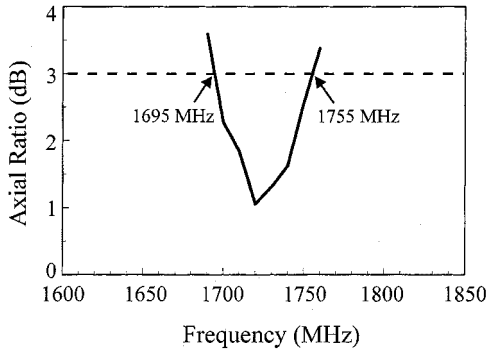

Fig. 6. Measured axial ratio in broadside direction for antenna B; $R_1 = 20$ mm, $R_2 = 16$ mm, $W = 4$ mm, $\ell_1 = 15$ mm, $\ell_2 = 12.5$ mm, $\ell_t = 10$ mm, $w_t = 6$ mm, $w_f = 3.1$ mm, $h = 1.6$ mm, $\epsilon r = 4.4$, ground-plane size $= 80 \times 80$ mm^2.

also lower than the fundamental resonant frequency (about 2.1 GHz) of a corresponding conventional annular-ring-slot antenna. The measured antenna gain for frequencies within the CP bandwidth is about 3.2 to 3.8 dBi. Finally, it should be noted, that owing to the meandered slot section introduced in the proposed design, the CP radiation occurs at a lowered frequency compared to the fundamental resonant frequency of a corresponding conventional ring-slot antenna, which suggests that reduced ring-slot dimensions can also be obtained for the proposed antenna at a fixed frequency. Also, the obtained CP's center frequency for the proposed ring-slot antenna can be approximately determined from (1) and (2) by modifying the ring slot's mean circumferences to be $2(L_1 + L_2) + \ell_1 + \ell_2$ and $\pi(R_1 + R_2) + \ell_1 + \ell_2$, respectively. In this case, the differences between the measured data and calculated results from (1) and (2) are about 9% and 3%, respectively, for square and annular ring slot antennas.

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Efficient Calculation of Self/Mutual Impedances in MoM Analysis of a Monopole in Free Space

K. W. Leung

***Abstract*—This paper presents an analysis of a monopole in free space. The result is given in a concise form that facilitates the numerical programming. Moreover, the calculation involves no numerical integration and, thus, the computation is extremely fast.**

***Index Terms*—Moment methods (MoM), monopole antennas.**

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I. INTRODUCTION

The dipole antenna is one of the most popular antennas. Tremendous effort has been devoted to analyze the dipole antenna rigorously [1]–[3] and a concise formula has been developed for its efficient numerical implementation [4]. The problem of a monopole protruding from an infinite ground plane is also frequently found. This problem can be solved easily using the dipole result by invoking the image theory. The dipole result, however, cannot be applied for the problem of a monopole in free space. This problem is found when the monopole is mounted on a finite-size object instead of the infinite-ground plane. For example, Tesche *et al.* encountered this problem in solving the problem of a monopole located on a spherical vehicle [5], [6], where the particular solution [7] is in fact the free-space monopole problem. Tesche *et al.* used the moment method (MoM) and employed a pulse expansion with a delta function testing basis set. The choice of the expansion and testing functions was merely to minimize the calculation of the homogeneous solution that accounts for the presence of the spherical body [7]. To speed the MoM convergence for current distributions, however, the piecewise sinusoidal (PWS) basis function and the Galerkin's procedure are usually used [4]. In this paper, a formulation that employs the PWS basis and testing functions is carried out for a monopole in free space. A concise result, analogous to the dipole one [4] is presented for the first time for the evaluation of the self/mutual impedances. Since the result involves no numerical integration, it is computationally very efficient.

II. THEORY

Fig. 1(a) shows a monopole of length l and radius y_1, which is excited at $z = 0$. The negative voltage is on the actual object to which the monopole is attached and is omitted from the figure. It is assumed that the current flows on the z-axis and its field reacts with a current on the monopole surface to give the self/mutual impedances. This approximation leads to the so-called reduced kernel [7], which is widely accepted and used in the literature [8]. Employing the MoM, the monopole current is expanded as $I(z) = \sum_{q=1}^{N} I_q f_q(z)$ where I_q is the unknown expansion coefficient and $f_q(z)$ is a normalized PWS function given by $f_q(z) = [\sin k\,(d - |z - z_q|)] \,/\, \sin kd$ for $|z - z_q| < d$ and $f_q(z) = 0$ otherwise, with $z_q = (q-1)d$ and $d = l/N$. The normalized PWS expansion modes are shown in Fig. 1(b). Note that the half PWS current [9] is used for the first $(q = 1)$ current mode. Because of this current mode, the current expansion is asymmetric, substantially increasing the complexity of the analysis. To begin with the self impedance Z_{11} for the first current mode is determined. Following the procedure given in [10], the H_ϕ component due to the half PWS current is found

$$H_\phi = \frac{j}{4\pi \sin kd} \cdot \frac{1}{y_1}\left(e^{-jkR_1} - \cos kd\, e^{-jkr} - j\frac{z}{r}\sin kd\, e^{-jkr}\right) \quad (1)$$

where $R_1 = \sqrt{(z-d)^2 + y_1^2}$ and $r = \sqrt{z^2 + y_1^2}$. It should be mentioned that the third term inside the bracket, $-j(z/r)\sin kd\, e^{-jkr}$, arises from the asymmetry of the current mode and is not present in the dipole case. From (1), the z-directed E-field is found by using

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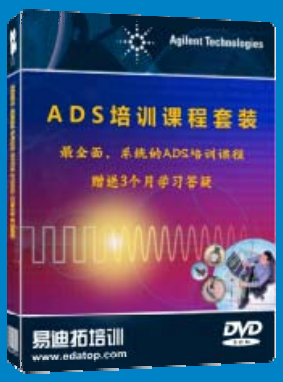

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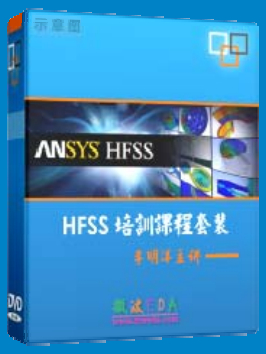

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