Ellipse-Shaped Slotted Patch Antenna with Broadband Circular Polarization

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***Abstract*—A simple design for circularly-polarized (CP) patch antennas with broadband operation is presented. The design uses a cross slot antenna with an ellipse-shaped ground plane, and it is found that a broadband CP operation can be realized by selecting a proper aspect ratio of the ground plane. A design guideline is given. Three examples are designed by the guideline, and their antenna prototypes are also accomplished and tested. Measured results indicate that the 3dB-axial-ratio bandwidths of the three prototypes, centered at 0.9, 1.4, 2 GHz, are 26, 37, and 32 %, respectively. HFSS Simulated results validate the experiments. In addition, the possible methods of further improving the 3dB-axial-ratio bandwidth are also addressed.**

***Index Terms*—slot antenna, circular polarization**

I. INTRODUCTION

Circularly polarized (CP) antennas with broadband operation have received much attention over the last decade because they can be used to avoid the problems of polarization alignment and integrate different communication systems into one wireless device. Due to the advantages of low profile and easy manufacture, a slot antenna is often employed to design a broadband antenna suitable for practical applications, and its CP operation can be realized with an unsymmetrical structure and an elaborated feed mechanism [1]-[5]. Several of the reported designs deliver a 3dB-axial-ratio operation bandwidth of more than 30 %. What seems to be lacking, however, is a simple design guideline for the CP antennas. The reason may be that quite a few parameters are involved in the antenna designs. In addition, little attention has been given to the impact of the ground-plane size on the CP performances, which is important information for realizing a compact antenna.

In this paper, a simple CP design based on a traditional cross slot antenna with an ellipse-shaped ground plane is proposed. For the proposed antenna, the radiation is contributed from the electric currents flowing on the ground plane rather than the magnetic currents in the slot, and the CP performances are much related to the aspect ratio of the ground plane. As a consequence, the proposed antenna is more suitably treated as a patch antenna fed by a coplanar cross slot or named slotted patch antenna. Moreover, few independent parameters are involved in the antenna design, and their dimensions can be directly scaled up (down) to decrease (increase) antenna operating frequencies. A design guideline for the CP slotted patch antenna is shown, and it gives the entire dimensions for the antenna operating at any frequency band. Three design samples are exhibited and their experimental results are shown. The possible methods of enhancing the CP bandwidth are also addressed.

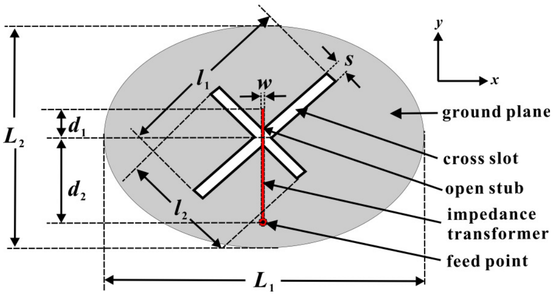

Fig. 1 Layout of a cross slot etched on a printed circuit board.

II. ANTENNA STRUCTURE AND PERFORMANCES

Fig. 1 depicts the layout of a cross slot printed on one side of a printed circuit board. The slot is cut from an ellipse-shaped conducting patch whose major and minor axes are L_1 and L_2, respectively. The lengths, l_1 and l_2, of the cross slot are unequal and the slot width is s. The slotted patch can be regarded as a traditional slot antenna in structure, and consequently it can be excited with a microstrip feed line, etched on the other side of the printed circuit board, through coupling. The feed line is composed of an open stub, having the dimensions of d_1 and w, and an impedance transformer, having the dimensions of d_2 and w. An example (Sample A) is selected to show the performances of the slotted patch antenna. The example antenna is fabricated on a FR4 substrate of thickness 1.6 mm and relative permittivity 4.4, and it has the dimensions of L_1 = 81 mm, L_2 = 54 mm, l_1 = 54 mm, l_2 = 36 mm, s = 4 mm, d_1 = 5 mm, d_2 = 18 mm, and w = 0.6 mm. Fig. 2 presents the measured and HFSS simulated results for Sample A. Satisfactory agreements between them are observed. From the experimental results, the CP bandwidth, determined by 3 dB axial ratio, is from 1.67 to 2.32 GHz, and the impedance bandwidth, referred to 10 dB return loss, can totally cover the CP bandwidth. Moreover, the radiation patterns are stable across the CP operating frequencies, and typical results, measured at 2 GHz, are plotted in Fig. 3. Bidirectional radiations with a peak gain of about 3.5 dBic are seen. Moreover, the main beams are symmetrical with respect to z-axis and the half-power beamwidth in y-z plane is more than 90°. The polarization senses are right-handed circular polarization (RHCP) and left-handed circular polarization (LHCP) for $z > 0$ and $z < 0$ planes, respectively.

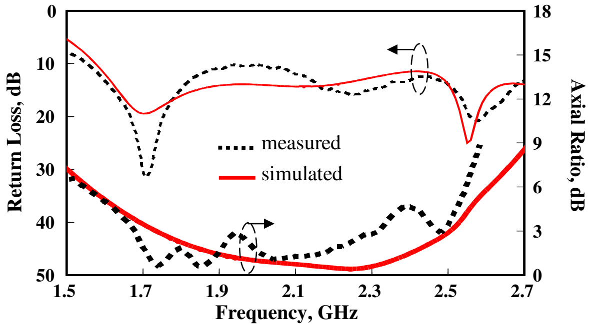

Fig. 2 Measured and simulated results of Sample A.

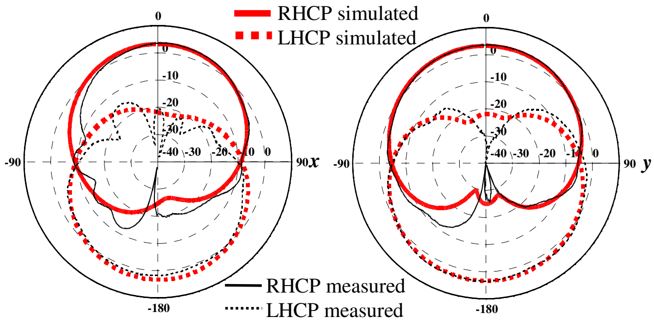

Fig. 3 Measured and simulated radiation patterns of Sample A.

III. Design Guideline and Discuss

As shown in Fig. 1, the CP slotted patch antenna includes eight parameters, in which (L_1, L_2, l_1, l_2) are used to optimize the axial ratio and (d_1, d_2, w) are used to achieve the impedance matching. Observing the dimensions of Sample A, it is found that the aspect ratio of the ellipse-shaped slotted patch is equal to the ratio of the two slot lengths of the cross slot; in addition, the length of the major axis of the ellipse is equal to the length of the longer slot of the cross slot. Therefore, L_1, L_2, and l_1 can be expressed in terms of l_2, and their equations are shown as follows

$$L_1 = 2.25 l_2 \quad (1)$$

$$L_2 = l_1 = 1.5 l_2 \quad (2)$$

Note that as long as the above two equations are satisfied, the slotted patch antenna can produce a wide 3dB-axial-ratio bandwidth where the lowest frequency point (f_L) can be approximately evaluated by the following equation

$$f_L \sim \frac{c}{2(l_1 + l_2)} = \frac{c}{5 l_2} \quad (3)$$

, where c is the speed of light. Eq. (3) is derived based on the fact that the operation mode of the slotted patch antenna is due to the one-wavelength distribution of the electric current along the circumference of the cross slot. The parameters (d_1, d_2, w) are the dimensions of the microstrip feed line. Based on several simulation results, the initial values of (d_1, w) and (d_2, w), the lengths and widths of the open stub and impedance transformer, can be referred to a 100 Ω microstrip line with 20° and 75° electrical lengths, respectively. As for s, it is a key parameter of determining the available CP bandwidth. The larger the slot width is, the more the available bandwidth is. Unfortunately, the dimensions L_2 will limit the tunable range of the slot width. An alternative method is moving the four intersections of the cross slot outward. Another possible method is using a printed circuit board with low permittivity. With these methods, a CP bandwidth of more than 50 % can be achieved.

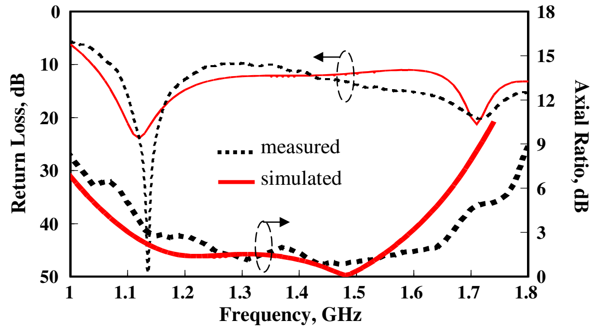

Fig. 4 Measured and simulated results of Sample B.

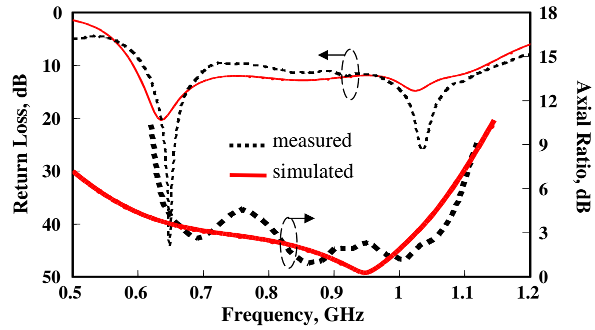

Fig. 5 Measured and simulated results of Sample C.

According to the above discussions, the CP operating band of Sample A would be moved to lower (upper) frequencies when all of the antenna dimensions are scaled up (down) except w. Figs. 4 and 5 respectively demonstrate the results of the two samples with scaling factors of 1.55 (Sample B) and 2.78 (Sample C). For Sample B, its measured CP bandwidth is from 1.14 to 1.67 GHz (37 %), covering the spectra of the global navigation satellite systems. As regards Sample C, its measured CP bandwidth is from 0.81 to 1.05 GHz (26 %), covering the spectra of universal readers in RFID systems. It has to be mentioned that the CP bandwidths of Sample A, B, and C would be somewhat increased by fine tuning (L_1, L_2, l_1, l_2).

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