A Circularly Polarized Cavity-Backed Slot Antenna With Enhanced Radiation Gain

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***Abstract*—A class of circularly polarized (CP) cavity-backed slot antennas with enhanced gain is formed up. All the proposed antennas are implemented in a single rectangular metal cavity. One slot is formed at the bottom side of this cavity as a feeding slot to excite two orthogonal resonant modes. The slot antenna is then constituted at the opposite side of the feeding slot to radiate electromagnetic wave. A two-element array is further implemented to improve the radiation gain with 3 dB enhancement without size increment of the original antenna. Finally, two CP cavity-backed slot antennas are fabricated and tested for experimental verification of the proposed design methodology. A good agreement between measurement and simulation shows the feasibility of the proposed cavity-backed slot antenna.**

***Index Terms*—Cavity-backed slot antenna, circular polarization, enhanced gain, multiple mode resonator.**

I. Introduction

CIRCULARLY polarized (CP) antennas have been widely used in modern wireless communication systems due to their attractive features, i.e., effective reduction in multipath fading and enhancement in channel capacity. A CP antenna has good capability in the enhancement of channel capacity, and has been a basic antenna for base stations in the past years.

Recently, the cavity-backed technology is introduced to make the slot antenna more compact in size and advantageous in performance as discussed in [1]–[3]. As usual, a low-cost cavity-backed structure can be formed by a printed circuit board (PCB) process. In this aspect, high substrate loss and low power capacity are the disadvantages of a PCB circuit. Metal cavity was usually utilized in antenna and filter design because of its high power capacity and lower dielectric loss [4]–[8]; hence, high radiation efficiency can be realized by the full metal antennas. Thus, this kind of antenna can be applied to long-distance and high-power wireless communication.

In the past, the CP antenna arrays were researched intensively [9]–[13]. In most instances, gain enhancement was realized by increasing the number of radiation elements and adding the power-dividing network in the meantime. As a consequence of that, the power-dividing feeding networks are essential for these arrays. Those feeding networks may increase the volume and the loss of the metal cavity antenna array dramatically. A Yagi array antenna was proposed in [13], based on a compact combination of a pair of complementary Yagi arrays, which was fed by only one feeding coaxial line. In this work, a method is proposed for gain enhancement without affecting the original circuit size. This proposed method can reduce the complexity, volume, and loss of the full metal cavity-backed antenna.

Some CP antennas were proposed in [14]–[17]. Cross dipoles were printed on the PCB board to achieve circular polarization with cavity-backed reflector in [14] and [15]. However, it is inevitable that the antennas printed by PCB have dielectric loss and low power capacity. In addition, antennas in [14]–[16] were fed by a coaxial cable, which has a lower power capacity than the waveguide-fed. A class of full metal waveguide-fed CP antenna arrays was proposed by Zhou *et al.* [17]. A complicated feeding network is required to realize a high gain in [17]. In addition, some full metal cavity-backed antenna arrays were proposed by Huang *et al.* [18]–[21]. They all suffer from the same problem with complicated and large size of feeding networks as mentioned by Zhou *et al.* [17]. In this work, a two-element array achieves an enhanced antenna gain without any power-dividing network. This means that half the amount of T-junctions in feeding networks can be reduced for the same number of array elements.

In this letter, a class of CP cavity-backed slot antennas with enhanced gain is presented. The initial antenna is a linear-polarized (LP) cavity-backed slot antenna with resorting to a TE_{011} mode in a rectangular cavity. Afterwards, one inclined slot is used to excite two orthogonal degeneration modes inside a single cavity, e.g., TE_{011} mode and TE_{101} mode. These two resonant modes excite a cross-shape slot to generate a CP wave.

Manuscript received March 12, 2018; accepted April 20, 2018. Date of publication April 24, 2018; date of current version June 4, 2018. This work was supported in part by the Shenzhen University Research Startup Project of New Staff under Grant 20188082; in part by the NTUT-SZU Joint Research Program under Grant 2018009; in part by the Fundamental Research Funds for the Central Universities under Grant 2017ZD044; in part by the Shenzhen Science and Technology Programs under Grant ZDSYS 201507031550105, Grant JCYJ 20170302150411789, Grant JCYJ 20170302142515949, and Grant GCZX 2017040715180580; and in part by the Guangdong Provincial Science and Technology Program under Grant 2016B090918080. *(Corresponding author: Sai-Wai Wong.)*

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Digital Object Identifier 10.1109/LAWP.2018.2829717

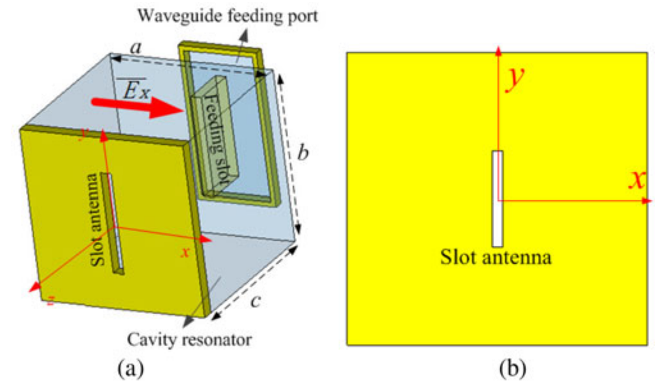

Fig. 1. Single-polarized LP cavity-backed slot antenna. (a) 3-D view. (b) Front side view.

Next, an enhanced gain is achieved by replacing the cross-shape slot with four slots without adding extra volume in comparison with the cross-shape slot case.

II. LP Cavity-Backed Slot Antenna

Fig. 1(a) and (b) indicates the three-dimensional (3-D) view and side view of the proposed LP cavity-backed slot antenna. The rectangular cavity comprises the main body of the slot antenna. A waveguide is utilized as a feeding port at the opposite side of the slot antenna. The feeding slot is located at the center of the cavity surface, and its long side is oriented along the *y*-axis to excite the mode of TE_{011} with an electric field along the *x*-axis as shown in Fig. 1(b). The TE_{011} inside the cavity excites the radiative resonant mode in the slot radiator for electromagnetic (EM) wave radiation to the air.

The simulated $|S_{11}|$ of this LP antenna is depicted in Fig. 2(a). It shows that a resonant mode is excited at the frequency of 2.98 GHz with a good impedance matching. Fig. 2(b) indicates that its electric field distribution inside the cavity on the *xoy* plane is oriented along the *x*-axis, thus generating the TE_{011} mode. Fig. 2(c) describes the simulated radiation patterns in the E-plane (*xoz* plane) and H-plane (*yoz* plane) at the center frequency of 2.98 GHz. It shows that this slot antenna has a unidirectional radiation pattern with a gain of 6.02 dBi.

III. CP Cavity-Backed Slot Antenna

In this section, the LP cavity-backed antenna is modified to realize a CP antenna. The antenna has only one feeding port for appropriate excitation of two orthogonal degeneration modes for CP radiation.

A. Initial CP Cavity-Backed Slot Antenna

The initial structure of the proposed CP slot antenna is shown in Fig. 3(a), namely antenna A. For convenience, the structure is divided into two components. One is the inner cavity with a rotated feeding slot, namely "component 1"; another one is the metal cover placed above the cavity. A cross-shape slot antenna opens on this metal cover, namely "component 2." The rotating angle θ of the feeding slot is set as 45° to equally excite two orthogonal modes, e.g., TE_{011} mode and TE_{101} mode as shown in Fig 3(b). The cross-shape slot picks up these two orthogonal modes with slight length difference for perturbation of two modes with an equal magnitude and a 90° phase difference. Fig. 4 exhibits that the widths of the cross-shape slot can improve the performance of the axial ratio (AR). Thus, by properly selecting the value of widths, the AR can be below 3 dB. The

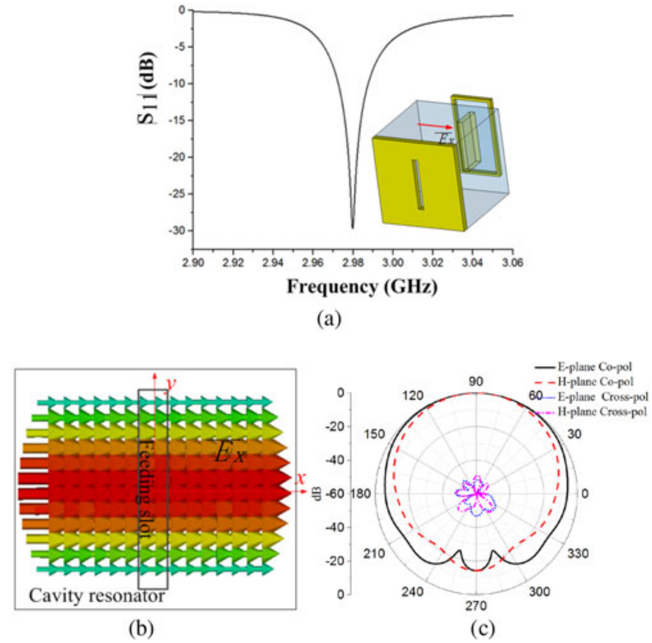

Fig. 2. Simulated results of LP slot antenna. (a) Reflection coefficient. (b) Electric field distribution at $f = 2.98$ GHz. (c) Simulated radiation patterns in the E- and H-planes at 2.98 GHz.

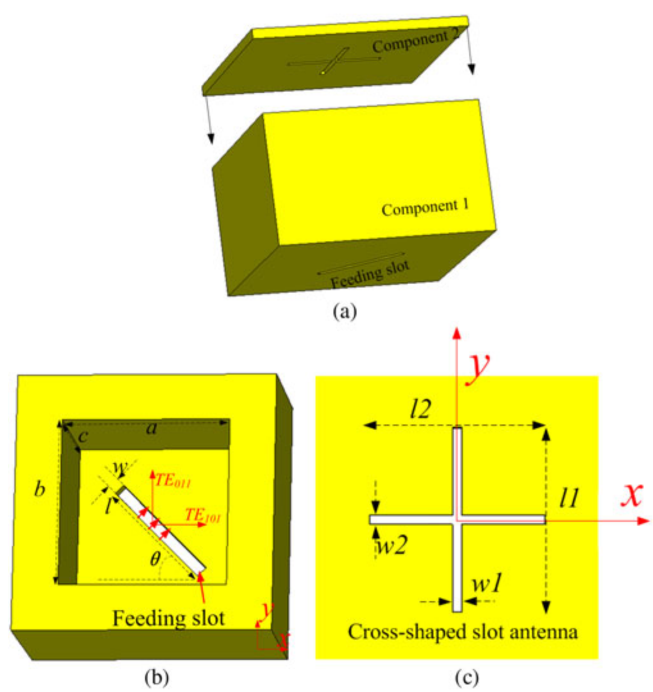

Fig. 3. Geometry of the proposed CP cavity-backed antenna A. (a) 3-D view. (b) Inner view of "component 1." (c) Top view of the "component 2."

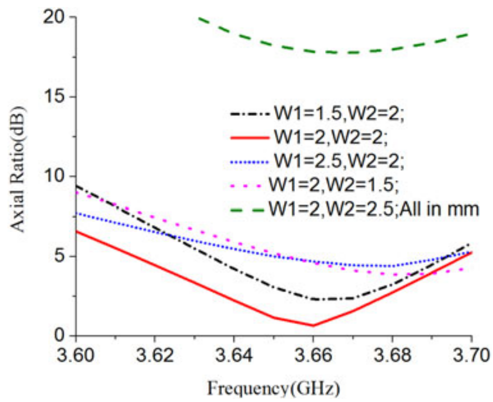

Fig. 4. AR is optimal when $w1 = 2$ mm, $w2 = 2$ mm.

TABLE I
DIMENSIONS OF CP CROSS-SHAPE ANTENNA A (UNIT: MM)

Parameters	*a*	*B*	*c*	*L*	*W*	*w1*
Values/mm	58	58	48	39	2.4	2
Parameters	*l1*	*w2*	*l2*			
Values/mm	40	2	38			

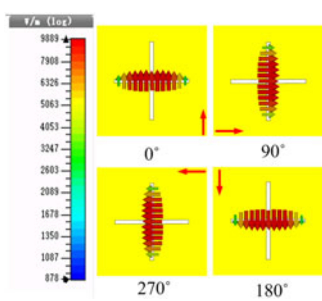

Fig. 5. Electric field distributions of the CP slot antenna A, four states of the electric field when $t = 0$, *T*/4, *T*/2, and *T* (*T* is a period of time).

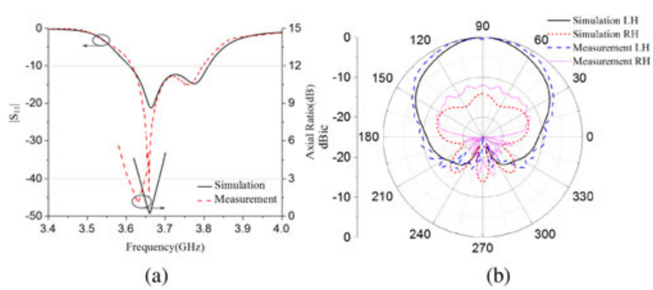

Fig. 6. CP antenna A. (a) ARs and the reflection coefficient. (b) Radiation patterns.

detailed dimensions of the optimized antenna are illustrated in Table I.

The electric field distribution of the cross-shape slot is given in Fig. 5. The four states of electric field are also shown in Fig. 5. Consequently, the left-handed CP (LHCP) radiation is produced. Fig. 6(a) shows the measured and simulated $|S_{11}|$ and ARs. A good impedance matching and a good AR are observed.

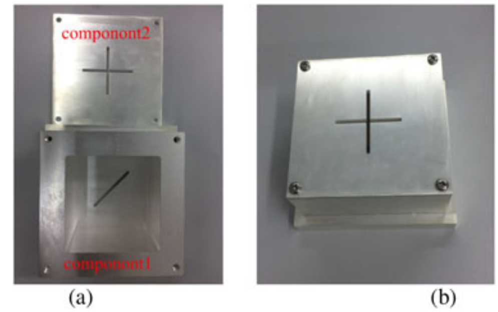

Fig. 7. Photographs of the fabricated CP cavity-backed slot antenna A. (a) Inner view. (b) Outside view.

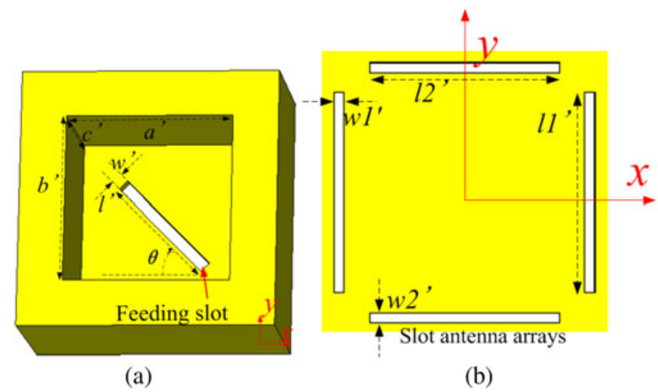

Fig. 8. Geometry of the proposed cavity-backed antenna B with enhanced gain. (a) Inner view of "component 1." (b) Top view of the "component 2."

TABLE II
DIMENSIONS OF CP CAVITY-BACKED SLOT ANTENNA (UNIT: mm)

Parameters	*a'*	*b'*	*c'*	*l'*	*w'*	*w1'*
Values/mm	55	55	45	39.6	4	2
Parameters	*l1'*	*w2'*	*l2'*			
Values/mm	40	2	38			

From Table I, an LHCP can be realized when $l1>l2$. Similarly, the right-hand CP (RHCP) can be realized when $l1<l2$. Fig. 7 is the photographs of the fabricated CP cavity-backed slot antenna showing the inner view and outside view of the proposed CP antenna. The peak realized gain of this proposed CP cross-shape slot antenna is 5.91 dBic.

B. CP Cavity-Backed Slot Antenna With an Enhanced Gain

The gain of the proposed antenna A can be enhanced by replacing the cross-shape slot with four radiative slots opened on the metal cover as shown in Fig. 8. The geometry of the structure is illustrated in Fig. 8, namely antenna B. The rotating angle θ' of the feeding slot is set as 45° to equally excite two orthogonal modes. The detailed dimensions of the antenna are illustrated in Table II. Similar to the antenna A, the two excited orthogonal cavity modes are perturbed by the four slot antenna elements to form a CP EM wave. The four pictures in Fig. 9 display the four states of the electric field. It shows that the polarization of

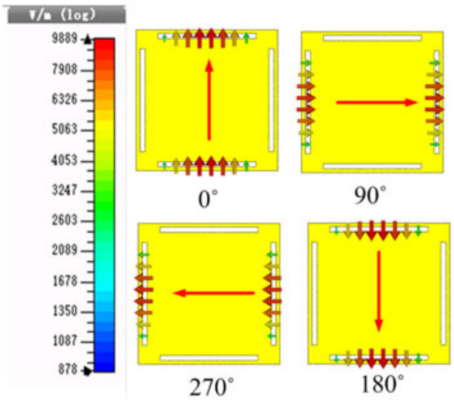

Fig. 9. Electric field distributions of the CP slot antenna B with enhanced gain, four states of the electric field when $t = 0$, $T/4$, $T/2$, and $3T/4$ (T is a period of time).

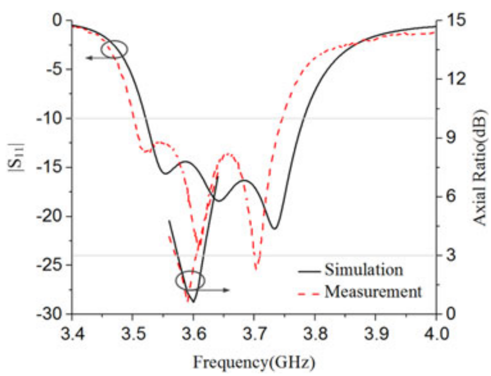

Fig. 10. AR and the reflection coefficient of the improved CP antenna B.

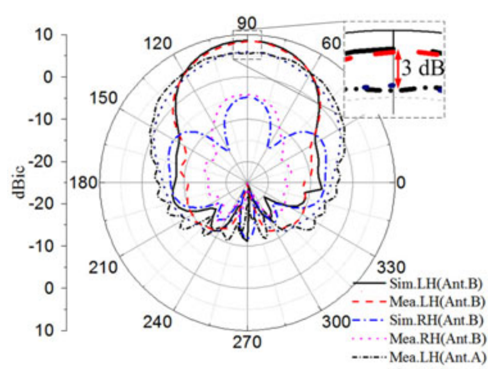

Fig. 11. Simulated and measured radiation patterns at 3.59 GHz.

the antenna is an LHCP wave. In this part, $l1'>l2'$ makes the antenna an LHCP wave, whereas $l1'<l2'$ makes the antenna an RHCP wave. Fig. 10 indicates the simulated and measured ARs. The AR curve exhibits a minimum at the frequency of 3.59 GHz in measurement. Moreover, the simulated and measured radiation patterns are given in Fig. 11. The peak realized antenna gain is equal to 8.8 dBic, which is obviously 3 dB higher than that of antenna A. It is noteworthy that although there is 3 dB gain enhancement in antenna B, the cavity size of both antenna B

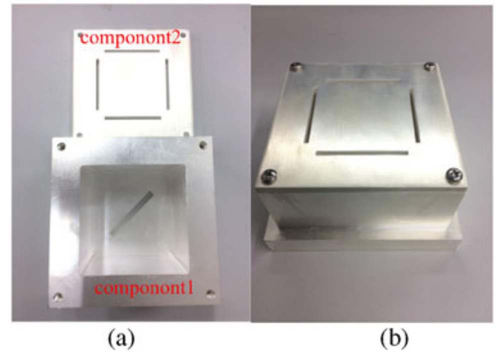

Fig. 12. Photographs of the fabricated CP cavity-backed slot antenna B. (a) Inner view. (b) Top view.

and antenna A is the same. This provides an attractive feature of miniaturization of waveguide feeding network. Fig. 12 shows the photographs of antenna B with its inner and outside views.

IV. Conclusion

A class of CP cavity-backed slot antennas with enhanced gain is presented in this letter. A LP cavity-backed slot antenna is at first proposed to verify waveguide theory. Based on this LP antenna, a CP radiation is achieved by using a cross-shape slot. As verified in simulation and test, an enhanced gain is achieved by replacing the cross-shape slot with a four-slot antenna without adding extra volume to the original structure. In this way, antenna B has 3 dB antenna gain enhancement than does antenna A. This provides a good solution for miniaturization of a waveguide feeding network of CP antenna array. At least half of the waveguide T-junction can be saved using this proposed method. The two proposed CP cavity-backed slot antennas are fabricated and measured. A good agreement between the simulated and measured results is attained in the operating band. These two CP antennas were fabricated using full metal cavity and fed by rectangular waveguide. Compared with those antennas with PCB, the proposed antenna has advantages of high efficiency, low loss, and high power capacity.

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