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Research Article

Substrate Integrated Waveguide Fed Cavity Backed Slot Antenna for Circularly Polarized Application

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A novel planar low-profile cavity-backed slot antenna for circularly polarized applications is presented in this paper. The low-profile substrate integrated waveguide (SIW) cavity is constructed on a single PCB substrate with two metal layers on the top and the bottom surfaces and metallized via array through the substrate. The SIW cavity is fed by a SIW transmission line. The two orthogonal degenerate cavities resonance TM_{110} mode are successfully stimulated and separated. The circularly polarized radiation has been generated from the crossed-slot structure whose two arms' lengths have slight difference Its gain is higher than 5.4 dBi, the peak cross-polarization level is lower than −22 dB, and the maximum axial ratio (AR) is about −1.5 dB. Compared with the previous presented low-profile cavity-backed slot antenna work, the spurious radiation from the proposed antenna's feeding element is very low and it has less interference on the following circuits.

1. Introduction

With development of modern wireless communication technology, high-performance antennas become more and more important. Cavity-backed antenna, as one of high gain antennas, has been extensively investigated by many researchers. The conventional cavity-backed antenna is very bulky. Its cavity height is roughly one-quarter wavelength. It is also heavy and expensive because it is fully metallic and is fabricated by mechanical process. Some novel cavity-backed antennas are presented in [1–5], in which the substrate integrated waveguide technique is employed in the cavity design. The backed cavity is fully constructed on a single PCB substrate with metallized via array through the substrate and two metallic layers on the top and the bottom surfaces of the substrate. When some conditions are satisfied, the attenuation constant will be small enough and the leakage from two adjacent vias can be neglected. Then, the novel SIW cavity is equivalent to the conventional metallic cavity. These novel cavity-backed antennas can keep the high radiation performance of conventional cavity-backed antenna, such as high gain, low back lobe, and low cross-polarization level. They can also retain the advantages of the conventional planar antenna, such as low profile, light weight, good conformability, and seamless integration with planar circuits. They can be easily fabricated by using the low-cost single-layer printed circuit board (PCB) process.

Linearly polarized SIW cavity-backed slot antenna has been presented in [1], in which the antenna is fed by transition between microstrip lines and grounded coplanar waveguides (CPWG). Dual frequency, dual linearly polarized SIW cavity-backed antenna has been investigated in [2], in which a single CPWG feed element is used to stimulate two cavity resonances in the SIW cavity. Circularly polarized SIW cavity-backed antenna also has been discussed in [2], in which a single CPWG is used to excite two orthogonal and degenerate cavity resonances in a circular or square SIW cavity. In order to avoid the spurious radiation generated by the opening feed structures such as microstrip line, coplanar waveguide (CPW), and CPWG, a single probe SIW cavity crossed-slot antenna for circularly polarized application has been proposed in [3]. Even though the spurious radiation of the feeding structure has been eliminated, one drawback of

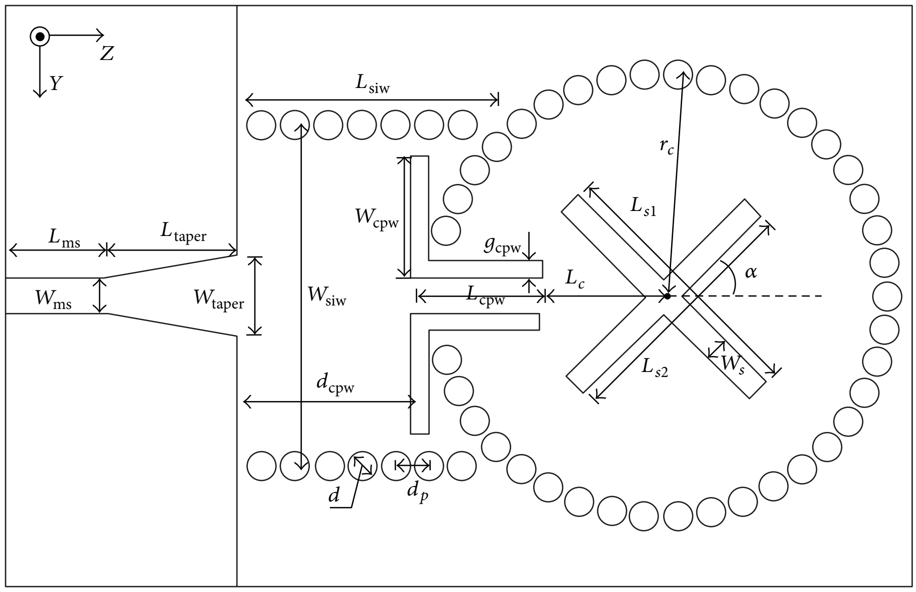


Figure 1: Geometry of the proposed antenna.

hardly planar integration has been introduced for the probe feed.

A CPW-fed filtering antenna has been presented in [4], in which its filtering performance is generated by two cascading SIW cavities. Slot etched in the SIW cavity metallic surface not only serves as a radiator but also acts as an equivalent load to the filter. This filtering antenna is fed by a composite structure which comprise CPWG and SIW. A closely spaced array of SIW cavity-backed slot antennas has been investigated in [5], in which a low mutual coupling antenna array has been achieved. The presented antenna array is also fed by a composite structure comprising stripline and SIW, and then a low mutual coupling is achieved by the fully closed feeding structure. Circularly polarized SIW cavity-backed patch antennas with two different feeding transitions are shown in [6], in which the two feeding transitions are constructed by microstrip line to SIW and coax line to SIW. The circularly polarized SIW cavity-backed square ring slot antenna is shown in [7], in which the antenna is fed by coax line to SIW transition.

In this paper, we propose a SIW cavity-backed crossed, slot antenna for circularly polarized application. Its feeding network comprise CPWG and SIW. The whole antenna including its feeding element is a completely closed structure except the crossed-slot radiator. The spurious radiation generated by the feeding element is suppressed and the mutual coupling interference between the proposed antenna and the following circuits is greatly reduced.

2. Antenna Design

Geometrical configuration of the proposed circularly polarized SIW cavity-backed crossed-slot antenna is shown in Figure 1. Its circular backed cavity is constructed by metallized vias' arrays on a single substrate. Crossed slot etched on the bottom metallic surface is used as radiator, whose

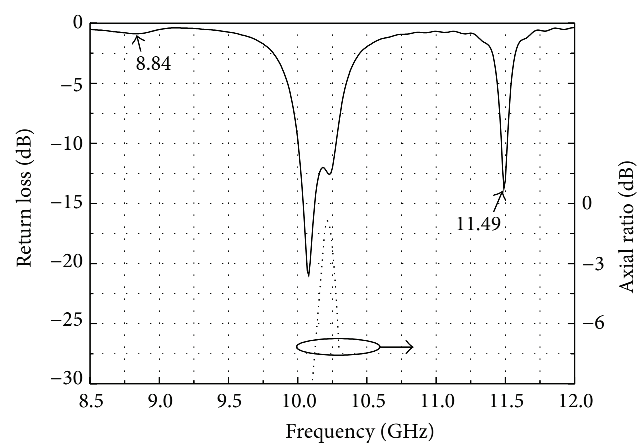
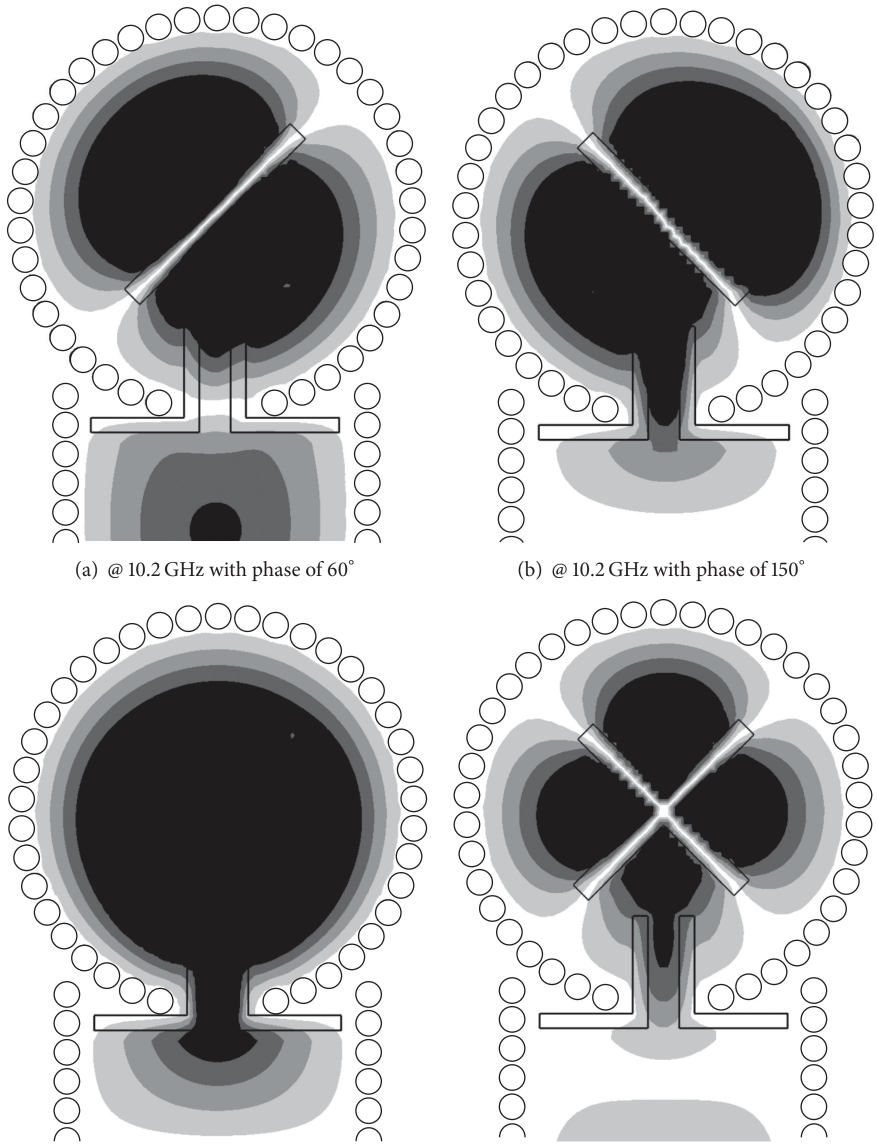


Figure 2: Simulated return loss and axial ratio of the proposed antenna.

two arms are orthogonal and has the same width W_s and different lengths of L_{s1} and L_{s2}. A composite feeding element, comprising SIW and CPWG, is located at the angular bisector of the crossed slot and adopted to excite the circular SIW cavity. A transition between microstrip and SIW is introduced for convenience measurement. A sample of the proposed antenna has been discussed, and its detailed geometrical parameters are listed in Table 1.

Full wave simulations of the proposed antenna have been carried out by using commercial software, and its simulated return loss and the axial ratio (AR) are plotted in Figure 2. Frequency ranges of its return loss less than −10 dB are 10.04~10.28 GHz and 11.47~11.52 GHz and the measured AR more than −3 dB is 10.16~10.26 GHz, respectively. Frequency response of the proposed antenna is caused by some different cavity resonances generated in the SIW cavity. From Figures 3(a) and 3(b), it can be found that two cavity resonances



(a) @ 10.2 GHz with phase of 60°

(b) @ 10.2 GHz with phase of 150°

(c) @ 8.84 GHz

(d) @ 11.49 GHz

Figure 3: Electric field profiles of the proposed antenna.

TM_{110} have been generated in the circular SIW cavity at the frequency range of 10.04~10.28 GHz. These two orthogonal and degenerate cavity resonances TM_{110} can be successfully stimulated by tuning the two arms' lengths of the crossed slot with a slight difference.

The dominant electric field at the two sides of the crossed slot's two arms has opposite phase. There are transverse electric fields across the slot arms; thus, energy can be radiated into outer space by the crossed slot. Radiations from the two orthogonal arms have equal magnitude for the two orthogonal and degenerate resonances TM_{110}. A 90° phase difference has been achieved by tuning the length difference between the crossed-slot two arms. Then, circular polarization is produced in the far field. The simulated AR of the proposed antenna plotted in Figure 2 shows that the circularly polarized radiation has been generated at 10.16~10.26 GHz.

From Figures 2 and 3(c), it can be found that a weak TM_{010} cavity resonance has been stimulated at 8.84 GHz but no radiation can be generated for its field distribution. The TM_{210} cavity mode resonating at 11.49 GHz is a quadrupole mode. The electric field across the crossed-slot two arms has opposite polarity at its half two ends of each arm, and thus only a very weak radiation is produced.

3. Antenna Performance

A prototype of the proposed antenna is shown in Figure 4, which is fabricated by using low-cost PCB process. The whole antenna is constructed on a single-layer Rogers Duroid 5880 substrate with two copper films on its top and bottom surfaces, with permittivity ε_r of 2.2, loss tangent of 0.001, and thickness h of 0.5 mm.

Table 1: Geometrical parameters of the proposed antenna.

L_{ms} (mm)	4.0
L_{taper} (mm)	5.4
L_{siw} (mm)	8.0
L_{cpw} (mm)	4.2
g_{cpw} (mm)	0.7
L_{s1} (mm)	10.8
W_s (mm)	1.0
r_c (mm)	9.1
r (mm)	0.5
W_{ms} (mm)	1.45
W_{taper} (mm)	3.2
W_{siw} (mm)	14
W_{cpw} (mm)	5.0
d_{cpw} (mm)	7.0
L_{s2} (mm)	10.2
L_c (mm)	4.9
d_p (mm)	1.35
α (deg)	45

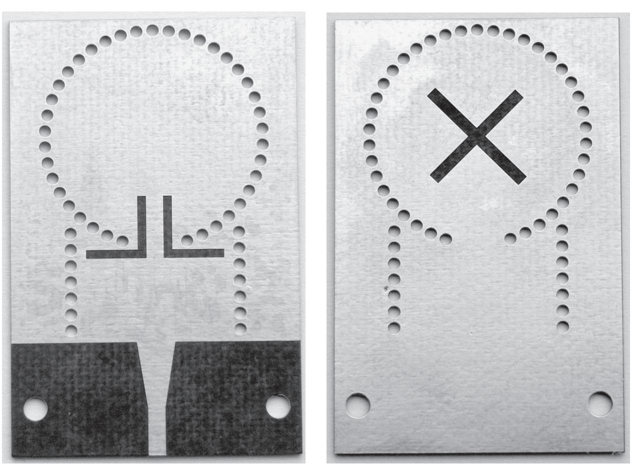


Figure 4: Photographs of the fabricated antenna.

Return loss measurements were carried out by an Agilent vector network analyzer. As shown in Figure 5, the measured return loss has a slight discrepancy compared with the simulated one, which is mainly caused by additional transition between microstrip line and SMA connector and slightly caused by fabrication error of the arm length.

Measured gain of the proposed antenna at the boresight direction is shown in Figure 6, in which there is a slight frequency shift between the measured result and the simulated one. The measured gain is slightly smaller than the simulated one. But all of them are more than 5.3 dBi and they are obviously more than that of the conventional planar patch or slot antennas with the same profile.

The measured AR of the proposed antenna at the boresight direction versus frequency has been plotted in Figure 7, in which the AR is defined as a ratio of the minor axis to the major axis of the polarization ellipse. The measured AR curve is in agreement with the simulated curve. There is also a slight frequency shift of 0.1 GHz between the measured peak AR and the simulated peak AR. This slight discrepancy may be caused by the fabrication error of the crossed-slot arm length. The phase difference between the radiations generated by the crossed-slot two arms is mainly determined by the two arms' length difference, which affects the AR directly. Both the measured AR and the simulated one change rapidly with frequency. It is an inherently characteristic of a single-feed low-profile circularly polarized antenna. The phase variations with frequencies are more rapid than that of the magnitudes. The phase error has stronger influence on the AR than that of the magnitude error. The 3 dB AR bandwidth is the limiting factor in the operating bandwidth of the proposed antenna.

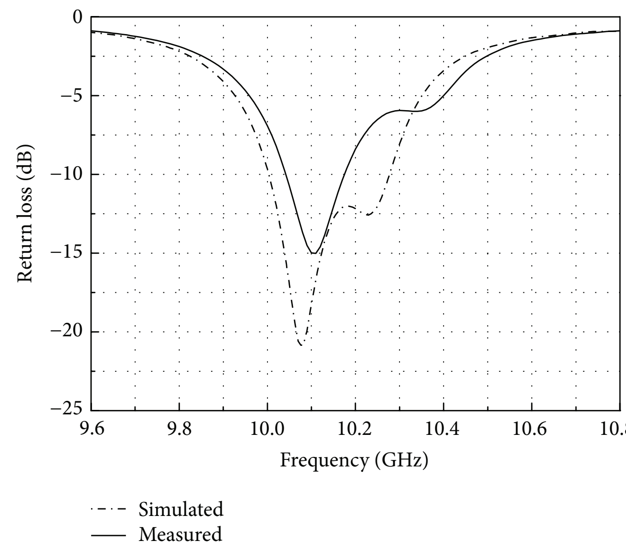


Figure 5: Measured return loss of the fabricated antenna compared with its simulated result.

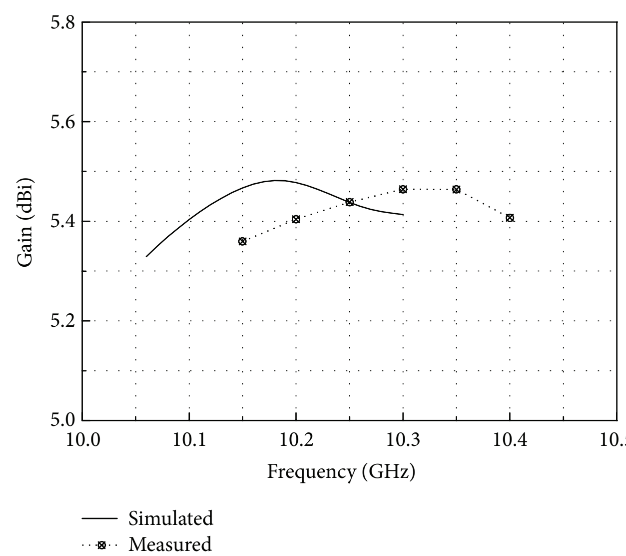


Figure 6: Gain of the fabricated antenna at the boresight direction.

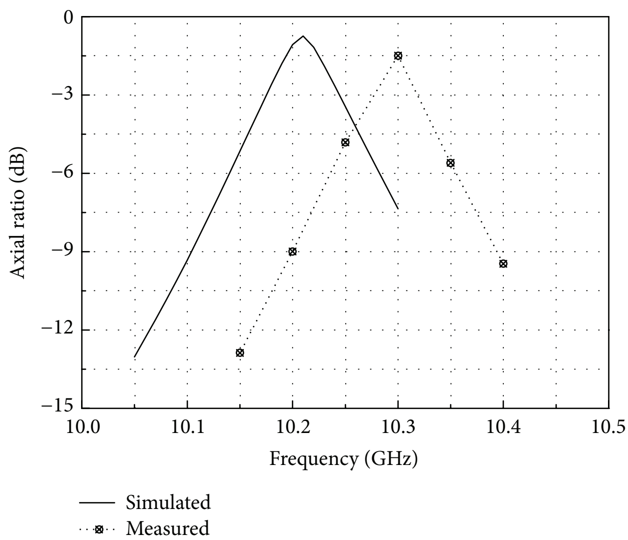


Figure 7: AR of the fabricated antenna at the boresight direction.

In order to improve the AR bandwidth, multi-feed configurations such as series feed and parallel feed can be adopted.

Radiation patterns at 10.3 GHz of the fabricated antenna in its two orthogonal cut planes have been plotted in Figure 8. From the figure, it can be found that a left-hand circular polarization (LHCP) radiation is generated from the fabricated antenna because its L_{s1} is more than L_{s2}. Right-hand circular polarization (RHCP) radiation can be easily achieved by setting the arm length L_{s1} less than L_{s2}.

In the x-y cut plane, measured half-power bandwidth (HPBW) of LHCP is 105° (135°~240°). Measured cross-polarization level within HPBW in this plane is lower than −16 dB. Circular polarization operating angle θ_{cp}, characterized as the angle off boresight direction for which AR is more than −3 dB, is about 105° (120°~225°). In the x-z cut plane, measured HPBW of LHCP is 105° (135°~240°). Cross-polarization performance in this plane is better, whose measured result is lower than −18 dB within the HPBW. The measured θ_{cp} is about 105° (135°~240°). The measured peak cross-polarization level and the back lobe level are about −22.7 dB and −15.8 dB, respectively. From the measured results, it can be found that the fabricated antenna presents a satisfactory circularly polarized radiation performance.

4. Conclusions

A single SIW-fed cavity-backed crossed-slot antenna is presented in this paper. Its circularly polarized radiation is obtained by tuning the length difference between two arms of its cross slot. The whole antenna including its SIW feed and SIW backed cavity is constructed by metallized via array on a single substrate. The proposed antenna has low profile and can be conveniently manufactured. Single SIW is adopted to stimulate the circular SIW cavity and excite the two orthogonal and degenerate TM_{110} cavity resonances. The presented antenna provides promising circularly polarized radiation performance, which has been validated by the measurements.

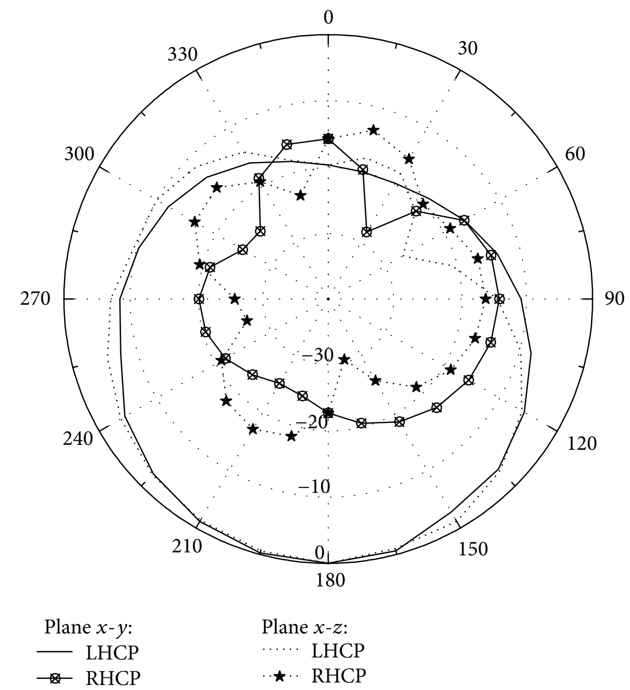


Figure 8: Radiation patterns of the fabricated antenna at 10.3 GHz.

Its measured gain is higher than 5.3 dBi, the maximum AR is −1.5 dB, and the peak cross-polarization level and the back lobe level are lower than −22.7 dB and −15.8 dB, respectively.

Acknowledgments

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