A New Kind of Circularly Polarized Leaky-Wave Antenna Based on Corrugated Substrate Integrated Waveguide

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***Abstract*—In this paper a novel circularly polarized (CP) leaky-wave antenna (LWA) based on the corrugated substrate integrated waveguide (CSIW) is proposed. It is composed of eight slot pair elements on top surface of the CSIW, and is designed to operate around 16.4GHz. The design approach is based on the analysis and optimization of the aperture fields of one radiation unit cell in order to produce good performance of circular polarization. The simulation results show that broadside radiation can be realized that is useful in practical application, and good axial ratio (AR) can be obtained in the main beam direction.**

Keywords- leaky wave antenna; circular polarization; SIW; slot; array

I. INTRODUCTION

The substrate integrated waveguide (SIW) has attracted considerable attentions in recent years [1, 2]. It is similar to the conventional rectangular waveguide but with more advantages than conventional one. The SIW has attractive characteristics, such as high power capacity, lower profile, and smaller leakage loss. In addition, it can be simply fabricated by the printed circuit board (PCB) technique.

Considering the obvious advantages of the SIW, many types of leaky-wave antennas (LWAs) have been developed using SIW structures [3-5]. The SIW LWA has no surface-wave mode and spurious mode which can be found in some other types of LWAs with open planar structures.

The circularly polarized (CP) antennas have been widely used in modern communication system for many years because of its anti-interference ability and well receiving performance. Recently, CP antennas based on the SIW technology were proposed. This kind of antennas have low profile and are easy to be integrated with integrated circuits [6-9]. The cross-slot SIW antennas for CP applications with different feeding methods were presented in [6] and [7]. A CP LWA based on SIW with H-shaped slots was proposed in [8]. A SIW top-wall compound slot array antenna was reported in [9], and this type of slot has been proven to be more suitable than the single compound slot for the planer waveguide structure, which has a large width-to-height ratio as SIW or CSIW [9]. All of these designs have good performance of circularly polarization, while most of them keep a small beam tilting angle around 45°.

Although the SIW can be easily fabricated, the metal via-hole array acting as the equivalent electric wall is still a problem, especially for the fine structure. Consequently, a novel structure of SIW -- corrugated substrate integrated waveguide (CSIW) was proposed in [7]. The open-circuit quarter-wavelength microstrip stubs were introduced to form a perfect electrical conductor (PEC) boundary condition at a particular frequency instead of the metal via-holes at both lateral sides of the waveguide. It has been verified that the CSIW can serve as a rectangular waveguide at a particular frequency and support the TEm0 mode. However, this novel type of waveguide has not been used in antenna design yet.

In this paper, we propose a CP leaky-wave antenna based on the CSIW. This CP antenna is designed as a matched two-compound slot pair array. The slot is similar to that in the conventional SIW in [9], but it was optimized intensively in this paper in order to be suited for the CSIW structure. The near electrical field of the slot pair is analyzed and an eight-element CP CSIW LWA is studied in detail.

II. ANTENNA DESIGN

A. The CSIW structure

The microstrip stubs on both of the waveguide sides are arranged with the same spacing period *P*, as shown in Fig.1. The stub width w_s is equal to 0.5*P*. The length of the microstrip stub l_s is set to 3.44 mm at 16.4 GHz, which is determined by one quarter of the guide wavelength λ_g in theory. The CSIW waveguide width a is chosen to the equivalent width of the SIW other than the real width. To make sure that TE_{m0} mode can be

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supported, both the l_s and the substrate thickness h should be much smaller than the width a. Theoretically, the CSIW can be regarded as a rectangular waveguide only at a particular frequency point accurately, but actually the waveguide effect can expand to a small frequency range. Fig.2 shows the electrical field distribution on the CSIW top-wall at 16.4 GHz. Obviously, the CSIW can support TE_{10} mode very well.

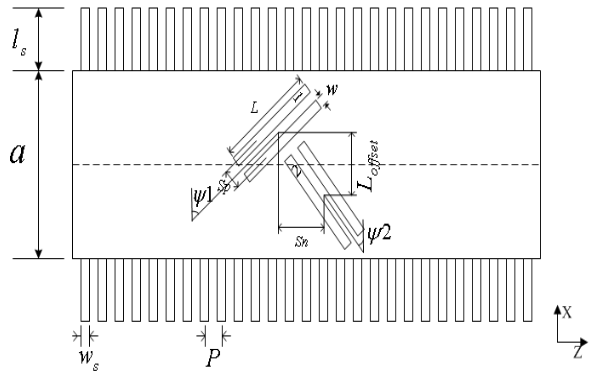


Figure.1 One compound slot pair on CSIW

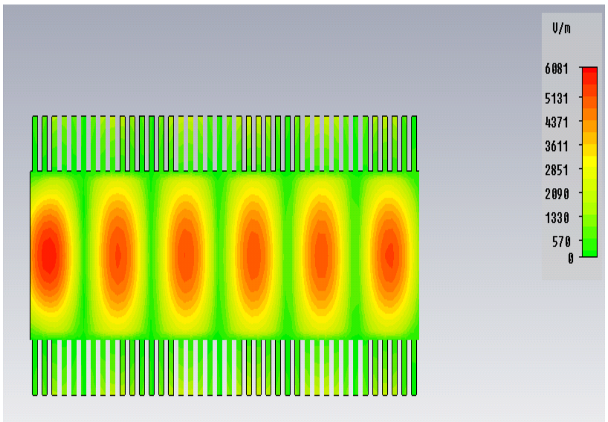


Figure.2 The electrical field at 16.4 GHz

B. Compound slot pair

The top view of the one compound slot pair on CSIW is shown in Fig.1. The w and L are the width and length of each single slot respectively. Two parallel and identical slots are set as a pair, and the distance between the centers of the two slots is denoted by S_p. The other pair of slots is moved along the longitudinal direction as shown in Fig. 1, and the distances between the centers of the two slot pairs are S_n in longitudinal direction and L_{offset} in the transverse direction respectively. The two pairs of slots are nearly perpendicular to each other to realize the circular polarization. The angles between the slots axes and the x-axis are ψ_1 and ψ_2 respectively, as shown in Fig. 1.

To realize circular polarization, the directions of aperture fields on the two pairs of slots have to be orthogonal to each other and with a phase difference of $\pi/2$.

III. SIMULATION

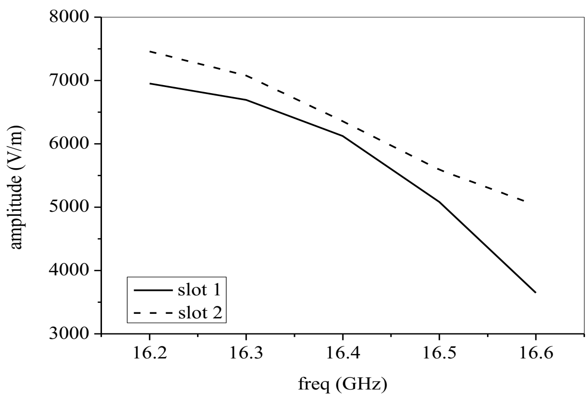
A. Radiation unit cell of the slot pair

Rogers 5880 laminate with permittivity of ε_r = 2.2 and loss tangent of 0.0009 is employed as the substrate of the CSIW LWA antenna. The substrate has a thickness of h = 1.5748 mm. To achieve a low axial ratio (AR), the structural parameters of the radiation unit cell are optimized, and the final values are shown in Table I.

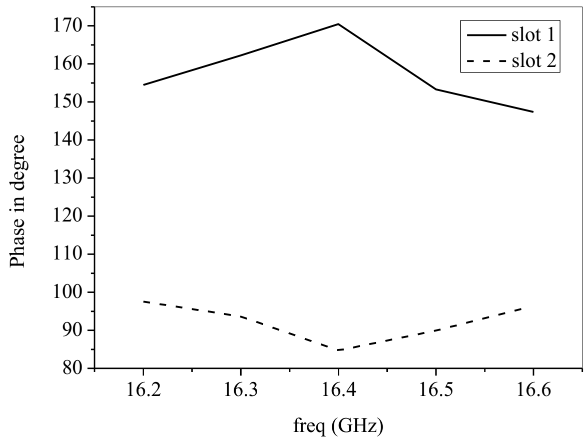
Table.I Parameters of the slot pair

Parameter	value
L	6.0 mm
w	0.5 mm
S_n	2.525 mm
S_p	0.7 mm
ψ_1	45°
ψ_2	45°
L_{offset}	3.78 mm
a	10.77 mm
P	0.1 mm
w_s	0.5 mm
h	1.5748 mm
l_s	3.44 mm

The field at the center point on each slot is picked up for analyzing. As well known, the field vector is perpendicular to the slot axis since the slots are very narrow. Fig. 3 shows the amplitudes and phases of the fields on slot 1 and slot 2 as shown in Fig. 1. It can be observed that at the designed frequency 16.4GHz, the field amplitudes on the two orthogonal slots are close to each other, and the phase difference is almost 90°. If the frequency is getting lower or higher, the amplitude difference will become greater and the phase difference will also shift away from 90°. As a result, the AR at 16.4GHz is inferred to be better than other frequencies.



(a) Amplitudes



(b) Phases

Figure.3 Variations of field amplitudes and phases at centers of different slots with the frequency

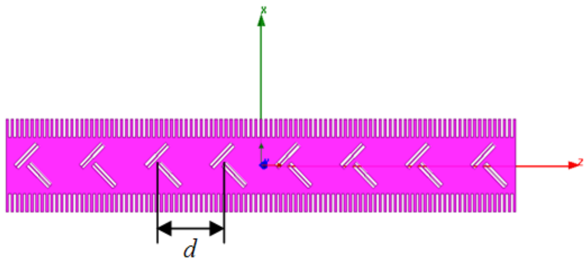


Figure.4 Top view of the eight-element CSIW CP leaky-wave antenna

B. The eight-element CSIW CP LWA

As shown in Fig. 4, an eight-element CP LWA with two-compound slot-pairs linear array is simulated with Ansoft HFSS, the parameters of the radiation unit cells are in Table I. The period between each pair of slots is d = 13.1 mm, as shown in Fig. 4.

Fig.5 and Fig.6 give the simulation results of the S-parameters and the normalized attenuation constant of the CSIW CP LWA. Within the designed frequency band from 16.2 GHz to 16.8 GHz, S11 is less than -10dB. At the designed operation frequency 16.4 GHz, S11 is -13.5 dB and S21 is -15 dB. Therefore, the antenna efficiency can be calculated using the following expression

$$\eta = 1 - S_{11}^2 - S_{21}^2 \quad (1)$$

and we can get the antenna efficiency is 92.7% at 16.4 GHz.

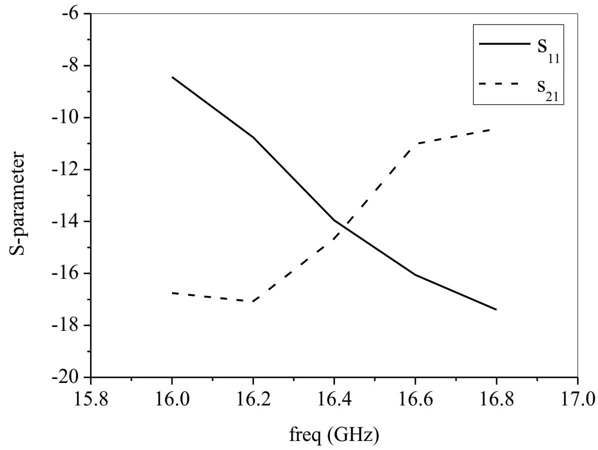


Figure.5 The *S*-parameters of the eight-element CSIW linear array

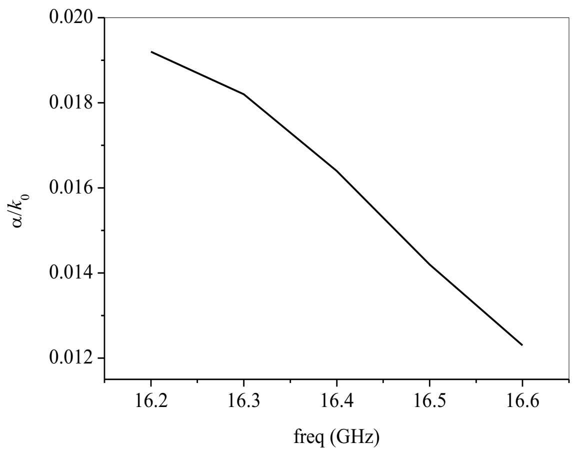


Figure.6 The attenuation constant of the CSIW CP LWA

The normalized radiation pattern of the linear array in YOZ plane at 16.4 GHz is shown in Fig.7. It can be observed that the main beam direction θ_M is about 89°, so the broadside radiation is realized which is more useful in practical application. The 3 dB beam width $\triangle_\theta$ is 10.4° and the SLL is -3.9dB. The radiation patterns at a lower frequency of 16.2 GHz and a higher frequency of 16.6 GHz are also given in Fig. 7, showing a continuous beam scanning property in a small angle range from 90° to 87°.

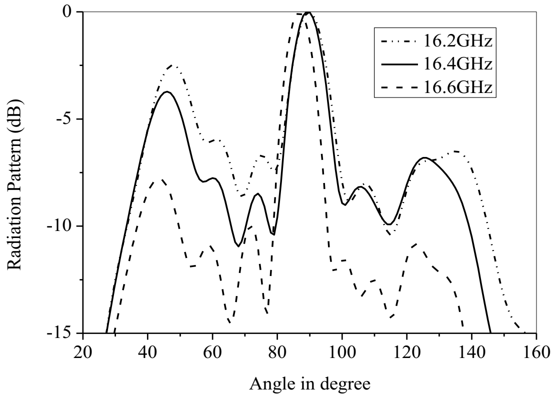


Figure.7 The normalized radiation pattern in YOZ plane

Fig. 8 shows the axial ratio of the CSIW CP antenna within the frequency range of 16.2GHz~16.6GHz. The AR is 0.73 dB at the maximum beam direction at 16.4 GHz, and the 3 dB angle range for CP is about 7°. At 16.2 GHz, the AR and the angle range are 1.83 dB and 6°. When the frequency increases to 16.6 GHz, the AR increases to 2.46 dB. The reason for the worse AR at non-center frequency is the leakage of the quarter-wave-length microstrip stubs. Although the CSIW can be regarded as a rectangular waveguide supporting the TE_{10} mode within a frequency range, the ability of restricting the waves would be weakened if the CSIW is not working at the specific frequency point. And then the two orthogonal components of the CP far fields would be influenced by the leakage by the microstrip stubs, which lead to a worse AR. The AR as a function of frequency is showing in Fig.9, demonstrating that the useful AR bandwidth is approximately from 16.1 to 16.7 GHz, which is 3.6 % around 16.4 GHz.

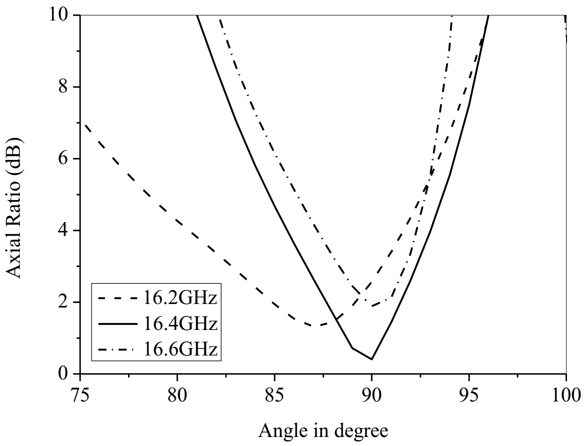


Figure.8 The axial ratios of the CSIW eight-element leaky-wave antenna for different frequencies

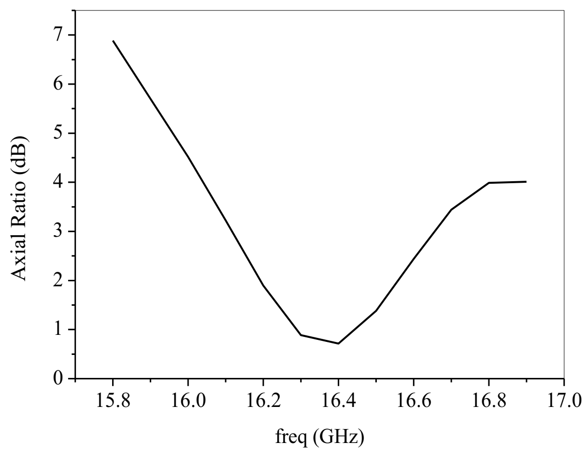


Figure.9 The variation of the axial ratio with frequency

IV. CONCLUSION

In this paper, a novel circularly polarized LWA based on the CSIW is proposed. An eight-element two-compound slot-pair antenna is simulated and analyzed. The CP antenna can achieve 0.73 dB of AR in the main beam direction. The relative AR bandwidth is about 3.6%, and the radiation efficiency at center frequency 16.4 GHz is about 92.7%. Compared with the CP antennas in [3-5], broadside radiation can be realized by the proposed antenna which is more useful in practical application. Compared with the conventional SIW antennas, the proposed antenna can be more easily fabricated without via-holes.

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