Composite Right/Left-Handed Substrate Integrated Waveguide Leaky-Wave Antenna Array with Low Sidelobe Level and High Gain

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***Abstract*—Composite right/left-handed (CRLH) substrate integrated waveguide (SIW) leaky-wave antenna array with low sidelobe level and high gain is proposed. By controlling leakage amount of each interdigital slot etched on the broadside of the SIW, the sidelobe level of the antenna can be reduced effectively. A four-way SIW power divider with Chebyshev current distribution in magnitude is proposed to improve the main lobe and to suppress the sidelobe. The simulated results show that both the gain and radiation efficiency are improved by using antenna array. The proposed CRLH antenna array has a sidelobe level of -13.3dB and a high gain up to 23.67dB at 5.8GHz.**

Keywords—Composite right/left handed (CRLH), leaky-wave antenna (LWA), substrate integrated waveguide (SIW), sidelobe level (SLL), Chebyshev current distribution

I. INTRODUCTION

The left-handed material is a synthetic structure with a negative permittivity and permeability. It was proposed by V. G. Veselago, a former Soviet scientist, in 1968 [1]. Different from right-handed materials, left-handed materials have some particular electromagnetic properties, such as, inverse Cherenkov radiation, reversed Doppler effect, negative refraction characteristics and so on [2]. When used in microwave and millimeter-wave systems, composite right/left-handed (CRLH) structures show unique and favorable characteristics, for example, supporting both the backward and forward waves, and even the waves with infinite-wavelength can be supported in the structure [3]. Because of these special characteristics of CRLH structure, it has been widely used in design of leaky wave antennas, which can achieve continuous beam scanning from backfire to endfire by varying the frequency [4].

In this paper, the right/left-handed transmission line structure is achieved by the "Z" groove etching on the surface of substrate integrated waveguide (SIW). Transversely slotted SIW leaky wave antennas (LWA) have shown its advantages of high gain, small size and simple design. There are several ways to reduce the sidelobe of transversely slotted leaky wave antennas, one of the method is to change the radiation using different antenna apertures. The transversely slotted leaky wave antenna proposed in [5] has a non-uniform slot width which varies in geometric progression to reduce sidelobe level. In [6], the Taylor aperture distribution of the proposed antenna is achieved by tapering the slots length. In this paper, the leakage rate of the proposed antenna was controlled by changing the geometrical dimensions of the "Z" groove, so that it can realize a Taylor aperture distribution.

In order to improve the main lobe and reduce the sideloble level, a four-way SIW power divider is designed to achieve the Chebyshev current distribution. Unequal power division of the four-way SIW power divider is achieved by using a coupling window defined by the step 'ss' at the junction [7].

II. DESIGE OF CRLH SIW LWA ARRAY

A. Unit Cell of CRLH SIW

Fig.1 shows the structure of a unit cell of the CRLH SIW LWA. The equivalent circuit of this unit structure is shown in Fig.2. A CRLH transmission line consists of a series inductance L_R and a shunt capacitance C_R, which show RH property, and a shunt inductance L_L and a series capacitance C_L, which show RH property. The series inductance and shunt capacitance are inherently parameters of the transmission line. The shunt inductance and series capacitance are provided by the additional metal vias and "Z" slots etched on the top layer of SIW.

The prototype is built on the substrate of Rogers RT5880 with dielectric constant of ε_r=2.2, loss tangent of $\tan\delta$=0.001 and thickness of h=1.575 mm. The parameters of a unit cell are shown in Table 1 (except the parameter y_x).

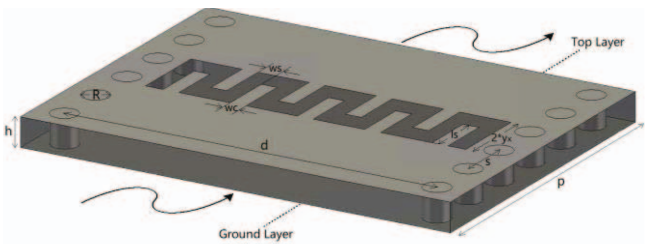

Fig. 1. Configuration of the unit cell of proposed CRLH SIW LWA.

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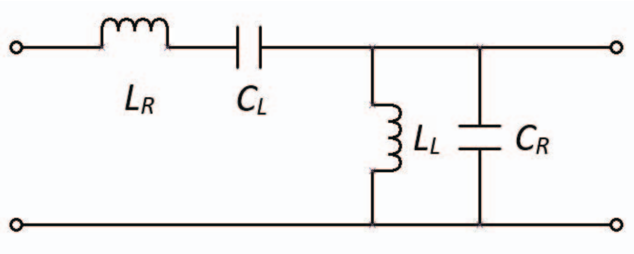


Fig. 2. Equivalent circuit model of the CRLH unit cell.

TABLE I. DIMENSIONS OF UNIT CELL OF THE CRLH SIW

Parameter	*h*	*p*	*d*	*R*
Unit: mm	1.575	18	20.8	1.5
Parameter	*s*	*wc*	*ws*	*ls*
Unit: mm	3	0.89	0.99	3.01

B. LWA with Non-Uniform Unit Cell

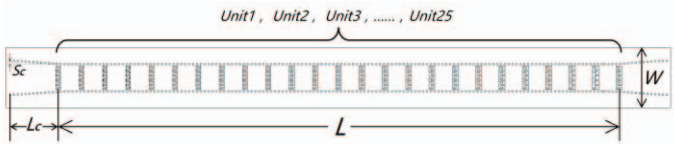
In the application of a leaky wave antenna, the power distribution in the aperture of the antenna can be controlled by changing the leakage of the radiation unit, which will result in a lower SLL. In the study of [8], they found that the leakage amount can be controlled by adjusting the structure of the unit cell, so in this paper, we also apply this method to design the leaky wave antenna.

In order to reduce S_{11}, the distance between the vias increased from 20.8mm to 25.86mm following the laws of cosine functions, as shown in Fig.3 (a). The length of the radiation section of a single antenna is set to *L*. The equivalent width ω_{eff} can be calculated by equations given in [9] (dimensions of the SIW can be found in Table Ⅰ). Total of 25 "Z" slots were etched on the radiation section of the antenna, as indicated by Unit1, Unit2... and Unit25. The proposed antenna was designed to realize a Taylor aperture amplitude distribution A(z) with a sidelobe level of -17 dB. So we can calculate the attenuation constant α(z) by the following formula [10]:

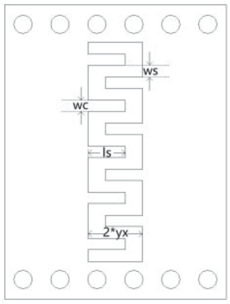
$$\alpha(z) = \frac{0.5 * |A(z)|^2}{\frac{1}{e_r}\int_0^L |A(z)|^2\, dz - \int_0^z |A(z)|^2 dz} \tag{1}$$

In this paper, the efficiency of the antenna e_r is set to 0.95, the calculated attenuation constant is shown in Fig. 4.

Fig. 3 (b) shows dimensions of the "Z" slots. One of the main parameters affecting the attenuation constant α(z) is y_x'. Fig.5 shows the attenuation constant at different frequencies with variable y_x'. The attenuation constant increases with y_x' at 5.8 GHz, as shown in Fig.6. Combining the data in Fig. 4 and Fig. 6, the value of y_x' for each "Z" slot can be easily obtained, which is shown in Fig. 7.



(a)



(b)

Fig. 3. Geometry of the single CRLH SIW LWA, (a) the LWA, (b) the "Z" slots, *W* = 45.77mm, *L* = 432mm, *Lc* = 36mm, *Sc* = 2.53mm.

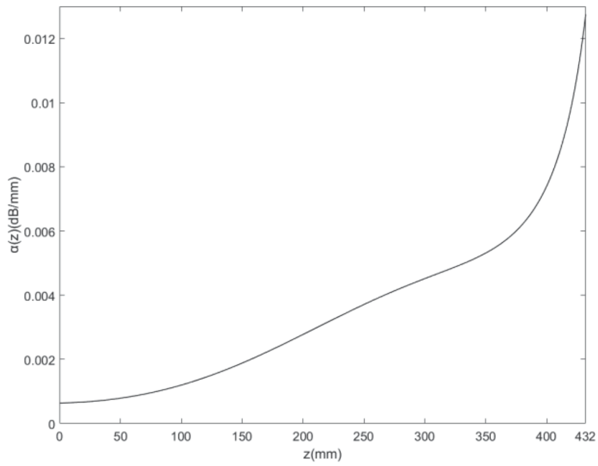


Fig. 4. Attenuation constant α(z) in the aperture of the antenna.

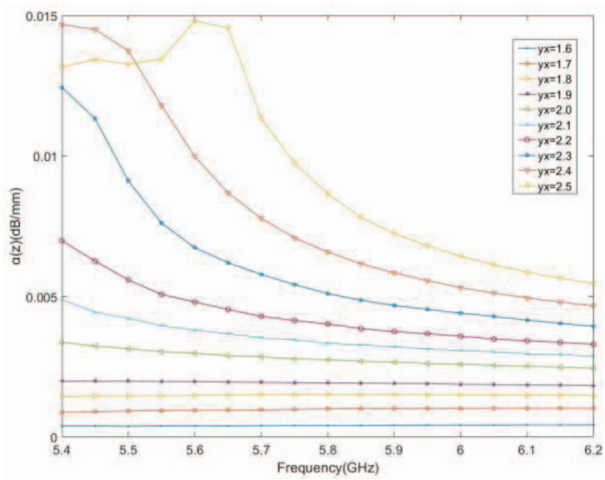


Fig. 5. Attenuation constant at different frequencies with various y_x

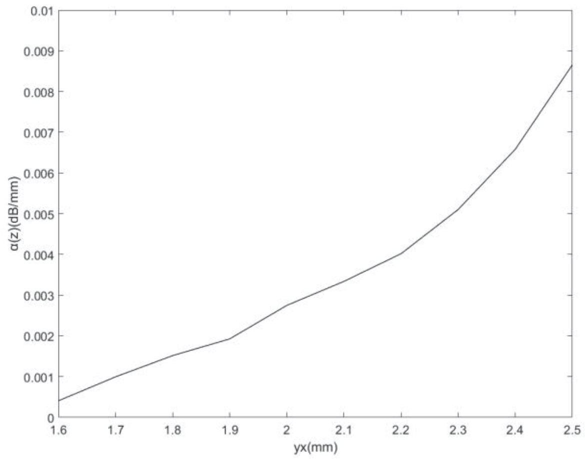


Fig. 6. Attenuation constant at 5.8GHz with various y_x'.

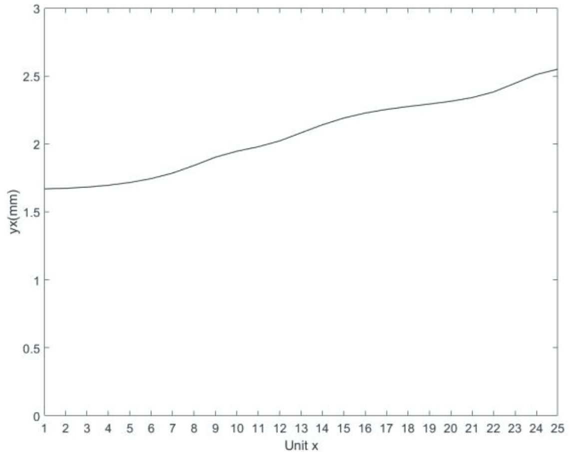


Fig. 7 The value of y_x' of each slot.

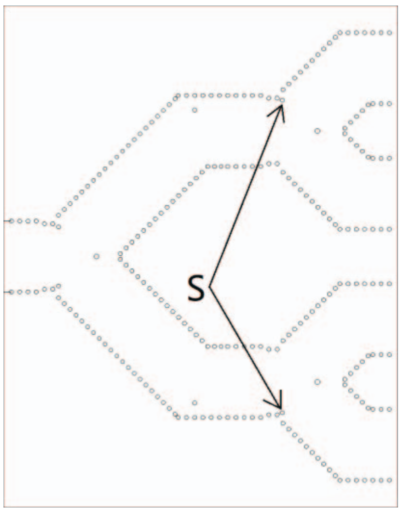


Fig. 8 Four-way power divider with Chebyshev current distribution.

C. The four-way SIW power divider with Chebyshew current distribution

In order to improve the directivity, a four-way Chebyshev broadside antenna array with sidelobe level of -15dB is designed. The distance between the array elements is set to 0.885 wavelength. The ratio of output power is designed to be 1:1.33:1.33:1. The output power ratio was adjusted by two vias 'S' at the junction of the power divider, shown in Fig. 8.

III. Result

Fig. 9 gives the simulated S-parameters and the gain of the proposed Leaky wave antenna array, the bandwidth is 0.8 GHz, from 5.47 GHz to 6.27 GHz, for $|S_{11}| < 10dB$. The radiation patterns of the proposed CRLH antenna with variable y_x' and invariable y_x' ('y_x'=2.3 mm) at 5.8 GHz are shown in Fig. 10. The sidelobe levels of the former and the latter antenna array are -16.3 dB and -14.3 dB, respectively. After varying the parameter y_x' of the slots, there is a noticeable reduction in sidelobe level of 2dB. The radiation patterns of the main beam at frequency 5.8GHz has been shown in Fig. 11 (a) and (b). The 3dB beamwidths in the E-plane and H-plane are 7.6° and 15.3° respectively.

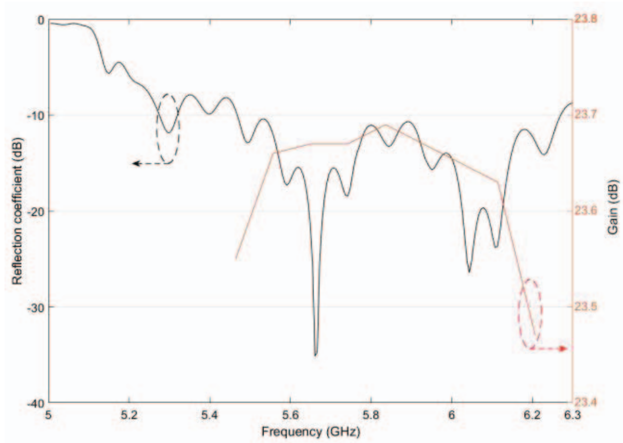


Fig. 9 Reflection coefficient and gain of the antenna array.

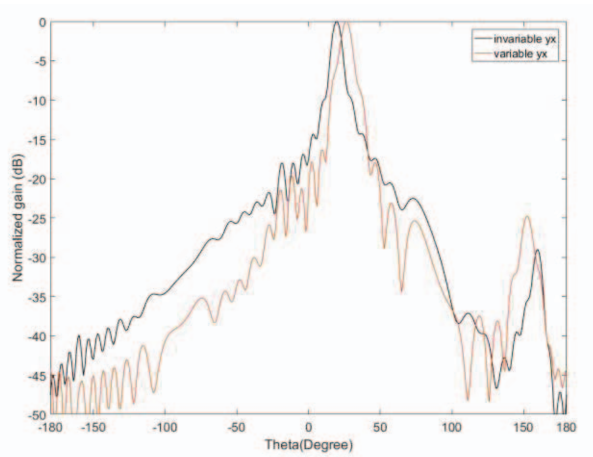
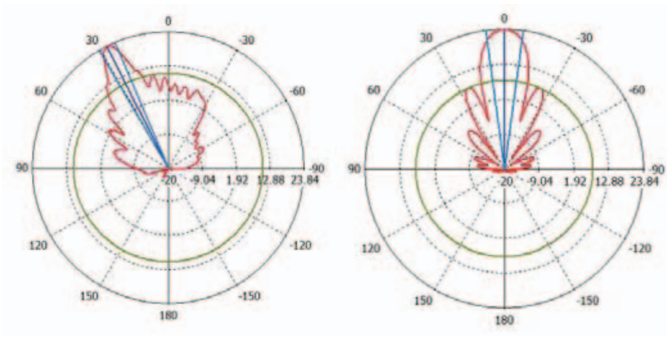


Fig. 10 Radiation patterns of the CRLH antennas with invariable and variable 'y_x' at 5.8GHz.



(a) (b)

Fig. 11 Radiation patterns at 5.8GHz, (a) E-plane, (b) H-plane.

IV. Conclusion

A Composite right/left-handed substrate integrated waveguide leaky-wave antenna array with low sidelobe level and high gain is proposed in this paper. This antenna array achieves a lower sidelobe level of -13.3dB at 5.8GHz by controlling leakage amount of each interdigital slot etched on the broadside of the SIW antenna. The bandwidth of the antenna array is 13.8% with stable gain. The simulated results show that both the gain and radiation efficiency are improved when using the Chebyshev current distribution antenna array, and the gain can up to 23.67dB at 5.8GHz.

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