Design of a Novel Dual-Beam Scanning Leaky-Wave Antenna

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Abstract ─ In this article, a novel dual-beam scanning leaky-wave antenna is proposed and investigated. Antenna parameters, such as return loss, radiation patterns, gain, efficiency and scanning angles, are provided and discussed. Besides its low profile and miniaturized size, the proposed antenna can realize dual-beam scanning and quasi-omnidirectional radiation. Moreover, it provides much design flexibility for real applications. Different simulation software are adopted to verify the accuracy of our design.

Index Terms ─ CRLH TL, dual-beam scanning, LWA, SIW.

I. INTRODUCTION

Over the past decade, novel metamaterial structures, and in particular composite right/left (CRLH) transmission line (TL) metamaterial structures, have led to efficient and more versatile leaky-wave antennas (LWAs). The first papers based on a TL approach of metamaterial dealt specifically with left-handed (LH) TL metamaterials and were published by three different groups [1-3]. This concept matured quickly and led to the first backfire-to-endfire CRLH LWA [4], which exhibits important advantages over conventional LWAs [5]. The conventional LWAs require complex narrow-band feeding circuits due to the harmonic operation, and cannot radiate a true broadside radiation pattern with scanning. The CRLH LWAs offer full scanning capability in its fundamental harmonic with a simple feeding TL. Recently, a CRLH structure based on substrate integrated waveguide (SIW) has been proposed and shown its advantages [6-9].

The developed antenna in this article not only retains the advantages mentioned above but demonstrates a new feature of dual-beam scanning. In this design, the spatial scanning range $(-60^\circ, +60^\circ)$ can be achieved when f varies in the range from 8.8 to 10 GHz in LH region, and $(-60^\circ, +55^\circ)$ can be achieved when f varies from 10 to 12.8GHz in RH region. Thus this antenna realizes the same function as the conventional leaky-wave antennas, but it uses only part of the frequency spectrum. This performance is confirmed by comparing the radiation patterns at different frequencies in the following section.

II. ANTENNA DESIGN

In this design, the prototype is built on the normally used substrate of Rogers 5880 with a relative permittivity of 2.2, a loss tangent of 0.001 and a thickness of 0.508 mm.

A. Unit cell structure and dispersion relation

The balanced CRLH SIW unit cell and its dispersion diagram are shown in Fig. 1(a) and (b), respectively. The dispersion relation for the unit cell is investigated by using Ansoft's HFSS software package and calculated based on the S-parameters from driven mode simulation [10-11]. From Fig. 1 (b), the dispersion curve traverses four distinct regions as frequency increases, where the radiation regions are characterized by a phase velocity larger than the speed of the light. By applying the inter-digital structure and moving the LH region far below the waveguide cut-off frequency, miniaturization can be obtained. It has been shown that the group velocity is nonzero when f=10 GHz despite infinite phase velocity, which allows leaky-wave broadside radiation.

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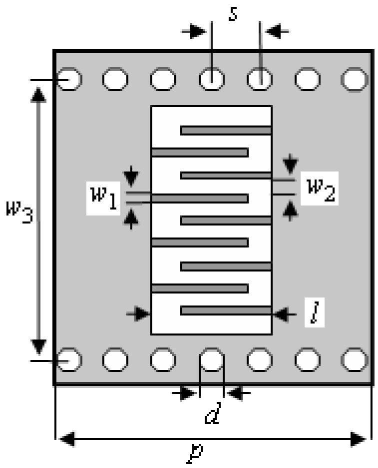
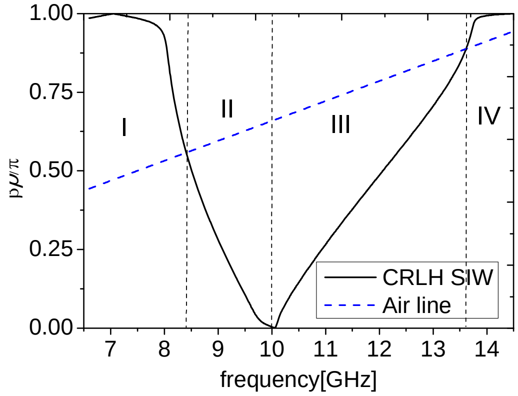


(a)



(b)

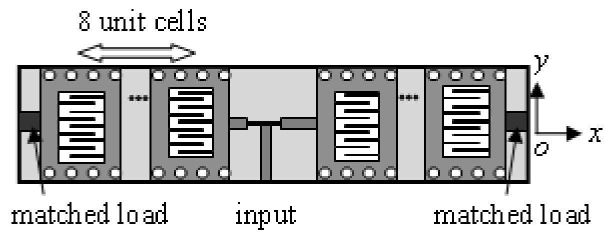
Fig. 1. (a) CRLH unit cell. The parameters are: w_1=0.33mm, w_2=0.45mm, w_3=9.2mm, p=8.2mm, l=3.3mm, d=0.8mm, s=1.45mm, and n=9 (number of fingers). (b) Dispersion diagram of the unit cell (I. LH guided wave region, II. LH radiation region, III. RH radiation region and IV. RH guided wave region).

B. The prototype of CRLH SIW antenna

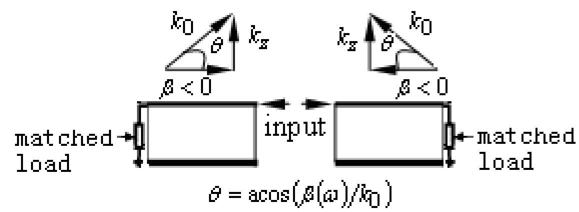
The prototype of CRLH SIW antenna shown in Fig. 2(a) has two paths and each path has eight identical elementary cells. As indicated in Fig. 2(b), the radiation angle of the main beam is straightforward determined by

$$\theta(\omega) = \mathrm{acos}\left(\beta(\omega)/k_0\right), \qquad (1)$$

where β is the phase constant and k_0 is the wave number in free space. The two paths in the opposite direction result in two opposite main beams for a special frequency ($\beta(\omega) < 0$), as shown in Fig. 2 (b). A similar phenomenon will appear when $\beta(\omega) > 0$. It is also shown that a full space scanning can be achieved twice if $\beta(\omega)$ varies in the range of $(-k_0, +k_0)$.



(a)



(b)

Fig. 2. Configuration of CRLH SIW leaky-wave antenna, (a) overall antenna prototype, (b) working principle of the antenna.

The broadside radiation cannot be achieved if two paths are absolutely symmetrical about the feeding strip. Figure 3 plots the electric field distribution on metal surfaces when f=10 GHz. Since the amplitudes of electric fields along the two paths are identical and the phase difference between them is 180 degrees, their radiation cancels out each other in the broadside direction. To get the broadside radiation, the length of one path in Fig. 4 is extended to eliminate the phase difference, and a T-junction used as a power divider is adjusted to obtain impedance matching, where Z_0 is the input impedance of the antenna, λ_g is the medium wavelength when f=10 GHz, and $\Delta L_T = \lambda_g/2$.

III. RESULTS AND DISCUSSION

Figure 5 shows the simulated S-parameters of this antenna with using Ansoft's HFSS and CST Microwave Studio. The data from the two softwares are in a good agreement from Fig. 5. A satisfactory return loss below -10 dB in the band of interest is achieved. The curves of S_{21} and S_{31}

also show that the radiation in the LH region is more effective than that in the RH region.

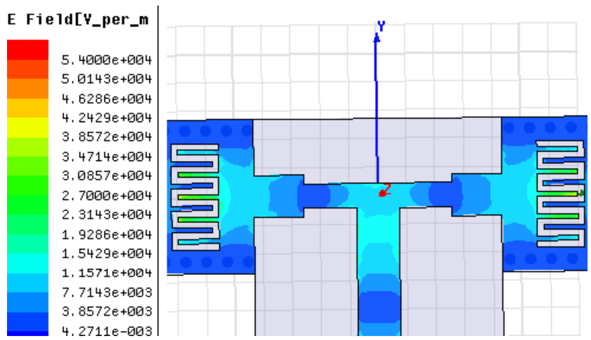


Fig. 3. Electric field distribution on the metal surface at 10 GHz.

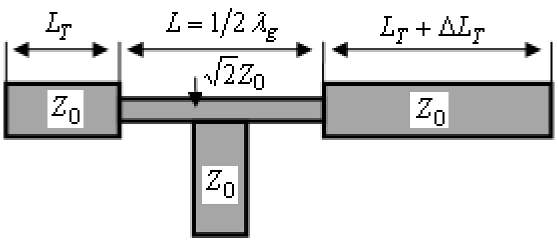


Fig. 4. T-junction feeding port.

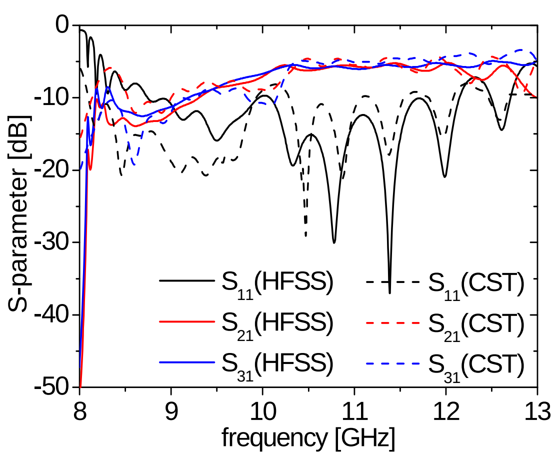
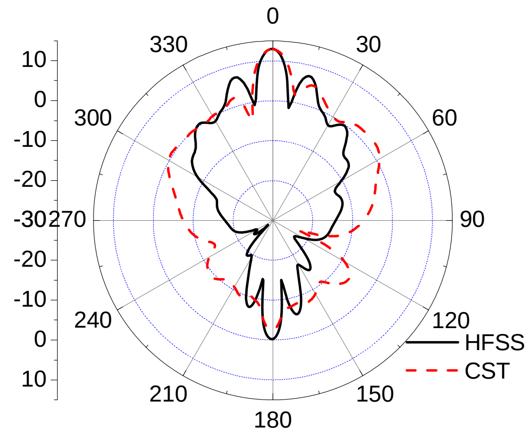
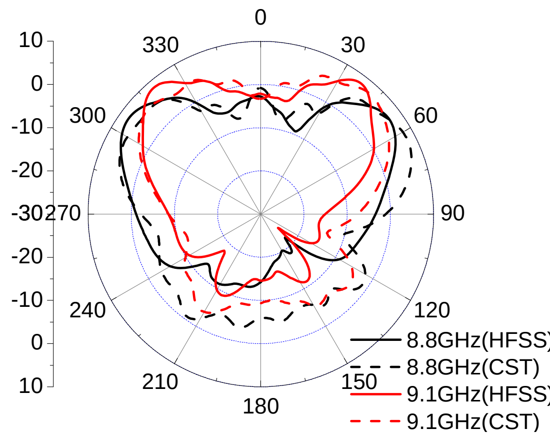


Fig. 5. Simulated S-parameters for the antenna.

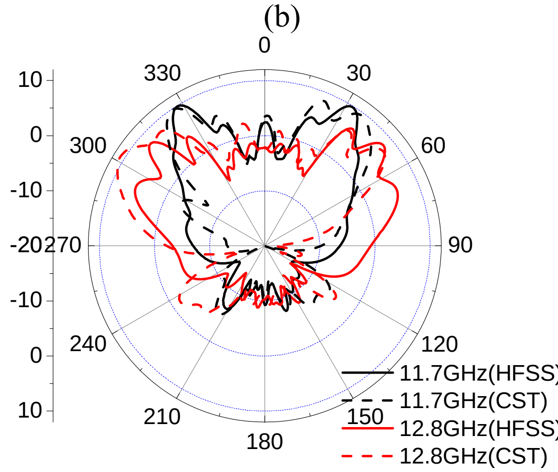
Here the performance of dual-beam scanning is presented by comparing radiation patterns at different frequencies in Fig. (6). Figure 6 (a) displays the broadside radiation pattern at 10GHz. The E-plane (*xoz* plane) radiation patterns at 8.8 and 9.1 GHz in the LH region are given in Fig. 6(b). It is found that at 8.8 GHz the two beam angles θ are about -60° and $+60^{\circ}$, respectively.



(a)



(b)



(c)

Fig. 6. Simulated radiation patterns at different frequencies. (a) 10 GHz at the transition point, (b) 8.8 and 9.1 GHz in LH region, (c) 11.7 and 12.8 GHz in RH region.

Figure 6(c) presents the E-plane radiation patterns at 11.7 and 12.8 GHz in the RH region.

The main beams at 12.8 GHz are about -60° and $+55^\circ$, respectively. Numerical results show a reasonably good agreement between the two commercial softwares. Based on the radiation principle shown in Fig. 2 (b) for the studied frequency region, the proposed antenna can realize pattern scanning towards two opposite directions synchronously.

Figure 7 shows the antenna gain and radiation efficiency responses from the simulation (Ansoft HFSS). The antenna has an average radiation efficiency of 74%.

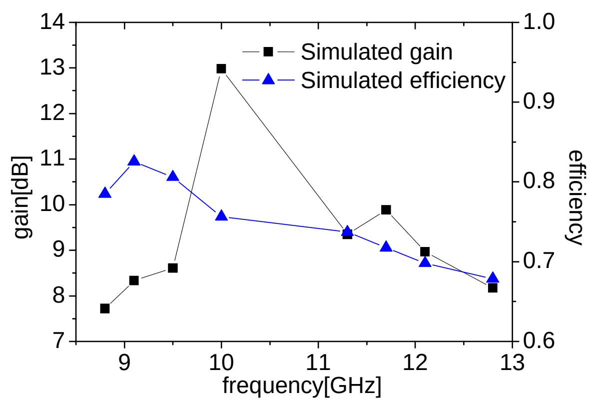


Fig. 7. Simulated gain and radiation efficiency of the antenna.

IV. CONCLUSION

A novel dual-beam scanning leaky-wave antenna is presented. Its dispersion relation and radiation mechanism are discussed, and dual-beam scanning performance is confirmed by simulation results. This antenna also exhibits advantages in low fabrication complexity, low profile, and easy integration with other planar circuits.

ACKNOWLEDGMENT

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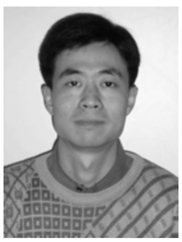

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