Composite Right/Left-Handed Leaky Wave Antenna with Half Mode Substrate Integrated Waveguide Structure

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Abstract—**Composite right/left-handed (CRLH) structure used to design leaky wave (LW) antenna on half mode substrate integrated waveguide (HMSIW) is proposed and investigated in this paper. With the CRLH structure, the antenna can realized continuous beam scanning from endfire to backfire through varying the frequency. The proposed antenna is a planar passive circuit and fabricated by the normal low-cost printed circuit board process. The HMSIW structure contributes to reduce the size of antenna by half compared to the SIW structure. Etching interdigital slots on the HMSIW is equivalent to add series capacitors leading to a CRLH structure. Their radiation characteristic and propagation properties are researched extensively. From numerical simulation, the CRLH HMSIW LW antenna demonstrates scanning angles between -51^o to 52^o with the frequency ranging from 8.2GHz to 10.5GHz. The return coefficient and insert coefficient are found to be low than -10dB in most cases.**

Keywords-composite right/left-handed (CRLH); leaky wave (LW) antenna; half mode substrate integrated waveguide (HMSIW)

I. INTRODUCTION

Leaky wave (LW) antenna owns certain advantages over conventional antenna arrays, such as superior frequency scanning ability and ease of feeding. Furthermore, the LW antenna can be simply adjusted to obtain high gain and wide frequency band. Some papers [1]-[3] present that LW antenna can exhibit beam steering with electronically tuning capacitors. Nevertheless, the electronically adjustable LW antennas need complex control system to change the capacitors, which are not suitable for passive environment. Thus, composite right/left-handed (CRLH) frequency scanning antennas have been introduced [4-5].

Substrate integrated waveguide (SIW) have been very popular types of the low-profile, low-cost guided-wave structures over the past decade [6]-[8]. The SIW is fabricated by the normal low-cost printed circuit board process. In addition, the half mode SIW (HMSIW) structure maintains same performance and processing, but the size of antenna can be reduced by half compared to the SIW structure. So in the small size and high gain antenna region, the HMSIW have been taken more attention [9-10].

In this paper, a CRLH LW antenna based on the HMSIW scheme is proposed. It is organized as follows. The geometry of the proposed leaky wave structure is illustrated in Section II. Section III gives a discussion on the design of HMSIW, the equivalent circuit and dispersion properties of the unit cell. Section IV presents the simulation results of S-parameters and radiation patterns. Finally, a conclusion is drawn in Section V.

II. CONFIGURATION

The configuration of the CRLH LW antenna with HMSIW structure is shown in Figure.1. It is constructed by two microstrip feed lines and HMSIW LW antenna. The LW antenna has six -45^o interdigital radiating slots arranged on the broad wall of the HMSIW. It is long enough to make the input power reduced to an acceptable level after radiating from these slots. All the prototypes are built on the normally used substrate of Rogers 5880 with a permittivity of 2.2, a loss tangent of 0.001 and a thickness of 1.27mm. The vias used in the model share a common diameter of 0.6mm and a center to center spacing around 1mm. The structure of interdigital radiating slots can realize continuous beam scanning from endfire to backfire through varying the frequency, as shown in Figure.2. The interdigital slots are -45^o inclined depending on their longer slots compared to the propagation direction (x-direction). The -45^o interdigital radiating slots are able to obtain -45^o linear polarization as a result of the electric current of the antenna flowing along the longer slots. The detailed structures of microstrip feed line and unit cell of antenna are presented in Figure.3. After simulation and optimization with Ansoft HFSS, The detailed parameters are presented in Table I.

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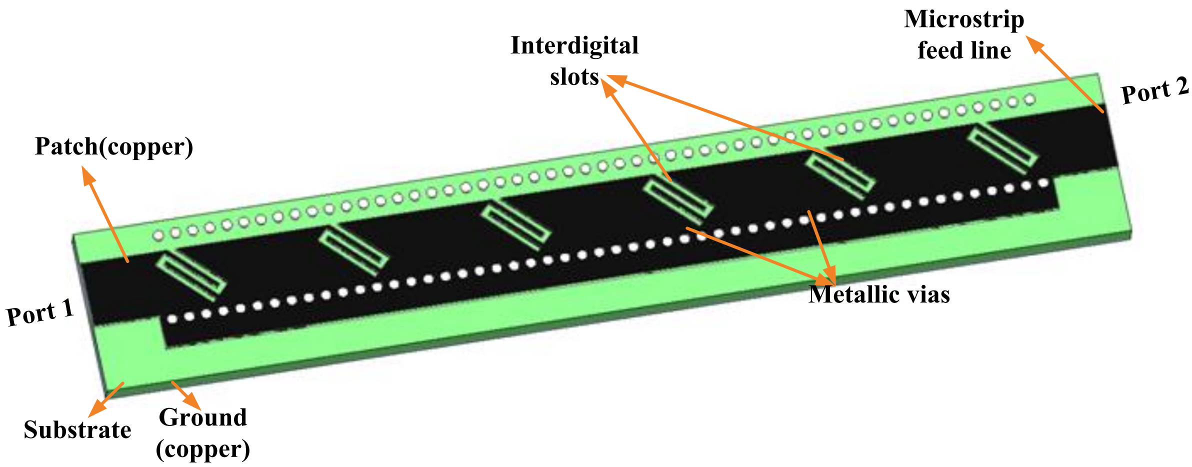


Figure 1. The configuration of the CRLH LW antenna with HMSIW structure.

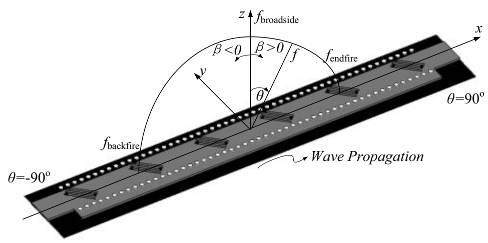


Figure 2. The wave propagation of the CRLH LW antenna.

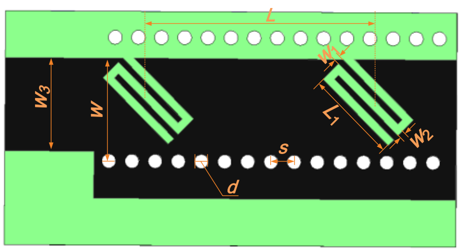


Figure 3. Detail structure of microstrip feed line and unit cell of antenna.

III. Working Mechansim

A. The Design of Half Mode Substrate Integrated Waveguide

The fabrication complexity for HMSIW structure maintains the same level as for SIW, but the waveguide width and the surface area of the metallic sheets can be reduced by nearly half compared with the SIW. So in this design, we choose HMSIW structure to design the LW antenna. The detailed propagation properties of the HMSIW are described in [11]. According to the article [12], we should take the following steps to design a SIW device. First of all, in order to ensure that SIW can be equivalent to the traditional rectangular waveguide, two conditions must be met, that is

TABLE I. Parameters of Unit Cell of Antenna and Microstrip Feed Line

Parameters	Length (*mm*)
w	4.4
L	9.5
d	0.6
s	1
L_1	4
w_1	0.25
w_2	0.35
w_3	4

$$s / d < 2 \tag{1}$$

$$d / w < 0.2 \tag{2}$$

where s is the space between two vias, d is the diameter of the vias, w is the width of the SIW.

Then calculate the w, which is determined by the SIW operating frequency, as shown in [13]. Finally, the d and s can be calculated by (1) and (2). Toward the HMSIW, the width of it could be set to be approximately half of the corresponding SIW structure. The substrate should be extended only a little in the horizontal direction.

B. Equivalent Circuit of Unit Cell

The antenna structure proposed in this paper is CRLH LW structure. The CRLH LW antenna can radiate wave directing left-handed (LH) region at low frequencies and right-handed (RH) region at higher frequencies. The RH contribution comes from the distributed shunt capacitance C_R and distributed series

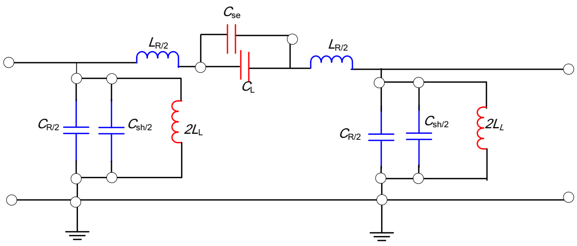


Figure 4. The equivalent circuit of the CRLH-HMSIW unit cell.

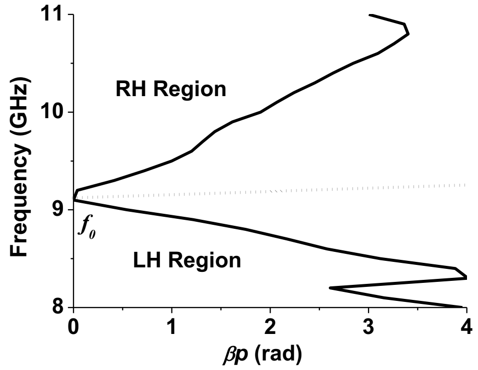


Figure 5. Dispersion diagram for the CRLH-HMSIW unit cell.

inductance L_R. The LH contribution comes from the

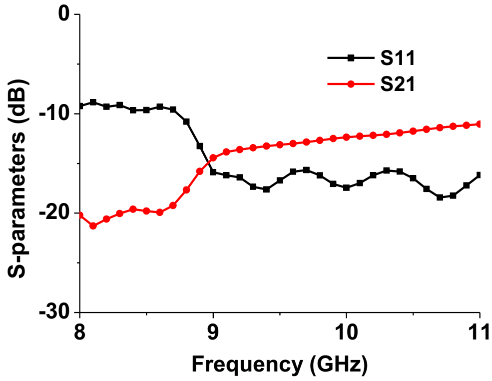
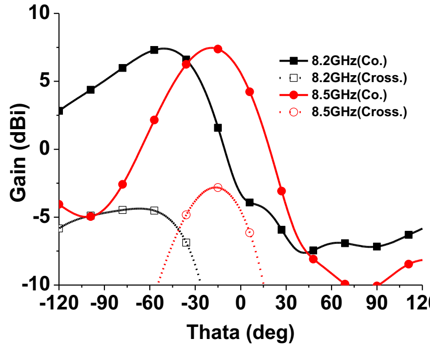


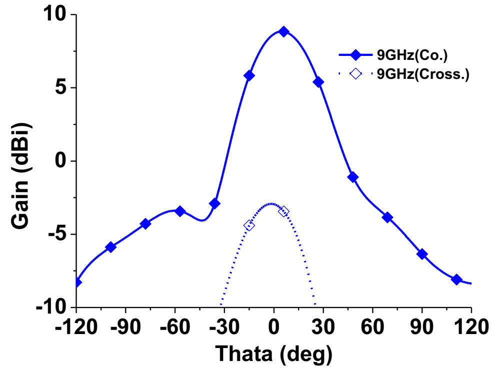
Figure 6. The simulated S-parameters.

distributed series capacitance C_L and distributed shunt inductance L_L. Its equivalent circuit of unit cell is presented in Figure.4. The top metal surface and the ground of HMSIW are modeled as a two-wire transmission line with distributed series capacitance C_R and distributed shunt inductance L_R. The interdigital capacitor is introduced into the model as C_L, and the L_L is generated by the via-wall [14]. As we know, increasing the width and the length of the slots will make the radiation more efficient. But bear in mind that increasing the slot length results in an increase of C_L while increasing the slot width leads to a decrease of C_L. Thus enhancing the radiation does not conflict with achieving a balanced case.

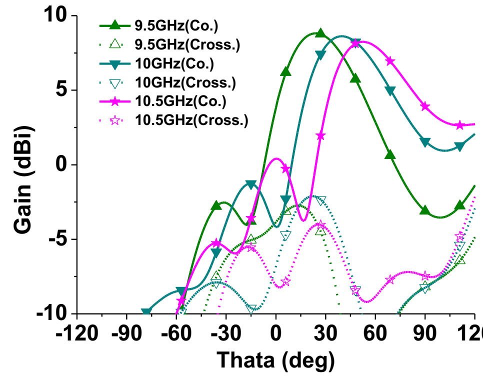
C. Dispersion Properties of Unit Cell



(a)



(b)



(c)

Figure 7. Simulated patterns in terms of realized gain in the E-plane in the (a) LH region, (b) broadside, and (c) RH region.

The dispersion diagram for the unit cell is investigated based on the fast driven-mode simulation of HFSS [15]. Figure.5 plots the dispersion curve for the CRLH-HMSIW unit cell. It is seen that a balanced case is almost achieved with the balancing point located at f_0, and f_0 is almost 9GHz, which ensures a seamless transition from the LH to the RH band. The LH and RH regions are separated by the transition frequency f_0. It happens when the series resonance frequency and shunt resonance frequency are equal, which is equivalent to

$$L_R C_L = L_L C_R \tag{3}$$

and the transition frequency f_0 is obtained by

$$f_0 \,|_{\beta=0} = \frac{1}{2\pi\sqrt{L_R C_L}} = \frac{1}{2\pi\sqrt{L_L C_R}} \tag{4}$$

The beam direction can be obtained by the following.

$$\beta(w) = \frac{w}{p}\left(\sqrt{L_R C_R} - \frac{1}{w^2\sqrt{L_L C_L}}\right) \tag{5}$$

$$\theta(w) = \sin^{-1}\left[\frac{\beta(w)}{k_0}\right] \tag{6}$$

where p is the length of the unit cell.

From (5) and (6), we know that the beam direction ranges from endfire to backfire through varying the frequency. In details, as Figure.4 shows, when the $f > f_0$ and $\beta\,(w) > 0$, we can obtain the forward beam based on (6). Otherwise, when the $f < f_0$ and $\beta\,(w) < 0$, we can obtain the backward beam. The forward or backward is relative to the current direction of the antenna.

IV. Results

The LW antenna is designed and simulated in HFSS. As shown in Figure. 6, the simulated return coefficient (S_{11}) of the leaky wave antenna is almost below -10dB from 8.5GHz to 11GHz and the insertion coefficient (S_{21}) is nearly better than -15dB in the range of 8GHz-11GHz. So we can see that the energy of antenna can be radiated out effectively. Figure.7 demonstrates the simulated gain patterns in the E-plane (scanning plane), including both co-polarization and cross-polarization. Low cross-polar level and beam scanning are observed. The realized maximum gain is 7.5GHz in the LH region and 9dB in the RH region approximately. Figure.7(a) and Figure.7(c) show scanning angles between -51^{o} to 52^{o} over the frequency range of 8.2GHz-10.5GHz.

V. Concusion

A CRLH HMSIW LW antenna with capability of beam scanning is presented in this paper. Its circuit model is analyzed. Its dispersion relation and radiation mechanism are discussed. Its full space beam scanning performance is confirmed by simulation. The antenna with CRLH HMSIW structure possesses advantages in their low fabrication complexity, full space beam-scanning capability, low cost, low profile and easy integration with other planar circuits. It is a promising technique for applications requiring beam steering.

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