Progress In Electromagnetics Research Letters, Vol. 19, 93–102, 2010

A PLANAR D-CRLH AND ITS APPLICATION TO BANDSTOP FILTER AND LEAKY-WAVE ANTENNA

C.-Y. Liu, Q.-X. Chu, and J.-Q. Huang

School of Electronic and Information Engineering
South China University of Technology, Guangzhou 510640, China

Abstract—A planar dual-composite right/left-handed (D-CRLH) transmission line (TL) structure is proposed. The characteristics such as dispersion relation and frequency response of this D-CRLH TL are analyzed by equivalent circuit analysis, Bloch-Floquet theory, full wave simulation and experiment. To demonstrate applications of the proposed structure, both bandstop filter and leaky-wave antenna are designed and implemented by the conventional print circuit board technology. The fabricated filter has a broad application because of its planar structure, small size and tunable stopband. The measured results also suggest that the leaky-wave antenna based on the D-CRLH concept can offer a scanning angle covering almost backfire-to-endfire directions.

1. INTRODUCTION

Recently, composite right/left-handed transmission line (CRLH TL) has attracted much attention due to its unique characteristics with a broad passband and low insertion losses [1–12]. In 2006, the dual-composite right/left-handed (D-CRLH) TL was proposed by Caloz [13]. D-CRLH TL has a series parallel L_R and C_L tank and a shunt series L_L and C_R tank, which is dual of CRLH TL. The D-CRLH indeed exhibits its left-handed (LH) band at high frequencies and its right-handed (RH) band at low frequencies and is of stop-band nature between them. Due to the different characteristics from these of CRLH TL, the realization and application of the D-CRLH TL have been investigated extensively [14–21].

In this paper, a novel planar D-CRLH structure is proposed, which can be realized easily by using conventional printed circuit

Received 17 October 2010, Accepted 29 November 2010, Scheduled 3 December 2010
Corresponding author: Qing-Xin Chu (qxchu@scut.edu.cn).

board technology. Furthermore, two applications of the structure, bandstop filter and leaky-wave antenna, are proposed. The stopband of the compact filter is tunable. The leaky-wave antenna (LWA) utilizing the proposed structure with frequency-scanning characteristic is investigated by theoretical and simulated dispersion curves of the TL. Both the measured and simulated results suggest that the LWA is capable of backfire-to-endfire scanning from −30 to 45 deg.

2. CHARACTERISTIC ANALYSIS OF D-CRLH TL UNIT STRUCTURE

Figure 1(a) shows the proposed D-CRLH TL structure of the unit cell. The unit cell consists of one interdigital capacitor paralleled by two high impedance stubs, and four series branches of the plane capacitor and stub. The equivalent circuit of the unit cell with respect to the parasitical effect is shown in Figure 1(b). The interdigital structure can be modeled as the series capacitor C_1, parasitical capacitor C_3 and inductance L_3. The stubs paralleling the interdigital structure are equivalent to the inductance L_2. So the transmission matrix of the unit cell is:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{\text{unit}} = \begin{bmatrix} 1+\frac{Y_1'}{Y_2'} & \frac{1}{Y_2'} \\ 2Y_1'+\frac{Y_1'^2}{Y_2'} & 1+\frac{Y_1'}{Y_2'} \end{bmatrix} \tag{1}$$

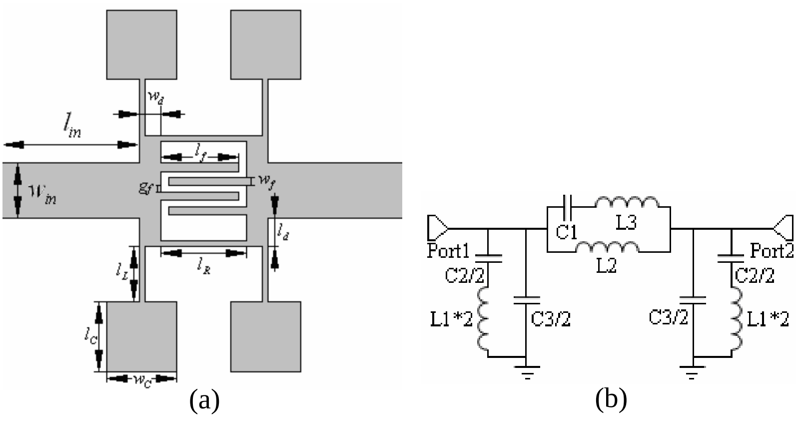

Figure 1. (a) Unit cell, (b) equivalent circuit of the proposed D-CRLH TL.

where

$$Y_1' = \frac{j\omega C_3}{2} + \frac{1}{2j\omega L_1 + \frac{2}{j\omega C_2}}, \quad Y_2' = \frac{1}{j\omega L_2} + \frac{1}{j\omega L_3 + \frac{1}{j\omega C_1}} \tag{2}$$

where Y_1' denotes the admittance of the parallel tank of $C_3/2$ and the series branch of $L_1/2$ and $C_2/2$, and Y_2' is the admittance of the parallel tank of L_2 and the series branch of L_3 and C_1.

The corresponding S-parameters are then computed by

$$S_{11} = \frac{A + \frac{B}{Z_0} - CZ_0 - D}{A + \frac{B}{Z_0} + CZ_0 + D}, \quad S_{21} = \frac{2(AD - BC)}{A + \frac{B}{Z_0} + CZ_0 + D} \tag{3}$$

The dispersion characteristic $\beta(\omega)$ is given by $\beta p = \cos^{-1}(\frac{1 - S_{11}S_{22} + S_{12}S_{21}}{2S_{21}})$, where p represents the total physical length of the TL.

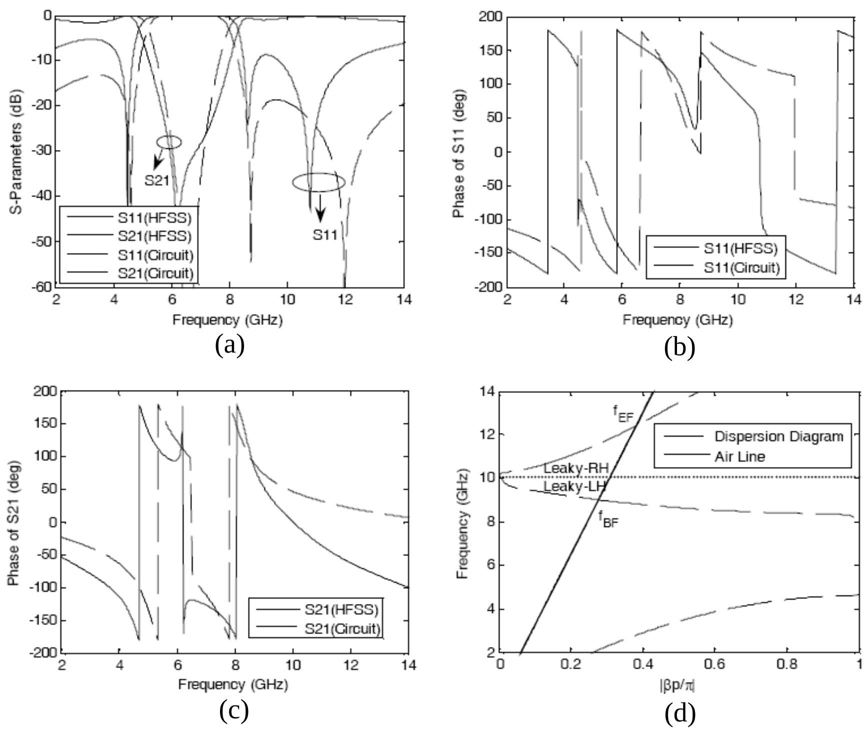

Figure 2. S-parameters and dispersion diagram of the proposed D-CRLH TL. (a) Magnitude of S-parameters, (b) phase of S_{11}, (c) phase of S_{21}, (d) circuit-calculated dispersion diagram.

With the guidance of the equivalent circuit model and the aid of Ansoft's HFSS, the unit cell structure can be optimized as: l_f = 2.8 mm, w_f = 0.3 mm, g_f = 0.22 mm, l_l = 2 mm, l_R = 3.1 mm, l_C = w_C = 2.5 mm, l_d = 1 mm, w_d = 0.75 mm, l_{in} = 5 mm, w_{in} = 2 mm. It is fabricated on a substrate with a dielectric constant of 2.55 and the thickness of 0.8 mm. The corresponding parameters of the equivalent circuit are: C_1 = 0.6 pF, C_2 = 0.32 pF, C_3 = 0.09 pF, L_1 = 1.8 nH, L_2 = 0.9 nH, L_3 = 0.1 nH. The circuited and HFSS simulated S-parameters of the one-cell are presented in Figure 2 for comparison. Good agreement between them was obtained. It can be seen from Figure 3 that the structure can be used as bandstop filter.

The dispersion diagram is shown in Figure 2(d), from which it can be concluded that the proposed structure has a similar dispersion diagram with balanced CRLH TL. The velocity of phase is zero at 10 GHz, which is the boundary of the LH and RH. The dispersion is divided to two parts by the air line. The part above the air line is the fast wave region and another part is the slow wave region. The fast wave region from 9.3 GHz to 12.4 GHz has the endfire to back-fire radiant capabilities due to backward and forward leakage.

3. EXPERIMENTAL RESULTS

3.1. Bandstop Filter

Figure 3 shows the S_{21} parameters of the D-CRLH TL unit structure when altering l_f or l_L while keeping other parameters unchanged. It can be seen that the left-hand band or the right-hand band can be

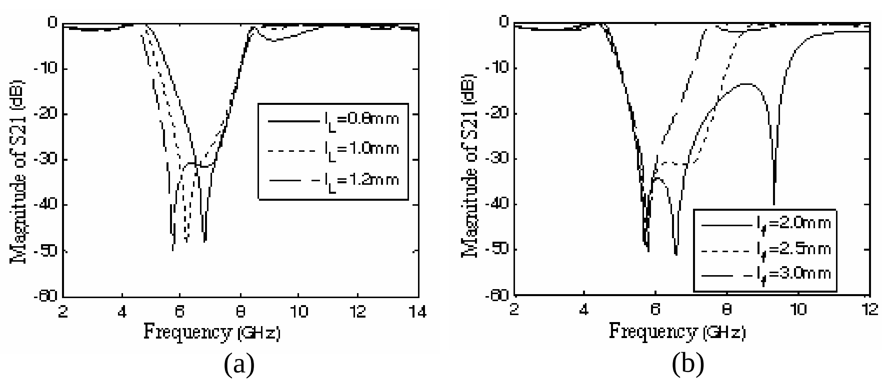

Figure 3. FW-simulated impact of changing l_L or l_f respectively. (a) Changing l_L, (b) changing l_f.

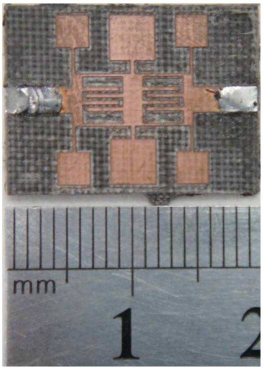

Figure 4. The fabricated bandstop filter.

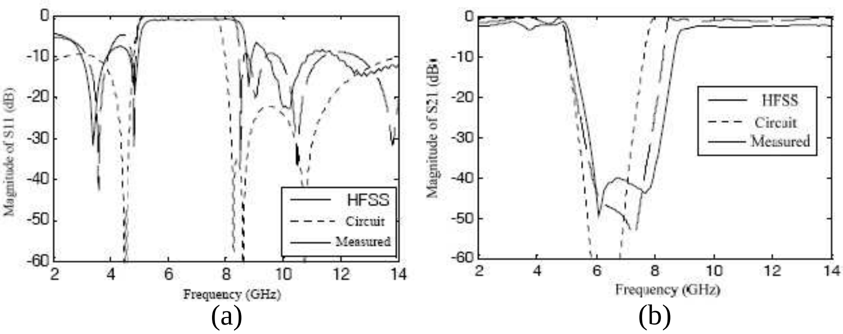

Figure 5. Measured and simulated S-parameters of the bandstop filter. (a) S_{11}, (b) S_{21}.

changed respectively, which means the stopband is tunable. Figure 4 shows the fabricated bandstop filter, which has 2 proposed unit cells. As shown in Figure 5, the experimental S-parameters are in good agreement with the simulated results. The stopband is from 5.1 GHz to 8.5 GHz.

3.2. Leaky-wave Antenna

The leaky-wave antenna comprised five D-CRLH unit cells is described in Figure 6. The LWA is measured with Agilent N5230 network analyzer. As shown in Figure 7, the experimental S-parameters are in good agreement with the simulated results. In the radiant region (from 9.3 GHz to 12.4 GHz), the return loss is lower than 10 dB. The complicated fed net is not required for the proposed LWA.

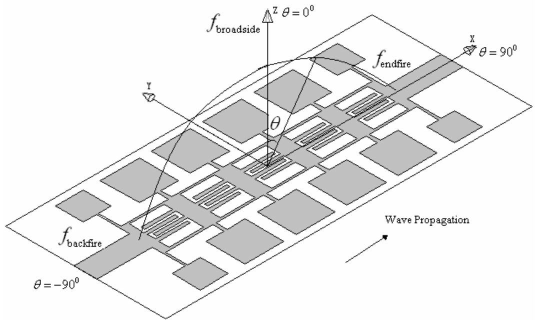

Figure 6. Backfire-to-endfire scanning.

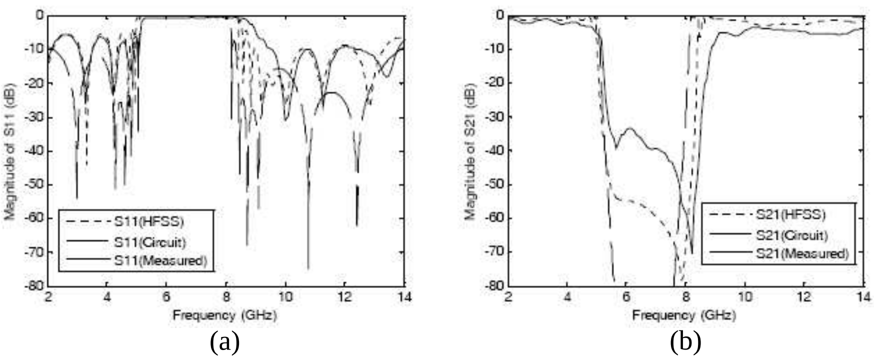

Figure 7. S-parameters of HFSS, circuit and measured of the D-CRLH LWA. (a) S_{11} and (b) S_{21}.

The measured radiant patterns at 9.6 GHz, 10 GHz and 12.4 GHz are shown in Figure 8. From the radiation patterns, which are measured at outdoors, a backfire-to-endfire beam steering is shown. The beam angle θ is taken from the backward to the forward direction, and the angles at the above-mentioned frequencies are about -30, 0 and 45 deg, respectively. The broadside radiant can not be realized by the conventional uniform or periodical leaky-wave antenna. The full-wave simulated and measured total power radiation and dissipation of the proposed LWA are shown in Figure 9, which demonstrates the radiation efficiency of the LWA. The maximum measured level of 79.4% total power radiation and dissipation is observed at 9.41 GHz. This is little larger than the simulated one, which is most likely due to the insertion loss mainly caused by the discontinuousness between the LWA and SMA connector.

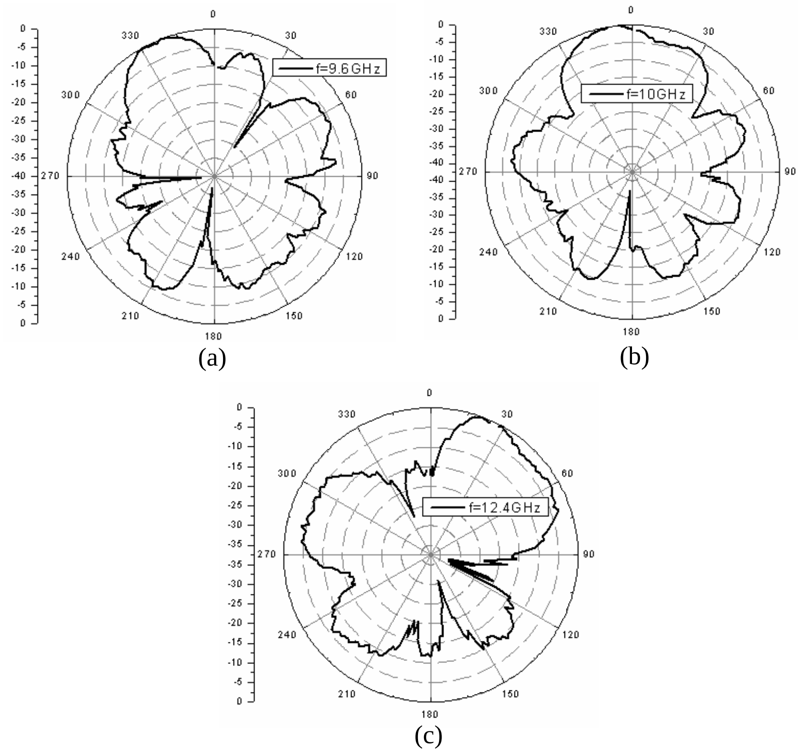

Figure 8. Measured X-Z plane radiation pattern of the proposed D-CRLH LWA at (a)9.6 GHz, (b) 10 GHz and (c) 12.4 GHz.

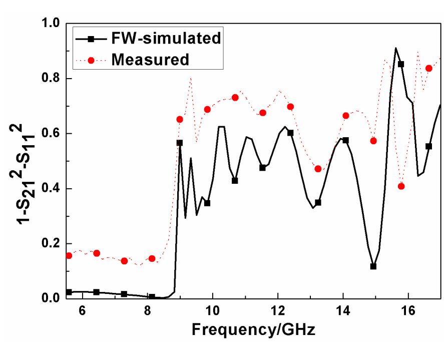

Figure 9. FW-simulated and measured total power radiation and dissipation of the proposed LWA.

4. CONCLUSION

A planar D-CRLH TL structure is proposed. Utilizing the structure, a bandstop filter and a leaky-wave antenna are illustrated. The stopband of the compact filter is tunable. The leaky-wave antenna can offer a scanning angle covering almost backfire-to-endfire directions. Agreements between simulated and measured responses are demonstrated.

ACKNOWLEDGMENT

This project is supported by the Science Fund of China under Grant U0635004 and Grant 60801033.

REFERENCES

1. Caloz, C. and T. Itoh, *Electromagnetic Metamaterials: Transmission Line Theory and Microwave Applications*, Wiley, New York, 2005.
2. Rahman, A., Y. Hao, Y. Lee, and C. G. Parini, "Effect of unit-cell size on performance of composite right/left-handed transmission line based leaky-wave antenna," *Electronics Letters*, Vol. 44, No. 13, 2008.
3. Caloz, C. and T. Itoh, "Novel microwave devices and structures based on the transmission line approach of meta-materials," *IEEE-MTT Int'l Symp.*, Vol. 1, 195–198, Jun. 2003.
4. Casares-Miranda, F. P., E. Marquez-Segura, P. Otero, and C. Camacho-Penalosa, "Composite right/left-handed transmission line with wire bonded interdigital capacitor," *IEEE Microwave Wireless Compon. Lett.*, Vol. 16, No. 11, Nov. 2006.
5. Gao, J. and L. Zhu, "Characterization of infinite- and finite-extent coplanar waveguide metamaterials with varied left- and right-handed passbands," *IEEE Microwave Wireless Compon. Lett.*, Vol. 15, No. 11, Nov. 2005.
6. Horii, Y., C. Caloz, and T. Itoh, "Super-compact multilayered left-handed transmission line and diplexer application," *IEEE Trans. Microwave Theory and Techniques*, Vol. 53, No. 4, Apr. 2005.
7. Yu, A., F. Yang, and A. Z. Elsherbeni, "A dual band circularly polarized ring antenna based on composite right and left handed metamaterials," *Progress In Electromagnetics Research*, Vol. 78, 73–81, 2008.

8. Jimenez Martin, J. L., V. Gonzalez-Posadas, J. E. Gonzalez-Garcia, F. J. Arques-Orobon, L. E. Garcia Munoz, and D. Segovia-Vargas, "Dual band high efficiency class CE power amplifier based on CRLH diplexer," *Progress In Electromagnetics Research*, Vol. 97, 217–240, 2009.
9. De Castro-Galan, D., L. E. Garcia Munoz, D. Segovia-Vargas, and V. Gonzalez-Posadas, "Diversity monopulse antenna based on a dual-frequency and dual mode CRLH rat-race coupler," *Progress In Electromagnetics Research B*, Vol. 14, 87–106, 2009.
10. Abdelaziz, A. F., T. M. Abuelfadl, and O. L. Elsayed, "Leaky wave antenna realization by composite right/left-handed transmission line," *Progress In Electromagnetics Research Letters*, Vol. 11, 39–46, 2009.
11. Huang, J.-Q., Q.-X. Chu, and C.-Y. Liu, "Compact UWB filter based on surface-coupled structure with dual notched bands," *Progress In Electromagnetics Research*, Vol. 106, 311–319, 2010.
12. Huang, J.-Q. and Q.-X. Chu, "Compact UWB band-pass filter utilizing modified composite right/left-handed structure with cross coupling," *Progress In Electromagnetics Research*, Vol. 107, 179–186, 2010.
13. Caloz, C., "Dual composite right/left-handed (D-CRLH) transmission line metamaterial," *IEEE Micow. Wireless Compon. Lett.*, Vol. 16, No. 11, 585–587, Nov. 2006.
14. Ryu, Y. H., J. H. Park, J. H. Lee, and H. S. Tae, "A novel planar lefthanded transmission line using defected ground structure with interdigital gap," *Proc. IEEE/AP Symp.*, 4991–4991, 2007.
15. Ryu, Y. H., J. H. Park, J. H. Lee, J. Y. Kim, and H. S. Tae, "DGS dual composite right/left handed transmission line," *IEEE Micow. Wireless Compon. Lett.*, Vol. 18, No. 7, 434–436, Jul. 2008.
16. Tong, W., Z. Hu, H. Zhang, and C. Caloz, "Study and realization of dual-composite right/left-handed coplanar waveguide metamaterial in MMIC technology," *IET Microwave, Antennas and Propogation*, Vol. 2, No. 7, 731–736, 2008.
17. Rennings, A., T. Liebig, C. Caloz, and I. Wolff, "Double-lorentz transmission line metamaterial and its application to tri-band devices," *IEEE/MTT-S Int. Microwave Symp.*, 1427–1430, 2007.
18. Li, B., J. P. Yang, and W. Wu, "A planar microstrip implementation of dual-composite right/left handed transmission line," *ICMMT 2008*, Vol. 4, 1617–1619, 2008.
19. Caloz, C., S. Abielmona, H. V. Nguyen, and A. Rennings, "Dual composite right/left-handed (D-CRLH) leaky wave antenna with

low beam squinting and tunable group velocity," *Phys. Stat. Sol. (b)*, Vol. 244, No. 4, 1219–1226, Mar. 2007.

20. Liu, C. and W. Menzel, "A microstrip diplexer from metamaterial transmission lines," *IEEE MTT-S International*, 65–68, 2009.
21. Ryu, Y. H., J. H. Park, J. H. Lee, and H. S. Tae, "Multiband antenna using +1, −1, and 0 resonant mode of DGS dual composite right/left handed transmission line," *Microwave and Optical Technology Letters*, Vol. 51, No. 10, 2485–2488, Oct. 2009.