Progress In Electromagnetics Research Letters, Vol. 35, 191–199, 2012

DUAL COMPOSITE RIGHT/LEFT-HANDED LEAKY-WAVE STRUCTURE FOR DUAL-POLARIZED ANTENNA APPLICATION

L. Geng*, G.-M. Wang, H.-Y. Zeng, and M.-W. Chui

Air-Defense and Anti-Missile Institute of Air Force Engineering University, Xi'an, Shaanxi 710051, China

Abstract—An effective development of a dual composite right/left-handed (D-CRLH) leaky-wave (LW) structure for dual-polarized antenna application is presented. The dual-polarized antenna consists of a two-section 3-dB rat-race hybrid and two symmetrical substrate integrated waveguide lines. Each of the waveguide lines is periodically loaded with 15 transverse slots and 15 longitudinal slots. The dual-polarization capability and D-CRLH LW property of the antenna are analyzed and discussed. The S-parameters and gain patterns are presented for the antenna. Measured results are consistent with the simulated ones. The proposed LW antenna shows some desirable merits, such as the simplicity in design, low-cost fabrication, multi-band operation, flexible radiation directions and dual-polarization capability.

1. INTRODUCTION

Composite right/left-handed (CRLH) transmission line (TL) metamaterials are understood as artificially engineered and structured media that exhibit some unique electromagnetic properties. They have received significant attention and have enabled numerous applications over the past decade [1–4], especially for the radiated-wave devices. Various CRLH leaky-wave (LW) antennas have already been studied and developed based on different techniques [5–9]. They all possess a full-space beam-steering capability by varying the frequency. Recently, the novel concept of dual composite right/left-handed (D-CRLH) TL is introduced by C. Caloz [10]. Compared with CRLH TL, the D-CRLH TL has more advantages at multi-band application due to its

Received 11 October 2012, Accepted 31 October 2012, Scheduled 1 November 2012
* Corresponding author: Lin Geng (genglin8603@163.com).

characteristic that dispersion curve has three branches in half periodicity [11, 12].

Polarization is an important parameter for antennas. Dual-polarized antennas are able to change their polarization state dynamically depending on the requirement [13–15]. They can be used to mitigate the multipath fading effect encountered in the wireless communication systems and increase the channel capacity.

In this paper, a novel D-CRLH LW structure is developed for the dual-polarized antenna application. The proposed antenna can be mounted on board or other different vehicles providing flexible radiation directions and polarization states. The D-CRLH feature is achieved by periodically loading the interdigital slots on the substrate integrated waveguide surface. The dual-polarization functionality is obtained by symmetrically aligning two leaky TLs excited by different inputs. Besides the CRLH LW property, the proposed antenna has a lower band that can provide the forward LW radiation.

2. PROPOSED STRUCTURE AND WORKING PRINCIPLE

2.1. Geometrical Layout

The geometric configuration of the proposed LW structure is shown in Figure 1, where the layout of the unit-cell elements [Figures 1(a) and (b)] and the prototype of the entire LW structure with its orientations in the coordinate system [Figure 1(c)] are displayed. As shown, the unit-cell is surrounded by vias on the two sides which are connected to a solid metallic ground. The interdigital transverse slots (X-directed) and longitudinal slots (Y-directed) are etched on the waveguide surface. Two symmetrical leaky TLs are side by side arranged as depicted in Figures 1(b) and (c). Each of them carries 15 transverse slots and 15 longitudinal slots which are periodically etched on the broad wall. These slots behave as radiators providing two orthogonal linearly polarized radiations. Besides, the two kinds of slots act like capacitances, which, along with the waveguide inherent shunt inductance provided by the vias, create the necessary condition to support the D-CRLH operation. A piece of 50-Ω microstrip line along with a transformer line for impedance matching is placed at the end of each waveguide to facilitate the outside connection. This LW structure is fabricated on a substrate of P4BM-2 with a thickness of 1 mm and a relative permittivity of 2.2. The metallic via holes are chosen to have a diameter of 0.8 mm and a center-to-center pitch around 1.5 mm.

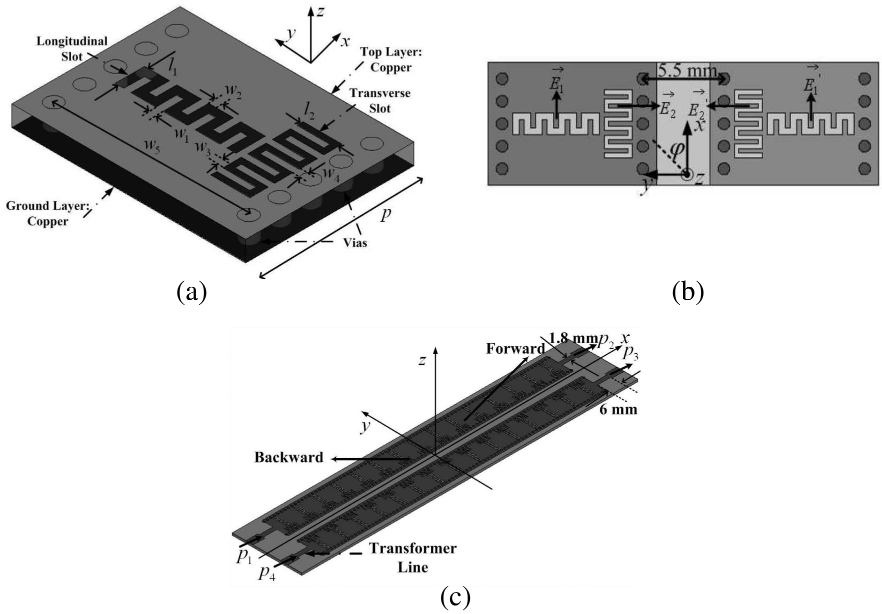

Figure 1. Configurations of the proposed structures. (a) Single D-CRLH radiating element. (b) Two-element unit-cell of the whole structure. (c) Overall LW antenna prototype.

2.2. Dual-polarization Capability

The polarization of an electromagnetic wave is defined as the orientation of the electric-field vector. As shown in Figure 1, the transverse slot radiates the Y-polarized wave, and the longitudinal slot provides the X-polarized wave. When the *port* 1 and *port* 4 are illuminated by two equal and in-phase signals simultaneously, the X-polarized (horizontal direction) wave will be produced for the proposed LW antenna. Similarly, Y-polarized (vertical direction) wave can be obtained with two inputs of the same magnitude and 180° out of phase.

2.3. D-CRLH Property

Figure 2 presents the equivalent circuit model for the single D-CRLH radiating element. The surface and the ground can be modeled as a two-wire TL with distributed inductance L_R and distributed capacitance C_R. The vias provide the shunt inductance L_L. The transverse and longitudinal slots achieve shunt capacitance C_1 and series capacitance C_2, respectively. Figure 3 shows the dispersion curve for the single D-CRLH radiating element. The extraction of the curve is based on the S-parameters from the fast driven-mode

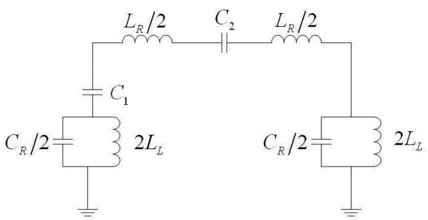

Figure 2. The equivalent circuit model of the single D-CRLH radiating element.

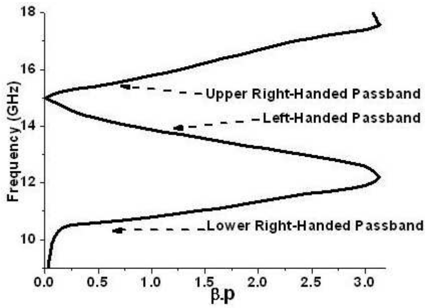

Figure 3. The dispersion diagram for the single D-CRLH radiating element.

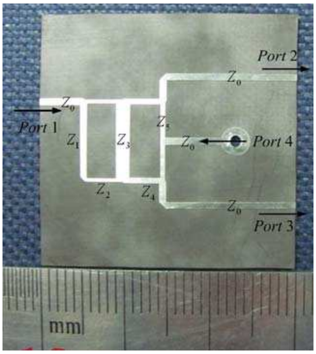

Figure 4. The photo of the fabricated hybrid. (*Port* 1 is excited for 180° out-of-phase operation. *Port* 4 is the input port for the in-phase case.).

simulation in HFSS [16]. It is observed that the single D-CRLH radiating element has three passbands (a left-handed passband and two right-handed passbands). Therefore, our LW antenna has a frequency band can provide backward radiation and two frequency bands can exhibit forward radiations.

3. DUAL-POLARIZED D-CRLH LW ANTENNA

3.1. Design of the Rat-race Hybrid for Excitation

In order to realize the input excitations depicted in Section 2, a broadband two-section 3-dB rat-race hybrid is designed and fabricated [17]. The hybrid is fabricated on the Rogers 5880 substrate with a thickness of 0.254 mm and a relative permittivity of 2.2. Its

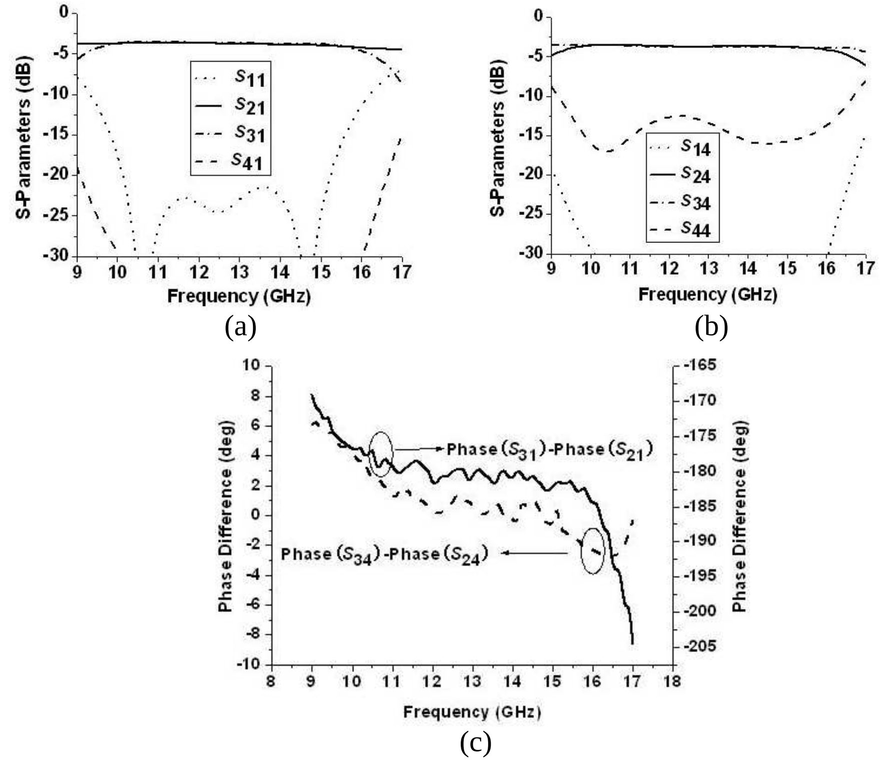

Figure 5. Measured performance for the two-section 3-dB rat-race hybrid. (a) Measured S-parameters for the out-of-phase case. (b) Measured S-parameters for the in-phase case. (c) Measured phase performance.

photo is shown in Figure 4. It consists of three vertical $\lambda_g/2$ and four horizontal $\lambda_g/4$ lines whose impedances are optimized to have good wideband matching from 9.7 to 16.1 GHz. Specifically, they are $Z_1 = 52.9\,\Omega$, $Z_2 = 74.1\,\Omega$, $Z_3 = 30.8\,\Omega$, $Z_4 = 56.7\,\Omega$, $Z_5 = 66.1\,\Omega$, and $Z_0 = 50\,\Omega$. Figure 5 shows the measured results for the hybrid, including magnitude and phase responses for the out-of-phase and in-phase cases. Over the frequency band from 9.7 to 16.1 GHz, small reflection (below -10 dB), good amplitude imbalance (less than 0.5 dB), small phase variation (less than $\pm 5^\circ$), and large isolation (better than 26 dB) are achieved.

3.2. Simulated Results

The simulated results of the proposed dual-polarized D-CRLH LW antenna are exhibited in this Section. To avoid handling large structures using HFSS, the hybrid here is not included in the simulation. For the X-polarization case, two identical signals are directly applied at *port* 1 and *port* 4 [Figure 1(c)], respectively. And for the Y-polarization case, two signals with 180° out of phase are directly applied at these two *ports*, respectively. Figure 6 shows the several simulated S-parameters. In the frequency bands from 10.08 to 11.73 GHz and from 13.54 to 17.18 GHz, small reflection is achieved. The simulated gain patterns at three different frequencies in the E-plane for the X-polarization case and in the H-plane for the Y-polarization case are shown in Figures 7 and 8, respectively. The antenna provides forward radiations at 10.1 GHz, 15.9 GHz, 16.4 GHz, backward radiations at 13.9 GHz, 14.4 GHz, broadside radiation at 14.9 GHz, which is consistent with the analysis in Section 2.

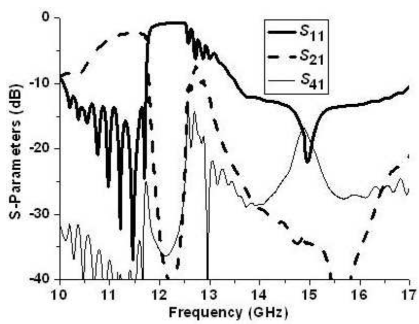

Figure 6. Several simulated S-parameters of the dual-polarized D-CRLH LW antenna.

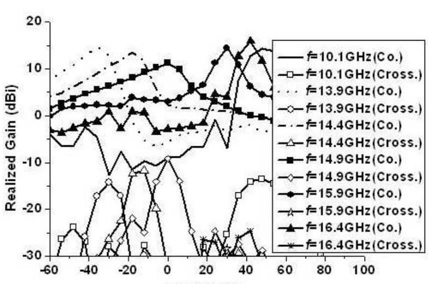

Figure 7. Simulated gain patterns in the x-z plane (scanning plane) for the X-polarization case.

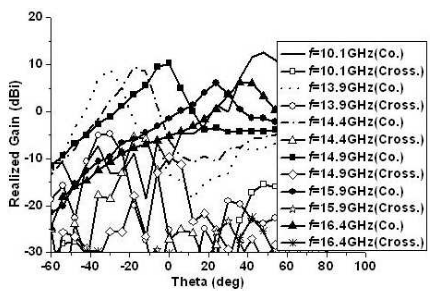

Figure 8. Simulated gain patterns in the x-z plane (scanning plane) for the Y-polarization case.

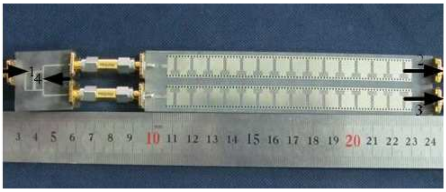

Figure 9. The prototype of the dual-polarized D-CRLH LW antenna (cascading the rat-race hybrid and the two-element LW structure).

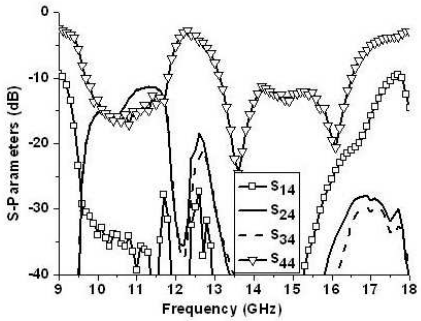

Figure 10. Measured S-parameters of the dual-polarized D-CRLH LW antenna for the X-polarization case.

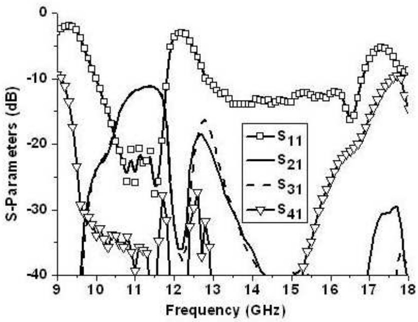

Figure 11. Measured S-parameters of the dual-polarized D-CRLH LW antenna for the Y-polarization case.

3.3. Measured Results

To measure the proposed dual-polarized D-CRLH LW antenna performance, we cascaded the fabricated rat-race hybrid and the two-element LW structure as the prototype shown in Figure 9. When the whole structure is fed at *port* 4, the antenna radiates X-polarized wave. Similarly, the Y-polarized wave can be obtained by feeding at *port* 1. The measured S-parameters for the X-polarization case and for the Y-polarization case are shown in Figures 10 and 11, respectively. In the interested frequency bands, small reflection and large isolation are achieved. The measured gain patterns for these two polarization cases are exhibited in Figures 12 and 13, respectively. A new forward LW radiation is obtained at a lower frequency (10.1 GHz) besides the CRLH scanning capability (backward LW radiations at 13.9 GHz, 14.4 GHz, forward LW radiations at 15.9 GHz, 16.4 GHz, broadside LW radiation at 14.9 GHz), which is consistent with the simulation.

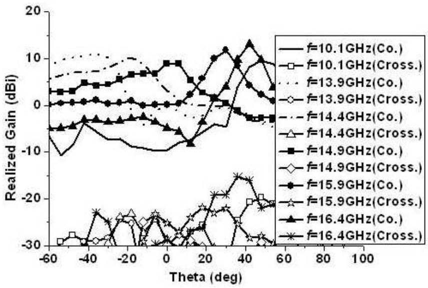

Figure 12. Measured gain patterns in the E-plane for the X-polarization case.

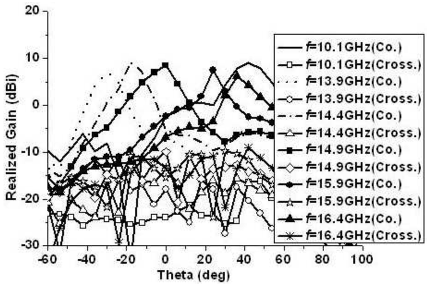

Figure 13. Measured gain patterns in the H-plane for the Y-polarization case.

4. CONCLUSION

In this paper, we have implemented a D-CRLH leaky TL structure used for dual-polarized antenna application. It is a low-loss passive component which can be realized on a planar substrate by a low-cost printed-circuit board process. Depending on the input excitation, it can support horizontal polarization and vertical polarization states. Besides the CRLH LW property, the proposed antenna has a lower band can provide the forward LW radiation.

REFERENCES

1. Caloz, C. and T. Itoh, *Electromagnetic Metamaterials: Transmission Line Theory and Microwave Applications*, John Wiley & Sons, New Jersey, 2005.
2. Eleftheriades, G. V. and K. G. Balmain, *Negative Refraction Metamaterials: Fundamental Principles and Applications*, John Wiley & Sons, New Jersey, 2005.
3. Engheta, N. and R. W. Ziolkowski, *Electromagnetic Metamaterials: Physics and Engineering Explorations*, John Wiley & Sons, New Jersey, 2006.
4. Kang, W., G. Yang, H. Wang, C. Miao, and W. Wu, "Miniaturized dual-mode composite-right/left-handed line resonator filter with wide harmonic suppression," *Progress In Electromagnetics Research Letters*, Vol. 28, 73–81, 2012.
5. Liu, L., C. Caloz, and T. Itoh, "Dominant mode leaky-wave antenna with backfire-to-endfire scanning capability," *Electronics Letters*, Vol. 38, 1414–1416, 2002.

6. Dong, Y. and T. Itoh, "Composite right/left-handed substrate integrated waveguide and half mode substrate integrated waveguide leaky-wave structures," *IEEE Transactions on Antennas and Propagation*, Vol. 59, 767–775, 2011.
7. 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.
8. Liu, C.-Y., Q.-X. Chu, and J.-Q. Huang, "Double-side radiating leaky-wave antenna based on composite right/left-handed coplanar-waveguide," *Progress In Electromagnetics Research Letters*, Vol. 14, 11–19, 2010.
9. Anghel, A. and R. Cacoveanu, "Improved composite right/left-handed cell for leaky-wave antenna," *Progress In Electromagnetics Research Letters*, Vol. 22, 59–69, 2011.
10. Caloz, C., "Dual composite right/left-handed (D-CRLH) transmission line metamaterial," *IEEE Microwave and Wireless Components Letters*, Vol. 16, 585–587, 2006.
11. 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, 2485–2488, 2009.
12. Wang, W., C. Liu, L. Yan, and K. Huang, "A novel power divider based on dual-composite right/left handed transmission line," *Journal of Electromagnetic Waves and Applications*, Vol. 23, Nos. 8–9, 1173–1180, 2009.
13. Wong, K. L., H. C. Tung, and T. W. Chiou, "Broadband dual-polarized aperture-coupled patch antennas with modified H-shaped coupling slots," *IEEE Transactions on Antennas and Propagation*, Vol. 50, 188–191, 2002.
14. Guo, Y. X., K. W. Khoo, and L. C. Ong, "Wideband dual-polarized patch antenna with broadband baluns," *IEEE Transactions on Antennas and Propagation*, Vol. 55, 78–83, 2007.
15. Ryu, K. S. and A. A. Kishk, "Wideband dual-polarized microstrip patch excited by hook shaped probes," *IEEE Transactions on Antennas and Propagation*, Vol. 56, 3645–3649, 2008.
16. Pozar, D. M., *Microwave Engineering*, John Wiley & Sons, New Jersey, 2005.
17. Caillet, M., M. Clenet, A. Sharaiha, and Y. Antar, "A compact wideband rat-race hybrid using microstrip lines," *IEEE Microwave and Wireless Components Letters*, Vol. 19, 191–193, 2009.