

LEAKY WAVE ANTENNA REALIZATION BY COMPOSITE RIGHT/LEFT-HANDED TRANSMISSION LINE

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Abstract—This paper presents a realization of composite right/left handed transmission lines using coupled microstrip lines. This structure exploits the advantages of the microstrip lines, while increases the coupling by a floating conductor at the ground plane. The performance of this composite right/left-handed line is demonstrated by both simulated and measured results, and they show good agreement. The designed line has broad bandwidth with low losses and small size. A novel dominant mode leaky wave antenna design, using the previous structure, is presented with backward to forward scanning capability.

1. INTRODUCTION

The left handed materials, which have simultaneously negative permittivity and permeability, were first investigated theoretically by Veselago [1]. He pointed out some of their unique properties such as reversal of Snells law, Doppler effect, and Cerenkov radiation. Composite right/left handed (CRLH) transmission lines support both right-handed (RH) and left-handed (LH) propagation. Realization of CRLH TL with its applications is surveyed in [2].

This paper presents a realization of CRLH TL using coupled microstrip lines with floating conductor in the ground plane. The realization of CRLH TL using coupled lines are first presented by Abdelaziz et al. [3]. Basically, any type of coupled lines can be used to construct CRLH TL; however, the available technology imposes some limitations. The theory was applied successfully using broadside coupled coplanar waveguides [4]. Attention is focused on the use of microstrip lines in microwave circuits due to the higher level of

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integration of microwave circuits on a single substrate. However, microstrip lines suffer from the weak lateral coupling between the lines in the conventional structure as shown in Fig. 1(a). Realization of CRLH TL using coupled microstrip lines with slotted ground was done in [3]. Another approach of realization can be done by adding the floating conductor in the ground plane, as shown in Fig. 1(b). The structure with the floating conductor has two advantages with respect to that with a simple slot in the ground plane: The first one is ease of the design as several dimensions can be chosen for the required even and odd impedances, and the second one is that the presence of a floating conductor allows for mode phase velocity matching when using low permittivity substrates; in this case the slotted ground will not completely match the mode phase velocity [5–7].

If the CRLH TL is open to free space and supports fast wave mode and leaky wave (LW) mode, it radiates and can be used as an antenna. CRLH LW antenna operates at its fundamental mode, so it has small size and simple feeder. The wave number of the structure has both negative and positive values, so it supports scanning from backfire to endfire directions [8]. In this paper, we present a novel CRLH LW antenna based on coupled microstrip lines with backfire (LH-lower frequencies) to endfire (RH-higher frequencies) scanning capability.

2. CRLH LINE IMPLEMENTATION

For our case, the floating conductor tends to equalize the even and odd mode electrical length, so the coupling will be described using homogeneous dielectric medium impedance matrix $[Z]$ [9]. As shown

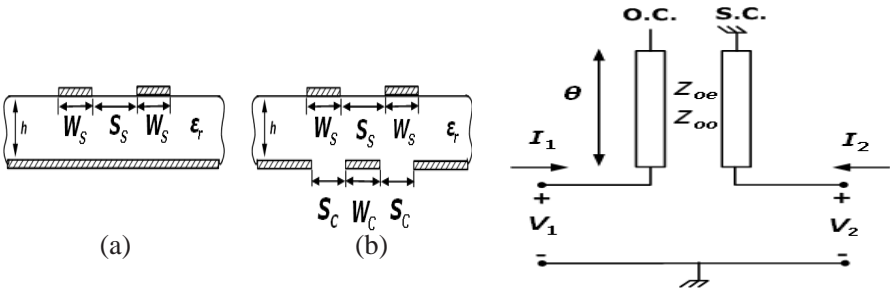


Figure 1. Coupled microstrip lines. (a) Edge coupled. (b) Edge coupled with floating strip in the ground plane.

Figure 2. Two port coupled TL.

in [3], we can realize the unit cell with a pair of the circuits shown in Fig. 2. The CRLH unit cell can be constructed by cascading the resulting circuit with its mirrored version. Matching the periodic structure to the terminating impedance (i.e., $Z_o = 50 \Omega$) imposes a relation between Z_{oe} and Z_{oo} [3].

Z_{oo} does not change much by the added floating conductor as a larger percentage of the electric field energy in the odd mode is located in the air region compared to the even mode. Owing to this fact, we design the conventional coupled microstrip lines to get the required Z_{oo} , then use an electromagnetic (EM) simulator (Ansoft Designer) for the fine tuning to get the required Z_{oe} by adding the floating conductor in the ground plane. In the present design, a substrate Rogers RT/Duroid 6006 with dielectric constant $\epsilon_r = 6.15$ and thickness $h = 0.635$ mm (loss tangent = 0.0019) has been used. The width of the floating conductor is designed to achieve $Z_{oe} = 173.2 \Omega$ and $Z_{oo} = 57.73 \Omega$. The design values for W_s , S_s , W_c , and S_c , as shown in Fig. 1, should be 0.585 mm, 0.5 mm, 0.5 mm, and 2.2 mm; respectively. The port width is 2.89 mm.

Figure 3 shows the unit cell of the designed CRLH transmission line circuit. Fig. 3(a) shows the layout of the unit cell with the upper and lower layers above each other. Fig. 3(b) shows the layout of the top layer; the shaded area represents the coupled microstrip lines. While Fig. 3(c) shows the layout of the ground plane, the filled area represents no metallization. The length of the coupled lines of a unit cell is 27 mm; the length of the floating conductor is 25 mm; the length of the unit cell itself is 6 mm (i.e., the unit cell is repeated periodically every 6 mm).

To compute the propagation constant and Bloch impedance for our periodic structure, the Z -parameters (Z_{11} and Z_{12}) of the unit cell are computed using the method of moments by the EM Ansoft

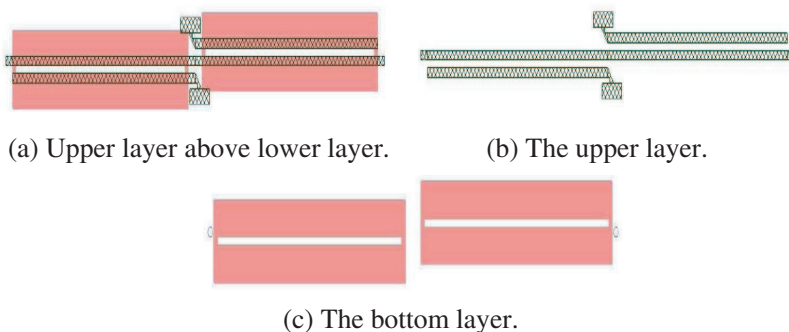


Figure 3. A layout of a unit cell of the CRLH TL.

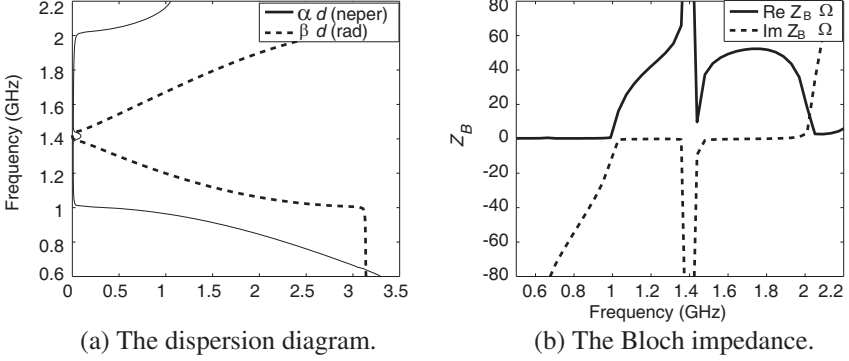


Figure 4. The performance of the left-handed cell.

Designer. As we have our unit cell represented by symmetrical T network, the unit cell characteristics are

$$\cosh \gamma d = \frac{Z_{11}}{Z_{12}} \quad (1)$$

$$Z_B = Z_{12} \sinh \gamma d$$

Figure 4 represents the dispersion and Bloch impedance of the unit cell. The attenuation in the pass-band is almost negligible. Bloch impedance has an imaginary value during the transmission band as the balanced structure is slightly deformed due to the added TL to avoid overlapping.

For our TL design, we use 5 cascaded unit cells. The length of the whole structure is 33 mm. The proposed CRLH transmission line has been fabricated, measured and compared to the simulation results. A photograph of the proposed CRLH transmission line is shown in Fig. 5.

The simulation results are shown in Fig. 6. This figure shows very small losses in the transmission band. The dip shown in Fig. 6(b) represents the transition from the LH region to RH region. The CRLH networks are band-pass filters. In our design, the passband extends from 1.06 GHz to 2 GHz.

3. DOMINANT MODE LW ANTENNA

Based on the previous CRLH TL approach, we design a dominant mode leaky-wave antenna with backfire to endfire scanning capability. CRLH LW antenna operates in its fundamental mode, so it can be fed by a very simple and efficient mechanism. This leads to a small structure. Fig. 7 represents the layout of the unit cell of the proposed

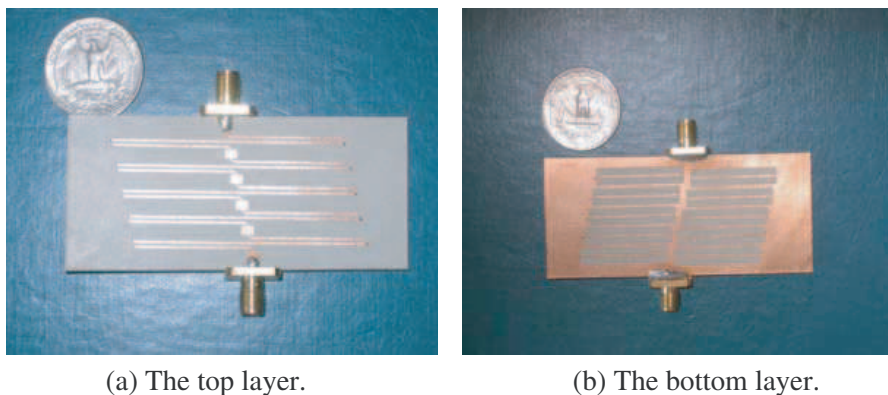


Figure 5. Photograph of the proposed CRLH TL.

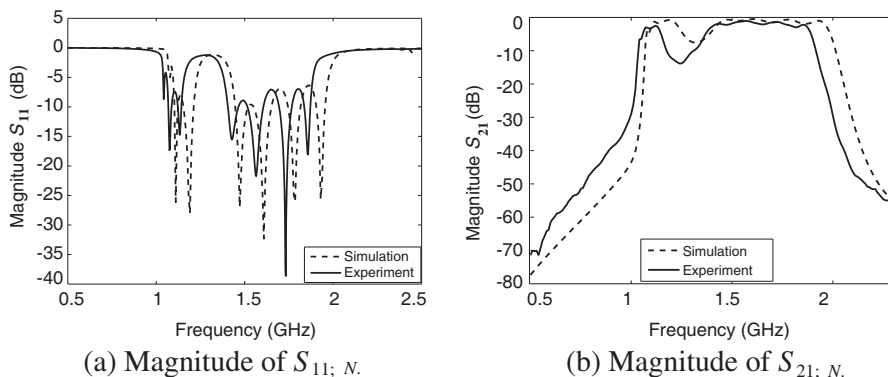


Figure 6. Frequency characteristics of the CRLH TL.

CRLH LW antenna with upper and lower layers. The design is based on RT/Duroid 6006. There is an added transmission line between the two cascaded coupled lines with length 1.33 mm for vertical alignment of the cascaded cells. the port height is 5 mm. The length of the coupled lines of a unit cell is 8 mm; the length of the floating conductor is 6 mm; its position is shifted to the right by 0.5 mm; the length of the unit cell itself is 13 mm (i.e., the unit cell is repeated periodically every 13 mm). The length of the coupled lines was chosen such that the CRLH matches the required frequency range. The antenna unit cell is slightly different compared with the previous shown cell to achieve the best antenna gain and return loss performance. Fig. 8 represents the dispersion diagram of the antenna unit cell with the air line $\omega = \kappa c$, where d is the unit cell length which is 13 mm. This $\omega - \beta$

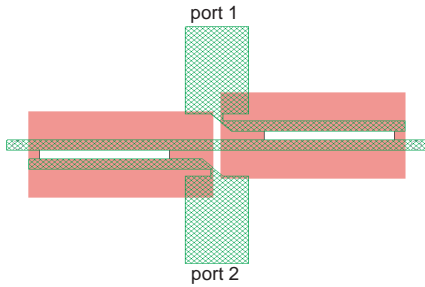


Figure 7. The unit cell of proposed LW antenna.

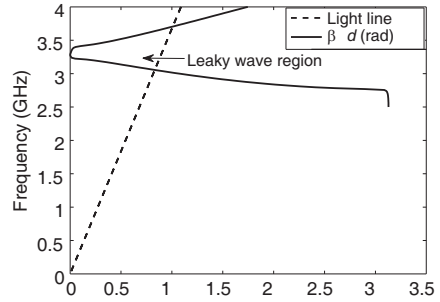


Figure 8. The dispersion diagram.

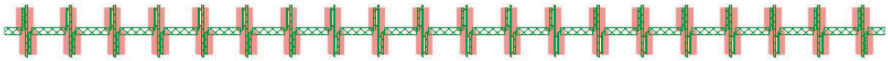


Figure 9. The proposed antenna.

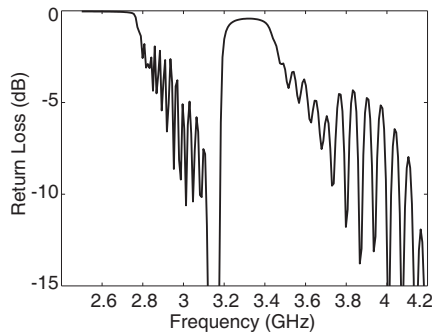


Figure 10. The return loss of the proposed antenna.

diagram indicates the LH-RH leaky regions which extend from 3 GHz to 3.8 GHz. We used 20 unit cells to construct the antenna. Fig. 10 represents the return loss (magnitude of S_{11} dB) which indicates the range of matching.

E -plane radiation patterns are shown in Fig. 11 obtained from the EM simulation. The radiation angle is measured with respect to the normal to the antenna axis. As predicted by the dispersion characteristic shown in Fig. 8, the main beam of this antenna is broadside at the transition frequency 3.26 GHz. All the sidelobe levels for the antenna at different frequencies are larger than 10 dB. The gain of this antenna is larger than 5 dB at all radiation frequencies.

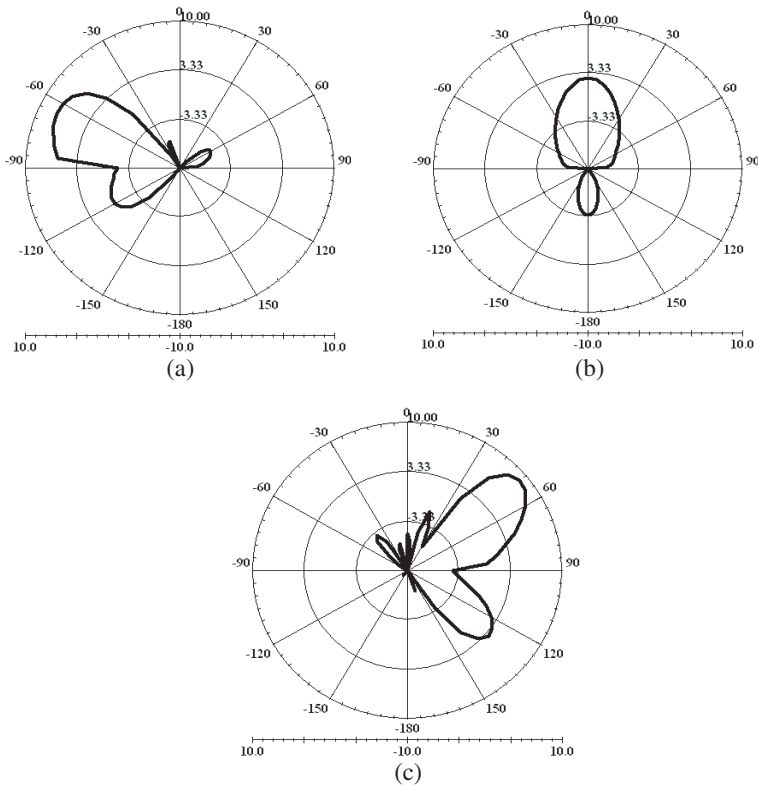


Figure 11. Radiation patterns of the novel MTM LW antenna. (a) Backward radiation, $f = 3.05$ GHz. (b) Broadside radiation, $f = 3.26$ GHz. (c) Forward radiation, $f = 3.63$ GHz.

4. CONCLUSION

Based on the coupling between a pair of microstrip lines, a CRLH TL has been designed. The coupling has been increased by adding a floating conductor in the ground plane. A novel CRLH LW antenna has been designed, and its scanning capabilities from backfire-to-endfire directions have been shown. The antenna operates at its fundamental mode which reduces its size.

REFERENCES

1. Veselago, V., "The electrodynamics of substances with simultaneously negative values of ϵ and μ ," *Soviet Physics Uspekhi*, Vol. 10,

- No. 4, 509–514, 1968.
2. Lai, A., T. Itoh, and C. Caloz, “Composite right/left-handed transmission line metamaterials,” *IEEE Microwave Magazine*, 34–50, Sep. 2004.
 3. Abdelaziz, A. F., T. M. Abuelfadl, and O. L. Elsayed, “Realization of composite right/left-handed transmission line using coupled lines,” *Progress In Electromagnetics Research*, PIER 92, 299–315, 2009.
 4. Abdelaziz, A. F., T. M. Abuelfadl, and O. L. Elsayed, “Realization of composite right/left-handed transmission line using broadside coupled coplanar waveguides,” *IEEE Inter. Symposium on Antennas and Propagation*, APS, 2009.
 5. Malherbe, J. A. G. and I. E. Losch, “Directional couplers using semireentrant coupled lines,” *Microwave Journal*, 121–128, Nov. 1987.
 6. Masot, F., F. Medina, and M. Horno, “Analysis and experimental validation of a type of three-microstrip directional coupler,” *IEEE Transactions on Microwave Theory and Techniques*, Vol. 42, No. 9, 1624–1631, Sep. 1994.
 7. Velazquez-Ahumada, M., J. Martel, and F. Medina, “Parallel coupled microstrip lters with oating ground-plane conductor for spurious-band suppression,” *IEEE Transactions on Microwave Theory and Techniques*, Vol. 53, No. 5, 1823–1828, May 2005.
 8. Liu, L., C. Caloz, and T. Itoh, “Dominant mode (DM) leaky-wave antenna with backre-to-endre scanning capability,” *Electron. Lett.*, Vol. 38, No. 23, 1414–1416, Nov. 2002.
 9. Jones, E. M. T. and J. T. Bolljahn, “Coupled-strip-transmission-line lters and directional couplers,” *IRE Transactions on Microwave Theory and Techniques*, 75–81, Apr. 1956.