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A NOVEL VIA LESS RESONANT TYPE ANTENNA BASED ON COMPOSITE RIGHT/LEFT-HANDED TRANSMISSION LINE (CRLH-TL) UNIT CELL WITH DEFECTED GROUND STRUCTURE

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Abstract—In this paper, a novel via-less balanced composite right/left handed transmission line (CRLH-TL) unit cell using defected ground structure (DGS) is presented, and a resonant type antenna based on the proposed CRLH-TL unit cell is designed. Equivalent circuit model is developed to analyze the CRLH-TL unit cell antenna. The resonant frequency is studied, and the resonant frequency tuned by adjusting the dimension of the antenna patch is simulated. The antenna simulated and measured results are presented. The measured central frequency is 5.55 GHz. A peak gain of 6.7 dBi with an efficiency of 75.6% is obtained at the central frequency.

1. INTRODUCTION

The rapid developments of wireless communication technology have led to an increasing demand for compact, low profile, high gain, and high efficiency antenna. Benefiting from the outstanding prosperities of planar technology, such as low cost, low profile, ability to be integrated with other planar circuits, and fabrication convenient of adopting standard printed circuit board (PCB) process, planar technology has drawn much attention in the design of low profile antennas [1–4]. Many new technologies based on planar technology, i.e., metamaterials [5–7], defected ground structures (DGS) [8], have been proposed in recent years, and new design methodologies for antenna design are proposed [2, 6, 9–11]. Composite right/left-handed transmission lines (CRLH-TLs) have been reported as practical metamaterial structures.

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The unique characteristics of the CRLH-TLs that cannot be realized by conventional right-handed (RH) transmission lines, i.e., anti-parallel group and phase velocities, zero propagation constant [12, 13], can be used for enhancing practical microwave devices [14–17] and antennas design [18]. Several CRLH-TL based antennas have already been presented, i.e., the CRLH leaky-wave antennas with backward and forward scanning capability [19, 20], the zeroth-order resonant (ZoR) antenna [3, 21–23], negative-order antenna (NOR) [24], and the multi-band antennas [18, 25, 26]. Recently, it shows that the CRLH-TL unit-cell can be used to implement the resonant type antennas [27–29].

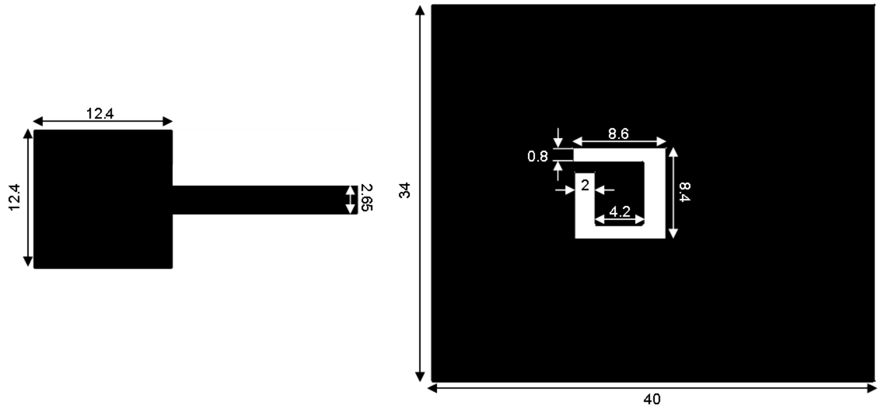
The traditional microstrip CRLH-TLs require vias to build the left-hand inductors [30]. Recently, DGS structure is used to implement via-less unbalanced CRLH-TL [31, 32], however, the microstrip DGS balanced CRLH-TLs have been rarely reported. In this paper, a novel via-less balanced CRLH-TL unit cell using defected ground structure is presented and a resonant type antenna based on the proposed CRLH-TL unit cell is designed. The designed antenna is presented in Section 2. The equivalent circuit model is developed to analyze the CRLH-TL unit cell antenna, and the tunable capability of the antenna is studied. The fabrication and measured results are presented in Section 3. Finally, conclusions are followed in Section 4.

2. ANTENNA DESIGN AND THEORY

2.1. The Balanced DGS CRLH-TL Unit-cell and Circuit Model

Figure 1 shows a new type of balanced CRLH-TL unit-cell antenna based on microstrip DGS. The configuration of the unit-cell consists of two metallic layers. The upper layer is a square radiating patch, and the defected ground structure is realized by etching a defected pattern on the ground layer. The defected ground structure can introduce serious capacitor and inductor LC network between the top layer patch and the ground.

An equivalent circuit model is developed to analyze the proposed structure, as shown in Fig. 2. The high impedance feed line connecting the low impedance patch is modeled as inductor L_R. C_R indicates the capacitor between the top patch to the ground plane. C_L is the capacitor between the top patch to the DGS patch. L_L is modeled as the DGS strip line connecting the ground. The equivalent circuit model in Fig. 2 shows that the CRLH-TL unit cell is balanced. The balanced CRLH-TL is simpler than the unbalanced one because series combined left handed (LH) and right handed (RH) contributions are decoupled from each other, which will be helpful for impedance match [33].



(a) (b)

Figure 1. Layout of the CRLH-TL unite-cell: (a) top view and (b) bottom view geometry.

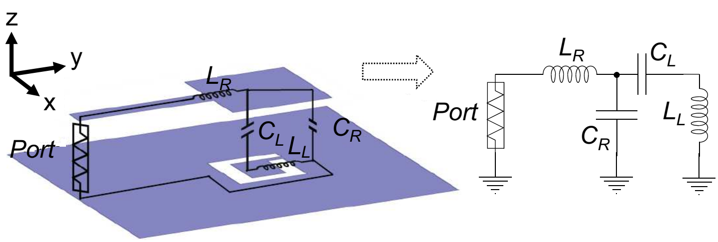


Figure 2. Equivalent circuit model of the CRLH-TL unit cell.

2.2. Antenna Simulation

Since any CRLH-TL unit-cell can be used to implement resonant type antenna [33], the structure proposed in Fig. 1 can be used as an antenna. The CRLH-TL unit cell antenna is designed on F4B-2 substrate with dielectric constant of $\varepsilon_r = 2.65$ and a thickness of 1 mm. The simulated current distributions along the metallic surface at the resonant frequency are shown in Figs. 3(a) and (b). We can observe that most of the surface current flows not only along the edge of the top patch, but also along the strip line and the edge of the bottom DGS. The surface electric field distributions at the center frequency are described in Figs. 3(c) and (d). The distribution shows that the top patch couples both the ground plane and the DGS internal patch.

The simulated return loss and the radiation pattern at the resonant frequency are presented in Figs. 4(a) and (b) respectively. The

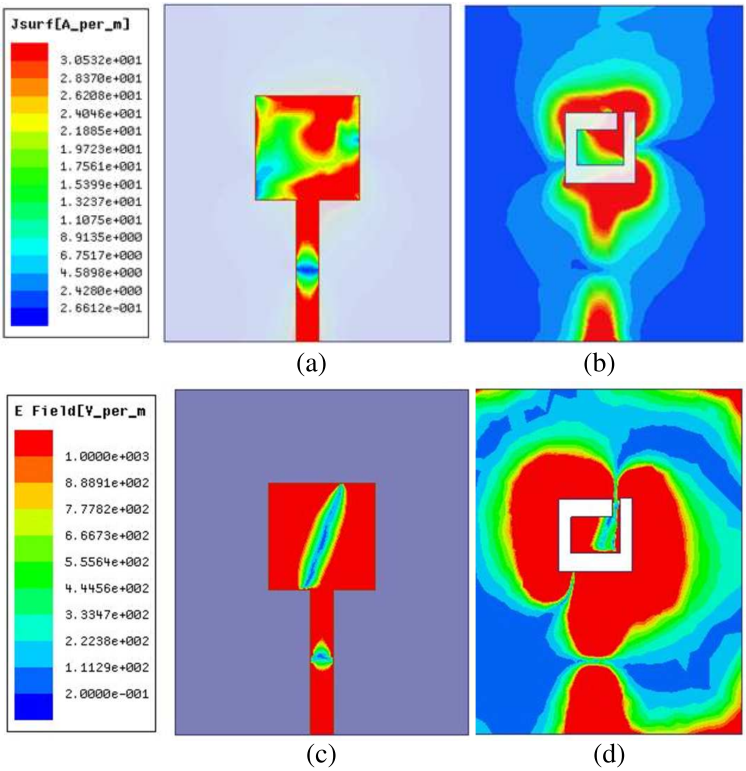


Figure 3. The surface current distribution of the antenna: (a) top and (b) bottom. The surface electric field distribution of the antenna: (c) top and (d) bottom.

Electromagnetic (EM) simulated central frequency is 5.5 GHz with a return loss of 30 dB and a peak gain of 7.2 dBi. Based on the simulated S-parameter and the circuit model, curve fitting technology is used to extract the element parameters. As shown in the inset of Fig. 4(a), two 377 Ω radiation resistor R_{ant} is loaded with the capacitors in the model. The extracted circuit parameters of the unit cell are: $L_R = 3\,\text{nH}$, $L_L = 1.15\,\text{nH}$, $C_R = 1.5\,\text{pF}$, $C_L = 1.7\,\text{pF}$, respectively. Fig. 4(c) shows that the equivalent circuit model calculated input impedance, EM simulated input impedance matches each other very well. Therefore, the proposed circuit model is valid and is fully capable of explaining the antenna.

By numerical studying the circuit model, we find that the resonant frequency can be mainly tuned by the capacitor C_R, C_L, and the inductor L_L. Therefore, the resonant frequency can be tuned

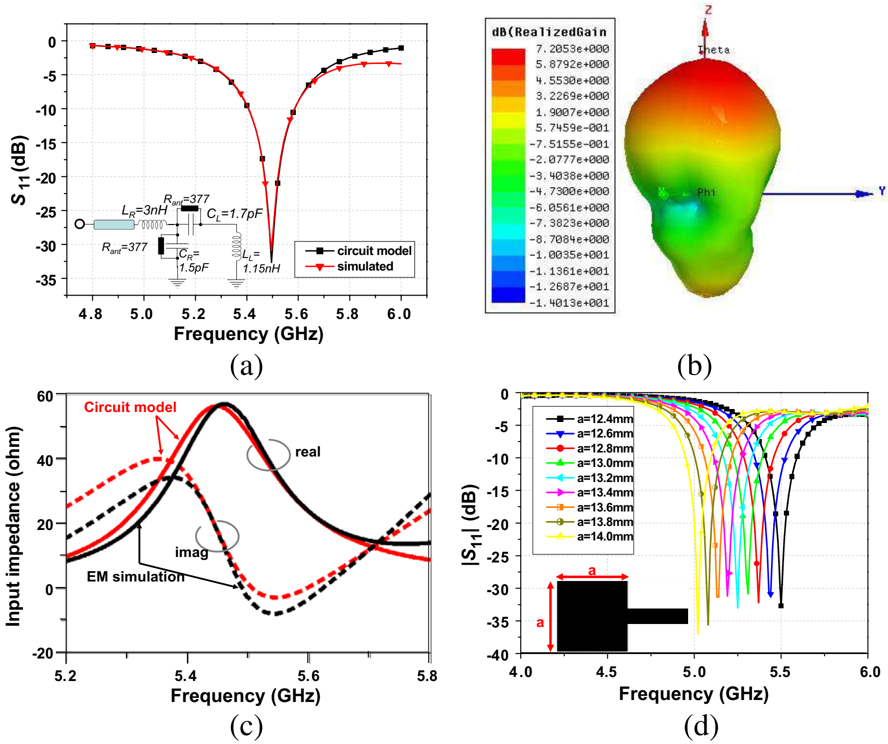


Figure 4. Simulated results of the CRLH-TL antenna: (a) simulated and calculated $|S_{11}|$, (b) 3-D radiation pattern, (c) comparison between the circuit model calculated and EM simulated input impedance, and (d) the resonant frequency shifting.

by adjusting the dimensions of the top patch or the DGS. As a demonstration, Fig. 4(d) shows that the resonant frequency can be tuned by adjusting the length of the radiation patch. The impedance matching remains very well under the changes of resonant frequency. Therefore, the proposed balanced DGS CRLH-TL unit cell antenna may be used for designing electrical tunable antennas.

3. ANTENNA FABRICATION AND MEASUREMENT

The antenna shown in Fig. 1 is fabricated on 1 mm thick F4B-2 substrate with dielectric constant of $\varepsilon_r = 2.65$, as shown in Figs. 5(a) and (b). Fig. 5(c) shows the microwave anechoic chamber for measuring the antenna radiation patterns. Agilent E5071C vector

(a) (b) (c)

Figure 5. Fabricated antenna based on the balanced CRLH-TL unit cell: (a) the top view, (b) the bottom view, (c) the antenna in microwave anechoic chamber.

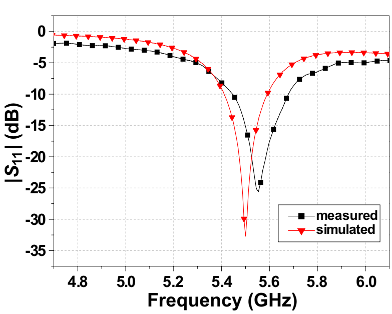


Figure 6. Measured and EM-simulated $|S_{11}|$.

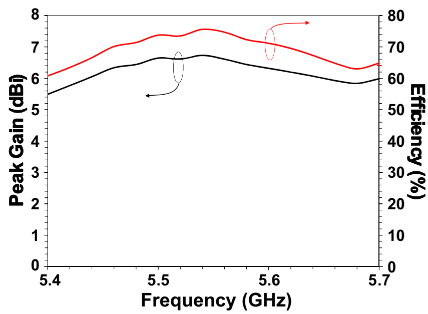


Figure 7. Measured radiation efficiency and peak gain.

network analyzer is used to measure the return loss of the antenna. The measured and simulated return losses are shown in Fig. 6. The measured central frequency is 5.55 GHz with a return loss of 25 dB, a -10 dB bandwidth of 240 MHz, and a 50 MHz frequency shift is occurred due to the parameter skew of the PCB process.

The measured radiation efficiency and peak gain of the antenna under different frequencies are shown in Fig. 7. It shows that a peak gain of 6.7 dBi and a maximum efficiency of 75.6% are obtained at 5.55 GHz. Fig. 8 shows the measured and simulated radiation patterns including the co-and cross-polarization in the H-plane (x-z plane) and E-plane (y-z plane) of the proposed antenna. It shows that the simulated and measured radiation patterns agree with each other very well. The radiation patterns of the proposed antenna at the resonant frequency are patch-like in the H-plane. The radiation is occurred mainly on the top plane rather than the defected ground plane, and the cross-polarization is less than the co-polarization.

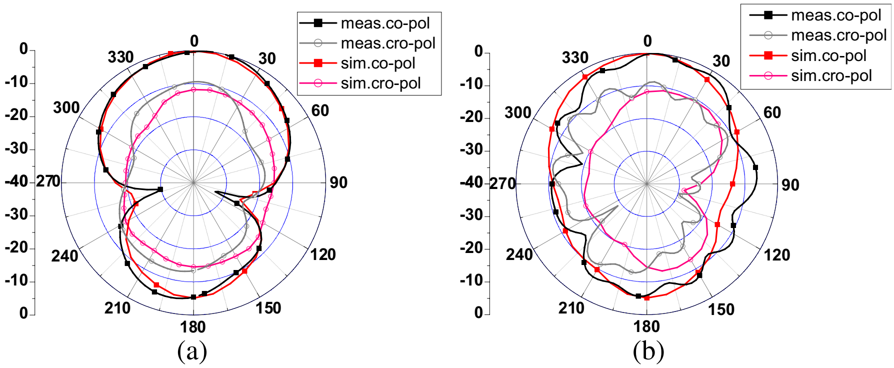


Figure 8. Measured and EM-simulated radiation patterns at center resonant frequency: (a) H-plane (x-z plane), (b) E-plane (y-z plane).

4. CONCLUSION

Based on the coupling between the top plane and the microstrip DGS, a novel via-less balanced CRLH-TL unit cell and its application to antenna design is proposed. Equivalent circuit model is developed to analyze the CRLH-TL unit cell antenna, and the resonant frequency tunable capability is studied. The antenna is designed, fabricated and measured. The measured -10 dB bandwidth is 240 MHz. The measured peak gain and efficiency are 6.7 dBi and 75.6% at the central frequency of 5.55 GHz, respectively. The measured minimum radiation peak gain and efficiency in the -10 dB bandwidth are 5.84 dBi and 63% at 5.68 GHz, respectively.

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