A Novel Tri-band Patch Antenna Based on Complementary Triangle Split Ring Resonator Pair

J.-G. Liang[1], **Z.-J. Song**[1], **L.-J. Yu**[2], **and X.-F. Zhang**[1]

[1]Air and Missile Defense College, Air Force Engineering University, Xi'an 710051, China
[2]Center for Health Management and Policy, Shandong University, Jinan 250012, China

Abstract— A new resonant-type composite right/left-handed transmission line (CRLH TL) is proposed based on the combination of a complementary triangle split ring resonator pair (CTSRRP) etched on the ground plane and a series gap embedded in the conductor strip of a microstrip line. The CTSRRP, which is composed of two identical complementary triangle split ring resonators (CTSRR) with back-to-back splits, demonstrates negative permittivity. Besides, a center branch is added to the middle of each triangle split ring to divide it into two parts. In virtue of this, two current paths of different length are formed which primely improve the multi-band characteristic of the transmission line (TL). The equivalent capacitor-inductor circuit model is put forward to analyze the TL. The S parameters are derived from electromagnetic full-wave simulation through simulation engine Ansoft HFSS13. Then the dispersion curve of the proposed structure is calculated based on S parameters to attest the left-handed characteristics. Two left-handed bands and two right-handed bands are observed from the dispersion curve. To demonstrate the applicability of the new type TL, a tri-band patch antenna of C band is designed and fabricated. Good agreement between simulated and measured return loss is obtained. Measured results present that three available bands centered at 4.45 GHz, 5.55 GHz and 7.35 GHz respectively are acquired. Peak gain of more than 7 dB and invariable radiation characteristics can be observed from the simulated radiation patterns. And the cross polarization in working bands is less than −15 dB with the minimal touching bottom of −55 dB.

1. INTRODUCTION

Left-handed metamaterials became a subject of intensive research when the first left-handed medium was fabricated and demonstrated with negative refractive index by Smith et al. [1]. Since then, metamaterial transmission lines have exhibited great value in the implementation of novel microwave components and antennas because of their unusual properties. In 2002, Caloz and Itoh [2] proposed a new method to realize metamaterials by using transmission line. Owing to the unavoidable parasitical right-handed effect, this metamaterial transmission line with composite right/left-handed (CRLH) behavior is also defined as the so-called composite right/left-handed transmission line (CRLH TL) with useful and unusual electromagnetic properties. In 2004, complementary split ring resonators(CSRRs) were proposed with negative permittivity [3] and were accompanied with a capacitive gap to obtain left-handed behavior by Falcone et al. [4], which was considered a breakthrough in this area and in turn opened a way to another crucial innovative orientation of metamaterial transmission line, namely the resonant-type CRLH TL.

In this paper, a new resonant-type CRLH TL based on a complementary triangle split ring resonator pair (CTSRRP) is proposed for a tri-band patch antenna. The CTSRRP is composed of two identical complementary triangle split ring resonators (CTSRRs) with back-to-back splits and a center branch is added to the middle of each triangle ring to divide the triangle split rings into two parts. The antenna which is easier to be fabricated because no grounded via is needed exhibits good performance in impedance width and radiation patterns.

2. ANALYSIS OF CTSRRP ELEMENT

As shown in Fig. 1, the CTSRRP is etched on the ground plane beneath two metal patches separated by a gap. The metal patches are depicted in grey in Fig. 1(a) and the CTSRRP is depicted in Fig. 1(b). The 1.5 mm-thick substrate with a dielectric constant $\varepsilon_r = 2.65$ and a loss tangent $\tan\delta = 0.001$ is chosen for all simulation and antenna design. After optimization, the dimensions are: $L = 10\,\mathrm{mm}$, $L_p = 13\,\mathrm{mm}$, $W_p = 18\,\mathrm{mm}$, $g = 0.3\,\mathrm{mm}$, $g_1 = 0.4\,\mathrm{mm}$. And the width of the slot between the two patches is $g_2 = 0.2\,\mathrm{mm}$.

Figure 1(c) depicts the lumped-element equivalent circuit model of this resonant-type CRLH TL. Two smaller CTSRRs are formed because of the center branches added to the middle of the triangle rings. Corresponding to the two current paths engendered by the CTSRRs of different

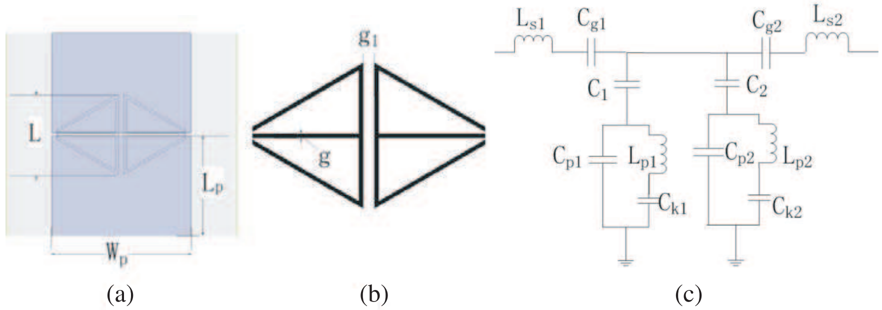


Figure 1: Topology of the proposed CRLH TL. (a) Top view. (b) Bottom view. (c) Equivalent circuit model.

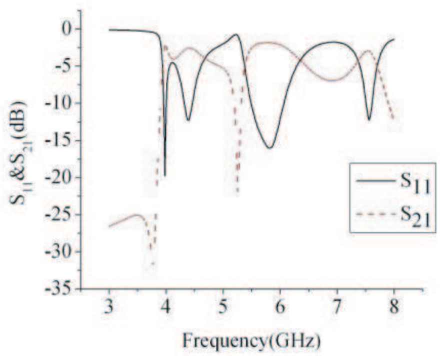


Figure 2: Frequency response of the CTSRRP-loaded CRLH TL.

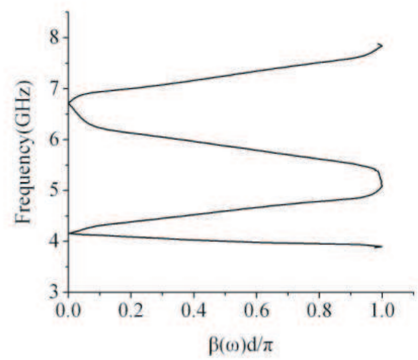


Figure 3: Dispersion curve of the CTSRRP-loaded CRLH TL.

size, there are two shunt resonant tanks formed by C_p, L_p and C_k modeling respectively the two CTSRRs of different size in the circuit model. The capacitances C_{g1} and C_{g2} model the series gap. The inductances L_{s1} and L_{s2} model the line inductance. C_1 and C_2 represent partially the line capacitance and partially the electrical coupling between the series gap and the CTSRRP. C_{k1} and C_{k2} are applied to model the resultant interaction between the two CTSRRs.

Figure 2 shows the frequency response of the CTSRRP-loaded CRLH TL obtained from electromagnetic full-wave simulation through simulation engine Ansoft HFSS13. As can be observed, the CRLH TL element performs nice characteristic of multi-band which foreshow its application in the following antenna.

The mathematical formula of dispersion curve is:

$$|\beta(\omega)d| = \left|\mathrm{Re}\left[\arccos\left(\frac{1 - S_{11}S_{22} + S_{12}S_{21}}{2S_{21}}\right)\right]\right| \tag{1}$$

Here d denotes the dimension of one CRLH TL element.

According to (1), the dispersion curve of the proposed structure that is shown in Fig. 3 can be derived from the S parameters. It is obvious that one element of the CTSRRP-loaded CRLH TL has two left-handed bands and two right-handed bands in which the four resonant frequencies in Fig. 2 situate respectively. In general, the results in Fig. 2 and Fig. 3 give strong support to demonstrate the left-handed performance of the proposed structure.

3. APPLICATION IN ANTENNAS

To demonstrate the possibility of employing this new kind of artificial CRLH TL in the design of antennas, a tri-band patch antenna has been designed and fabricated. The topology of the antenna is shown in Fig. 4. It is the same with that in Fig. 1 except for the two segments of feeding line added to match with the $50\,\Omega$ SMA connector. The geometrical parameters are $W_{s1} = 3\,\mathrm{mm}$, $L_{s1} = 7.8\,\mathrm{mm}$, $W_{s2} = 1.3\,\mathrm{mm}$ and $L_{s2} = 8\,\mathrm{mm}$. Other dimensions are the same with those in Fig. 1.

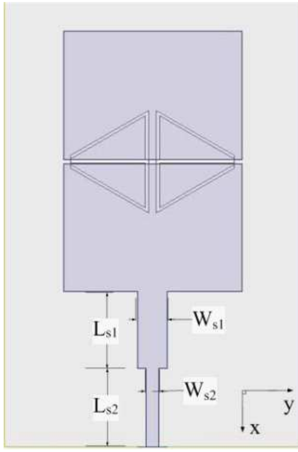
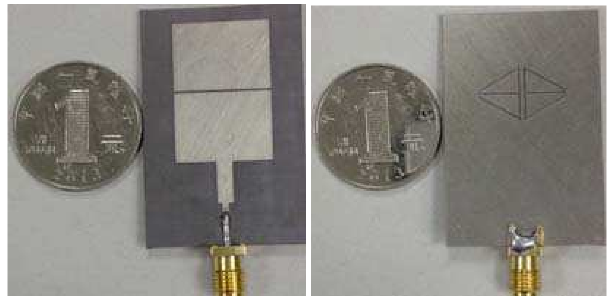


Figure 4: The topology of the designed antenna.



(a) (b)

Figure 5: Photograph of fabricated antenna. (a) Top view. (b) Bottom view.

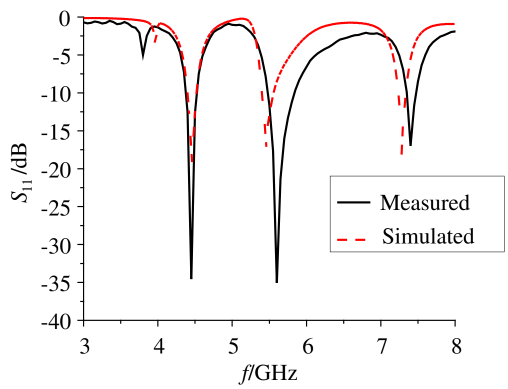


Figure 6: Simulated and measured return loss.

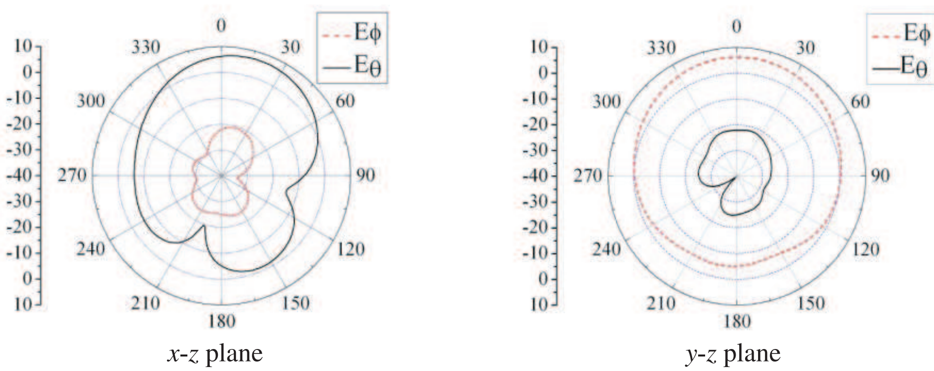
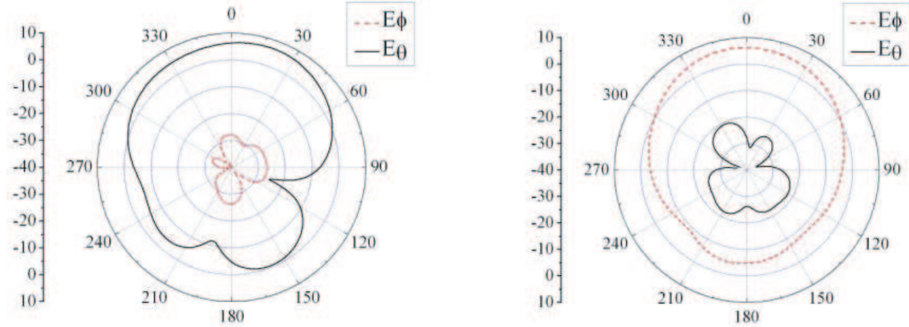


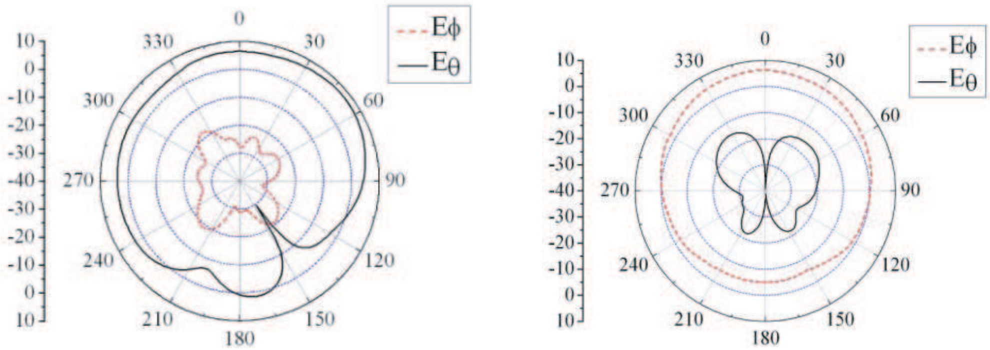
Figure 7: Radiation patterns at 4.45 GHz.

Figure 5 shows the photograph of fabricated antenna. Fig. 6 shows the simulated and measured return loss of the antenna. Good agreement between measured and simulated results is obtained except for a slight discrepancy in the higher bands. This discrepancy is partially attributable to the error of the dielectric constant of the utilized substrate and is partially induced by the tolerances of the dimensions that are inherent in the fabrication process. Almost the same results are obtained when regarding the tolerances in simulation. From the measured results, the three frequency bands are centered at 4.45 GHz, 5.55 GHz and 7.35 GHz with 10 dB impedance bandwidth of 130 MHz, 350 MHz and 110 MHz respectively. It is also observed that the first resonant point centered at 3.85 GHz can not work well. This is because the matching condition is not satisfied. It can be found that the first (centered at 3.85 GHz) and third (centered at 5.55 GHz) band belong to left-handed



x-z plane *y-z* plane

Figure 8: Radiation patterns at 5.55 GHz.



x-z plane *y-z* plane

Figure 9: Radiation patterns at 7.35 GHz.

bands and the second (centered at 4.45 GHz) and fourth (centered at 7.35 GHz) band belong to right-handed bands when comparing Fig. 3 with Fig. 6 together.

Further simulated results have shown that all the three useful bands shift downwards when L increases but the third band shift very slightly. The increase in L is in the mechanism directly enhancing C_{p1} and C_{p2} and indirectly enhancing C_1 and C_2. The increase of g_2 which brings on decrease of C_{g1} and C_{g2} will result in upwards shifting of the second and third bands. While changes in both g and g_1 make little influence.

The simulated radiation patterns for the center frequencies of the three useful bands are presented in Figs. 7∼9. It is can be observed that the antenna has a relatively invariable radiation patterns at different frequencies. The antenna radiates like the conventional patch antenna except for the comparatively big back lobe because of the existence of the CTSRRP on the ground. A peak gain of 6.8 dB to 7.9 dB is obtained for all the three center frequencies. The maximum cross polarization is less than −19 dB at *x-z* plane and −15 dB at *y-z* plane for all different center frequencies.

4. CONCLUSION

A new type of CRLH TL with performance of multi-band is proposed. Simulated and calculated results demonstrate that the new type TL has two left-handed bands and two right-handed bands. A novel tri-bands patch antenna of C band is proposed and fabricated based on the proposed TL. Measured and simulated results show that this antenna exhibits splendid impedance characteristic and radiation patterns and a peak gain of more than 7 dB is obtained.

ACKNOWLEDGMENT

This work is supported by the National Natural Science Foundation of China under Grant No. 61372034. Special thanks should also be delivered to the 206th study of China North Industries Group Corporation for the fabrication.

REFERENCES

1. Smith, D. R., W. J. Padilla, D. C. Vier, S. C. Nemat-Nasser, and S. Schultz, "Composite medium with simultaneously negative permeability and permittivity," *Phys. Rev. Lett.*, Vol. 84, 4184–4187, 2000.
2. Caloz, C. and T. Itoh, "Application of the transmission line theory of left-handed (LH) materials to the realization of a microstrip LH transmission line," *Proc. IEEE-AP-S USNC/URSI National Radio Science Meeting*, Vol. 2, 412–415, San Antonio, TX, Jun. 2002.
3. Falcone, F., T. Lopetegi, J. D. Baena, R. Marques, F. Martín, and M. Sorolla, "Effective negative-1 stop-band microstrip lines based on complementary split ring resonators," *IEEE Microw. Wirel. Compon. Lett.*, Vol. 14, 280–282, 2004.
4. Falcone, F., T. Lopetegi, M. A. G. Laso, et al., "Babinet principle applied to the design of metasurfaces and metamaterials," *Phys. Rev. Lett.*, Vol. 93, 197401, 2004.
5. Niu, J.-X., "Dual-band dual-mode patch antenna based on resonant-type mramaterial transmission line," *Electronics Letters*, Vol. 46, No. 4, 266–268, 2010.
6. Xu, H.-X., G.-M. Wang, C.-X. Zhang, Z.-W. Yu, and X. Chen, "Composite right/left-handed transmission line based on complementary single-split ring resonator pair and compact power dividers application using fractal geometry," *IET Microwaves, Antennas* & *Propagation*, Vol. 6, 1017–1025, 2011.
7. Liang, J.-G. and H.-X. Xu, "Harmonic suppressed bandpass filter using composite right/left handed transmission line," *Journal of Zhejiang University — Science C*, Vol. 13, No. 7, 552–558, 2012.