On the Study of Compact and Multi-Band CRLH Meta-Material Antenna for Wireless Applications

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Abstract: This paper presents a design of a small size composite right-left handed meta-material multi-band antenna for wireless applications. The proposed antenna consists of two left handed cells. The proposed antenna operates at different frequency bands. The proposed antenna has compact size (its size is only 38 X 22 mm2). The design represents size reduction of approximately 65 % compared to conventional patch antennas operating at the same frequencies. The size reduction and low frequency ratios have been achieved due to the nonlinearity behavior of the left-handed region of composite right-left handed transmission line.

Keywords: CRLH, left handed, meta-material, multi -band antenna

1. Introduction

The repaid growth of wireless communication leads to a greet demand in designing antennas with multi-band, high performance and easy to combine with other devices [1].Multi-band antennas are very useful for wireless applications due to only one antenna can cover several frequency bands. Several methods for obtaining multi-band characteristics have been developed. The multi-band operations are achieved by adopting multi-branched strips [2-4] and adding parasitic elements [5-8] to resonate at different frequencies in a single radiating device. However, these solutions generally suffer from certain drawbacks, including a large volume, a large ground plane, and a large frequency ratio. One possible solution to realize compact multi-band antennas with low frequency ratios could be utilization of metamaterial cells. Left handed (LH) transmission line (TL) is characterized by anti-parallel phase and group velocities. Also, it has a nonlinear progressive phase [9]-[11]. Because of these properties, compact microwave devices such as power dividers, filters, phase shifter, resonators, and antennas have been introduced [12]-[14]. Compact and multi bands antennas including novel zero[th] order resonator antenna (ZORA) are presented for different wireless applications [15]-[16].

In this paper, we introduce a design of CRLH (TL) metamaterial multi-band antenna. The proposed metamaterial antenna was designed employing only two cells of left handed transmission line. The left handed metamaterial consists of interdigital capacitor and short circuit stub work as inductor. The proposed antenna has compact size .The size reduction and low frequency ratios have been achieved due to the nonlinearity behavior of the left-handed region of CRLH(TL). The theoretical concepts of the designed antenna are introduced. The designed results have been validated using the electromagnetic full wave simulations.

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2. Theory

The explanation of TL approach of LHM as an ideal LHTL is not accurate so, the realization of LHM comprises both LH contribution due to the elements effect and RH contribution due to the parasitic series inductance and shunt capacitance effect of TL elements. Because of this contribution a practical TL approach LHM is referred as a composite right / left handed (CRLH) TL. The equivalent circuit approach of a lossless CRLH unit cell can be introduced as shown in Fig. 1.

In the equivalent circuit model, RH parameters consist of the series inductor and the shunt capacitor of the hosting TL while the series capacitor and shunt inductor are corresponding to the loading LH elements. It is seen that, at lower frequency, the RH elements, CR and LR, will be open circuited and short circuited respectively. Thus, the CRLH unit cell equivalent circuit reduces to that of LH equivalent circuit and hence it acts as a nearly ideal LH TL. Similarly, at higher frequency, the CRLH unit cell equivalent circuit reduces to that of RH equivalent circuit and hence it acts as an ideal RH TL.
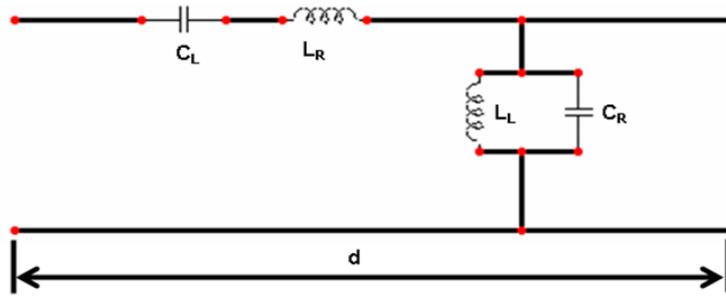

Fig. 1   The equivalent circuit model of CRLH transmission line.

The basic concept of transmission line resonating antenna is based on achieving resonance at frequencies which fulfill the full wave conditions as

$$\beta l = n\pi \tag{1}$$

where l is the total physical length of the resonating antenna, n is an integer specifies the resonating order and β is the guided propagation constants within the antenna substrate. In conventional microstrip patch antenna, the constant integer n is always positive. In conventional transmission line, the propagation constant is directly proportional to frequency; changes linearly with frequency. Thus, the operating condition for resonant antenna can be satisfied only at the harmonic frequencies of the antenna. On the other hand, the propagation constant is varying with the frequency in non linear way. Therefore, it can be implemented to introduce arbitrary operating multiband which is not essentially to be multiple of the fundamental frequency harmonic.

Also, by cascading metamaterial transmission line with conventional transmission line, the propagation constant can be arbitrary positive or negative or even zero. This can be illustrated in Fig.2. Hence, the radiation condition is

$$\beta l = \beta_l d_l + \beta_r d_r = n\pi \tag{2}$$

where β_l and β_r are the propagation constants of LH and RH sections, respectively, where d_l and d_r represent the length of the sections, respectively. In this case, the integer can be expressed as

$$n = 0, \pm 1, \pm 2, \pm 3, \ldots\ldots\ldots\pm(N-1) \tag{3}$$
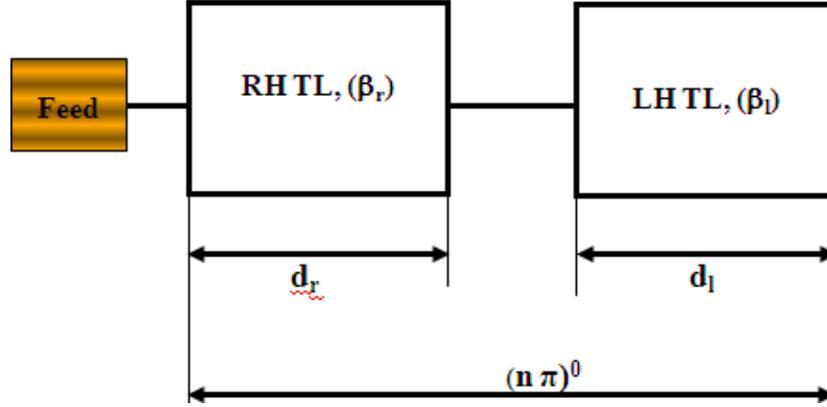
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**Fig. 2   The equivalent block diagram of metamaterial
left handed antenna**

The left handed and right handed propagation constants are determined according to the
loading elements and parasitic elements [11] which can be expressed as

$$\beta_l = \left(\frac{-1}{\omega \sqrt{C_L L_L}} \right) \tag{4}$$

$$\beta_r = \left(\omega \sqrt{C_R L_R} \right) \tag{5}$$

A practical LH unit cell contains a RH patristic effect which can do the theoretical cascading
LH and RH sections. Hence, the phase shift of a CRLH TL can be extracted from the phase of
the transmission coefficient S21 as follow in (6) as [11];

$$\varphi_{CRLH} = \tan^{-1}\left(\frac{\left(\left(\omega/\omega_{se} \right)^2 - 1 \right)\left(1 - \chi/4 \right) / C_L Z_{CRLH} \left(\left(\omega/\omega_{sh} \right)^2 - 1 \right) Z_{CRLH} / L_L}{\omega(2 - \chi)} \right) \tag{6}$$

$$\chi = -\left(\frac{\omega}{\omega_R} \right)^2 + \left(\frac{\omega_L}{\omega} \right)^2 - \left(\frac{C_R}{C_L} + \frac{L_R}{L_L} \right) \tag{7}$$

$$\omega_R = \frac{1}{\sqrt{L_R C_R}} \tag{8}$$

$$\omega_L = \frac{1}{\sqrt{L_L C_L}} \tag{9}$$

$$\omega_{sh} = \frac{1}{\sqrt{L_L \, C_R}} \tag{10}$$

$$\omega_{se} = \frac{1}{\sqrt{L_R \, C_L}} \tag{11}$$

$$Z_{CRLH} = Z_L \sqrt{\frac{(\omega / \omega_{se})^2 - 1}{(\omega / \omega_{sh})^2 - 1}} = Z_R \sqrt{\frac{(\omega_{se} / \omega)^2 - 1}{(\omega_{sh} / \omega)^2 - 1}} \tag{12}$$

3. Antenna Design Procedures

The layout of single element ZORA metamaterial antenna is shown in Fig. 3. The antenna was designed using one LH cell connected to a 50Ω RH feeding line. The antenna consists of a series interdigital capacitor and a shunt stub inductor. The antenna was designed on substrate FR4 with relative permittivity=4.4, a dielectric loss tangent =0.025 and thickness (h) =1.6 mm. The operation frequency of this antenna is 2.1GHz for UMTS application.
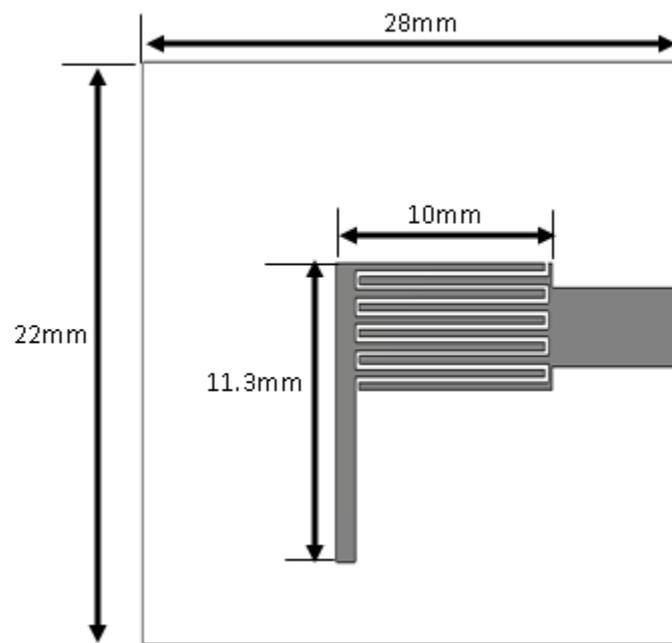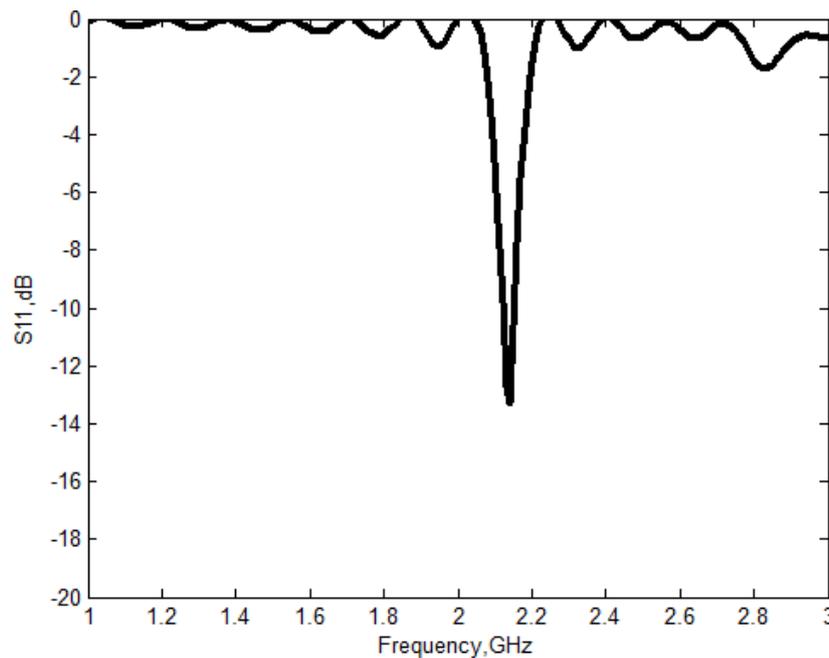

Fig. 3   2D layout of single element CRLH antenna

Fig. 4   Simulated return loss of single element CRLH antenna

The operating frequency of the resonant antenna was designed to fulfill the zero[th] order resonance (indicated in (1) for n=0). The antenna has compact size (its size is only 28 X 22 mm2) as compared with conventional antenna works at the same frequency. By optimizing the dimensions of the unit cell, a zero phase shift can be obtained at 2.1GHz. The simulated return loss of single element metamaterial antenna is shown in Fig. 4. As shown in the figure, the antenna can achieve better than -14 dB reflection coefficient at 2.1 GHz. For more confirmation about the single element metamaterial antenna initial design, its simulated radiation pattern in both E (XZ plane with Φ=0) and H plane (YZ plane with Φ=90) are shown in Fig.5 respectively. It is obvious that the patterns are very comparable of typical pattern of conventional microstrip patch antenna [17].
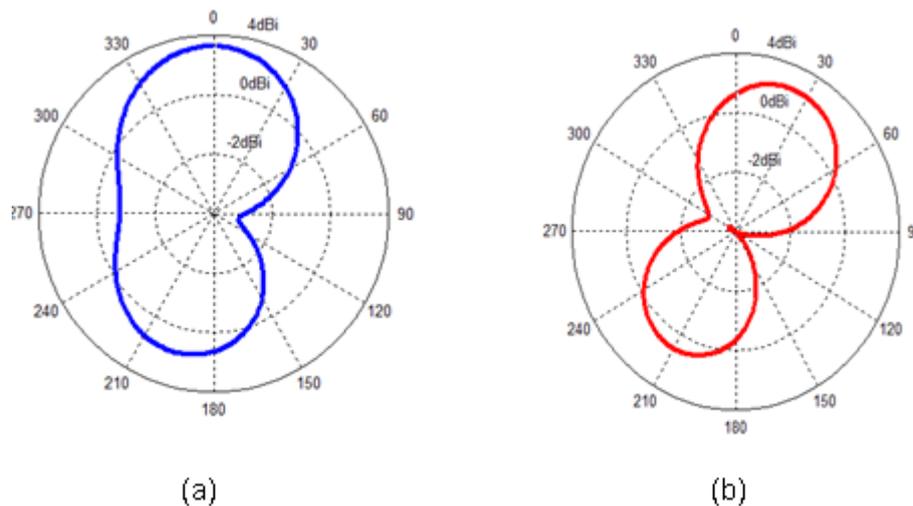

**Fig. 5   The Simulated field pattern of single element CRLH antenna
(a) E and (b) H Plane at 2.1GHz**

4. Proposed Multi-Band Antenna

The basic structure of the proposed antenna is shown in Fig.6. The antenna was designed using two LH cell connected to a 50Ω RH feeding line. Referring to (3) the number of n is equal to three 0,1 and -1 because of increasing the number of cells. So, the proposed antenna behaved like multi-band antenna. The antenna was designed on substrate FR4 with relative permittivity=4.4, a dielectric loss tangent =0.025 and thickness (h) =1.6 mm.

The simulated return loss of two elements metamaterial antenna is shown in Fig. 7. As shown in the figure, the antenna operates at triple frequency bands better than -12dB and lower than -9dB for certain frequency of 3.65GHz.The antenna operates at 2.4GHz for Bluetooth and wireless LAN applications,3GHz for security and surveillance applications and 4.3GHz for WIMAX applications. The antenna has compact size (its size is only 38 X 22 mm2) as compared with conventional antenna works at the same frequency. For more confirmation about the proposed multi band antenna, its simulated radiation pattern in both E (XZ plane with Φ=0) and H plane (YZ plane with Φ=90) are shown in Fig.8, Fig9and Fig.10. It is obvious that the directivity of this antenna at 2.4 GHz is 3.5dBi, 5dBi at 3GHz and 4.9dBi at4.3GHz.
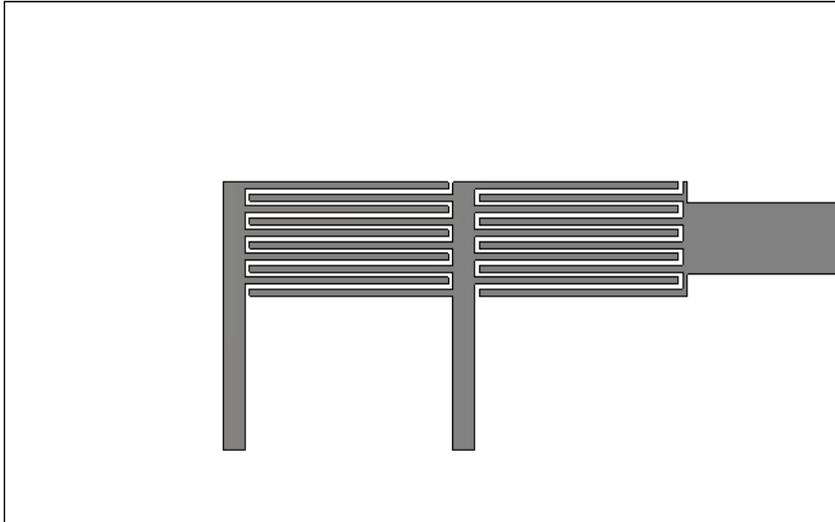
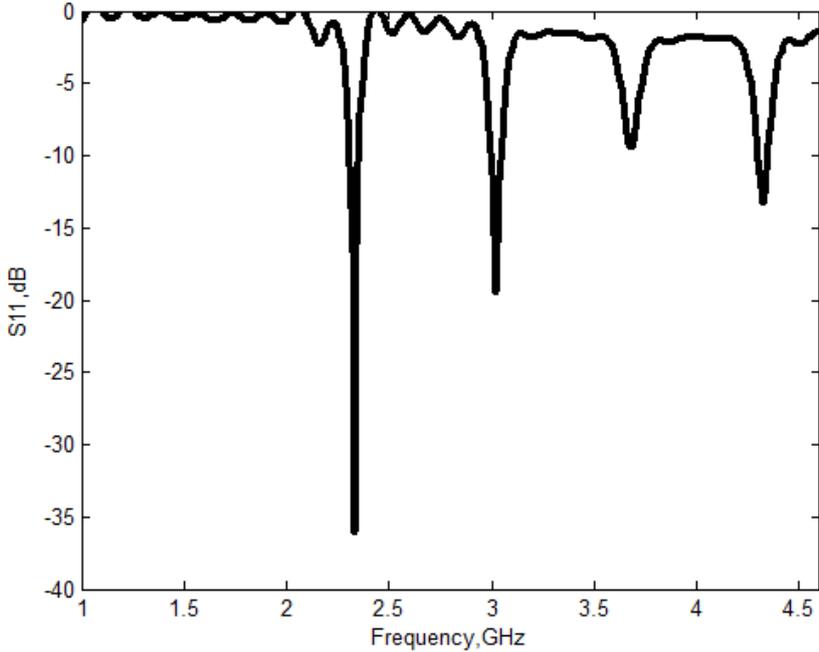**Fig. 6   2D layout of proposed Multi-band antenna**

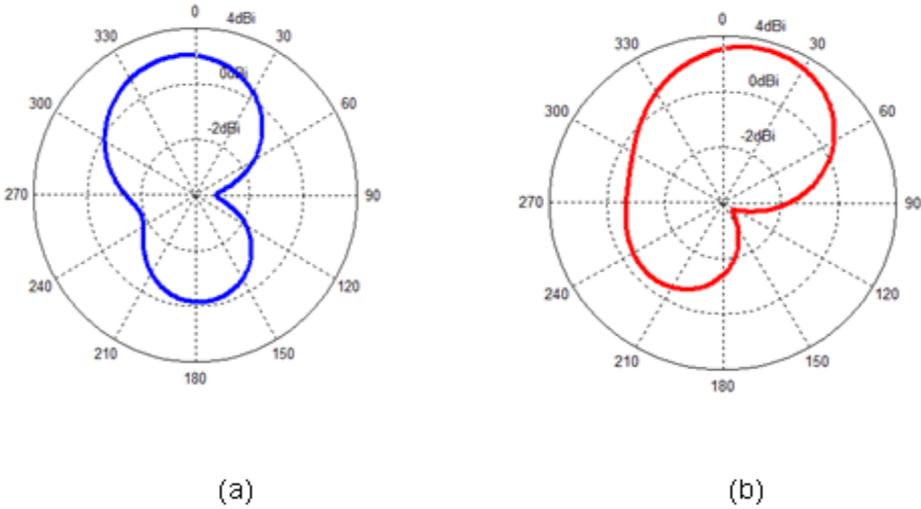**Fig. 7   Simulated return loss of proposed multi -band antenna**

(a) (b)

**Fig. 8   The Simulated field pattern of proposed antenna
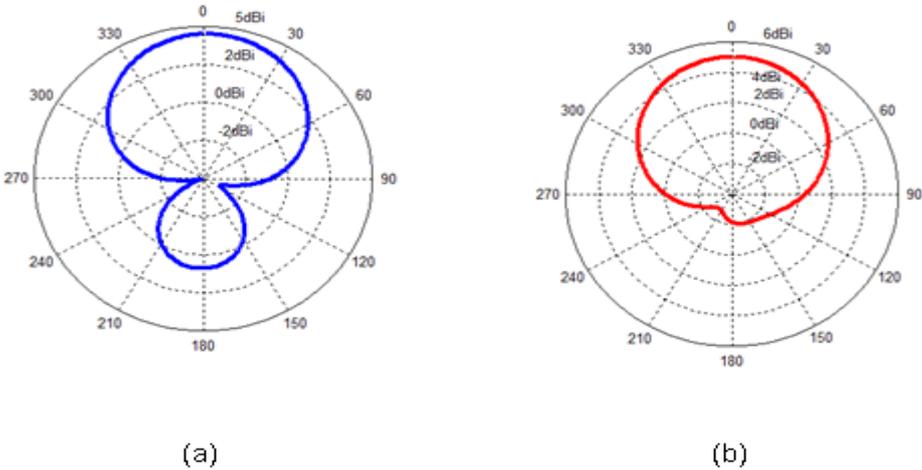(a) E and (b) H Plane at 2.4GHz**

(a) (b)

**Fig. 9   The Simulated field pattern of proposed antenna
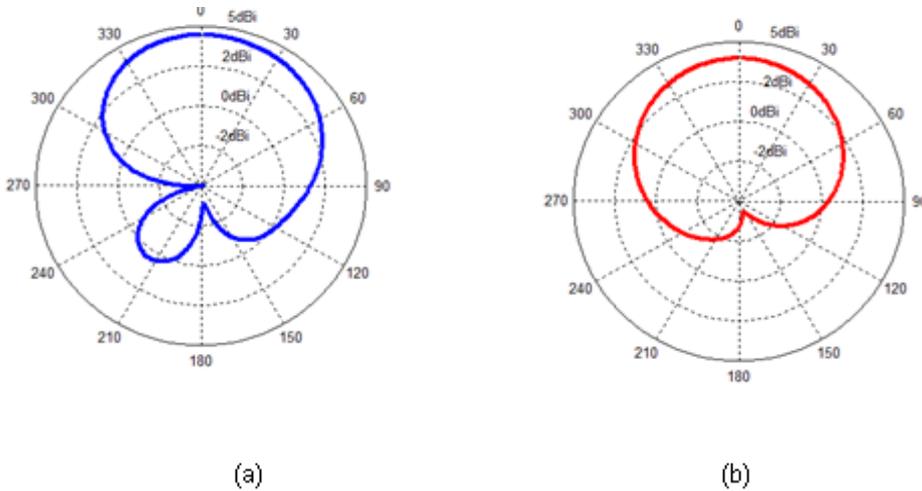(a) E and (b) H Plane at 3GHz**

(a) (b)

**Fig. 10   The Simulated field pattern of proposed antenna
(a) E and (b) H Plane at 4.3GHz**

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5. Conclusion

A design of a small size composite right-left handed meta-material multi-band antenna for wireless applications has been introduced. The proposed antenna consists of two left handed cells. The proposed antenna operates at different frequency bands. The design has been represented size reduction of approximately 65 % compared to conventional patch antennas operating at the same frequencies. The size reduction and low frequency ratios have been achieved due to the nonlinearity behavior of the left-handed region of composite right-left handed transmission line dispersion diagram.

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