Analysis of Asymmetrical Composite Right/Left Handed Transmission Line for Broad band Microwave Devices

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Abstract. *Metamaterials are artificial structures that can be designed to exhibit specific electromagnetic properties not commonly observe in nature . In this paper we use a new iterative method to evaluate the different parameter of asymmetrical composite right left handed transmission lines (CRLH TL). In order to define the scattering parameters of a given number of N CRLH TL unit cells mounted in cascade, an iterative method is proposed. Starting from the first unit ABCD parameter one can extract the whole cascade ABCD parameters, further the scattering parameter S of the cascade structure are easily extracted. Finally the CRLH-TL structure is simulated using the commercial software HFSS. Good agreement between our method and simulation results is observed.*

Keywords

CRLTH TL , metamaterials, scattering parameters,.

I. Introduction

The permittivity and the permeability of all materials are naturally positive; these materials are classified and named as right handed materials (RHMs). But now some artificial materials are produced to achieve negative permittivity and permeability, these artificial materials are classified and named as left handed materials (LHMs) .these materials with negative permittivity and permeability were firstly investigated theoretically by Russian Physicist Veselago [1]. in the beginning of 1990 Smith et al proposed and fabricated the first LHM using a periodic array of split-ring resonators (SSRs) combined with an array of straight conducting wires [2] using the theoretical work of Pendry [3,4]. Later transmission lines (TL) using LHM were proposed and realized [5]. However because of the parasitic effects occurred by the microstrip geometry which will result in right handed properties, a pure left handed transmission line (LH-TL) cannot be physically realized , then the LH-TL will be considered as a composite right left handed transmission line (CRLH-TL) [5].

The unit cell of CRLH-TL is generally composed of a series of inductor L_R and capacitor C_L, a shunt inductor L_L and capacitor C_R. The structure presents a band-pass filter, in the sense that it has left-handed (LH) high-pass with low frequency stop-band, and right-handed (RH) low-pass with high frequency stop-band. In regard of this, it is promising to apply CRLH-TL in microwave and millimeter wave devices for reducing physical length.

Generally analysis of the equivalent circuit of VRLH unit cell is done by using complex S-parameters at several distinct frequency points by full-wave simulation or by measurement, and the extraction of lumped elements in the equivalent circuit is achieved by converting *S* parameters of a CRLH TL unit cell to *ABCD* parameters [6, 7].

The use of equivalent circuit analysis is more efficient than the full-wave electromagnetic simulations for the case of CRLH-TL which is composed usually of cascaded periodic cells [8].

In our paper, a new recurrent method adapted to asymmetrical CLRH-TL model is used to obtain *ABCD* parameters of the equivalent circuit of N cascaded unit cells.

At first, the *ABCD* parameters are calculated in the case of a unit cell with respect to the series impedance *Z* and shunt admittance *Y*, and then the parameters in the case of two, three and more cells are obtained by recurrent relations, between i^{th} cell parameters and the equivalent ones of the (*i*-1) precedent cells [9]. After, the scattering parameters S are obtained using the relation between ABCD and S matrix [6].

In order to validate the results obtained by the proposed method, it is suggested to simulate a CRLH cell cascade by the HFSS simulator. We note a good agreement between the simulation results and those obtained by our method.

II. Unit Cell Model of CRLH-TL

The general CRLH TL model as shown in Fig. 1 contains an inductance L_R in series with a capacitance C_L and a shunt capacitance C_R in parallel with an inductance L_L. The components L_L and C_L govern the left-handed mode propagation properties, while L_R and C_R determine the right-handed mode propagation properties [8].

In electric equivalent unit cell, *Z* and *Y* are the impedance and admittance of the transmission line, respectively.

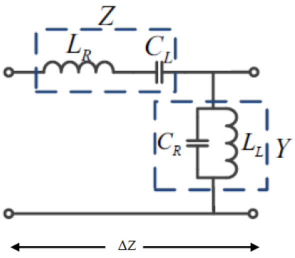

Fig. 1. Electric equivalent circuit of CRLH TL.

In the case of homogeneous CRLH TL, they are defined as:

$$Z(\omega) = j\omega L_R (1 - \frac{\omega_{se}^2}{\omega^2}) \quad (1)$$

Where

$\omega_{se} = \frac{1}{\sqrt{L_R C_L}}$ is the series resonant pulsation.

While the admittance *Y(ω)* can be given by the following expression:

$$Y(\omega) = j\omega C_R (1 - \frac{\omega_{sh}^2}{\omega^2}) \quad (2)$$

Where

$\omega_{sh} = \frac{1}{\sqrt{L_L C_R}}$ is the shunt resonant pulsation.

The characteristic impedance of the CRLH TL unit cell is given by:

Where Z_R is the RH (right hand)impedance given by:

$$Z_R = \sqrt{\frac{L_R}{C_R}} \quad (4)$$

Moreover, Z_L is the LH (left hand) impedance, which is given by:

$$Z_L = \sqrt{\frac{L_L}{C_L}} \quad (5)$$

As long as the frequency increases, the resonant circuit CRLH TL is increasingly dispersive, when the phase velocity is highly dependent on frequency, as a consequence, the CRLH TL has a double nature; at low frequencies is dominantly LH, and in contrast, in high frequencies the CRLH TL is dominantly RH [8].

Since the unit cell is smaller than quarter guided wavelength the CRLHTL is seen as homogeneous by electromagnetic waves [8].

III. Analysis of Cascaded Cells Structure

Considering a unit cell of a homogeneous CRLH TL as shown in Fig.1, and considering the *X* parameter used in this development to define *ABCD* parameters cell, defined as follows:

$$X = ZY + 1 \quad (6)$$

Then *ABCD* parameters of this cell are given as follows:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} X & (X-1)/Y \\ Y & 1 \end{bmatrix} \quad (7)$$

We first consider the propagation characteristics of the infinite loaded line shown in Fig. 2.

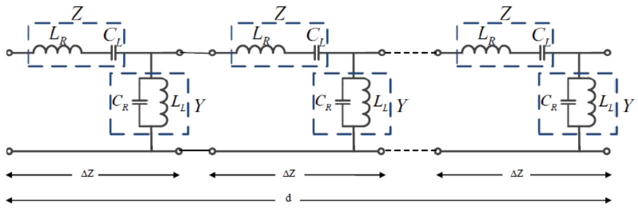

Fig. 2. CRLH transmission line of length d

Each unit cell of this line consists of a length *d*. If we consider the infinite line as being composed of a cascade of identical two-port networks, we can relate the voltages and currents on either side of the nth unit cell using the *ABCD* matrix:

$$\begin{bmatrix} V_n \\ I_n \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_{n+1} \\ I_{n+1} \end{bmatrix} \quad (8)$$

In the case of two cells in cascade, we obtain the equivalent *ABCD* parameters as:

$$\begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} = \begin{bmatrix} X^2 + X + 1 & (X^2 - 1)/Y \\ (X+1)Y & X \end{bmatrix} \quad (9)$$

A new method is applied to define equivalent *ABCD* parameters of *i* cascaded cells, using the parameter *X* defined by equation (9) and based on a set of equations expressed as[9]:

$$A_i = (X+1)A_{i-1} - D_{i-1} \quad (10)$$

$$YB_i = XA_{i-1} - D_{i-1} \quad (11)$$

$$C_i = C_{i-1} + YA_{i-1} \quad (12)$$

$$D_i = A_{i-1} \quad (13)$$

In the previous relations A_i, B_i, C_i and D_i represent the elements of *ABCD* matrix and *i* represents then number of cascaded unit cells.

It is easy to remark that the previous equations are a relation two successive state (*i*-1) and (*i*).

Furthermore, this structure based on *N* cells satisfies the following relationships:

$$A_i = D_i + YB_i \quad (14)$$

$$A_i D_i - B_i C_i = 1 \quad (15)$$

Also, equations (12) and (13) are fulfilled in the same state of the i^{th} cell.

The network scattering parameters *S* are found by evaluating its *ABCD* parameters [6], using the iterative method explained previously.

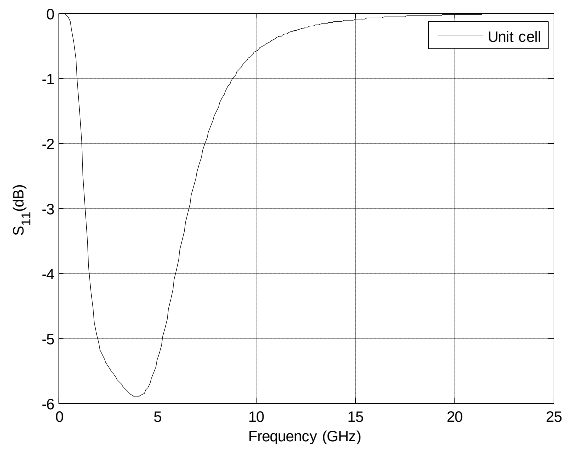

Fig. 3. Reflection coefficient in the case of a unit cell

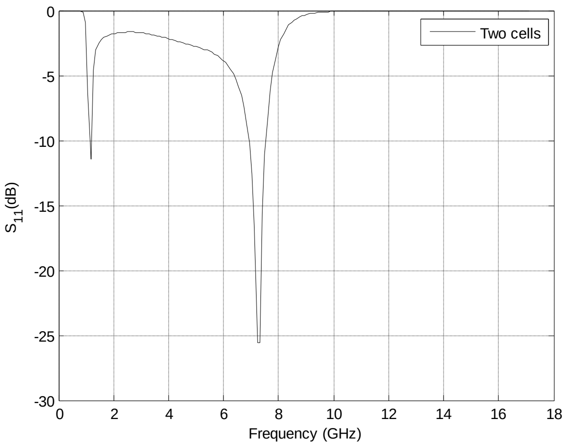

Fig. 4. Reflection coefficient in the case of two Cascaded cells

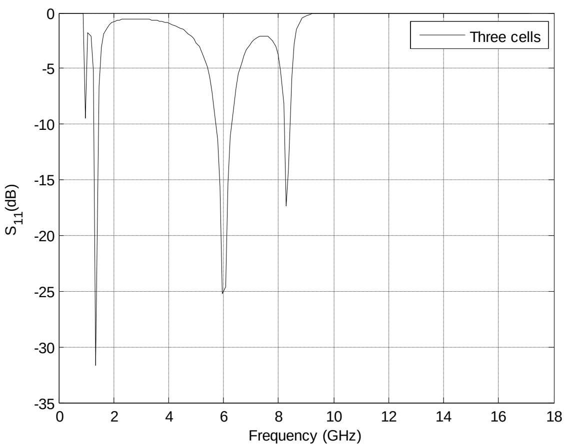

Fig. 5. Reflection coefficient in the case of three Cascaded cells

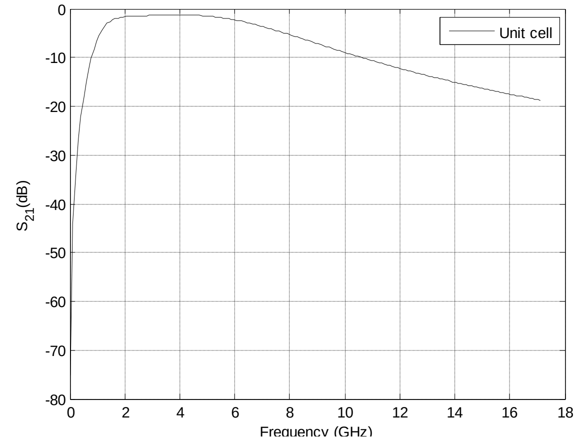

Fig. 6. Transmission coefficient in the case of a unit cell

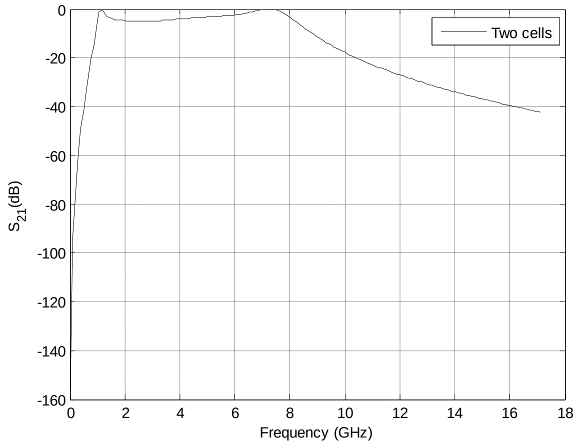

Fig. 7. Transmission coefficient in the case of two Cascaded cells

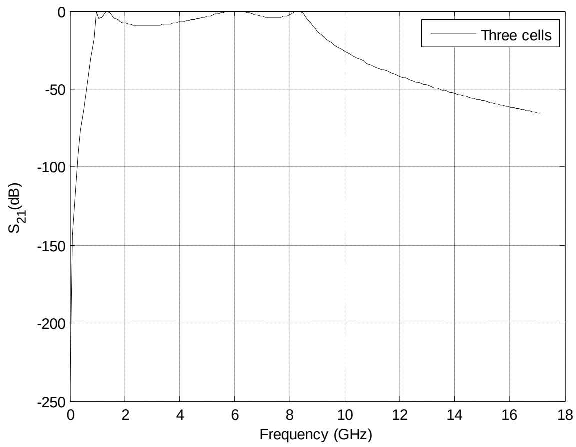

Fig. 8. Transmission coefficient in the case of three Cascaded cells

The variation of the reflection coefficient is shown in the fig.3-5 and that of the transmission coefficient is shown in fig.6-8, we note that the number of resonance frequency and the bandwidth increases as the number of cells in cascade increase.

IV. Simulation of the Asymmetrical CRLH-TL Structure

In this section we use HFSS simulator [10] to carry out the parameters of the proposed asymmetrical CRLH-TL structure based on interdigital capacitor (IDC) in series and vias to the ground plane at the stub ends in shunt as shown in Fig 9. The cascaded structure formed by two and three units of asymmetrical CRLH-TL is also analyzed.

In order to validate the results of the proposed method, we suggest to concept and simulate a circuit composed of one , two and three CRLH-TL cells designed on Rogers duroid 6006 substrate,

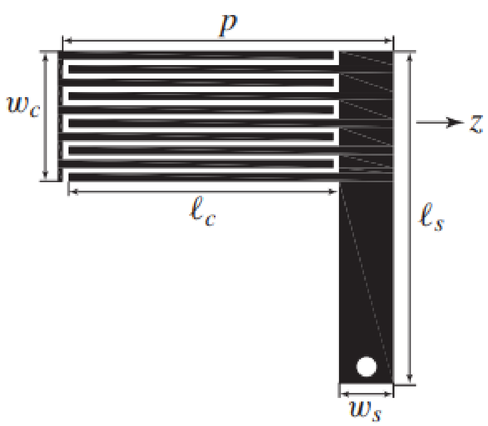

Fig.9. Microstrip implementation of the CRLH TL unit cell.

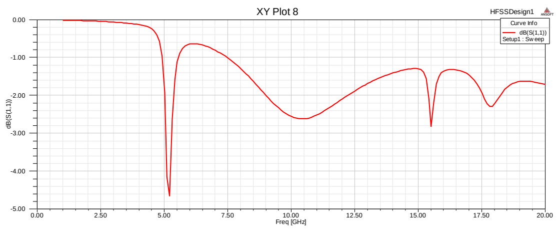

Fig. 10. Reflection coefficient obtained by HFSS in the case of a unit cell.

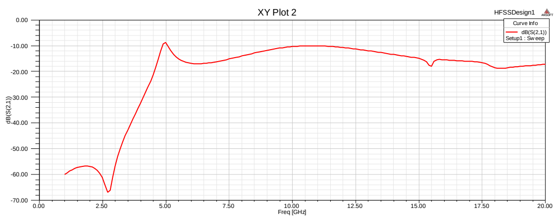

Fig. 11. Reflection coefficient obtained by HFSS in the case of two Cascaded cells.

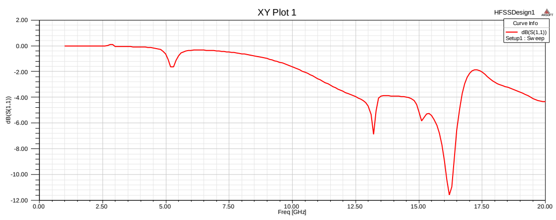

Fig. 12. Reflection coefficient obtained by HFSS in the case of three Cascaded cells.

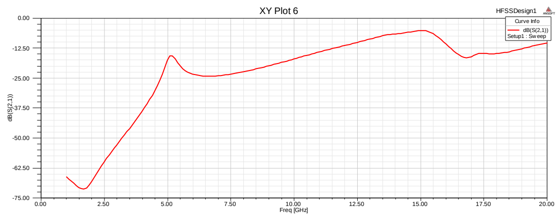

Fig. 13. Transmission coefficient obtained by HFSS in the case of a unit cell.

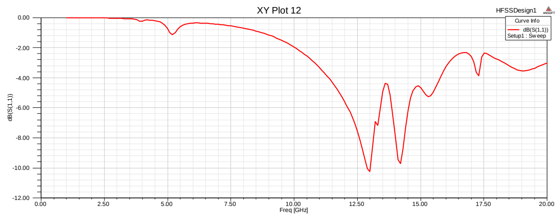

Fig. 14. Transmission coefficient obtained by HFSS in the case of two Cascaded cells

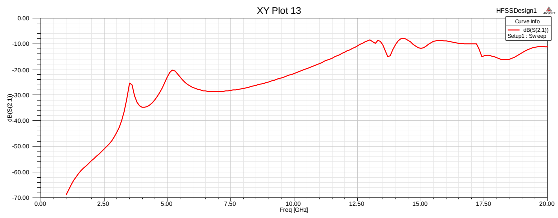

Fig. 15. Transmission coefficient obtained by HFSS in the case of three Cascaded cells

The results obtained by HFSS , shows good agreement with those obtained by the proposed method.

V. Conclusion

The progress in wireless communication and the rise in frequency in the fifth generation of cellular require components of reduced size; metamaterials play an important role in this field. The proposed method allows us to analyze the microwave circuits based on CRLH-TL in cascade, from the *ABCD* parameters of an elementary cell, the *ABCD* matrix of the overall circuit is obtained and from this result the matrix S is easily calculated. A CRLH-TL based circuit is designed and simulated using HFSS in order to validate the proposed method, a good agreement between the results of the simulation and those of the proposed method.

References

[1] VESELAGO,V. G. The electrodynamics of substances with simultaneously negative values of ε and µ, *Soviet Physics Uspekhi*, 1968,vol.10, no.4, pp.509-514.DOI:10.1070/PU1968v010n04ABEH003699

[2] R. Smith, W. J. Padilla, D. C. Vier, S. C. Nemat-Nasser, and S. Schultz, "Composite medium with simultaneously negative permeability and permivitty, " Phys.Rev.Lett.,84(18) :4184-4187,May 2000

[3] J. B. Pendry, A. J. Holden, D. J. Robbins, and W. J. Stewart, " Low Frequency Plasmons in thin wire structures," J. Phys. Condense Matter, vol. 10, pp. 4785–809, 1998.

[4] J. B. Pendry, A. J. Holden, D. J. Robbins, and W. J. Stewart, "Magnetism from Conductors and Enhanced Nonlinear Phenomena,"

IEEE Trans. Microwave Theory and Tech, vol. 47, no. 11, pp. 2075–2084, Nov. 1999.

[5] C. Caloz and T. Itoh, "Transmission line approach of left-handed (LH) materials and microstrip implementation of an artificial LH transmission line, " IEEE Trans. Antenas and Propaga., vol. 52, pp. 2701–2712, Dec. 2002.

[6] POZAR, D. M. *Microwave Engineering*.New York (USA): John Wiley& Sons, 2011. ISBN: 978-0470631553

[7] KOU, N., SHI, Y.,LI, L. New Equivalent Circuit Analysis and Synthesis for Broadband Composite Right/Left-Handed Transmission Line Metamaterials,*ACES Journal*,2006, no.8,vol.31, pp.884-893.

[8] BELATTAR, M.,LASHAB,M. Analysis of Metamaterial CRLH TL Antennas Parameters,*International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS'2019*), Morocco,2019, pp. 1–5.DOI: 10.1109/WITS.2019.8723817

[9] BELATTAR, M.,LASHAB,M.New Iterative Method for Analyzing Metamaterial CRLH TL Antennas Parameters,*International Conference on Advanced Electrical Engineering 2019 (ICAEE),* Algeria,2019,pp1-5.DOI: 10.1109/ICAEE47123.2019.9014770

[10] "High frequency structure simulator software package," HFSS v13, Ansoft Corporation.

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