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IMPLEMENTATION OF SINGLE CELL COMPOSITE RIGHT–LEFT HANDED TRANSMISSION LINE FOR ULTRA WIDEBAND BANDPASS FILTER

Fitri Yuli Zulkifli*, Andik Atmaja, Eko Tjipto Rahardjo

Antenna, Propagation and Microwave Research Group (AMRG), Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Kampus Baru UI Depok 16424, Indonesia

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ABSTRACT
A design and fabrication of a compact ultra-wideband (UWB) bandpass filter (BPF) using single cell Composite Right-Left Handed Transmission Line (CRLH-TL) is reported in this paper. This compact filter design is achieved using a single cell CRLH-TL structure which is implemented on the FR4 dielectric substrate with permittivitty of 4.4 and dielectric thickness of 1.6mm. The dimensions of the filter structure consider the capability of the fabrication tools in Indonesia. The compact filter operates from 4 GHz to 9.5 GHz with insertion loss less than -1.5dB.

Keywords: Bandpass filter; Composite right left handed transmission line; Ultra wide band

1. INTRODUCTION
Ultra Wideband Technology was first published and introduced by the Federation Communications Commission (FCC) in the USA on 14 February 2002. UWB technology has several advantages such as high speed access up to 110 Mbps and power consumption of only 100 mW (Tanahashi, 2005; Schell, 2002; Zhang et al., 2010).

Along with the development of UWB, research studies on metamaterials (MTMs) in recent years have also increased very rapidly. Metamaterials are also called artificial materials or defined as Left Handed (LH) material that is an artificial electromagnetic structure which is effectively homogeneous with unusual properties not available in nature (Caloz & Itoh, 2006). Metamaterials could be designed using several approaches, namely, the resonant approach and the transmission line approach. Purely LH TL (PLH TL) cannot exist physically, therefore the CRLH model represents the most general MTM structure possible (Caloz & Itoh, 2006), (Marques et al., 2008).

Recent studies of UWB CRLH-TL filters are published in several papers. (Mau et. al., 2007) shows filters with dual-passband, in (Liu et al., 2009) the filter design does not contain interdigital capacitors with bandwidth from 3.3 to 7 GHz. The paper (Bin & Xu-Ping, 2008) uses rectangular DGS and an interdigital capacitor with bandwidth ranging from 3.2 to 7.5 GHz. Different from (Lai et al., 2004) we used only one segment from the periodic structure of the CRLH-TL to make the component very compact. Moreover, our proposed filter is more compact compared to (Kahng & Ju, 2008), which has twelve interdigital capacitor lines, while the proposed filter has only six. Furthermore, the dimensions of the proposed filter consider the capability of the fabrication tools in Indonesia.

* Corresponding author's email: yuli@eng.ui.ac.id, Tel. +62-21-788888076. ext . 118, Fax. +62-21-788888076

2. CRLH UWB BANDPASS FILTER

A CRLH bandpass filter can be considered as equivalent L and C in series and L and C in shunt as shown in Figure 1a. In the ‘lossless’ condition this circuit gives lower cut off and upper cut off frequencies (Figure 1b) which show Pure Left Handed (PLH) and Pure Right Handed (PRH) Transmission lines (TL), respectively, following these equations:

$$\omega_{cR} = \frac{1}{\sqrt{L_R C_R}} \tag{1}$$

$$\omega_{cL} = \frac{1}{\sqrt{L_L C_L}} \tag{2}$$

$$\omega_o = \frac{1}{\sqrt[4]{L_R C_R L_L C_L}} \tag{3}$$

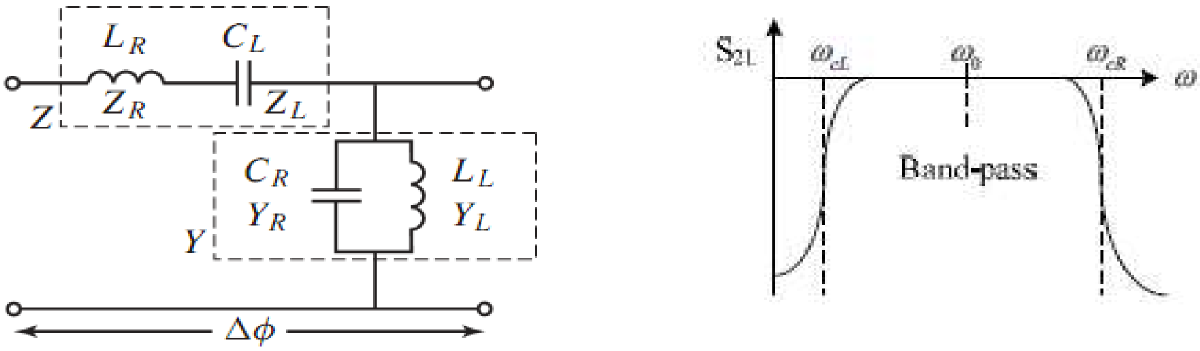

Figure 1 Single cell CRLH-TL: (a) equivalent circuit (b) band pass filter (Caloz & Itoh, 2006)

Where is a lower frequency cutoff which represents PLH TL, is upper frequency cutoff, which represents PRH TL and is the center frequency of BPF, while L_R, C_R, L_L and C_L, respectively, are designated as: a series inductor for PRH, a shunt capacitor for PRH, a shunt inductor for PLH and a series capacitor for PLH. Those parameters show metamaterial characteristics within a transmission line approach. The CRLH TL has a positive, negative and zero constant propagation according to the characteristics of effective permittivity and permeability (Caloz & Itoh, 2006).

The CRLH circuit is divided into 2 unit cells namely, asymmetric and symmetric unit cells. Figure 1a shows the circuit of a single cell CRLH asymmetric. For a symmetric CRLH circuit, it consists of the form T (T-shape) and the form phi (π-shape). The symmetric series is the development of the asymmetric series CRLH. Figure 2 shows the symmetric circuit for the phi-shape, which is used to design this UWB bandpass filter.

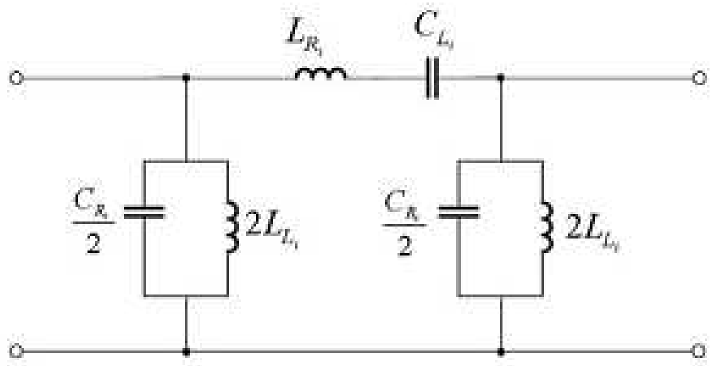

Figure 2 phi-shape symmetrical CRLH-TL circuit (Caloz & Itoh, 2006)

3. IMPLEMENTATION OF CRLH BANDPASS FILTER USING MICROSTRIP TECHNOLOGY

A Single cell CRLH BPF can be implemented using an interdigital capacitor of a microstrip circuit as shown in Figure 3. In order to determine the value of L and C, an asymmetric model of Figure 3 is shown in Figure 4, which represents a CRLH microstrip interdigital capacitor in the lumped circuit. It is equivalent to the impedance (Z), while the stub in the lumped circuit is equivalent to the admittance (Y) (Caloz & Itoh, 2006).

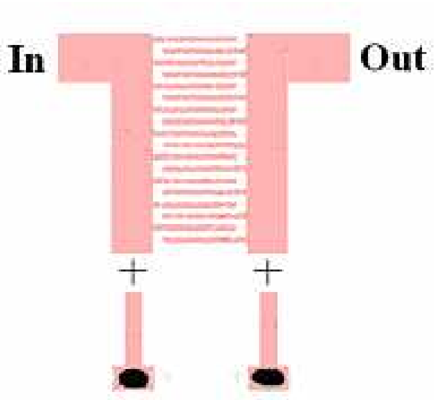

Figure 3 Unit cell CRLH microstrip (Caloz & Itoh, 2006)

Then the inductance and capacitance components of CRLH can be obtained using the following formula (Caloz & Itoh, 2006) as in the equations:

$$L_R = L_s^{ic} \tag{4}$$

$$C_R = 2C_p^{ic} + C_p^{si} \tag{5}$$

$$L_L = L_p^{si} \tag{6}$$

$$C_L = C_s^{ic} \tag{7}$$

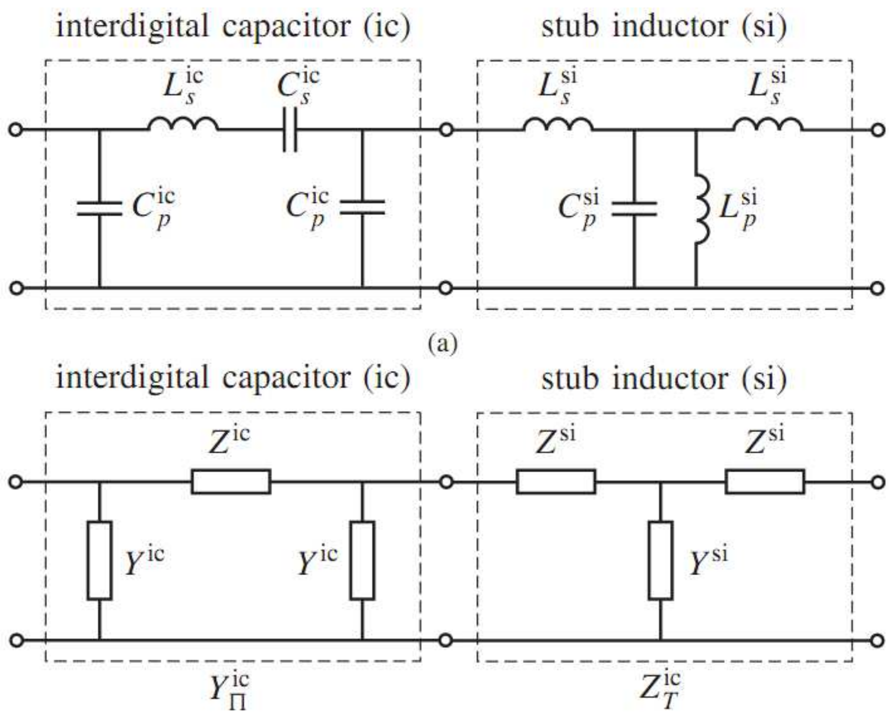

Figure 4 Equivalent circuit for CRLH microstrip (Caloz & Itoh, 2006)

3.1. Design of the interdigital capacitor

Figure 5 indicates a single cell CRLH microstrip interdigital capacitor, where *W* is width of a finger, *S* is the spacing between fingers, *l* is the length of finger, *W*' is the length of stub, *l'* is width of stub, *S*' is spacing between stub and finger and *h* is the dielecteric substrate thickness. It is important to note that the spacing or the width of finger or stub is limited to the available fabrication tools in Indonesia. In this case the minimum value is 0.2 mm. Therefore, in this design we used *W* = *S* = 0.254 mm.

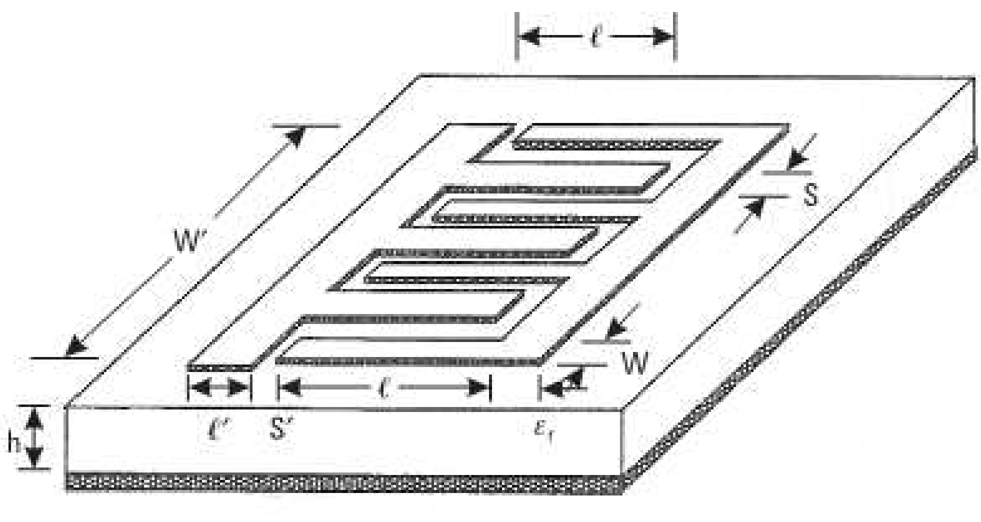

Figure 5 Design of single cell CRLH interdigital capacitor by using the following equations (Bahl, 2003)

$$C = (\varepsilon_r + 1) l \left[(N-3) A_1 + A_2 \right] \tag{8}$$

$$A_1 = 4.409 \tanh\left[0.55 \left(\frac{h}{W} \right)^{0.45} \right] \times 10^{-6} \tag{9}$$

$$A_2 = 9.92 \tanh\left[0.52 \left(\frac{h}{W} \right)^{0.5} \right] \times 10^{-6} \tag{10}$$

$$R = \frac{4}{3} \frac{l}{WN} R_s \tag{11}$$

$$C_s = \frac{1}{2} \frac{\sqrt{\varepsilon_{re}}}{Z_0 c} l \tag{12}$$

$$L = \frac{Z_0 \sqrt{\varepsilon_{re}}}{c} l \tag{13}$$

The finger length of the interdigital capacitor is determined to 2.365 mm and the number of finger is determined to 6.

3.2. Design of the ground stub

To design the ground stub, ε_{re} and Z_0 is calculated using the impedance calculation subprograms contained in the CST Microwave Studio. With C_l = 0.1022 pF, from the equation below, we obtain the length l.

$$L(nH) = 2 \times 10^{-4} l \left[\ln\left(\frac{l}{W+t} \right) + 1.193 + \frac{W+t}{3l} \right] Kg \tag{14}$$

$$R_s(\Omega) = \frac{K R_{sh} l}{2(W+t)} \tag{15}$$

$$C_l(pF) = 16.67 \times \frac{10^{-4} l \sqrt{\varepsilon_{re}}}{Z_0} \tag{16}$$

Therefore, the stub length l is 4.498 mm

4. RESULTS AND DISCUSSION

The design of the UWB bandpass filter using a CRLH single cell is simulated using the CST Microwave Studio. The filter is then fabricated and measured in an anechoic chamber at Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia.

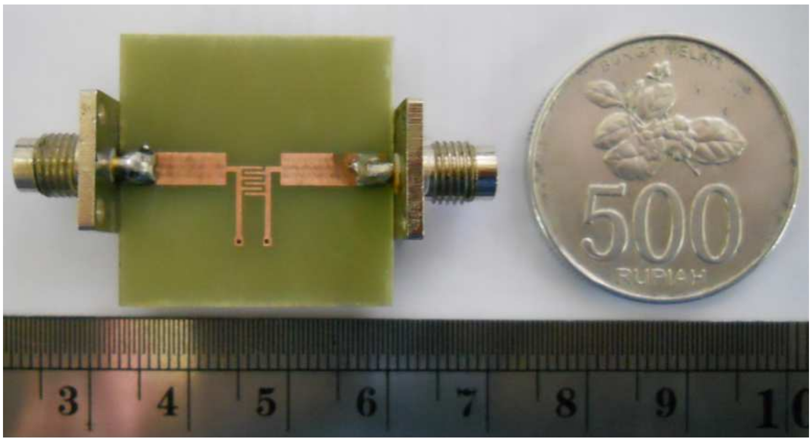

Figure 6 CRL Filter design results after the fabrication

The dimensions of the fabricated filter: interdigital finger length (*l*) is 2.3 mm, interdigital finger width (*W*) is 0.24mm, finger spacing (*S*) is 0.25 mm, and length of the ground stub (*W*') is 4.2 mm. This design with six interdigital fingers compared to (Kahng, 2008) which has twelve, results in a reduction of the filter area to 7%.

4.1. Simulation and measurements results of S_{21} (insertion loss)

The simulation and measurement result of S_{21} is depicted in Figure 7. Simulation results show that the bandpass filter at 3 dB works from a frequency 3.93 GHz to 9.2 GHz, while the measurement result shows a bandwidth from 4 GHz to 9.5 GHz. The measurement results of the bandpass filter using a single cell CRLH shows similar results compared to the simulation. Figure 7 also shows a lower insertion loss between various simulation values compared to the measurement result. The simulation result shows that the insertion loss is less than -1 dB; however, the measurement result shows less than -1.5 dB.

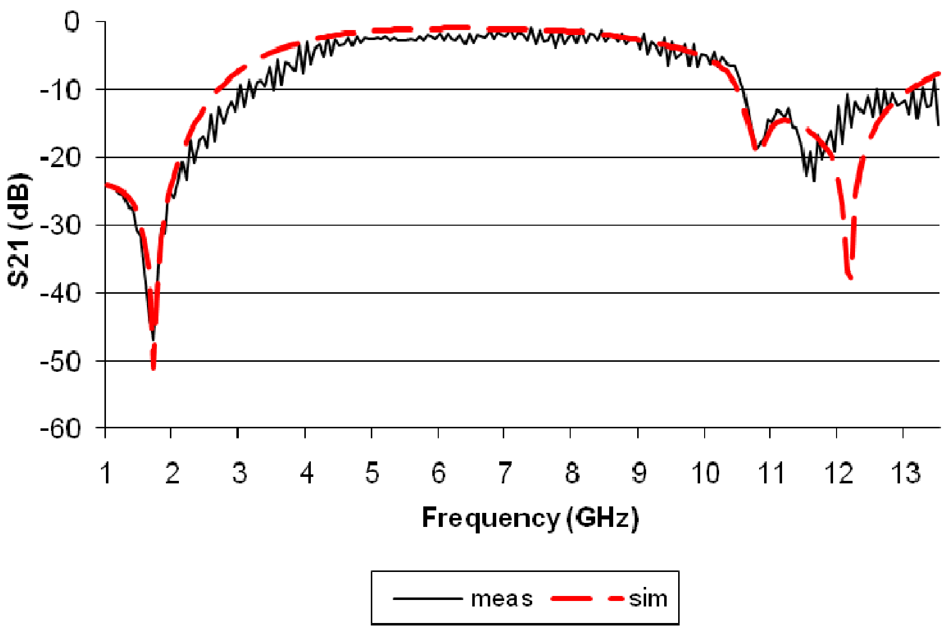

Figure 7 Comparison of S_{21} between measurement results and simulation results

4.2. Measurements results of S_{11} (coefficient reflection)

The measurement results of the S_{11} also shows that the bandpass filter using the single cell CRLH has a similar result with the simulation results as depicted in Figure 8.

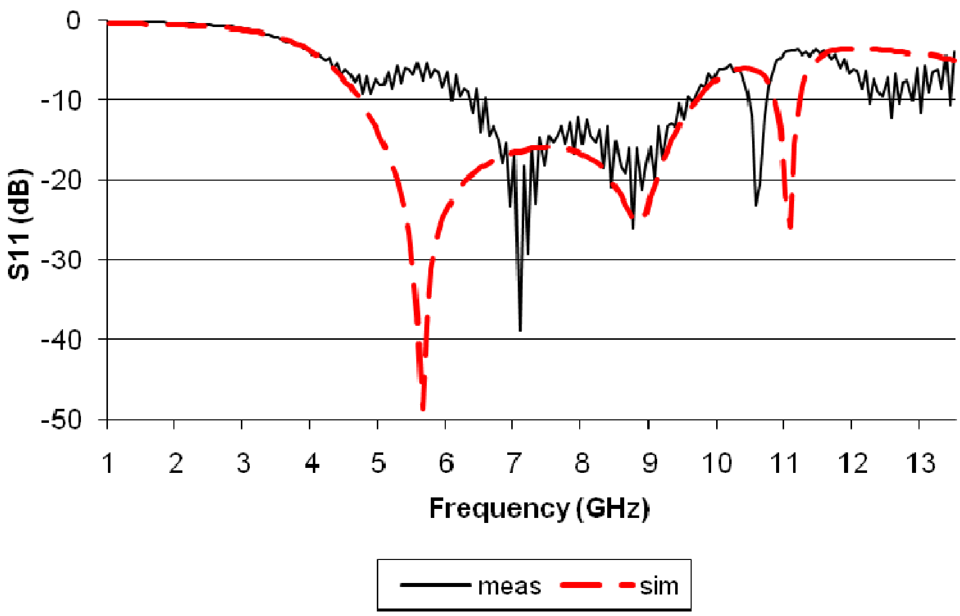

Figure 8 Comparison of S_{11} between measurement results and simulation results

Simulation results show that S_{11} is below -10 dB in the region between 4.75 GHz to 9.63 GHz, while measurement result shows from 6.37 GHz to 9.63 GHz. The slight difference between simulation and measurement results is due to imperfect fabrication of the filter.

5. CONCLUSION

An UWB bandpass filter using single cell CRLH-TL has been designed, fabricated and measured. The fabrication process uses tools available in Indonesia, where the six interdigital filters were designed and therefore they reduced the total area of the filter to 7%. The compact filter operates from 4 GHz to 9.5 GHz with insertion loss less than -1.5dB.

6. ACKNOWLEDGEMENTS

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