

Research Article

Design of Compact UWB Bandpass Filter with Sharp Rejection Characteristics

Gyuje Sung

Department of Electrical and Electronic Engineering, Institute for Information Technology Convergence, Hankyong National University, 327 Jungangro Ansong, Kyonggi-Do 456-749, Korea

Abstract: This study presents an Ultra-Wideband (UWB) filter with sharp rejection characteristics at the upper Wireless Local Area Network (WLAN) band. The filter adopts the modified Composite Right/Left-Handed (CRLH) Transmission Lines (TLs), the unit cell of which is theoretically analyzed to derive the design formulas. Subsequently, a UWB bandpass filter is designed using these formulas. The measurement results show that the fabricated UWB bandpass filter has an insertion loss of less than 1.1 dB, bandwidth of 3.1~4.9 GHz and a rejection of more than 50 dB at 5.8 GHz.

Keywords: Bandpass Filter (BPF), Composite Right/Left-Handed (CRLH) transmission line, sharp rejection characteristics, Ultra-Wideband (UWB)

INTRODUCTION

Since the Federal Communications Commission (FCC) released the frequency band of 3.1~10.6 GHz for Ultra-Wideband (UWB) communication in 2002, high data rate, short-range and short-pulse UWB communications have developed rapidly. A Bandpass Filter (BPF) is an essential component in an UWB system and UWB BPFs have thus been studied widely. Many filters have been designed using microstrip lines (Gao *et al.*, 2008; Duong and Kim, 2009; Watanabe *et al.*, 2009; Wu *et al.*, 2013) and a combination of microstrip lines and coplanar structures (Kuo *et al.*, 2007; Chen *et al.*, 2009), as well as ones with a combination of microstrip lines and defected ground structures (Huang *et al.*, 2010; Tian and Chu, 2011; Gao *et al.*, 2012; Kumar and Upadhyay, 2012). Some have been implemented using Composite Right/Left-Handed (CRLH) Transmission Lines (TLs) (Lin *et al.*, 2007; Gong and Chu, 2008; Shen and Law, 2012; Su *et al.*, 2012) Size reduction and bandwidth enhancement of bandpass filters can be achieved with the use of CRLH TLs (Lai *et al.*, 2004).

In this study, we present the design of a compact UWB BPF with sharp rejection characteristics. This is achieved using modified CRLH TLs, which help avoid interference between the UWB and WLAN systems. The simulated and measured results of the proposed UWB BPF are in good agreement.

METHODOLOGY

Design of uwb filter: The modified CRLH structure is described by the circuit model shown in Fig. 1. The right-handed series inductor, L_{Rs} and shunt capacitor, C_R

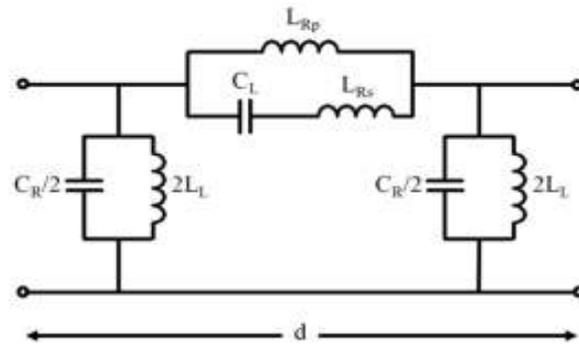


Fig. 1: Circuit model of the modified CRLH unit cell

and the left-handed shunt inductor, L_L and series capacitor, C_L , are similar to the ones founded in the conventional CRLH structure (Caloz and Itoh, 2006). Otherwise than the conventional CRLH structure, another right-handed series inductor, L_{Rp} , is in parallel with the series of L_{Rs} and C_L .

Since the circuit model is symmetrical, the even/odd-mode analysis can be used to derive the transfer function S_{21} . The even- and odd-mode admittances of the modified CRLH unit cell are as follows:

$$Y_{even} = j \frac{\omega_{sh} C_R}{2} \left(\frac{\omega}{\omega_{sh}} - \frac{\omega_{sh}}{\omega} \right) \quad (1)$$

$$Y_{odd} = j \left(\frac{\omega_{sh} C_R}{2} \left(\frac{\omega}{\omega_{sh}} - \frac{\omega_{sh}}{\omega} \right) - \frac{2}{\omega L_{Rp}} \frac{(\omega/\omega_{rej})^2 - 1}{(\omega/\omega_{se})^2 - 1} \right) \quad (2)$$

where,

$$\omega_{sh} = \frac{1}{\sqrt{L_L C_R}} \quad (3)$$

$$\omega_{rej} = \frac{1}{\sqrt{(L_{Rs} + L_{Rp}) C_L}} \quad (4)$$

$$\omega_{se} = \frac{1}{\sqrt{L_{Rs} C_L}} \quad (5)$$

Thus,

$$S_{21} = \frac{(Y_{odd} - Y_{even})Y_0}{(Y_{even} + Y_0)(Y_{odd} + Y_0)} \quad (6)$$

where, Y_0 is the admittance of the input/output port. A transmission zero is created when the transfer function S_{21} is equal to zero, i.e.:

$$Y_{even} = Y_{odd} \quad (7)$$

As a result, the transmission zero frequency is ω_{rej} , which is the resonant frequency of the series branch of the modified CRLH unit cell. The resonant frequency of the shunt branch is ω_{sh} and the resonant frequency of the series elements of the series branch is ω_{se} .

According to the Bloch-Floquet theory, the dispersion relation and characteristic impedance can be expressed as (Pozar, 2012):

$$\gamma(\omega) = \frac{1}{d} \cosh^{-1}(A) \quad (8)$$

$$Z_B(\omega) = B / \sqrt{A^2 - 1} \quad (9)$$

where, Z_B is the characteristic impedance normalized to the port impedance, Z_0 and:

$$A = 1 + \frac{2Y_{even}}{Y_{odd} - Y_{even}} \quad (10)$$

$$B = \frac{2}{Y_{odd} - Y_{even}} \quad (11)$$

Figure 2 shows the dispersions and attenuations of the modified CRLH unit cell. It operates as a CRLH TL when $\omega_{rej} < \omega_{sh}$ and as a Right-Handed (RH) TL when $\omega_{sh} < \omega_{rej}$. Unlike conventional CRLH TLs, only the characteristics of RH TLs appear in the unbalanced case of $\omega_{sh} < \omega_{rej}$. In the balanced case, $\omega_{rej} = \omega_{sh}$, it operates in the non-propagating mode. Figure 2 shows the sharp

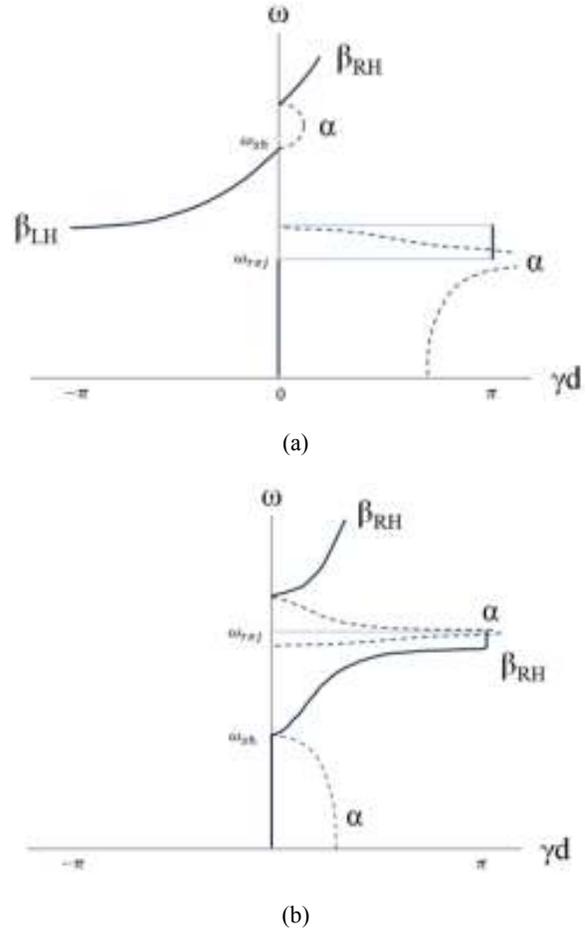
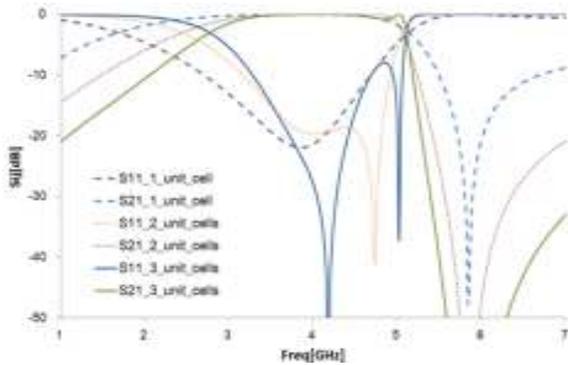
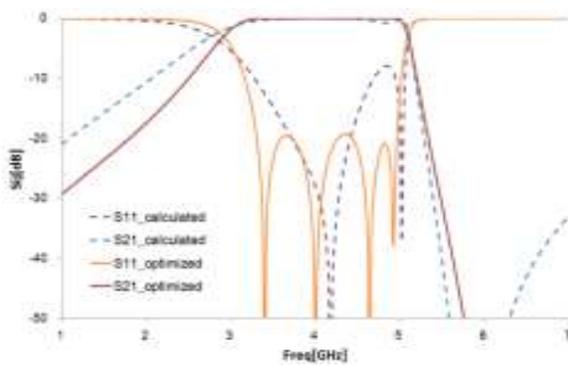


Fig. 2: Dispersion and attenuation diagram of the modified CRLH unit cell, (a) $\omega_{rej} < \omega_{sh}$, (b) $\omega_{sh} < \omega_{rej}$

attenuation characteristics in the lower stopband when $\omega_{rej} < \omega_{sh}$ and in the upper stopband when $\omega_{sh} < \omega_{rej}$. Thus, we can use the modified CRLH structure to obtain the sharp rejection skirts of a UWB BPF for avoiding interference between the UWB and WLAN systems. According to Eq. (3), (4), (6) and (9), we can calculate the element values of the modified CRLH unit cell. We have one degree of freedom among 5 element values of the unit cell. C_R determines the slope parameter of the shunt resonator that creates the passband of the UWB BPF. Therefore, C_R is regarded as a free variable element. Design specifications are as follows: the passband of the UWB BPF is 3.1~4.9 GHz, the attenuation pole frequency is 5.8 GHz and the characteristic impedance of the modified CRLH unit cell is 50 Ω at the center frequency. When the value of C_R is selected as 1.5 pF, the calculated element values are $L_{Rp} = 1.19$ nH, $L_{Rs} = 0.99$ nH, $L_L = 2.0$ nH and $C_L = 0.34$ pF, respectively. The design results are shown in Fig. 3. To satisfy the design specification, the number of unit cells is increased to three. Figure 3a shows 1, 2 and 3 unit cell characteristics with the



(a)



(b)

Fig. 3: Design results of the UWB BPF, (a) 1, 2 and 3 unit cell characteristics, (b) before and after optimization results

calculated element values. Following parameter optimization, we obtain the design values: $C_R = 2.58$ pF, $L_{Rp} = 1.04$ nH, $L_{Rs} = 1.02$ nH, $L_L = 1.08$ nH and $C_L = 0.32$ pF. The design characteristics before and after optimization are depicted in Fig. 3b.

RESULTS AND DISCUSSION

The UWB bandpass filter with sharp rejection characteristics was implemented on a 0.787-mm-thick Taconic TLX-9 substrate with a dielectric constant of 2.5 and a loss tangent of less than 0.002. Figure 4 shows the fabricated UWB bandpass filter, in which L_{Rs} and C_L are realized by the upper gap coupling structure, L_L is realized by the short-circuited stub and L_{Rp} and C_R are implemented by the main transmission line. With the aid of an Electromagnetic (EM) simulator, the dimensions of the structure can be optimized to $w_1 = 2.2$ mm, $w_2 = 1$ mm, $l_1 = 7$ mm, $l_2 = 5$ mm, $l_3 = 7$ mm, $l_4 = 6.5$ mm, $l_5 = 4.7$ mm, $l_6 = 4$ mm, $l_7 = 6.5$ mm, $l_8 = 1$ mm and $l_9 = 1.5$ mm. The size of the fabricated UWB BPF is 24.5×13.9 mm². The measurements are carried out using an Anritsu 37347C vector network analyzer. Figure 5a shows the simulated and measured

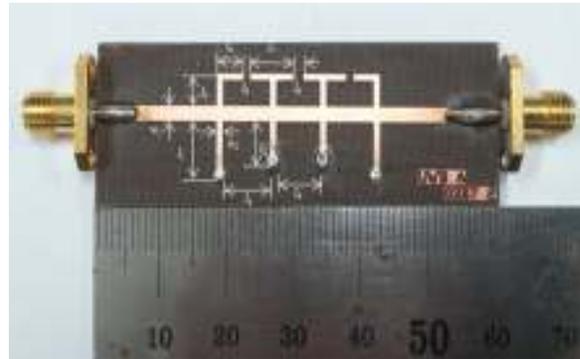
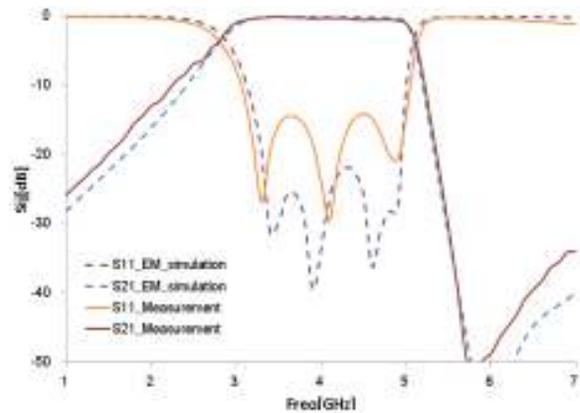
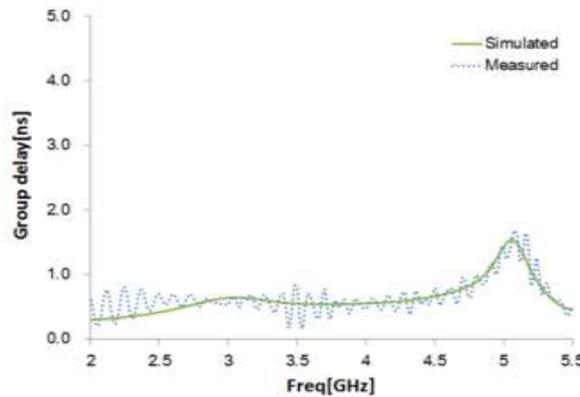


Fig. 4: Photograph of the fabricated UWB BPF



(a)



(b)

Fig. 5: Simulated and measured frequency responses of the UWB BPF, (a) amplitude response, (b) group delay

amplitude responses of the fabricated filter, which show good agreement. The measured results have an insertion loss less than 1.1 dB in the passband ranging from 3.1 to 4.9 GHz, as well as a rejection of more than 50 dB at the upper stopband of 5.8 GHz. The simulated and measured group delays of the filter are drawn in Fig. 5b. The measured one is less than 1.14 ns within the passband indicating good linearity of the proposed

UWB BPF. The fabricated UWB BPF has better insertion loss and attenuation than that of the previous works of Lin *et al.* (2007) and Watanabe *et al.* (2009). It is more compact than the one in Watanabe *et al.* (2009) and has a simpler single-layer structure compared to Shen and Law (2012), in which the UWB BPF is implemented using a three-layer structure.

CONCLUSION

This study proposes a UWB BPF with sharp rejection characteristics at the WLAN band that adopts the modified CRLH TLs. The fabricated filter has a compact size, low insertion loss and flat group delay; it also possesses a sharp skirt property near the passband. The measured results appear to agree with the EM simulation results.

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