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# 저지특성이 향상된 CRLH-TL Metamaterial 셀 형 UWB 대역통과여파기의 설계

## ( Design of the UWB BandPass Filter of Microstrip CRLH-TL Metamaterial Cell Type with Improved Rejection Performance )

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## 요 약

좌우현 합성 선로 메타재질구조 셀 형식인 UWB 대역통과여파기의 저지특성을 향상시키기 위해, 메타재질특성을 유지하면서도 소형화라는 설계목적에 적합한 저역통과여파기 개념을 제안한다. 따라서 대역통과여파기 자체는 파장의 0.25배보다 훨씬 작게 만들어지고, 이는 인터디지틀 결합기와 접지된 스텁으로 구성되며, 전후에 대칭형 소형 저역통과 블록을 가진다. 설계결과는, 예상대로, 관내파장의 1/8의 크기, 대역폭 100%, 1dB 이하의 삽입손실, 평탄한 군지연, 우수한 반사손실 특성을 보인다.

## Abstract

In order to enhance the rejection performance of the UWB bandpass filter based on the Composite Right- and Left-Handed Transmission-line(CRLH-TL) Metamaterial cell, we propose the lowpass filtering concept that fits into the design objectives : Keeping metamaterial property and miniaturization. So the bandpass filter itself is made far less than a quarter-wavelength and a pair of symmetric compact lowpass filtering blocks are placed before and after the center CRLH filter which comprises the interdigitated coupled lines and short-circuited stub. The design result will show the size of 'guided wavelength/8', the fractional bandwidth over 100%, the insertion loss much less than 1 dB, a flat Group-Delay and a good return loss performance, as expected.

**Keywords:** Metamaterial, Miniaturization, UWB Bandpass filter, Lowpass filter, Improved Rejection

## I. Introduction

Of late, numerous studies have been conducted to explore the benefits of the UWB communication, since its unlicensed use was open to the public by the US FCC. As one of many such research activities, the design methods of bandpass filters have been reported[1-5].

Araki et al[1] designed the UWB bandpass filter whose bandwidth is formed by adding zeros in the sections of the transmission line. The frequency response has notches at the specific points as the very narrow regions for out-of-band suppression. H. Wang et al[2] presented the microstrip-and-CPW bandpass filter for the UWB application, which is based upon the Multi-Mode Resonator(MMR) in the form of multiples of quarter-wavelength, to broaden the bandwidth and obtain the enlarged rejection region. The idea of the MMR of the half wavelength is also used in [3] where the coupled lines of a quarter-wavelength are used as the inverter. This

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work shows the extension of the lower and higher stopbands owing to the increased coupling. A composite UWB filter was designed by W. Menzel et al by combining lowpass and high pass filters as a suspended stripline structure with different planes[4]. Independently, C. Hsu et al presented the composite microstrip filters for the UWB application, where seven or eight TL sections of about quarter-wavelength are sequentially connected[5]. Presently, we describe the design method of a new UWB filter on the basis of the composite right- and left-handed transmission line(CRLH-TL)[6-8]. Most recently, in [9], we proposed the realization technique of the compact UWB bandpass filter by taking just one segment(smaller than one quarter-wavelength) from the periodic structure of the CRLH-TL, different from the reference[6]. Besides, instead of mixing two types, for instance, hybrid of the microstrip and CPW, the filter design is pursued with only the microstrip. However, the UWB filter is also limited in having wider rejection band from 10GHz to 14 GHz

In this paper, we suggest a new technique to improve the rejection performance in the aforementioned band by adopting the compact lowpass filtering parts. These lowpass filtering blocks are carefully designed to achieve the two design objectives of keeping the metameterial property and the successful miniaturization. This proposed methodology will be validated by the design result of the size reduction to the guided wavelength/8, the bandwidth more than 100%, the insertion loss lower than 1 dB with the good return loss.

## Ⅱ. Design of the CRLH-TL type UWB BPF

The left-handed medium as a metamaterial has been examined theoretically and experimentally as it plays the lumped high pass filter circuit, and its unit cell in a periodic transmission line is smaller than the guided wavelength. Instead of the pure left-handedness, the CRLH-TL as a more practical circuit has been portrayed by C. Caloz et al[6]. It is represented by Fig. 1.

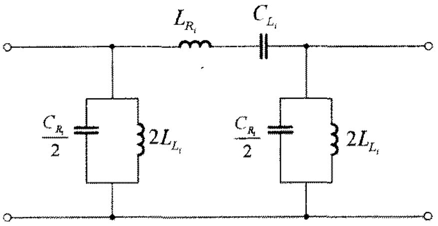


그림 1. CRLH 전송선 단위 셀의 회로모델

Fig. 1. Circuit model of the CRLH-TL unit cell.

There are three intermediate units of the periodic CRLH-TL and the $i$-th segment is marked by the dotted line block in Fig. 1. The $i$-th segment consists of ($C_{Li}$, $L_{Li}$) for the left-handedness and ($C_{Ri}$, $L_{Ri}$) for the right-handedness property. From the standpoint of the purely left-handed unit, $L_{Ri}$ and $C_{Ri}$ can be considered parasitic inductance and capacitance against $C_{Li}$ and $L_{Li}$, respectively. However, in our design, we use the effective inductance $L_{Ri}$and the effective capacitance $C_{Ri}$ for the purpose of forming a pass-band for the UWB filter. What is important in using the basic unit of the CRLH-TL in Fig. 1 is to determine the values of the elements ($CLi$, $L_{Li}$, $C_{Ri}$, $L_{Ri}$) that produce the performances appropriate to the UWB BPF. We adopt the concept of the Balanced CRLH-TL in [6] to achieve a single broad band without any gap in between the cut-off frequencies of highpass and lowpass filtering. In the Balanced case, the three from four resonance phenomena lead to the following relations.

$$f_{Li} = \frac{1}{2\pi\sqrt{L_{Li}C_{Li}}},\ f_{Ri} = \frac{1}{2\pi\sqrt{L_{Ri}C_{Ri}}}$$

$$f_{sei} = f_{shi} = f_O,\ f_O = \sqrt{f_{Li}f_{Ri}} \qquad (1)$$

where

$$f_{sei} = \frac{1}{2\pi\sqrt{L_{Ri}C_{Li}}},\ f_{shi} = \frac{1}{2\pi\sqrt{L_{Li}C_{Ri}}}$$

That $f_{sei}$ is let equal to $f_{shi}$ means the balance in the CRLH-TL, where $f_{Li}$, $f_{Ri}$, $f_{sei}$, $f_{shi}$, and $f_O$ correspond to the lower band-edge, upper band-edge, series resonance point, shunt resonance point and

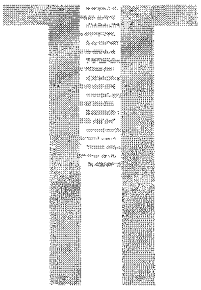


그림 2. 마이크로스트립 형의 인터디지틀 결합선로와 접지된 스텁

Fig. 2. Microstrip interdigital coupled lines and grounded stub.

center frequency, respectively. Solving the equations above, the circuit elements are identified.

As explained in the introduction with other design cases where the hybrid of the microstrip/CPW or the cascaded transmissions of wavelengths are used, $C_{Li}$ should be large enough, as the designers' main concern. Like them, we needa strong capacitive coupling, but proceed with the microstrip interdigital coupled lines. Even if the interdigital line has been around for quite some time, as is stated before, its geometric parameters will be explored to find the desired effective inductance $L_{Ri}$ as well as $C_{Li}$ in our design, different from others. Fig. 2 presents the typical interdigital line. The geometry of an $n_{IDF}$ fingered interdigital line described with $W$, $l$ and $S$ denoting the finger width, the finger length and the spacing betweenthe two adjacent fingers, respectively. The capacitance of Fig. 2 is given as follows.

$$C(pF) = \frac{\varepsilon_{re} 10^{-3}}{18\pi} \frac{K(k)}{K'(k)} (n_{IDF} - 1)\ell \qquad (2)$$

where

$$k = \tan^2\left(\frac{a\pi}{4b}\right), \quad a = \frac{W}{2}, \quad b = \frac{W+S}{2}$$

$K(\cdot)$ and $K'(\cdot)$ are the complete elliptic integral of the 1stkind and its complement. Along with the series interdigital line, the grounded shunt stub plays an important role. The expression as follows is commonly used for the inductance of the grounded stuband each finger in the interdigital line($L_{Ri}$). Though it is an approximate formula, it helps us quickly approach the initial size[10].

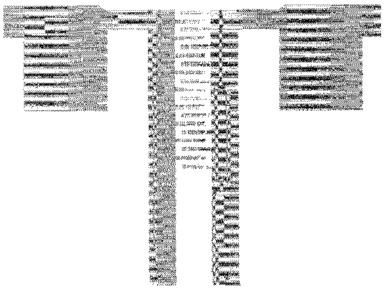


그림 3. 제안된 저역통과 블락을 가지는 CRLH 전송선 셀

Fig. 3. Proposed CRLH-TL cell with lowpass blocks.

$$L(nH) = 2\times10^{-4} l [\ln(\frac{l}{W+t}) + 1.193 + 0.224\frac{W+t}{l}] \cdot K_g \qquad (3)$$

where

$$K_g = 0.57 - 0.145\ln(\frac{W}{h})$$

$h$ and $t$ above mean the thickness of the substrate and metallizationin use.

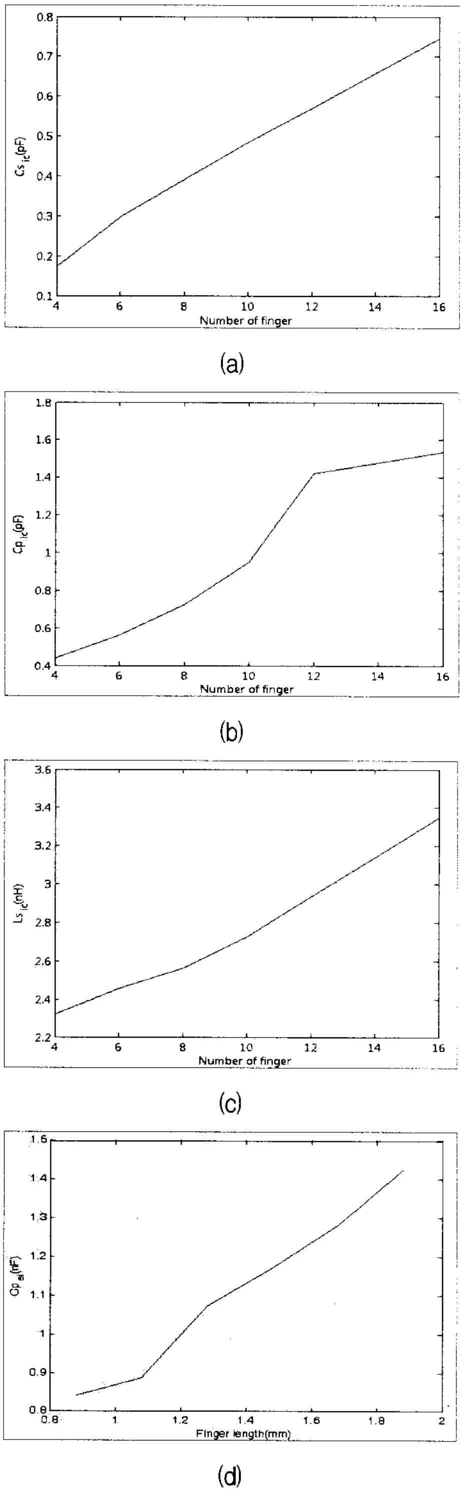
Now we present the lowpass filtering combined CRLH filter structure.

The lowpass filtering is obtained by the stepped impedance which also aims at the port matching. Its geometry is carefully determined to have its cut-off frequency around or above 10.6 GHz. The physical sizes are iteratively varied until the acquisition of the desired performance.

## Ⅲ. Results of implementation

Firstly, the interdigital line should have capacitance of 0.477pF and inductance of 5.53nH.

This is followed by finding the physical dimensions of the grounded transmission line stub whose $W$ and $l$ are 0.5 mm and 5.0 mm with 1.13nH and 0.20pF. For the substrate, FR4($\varepsilon r$ = 4.4 ) is used. And the circuit values result in the following dispersion diagram.



(a)

(b)

(c)

(d)

그림 4. 인터디지틀 결합선로의 기하변화에 따른 용량과 유도량
(a) Finger 갯수에 따른 Cs (b) Finger 갯수에 따른 Cp (c) Finger갯수에 따른 Ls (d) Finger 길이에 따른 Cp

Fig. 4. Interdigital line's capacitance and inductance V.S. geometric changes (a) Number of fingers V.S. *Cs*(b) Number of fingers VS. *Cp* (c) Number of fingers V.S. *Ls* (d) Length of the finger V.S. *Cp*

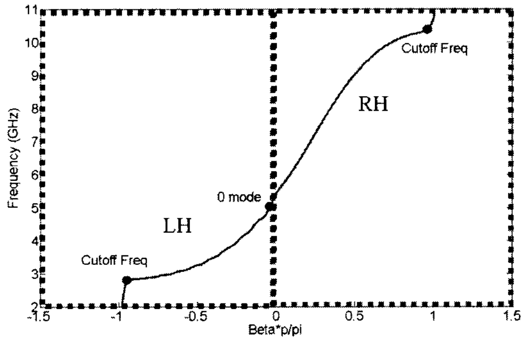


그림 5. CRLH 전송선 셀형 UWB 대역통과여파기 프로토타입의 분산도

Fig. 5. Dispersion curve of the prototype of the CRLH-TL cell UWB BPF.

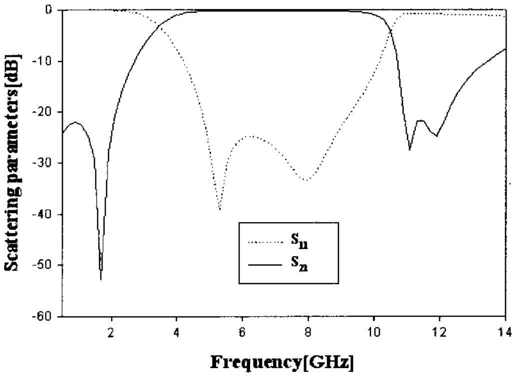


그림 6. CRLH 전송선 셀형 UWB 대역통과여파기 반사 및 투과특성

Fig. 6. $S_{11}$ and $S_{21}$ of the CRLH-TL cell UWB BPF

Resorting to the conventional periodic CRLH-TL concept, just for convenience, we check the critical points, say, transmission and stop bands. On the basis of all this matter, the filter is designed to show the following result.

Fig. 6 plots the scattering parameters $S_{11}$ and S21 verified by the bandpass filter with the CRLH-TL cell. The result tells us the bandwidth over 100 % and insertion loss less than 1dB. Also, good return loss is given.

Lastly, what is presented is the proposed bandpass filter combined the lowpass filtering blocks as in Fig. 3 to have the improved rejection performance.

In accordance with the original purpose of the present design, we can see the increased rejection above 10.6 GHz by using the lowpass filtering block. In detail, the minimum and the maximum of rejection

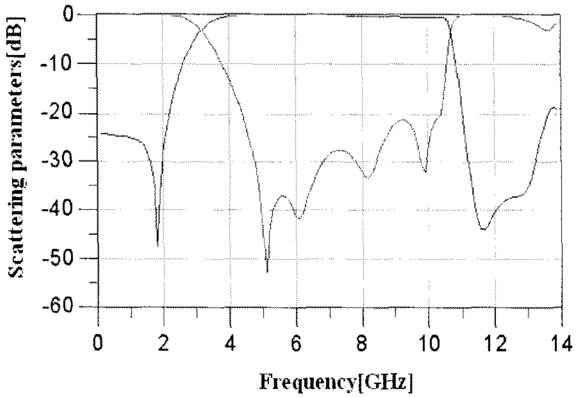


그림 7. 10.6 GHz 이후 향상된 저지특성을 갖는 CRLH 전송선 셀형 UWB 대역통과여파기 반사 및 투과특성

Fig. 7. $S_{11}$ and $S_{21}$ of the CRLH-TL cell UWB BPF with higher rejection beyond 10.6 GHz

improve from 10 dB and 24 dB to 20 dB and 44 dB, respectively. Additionally, we could lower the return loss level due to the extra factor for port matching.

## Ⅳ. Conclusion

For the purpose of increasing the rejection level in the upper stopband of the UWB BPF, we proposed the lowpass filtering blocks that go well with the CRLH-TL cell which is much less than a quarter wavelength. Based upon the miniaturized lowspass filtering technique, with very little change in the size, we could get the better rejection performance, still having the BW over 100%, good insertion and better return loss.

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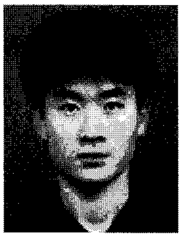
## 저자소개



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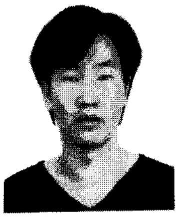

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