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Compact UWB Bandpass Filter as Cascaded Center-Tapped CRLH Transmission-Line ZORs for Improved Stopband

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Abstract – The design of a new compact UWB bandpass filter is proposed, which has cascaded center-tapped microstrip composite right/left-handed transmission-line zeroth-order resonators (CRLH-TL ZORs). In an attempt to reduce the size, instead of the conventional half-wavelength resonators or periodic and multiple CRLH-TL cells, only one cell ZOR geometry is adopted as each resonator in the filter. Additionally, two center-tapped ZORs are coupled to increase the slope of the skirt. Besides, stepped impedance matching parts are placed in the paths to the input and output ports to enhance passband and stopband performances. The proposed filter is shown to have the overall size of $0.69\lambda_g \times 0.70\lambda_g$, the insertion loss much less than 1 dB, and an acceptable return loss performance in the predicted and measured results.

Keywords: CRLH, ZOR, UWB Bandpass filter, Metamaterial, Stopband

1. Introduction

In recent years, numerous studies have been conducted to take the benefits of the UWB communication, as 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 [1-3]. Ishida and Araki [1] designed the UWB bandpass filter whose bandwidth is formed by adding notches in the sections of the transmission line. So, it shows very narrow stopband. Wang et al. [2] presented the microstripand-CPW bandpass filter for the UWB application, which is based on the multimode resonator in the form of multiples of quarter-wavelength, to broaden the bandwidth and obtain the enlarged rejection region. A composite UWB filter was designed by Menzel et al. [3] by combining low-pass and high-pass filters as a suspended stripline structure with different planes. Presently, we take a different design method hinted by the metamaterial concept of CRLH-TL to reduce the filter size [4-11]. Reference 5 shows filters as periodic CRLH-TLs.

However, we propose a two-cell center-tapped CRLH-TL ZOR UWB bandpass filter. As for the low-cost fabrication, instead of expensive multi-layered structures or lumped element loads, the 1-layer microstrip structure is used. Most of all, what features in our present work is that one center-tapped ZOR consists of the interdigital coupled lines much smaller than a quarter wavelength and the grounded stub that create the strong capacitive coupling and the inductance for the left-handedness, respectively, and the effective inductance of the interdigital capacitor and the effective capacitance of the short-circuited for the right-handedness characteristics, to form an ultra-wide band, and one ZOR is coupled to another to have the steeper skirt. And then, the impedance of the cascaded two-cell ZOR filter is matched to the ports by stepped impedance parts. The geometrical parameters of the ZORs and impedance matching parts are finalized and implemented, and the predicted performances of the filter are compared with the measurement, where the design of the proposed bandpass filter reveals the suitability for the UWB application. And the size of the filter is reduced to the guided wavelength/10 in terms of the wavelength of the center frequency 6.85 GHz, the bandwidth more than 100%, the insertion loss lower than 1 dB. In addition, the results show the stopband is increased and the skirt becomes steeper with the good return loss due to the cascading the two ZORs.

2. Design and Test Results

Firstly, the equivalent circuit is assumed to have the right and left-handedness and ZOR appropriate for the UWB filtering. This is for one ZOR and it is connected to its replica, when the cascading of the ZORs is considered.

Different from the periodic and multi-cell CRLH-TL ZORs [4], basically, one cell ZOR is dealt with to form a passband for the UWB communication. Its equivalent circuit is expressed as a pi-type configuration in Fig. 1(a), with its physical shape as the center-tapped ZOR for the realization. The one-cell ZOR will be expanded to a two-stage case as in Figs. 1(b) and 1(c) for the steeper skirt and stabilized return loss performance, which will be addressed after the metamaterial properties. Presently, we should know the circuit elements, and we use the balanced CRLH-

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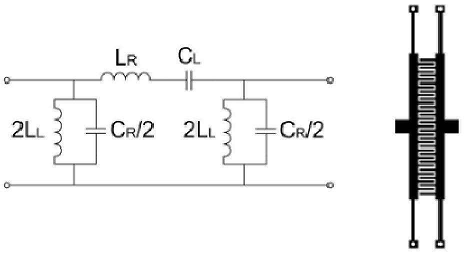
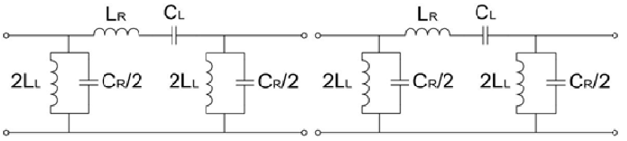
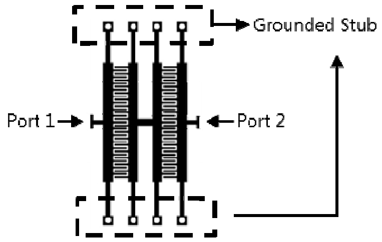


(a) Equivalent circuit of the 1-cell ZOR and its geometry.

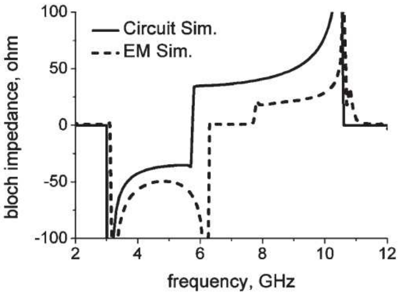


(b) Equivalent circuit of the 2 ZORs.

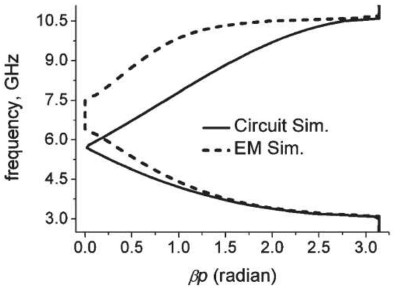


(c) Geometry of the 2 ZORs.

Fig. 1. Equivalent circuits and geometries of the proposed ZOR and two-stage version.



(a) Bloch impedance



(b) Dispersion diagram.

Fig. 2. Bloch impedance and dispersion diagram.

TL condition in [4] to achieve a single broadband without any gap ~~in~~ between the cutoff frequencies of high-pass and low-pass filtering. In the balanced case, we obtain four CRLH parameters, which are given as follows:

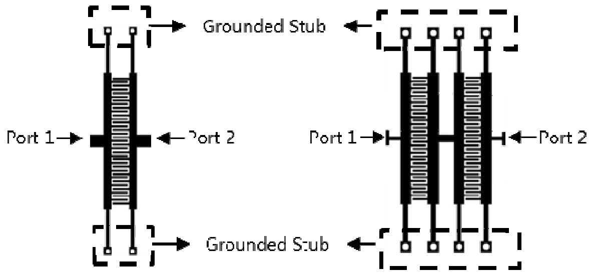
$$C_R = \frac{2}{Z_R(\omega_{cR} - \omega_{cL})},\ L_R = Z_R^2 C_R,$$

$$C_L = \frac{C_R}{\frac{(\omega_{cR} + \omega_{cL}) Z_R C_R^2}{2} - 1},\ L_L = Z_L^2 C_L \tag{1}$$

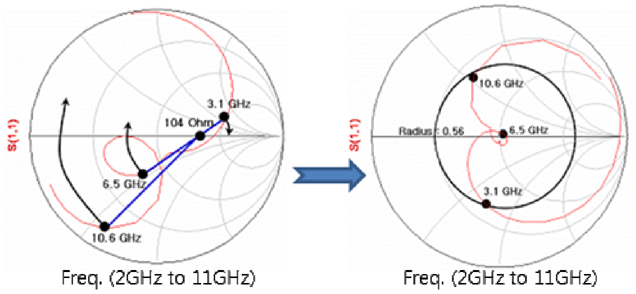
where Z_R, Z_L, ω_{cR}, and ω_{cL} correspond to the right-handed (RH) impedance, the left-handed (LH) impedance, and the exact LH high-pass and RH low-pass cutoff frequencies of the CRLH-TL, respectively. Solving the equations above, the circuit elements are identified. It is important to note that both ZR and ZL are identical to Z0 to make balanced CRLH-TL and Z0 have an effect on the return loss. Furthermore, the bandwidth of the CRLH filter is determined by the ωcR and ωcL. The CRLH bandpass filter is designed with Z0 = 35Ω, ωcL = 3.1 GHz, ωcR = 10.6 GHz, and the parameters obtained from Eqs. (1) are CR = 1.213 pF, LR = 1.485 nH, CL = 0.519 pF, LL = 0.636nH. To physically implement these elements of the equivalent circuit, the center-tapped ZOR is assumed and the corresponding geometrical values are found through the iterative electromagnetic(EM) simulations using the ADS Momentum. To check the performance of the circuit and physical structure, the Bloch impedance and the dispersion diagram are depicted in Fig. 2. In the Bloch impedance graph in Fig. 2a, the ± means the characteristic impedance for positively and negatively traveling waves, respectively. We can see the ZOR as a metamaterial property at the center frequency between the LH and RH regions in Fig. 2b. Particularly, the circuit and EM results have a gap in Fig. 2b due to the mismatched Bloch impedance of zero and high magnitude over the passband in Fig. 2a and a discrepancy between the circuit and EM structures. To remove the gap, we add a matching part to the center-tapped ZOR and the total length of this BPF becomes $0.69\lambda_g \times 0.70\lambda_g$.

As the symmetric center-tapped ZOR alone does not show good matching, which leads to imperfect balance in the dispersion diagram, there is a gap between the circuit simulation and the EM simulation in the vicinity of the center frequency. To mitigate this problem, the 2 ZORs are combined and their frequency response is adjusted with impedance matching parts. We couple the ZOR with its replicated structure and observe the skirt in the stopband and return loss.

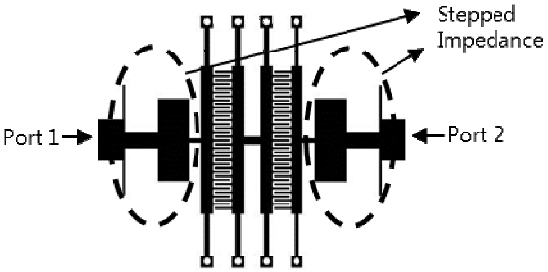
The simulated frequency responses of the CRLH bandpass filter are shown in Fig. 3 where the 1-cell ZOR is replicated and cascaded. The 2 incorporated ZORs are not sufficient to fit the impedance matching with the ports. As shown in Fig. 3(b), the 2-ZOR filter initially has the impedance locus away from the matching point, and the



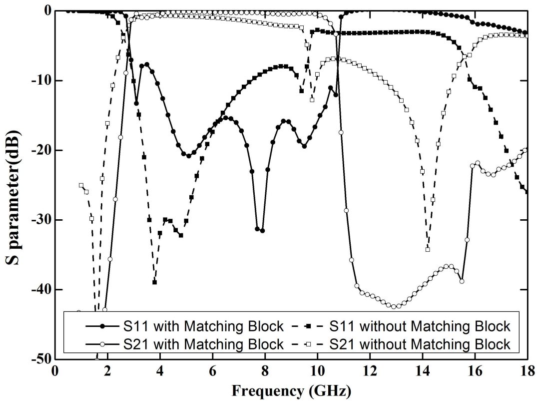
(a) 1 ZOR is expanded to the cascaded ZORs.



(b) The function of the impedance matching parts.

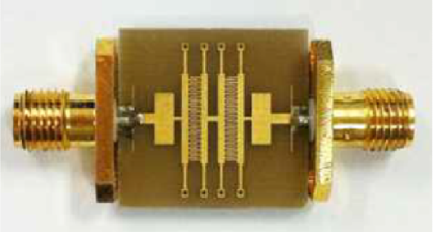


(c) The finalized cascaded ZOR UWB filter.

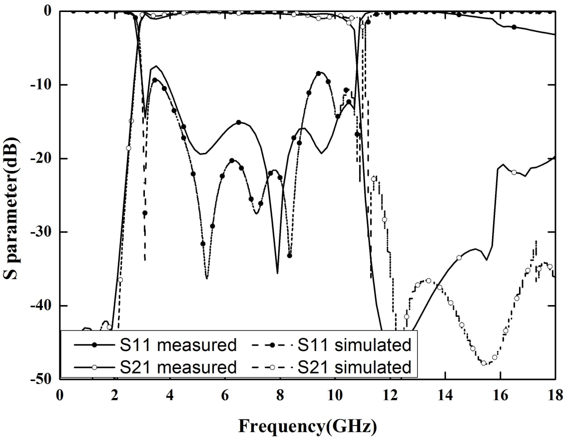


(d) S_{21} and S_{11} of the 1-ZOR and 2-ZOR cases.

Fig. 3. Structures and s-parameters of the 1-ZOR and 2-ZOR cases.



(a) Photo of the manufactured prototype.



(b) Measured results compared to the simulated ones.

Fig. 4. Photo of the manufactured 2-ZOR center-tapped UWB filter and measured results, compared to the simulated ones.

impedance changes by placing stepped impedance segments and stubs close to the ports as shown in Fig. 3(c), and finally the impedance locus passes the matching point near the passband. Especially, the stepped impedance blocks are used to enlarge the stopband with creating the bandgap effect, as it matches the impedance into the ports. Then, the multiple poles are generated having the 2-ZOR case, when the characteristic impedance of the CRLH-TL is 50Ω and βp equals ~~to~~ zero. The multiple poles stably control the return loss in the passband from 3.1 to 10.6 GHz as shown in Fig. 3(d). Particularly, the 2-ZOR bandpass filter has steeper skirt and improved stopband suppression, compared to the 1-ZOR case. Next, we fabricate the compact 2-ZOR center-tapped UWB filter and measure the performance as follows.

We fabricate the prototype with the substrate FR4 with 50 mil thickness and dielectric constant 4.4, because we can observe the advantage of the proposed design method that overcomes the higher loss problem of this material with loss tangent 0.02 by making the overall geometry much smaller than others'. The total size of the proposed bandpass filter including the matching part is 14.66×14.88 mm^2, which corresponds to $0.69\lambda_g \times 0.70\lambda_g$ in terms of the center frequency 6.85 GHz as presented in Fig. 4(a). Concerning the frequency response of the physically implemented filter, good agreement is shown between the simulated and measured S_{21} with the target bandwidth, the bandwidth over 100% and the insertion loss less than 1 dB. Besides, the stopband is obtained up to 18 GHz and the skirt in the proximity of the band-edge is steep as more than 7th order bandpass filters without the growth in the overall size. Also, good return loss is given despite the small discrepancy guessed due to the mechanical tolerance error.

3. Conclusion

A new compact UWB bandpass filter is proposed by cascading the two center-tapped CRLH-TL ZORs in series. Instead of periodic and multiple CRLH-TLs, we have optimized the proposed geometry by controlling the dominant and parasitic elements of the interdigital coupled line and grounded stubs and adding the impedance matching parts to meet the target function. The designed bandpass filter performs with the bandwidth over 100%, good insertion and return loss with the overall size to $0.69\lambda_g \times 0.70\lambda_g$. Also, the stopband is achieved up to 18 GHz and the skirt in the vicinity of the band-edge is steep as over 7th order bandpass filters without the growth in the overall size

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