Progress In Electromagnetics Research Letters, Vol. 40, 201–207, 2013

DESIGN OF COMPACT WIDEBAND BANDPASS FILTER WITH GOOD PERFORMANCES BASED ON NOVEL CRLH RESONATOR

Guo-Cheng Wu[1, *], Guang-Ming Wang[2], and Ya-Wei Wang[1]

[1]The No. 2 Team, Department of School of Air and Missile Defense, Air Force Engineering University, Xi'an, China

[2]Laboratory of Microwave Technology, Department of School of Air and Missile Defense, Air Force Engineering University, Xi'an, China

Abstract—A novel miniaturized composite right/left-handed (CRLH) transmission line based on the structure of spiral inter-digital is proposed and analyzed in this article. Compared with the conventional inter-digital CRLH, the proposed CRLH realizes a 25% resonance frequency shift, and the miniaturization is realized. Then, a compact bandpass filter centered at 1.00 GHz with minimum insertion loss 0.42 dB was designed, fabricated and measured. The measured results show that the bandwidth is 61.6% and that the sharpness at the two edges of passband is 212.5 dB/GHz and 607.1 dB/GHz. This designed filter has very high selectivity. Besides, the whole size of the designed filter is $0.114\lambda \times 0.054\lambda$. The filter realizes the miniaturization effectively, and this designed bandpass filter has good performances and smaller size than the same works in references.

1. INTRODUCTION

High performances microwaves/RF bandpass filters with small area, low loss, high selectivity and simple design play very important roles in modern wireless communications such as satellite and mobile systems [1–7, 9–14]. Recently, many researches on these filters have been published. In [2], the source/load-multiresonator is applied to design high-selectively filter, but its insertion loss reach to 3.5 dB. In [3], a high-selectively filter is designed by using the complementary

Received 4 May 2013, Accepted 4 June 2013, Scheduled 9 June 2013
* Corresponding author: Guo-Cheng Wu (wgc805735557@163.com).

split ring resonators (CSRRs); however, the defected ground structure (DGS) makes it difficult to encapsulate. In [4–6], the authors use the miniaturized composite right/left-handed stepped-impedance resonator, alternative J/K inverters and $\lambda/4$ resonators and cross-coupled multiple-mode resonator to design bandpass filters with small area and good performances.

In this article, a novel miniaturized CRLH based on the structure of spiral inter-digital is proposed and analyzed. The results indicate that its resonance frequency realizes a 25% frequency shift in comparison with the CRLH metamaterial presented in paper [8], which consists of inter-digital fingers and stub short line with via, proving that the proposed CRLH can realize miniaturization. Then, a compact wideband bandpass filter based on the proposed CRLH structure is designed, fabricated and measured. The simulated and measured results are in good agreement, showing that the insertion loss is 0.42 dB, the shape factor 0.856, the bandwidth 61.6%, and the sharpness at the two edges of passband 212.5 dB/GHz and 607.1 dB/GHz. Moreover, the size of this designed filter is $0.114\lambda \times 0.054\lambda$, which has a compact area in comparison with the same works in references.

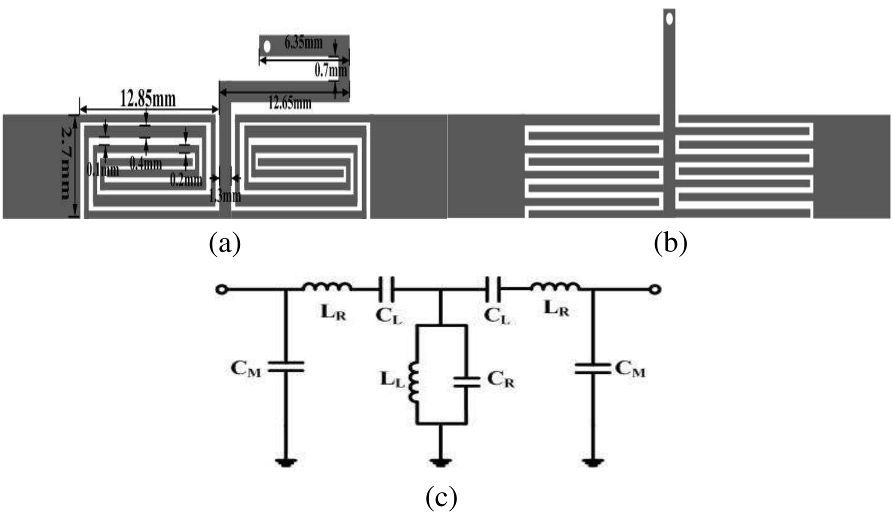


Figure 1. Layout structures and equivalent circuit model. (a) Layout structure of the proposed CRLH. (b) Layout structure of the conventional CRLH. (c) Equivalent circuit model of the proposed CRLH.

2. ANALYSIS OF SPIRAL INTER-DIGITAL BASED CRLH TL

Figures 1(a) and (b) show the unit cells of the proposed spiral inter-digital based CRLH-TL and the conventional inter-digital based CRLH-TL. The equivalent circuit model of the proposed CRLH-TL is shown in Figure 1(c).

The proposed CRLH-TL consists of a structure of spiral inter-digital and stub short line with via, whose radius is 0.25 mm. Compared with the conventional CRLH, the inter-digital figures are replaced by the spiral inter-digital figures, so the length of the inter-digital figures will increase while the whole structure keeps the same. The proposed CRLH is designed on a substrate with relative dielectric constant 2.65 and thickness 1.0 mm. In the equivalent circuit model, the interdigital fingers correspond to C_L; the shorted stub is used as L_L; C_R and L_R are the results of the naturally existing parasitic effects; C_M corresponds to the equivalent circuit model of each microstrip section.

Figure 2 is the compared results of the spiral inter-digital based CRLH and inter-digital based CRLH. We can see that the spiral inter-digital based CRLH has lower resonance frequency and realizes a 25% frequency shift, proving that the proposed spiral inter-digital based CRLH realizes miniaturization.

With dimension as shown in Figure 1(a), the extracted values of the equivalent circuit model are: $C_L = 2.24\,\text{pF}$, $C_R = 20\,\text{pF}$, $C_M = 4.0\,\text{pF}$, $L_L = 1.24\,\text{nH}$, $L_R = 14.32\,\text{nH}$. The dispersion diagram is presented in Figure 3.

As shown in Figure 3, the dispersion diagram of simulator and equivalent circuit model are in good agreement with each other in

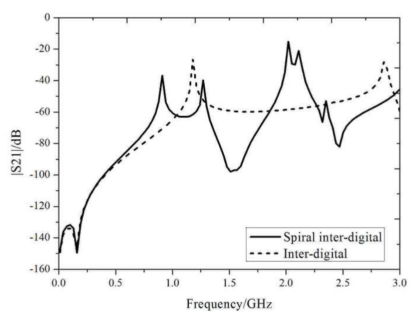


Figure 2. The comparison between spiral inter-digital based CRLH and inter-digital based CRLH.

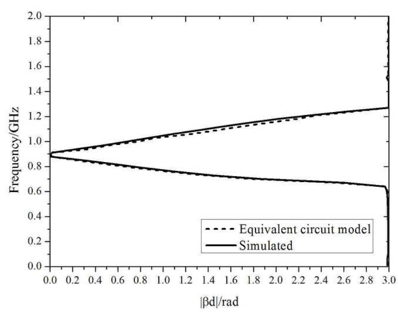


Figure 3. The comparison dispersion diagram of the proposed CRLH TL.

the passband. The balanced frequency point is centered at 0.90 GHz, the left-handed passband 0.60 GHz–0.90 GHz, and the right-handed passband 0.90 GHz–1.20 GHz. This proposed spiral inter-digital based CRLH is in balance.

3. DESIGN, FABRICATION AND MEASUREMENT OF THE DESIGNED FILTER

Based on the above, the proposed spiral inter-digital based CRLH not only is in balance, but also has a miniaturized structure, so it has a wide left/right-handed passband, and this characteristic can be used to design wideband bandpass filter. According to the design method proposed in [4], as shown in Figure 4, two unit cells are cascaded to synthesis a bandpass filter whose work frequency is designed to be 1.0 GHz; the distance between the unit cells is 3.6 mm, the cells are connected with two 50 ohm lines. Figure 5 is the photograph of the fabricated filter; the measured and simulated results are shown in Figure 6.

In Figure 6(a), the simulated and measured S-parameters are in good agreement, showing that the operating frequency is centred at 1.0 GHz, insertion loss 0.42 dB, and the bandwidth 61.6%. The 3-dB and 20-dB bandwidths are 0.70 GHz–1.34 GHz and 0.62 GHz–1.368 GHz, and the shape factor sf is 0.856 (the sharp factor sf is defined by $sf = BW_{-20\,\mathrm{dB}}/BW_{-3\,\mathrm{dB}}$, where $BW_{-20\,\mathrm{dB}}$ is 20-dB bandwidth, and $BW_{-3\,\mathrm{dB}}$ is 3-dB bandwidth). The sharpness ξ at the two edges of passband are 212.5 dB/GHz and 607.1 dB/GHz (sharpness ξ is defined by $\xi = (\alpha_2 - \alpha_1)/(f_2 - f_1)$ [12], where ξ is in dB/GHz, α_1 3 dB attenuation point, α_2 20 dB attenuation point, f_1 the frequency at 3 dB attenuation point, and f_2 the frequency at 20 dB attenuation point). Figure 6(b) is the phase response of the designed filter obtained

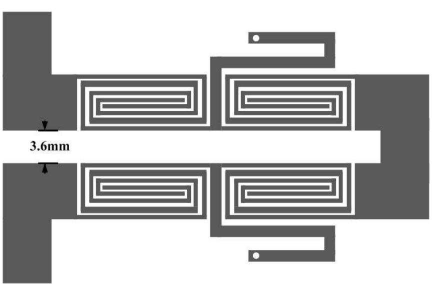


Figure 4. Structures of the proposed bandpass filter.

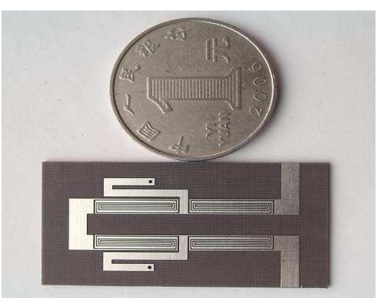


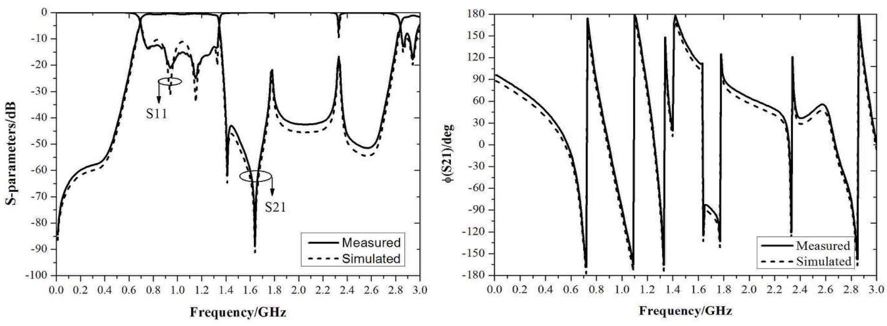
Figure 5. Photograph of the fabricated bandpass filter.

from simulation and measurement. It is observed that the simulation and measurement results are consistent with each other except at the stopband because the proposed structure operates in a different manner across the passband and stopband and because the simulator is not always accurate at all frequency bands. Besides, the size of the designed filter is $0.114\lambda \times 0.054\lambda$. If we define the whole size of this designed bandpass filter 100%, the comparison between this work and the previous works are shown in Table 1.

Table 1. Comparison with the previous works.

	bandwidth	*insertion loss*	*shape factor*	*size*	*relative*
This work	61.6%	0.42 dB	0.856	$0.114\lambda \times 0.054\lambda$	100%
Ref. [4]	6.89%	0.60 dB	0.514	$0.088\lambda \times 0.074\lambda$	106%
Ref. [5]	12.1%	0.80 dB	0.910	$0.18\lambda \times 0.072\lambda$	211%
Ref. [6]	67.8%	1.30 dB	0.863	$0.29\lambda \times 0.137\lambda$	648%
Ref. [7]	49.3%	0.60 dB	0.851	$0.242\lambda \times 0.038\lambda$	149%

Table 1 provides a comparison in terms of bandwidth, insertion loss, shape factor and size between the proposed BPF and most similar BPFs that have been reported in [4–7] recently. It is clearly evident that the proposed filter not only realizes wideband and good sharp factor, but also has a smaller size and better insertion loss.



(a) (b)

Figure 6. Measured simulated and results. (a) S-parameters. (b) Phase.

4. CONCLUSION

A compact wideband bandpass filter using the spiral inter-digital based CRLH TL unit cells is proposed in this article. The spiral inter-digital based CRLH is analyzed by simulator and equivalent circuit model, and the balanced CRLH and miniaturization are proved. Then, the proposed filter is designed, fabricated and measured. The results show that the operating frequency is centred at 1.0 GHz, insertion loss 0.42 dB, bandwidth 61.6%, shape factor 0.856, and the sharpness at the two edges of passband are 212.5 dB/GHz and 607.1 dB/GHz. This designed filter has very good performances. The comparison with recently works reported in [4–7] indicates that the designed filter in this article also has a very small size.

ACKNOWLEDGMENT

This work is supported by the National Natural Science Foundation of China (Grant No. 60971118), and special thanks should also be delivered to China North Electronic Engineering Research Institute for fabricating the device.

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