

NOVEL SIMPLIFIED DUAL-COMPOSITE RIGHT/LEFT-HANDED TRANSMISSION LINE AND ITS APPLICATION IN BANDPASS FILTER WITH DUAL NOTCH BANDS

Guo-Cheng Wu^{1, *}, Guang-Ming Wang², and Ya-Wei Wang¹

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

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

Abstract—In this article, a novel simplified dual-composite right/left-handed transmission line (S-D-CRLH-TL) is proposed according to the theory of dual-composite right/left-handed transmission line. The electromagnetic characteristics of S-D-CRLH-TL are analyzed by simulator, and the results indicate that the proposed structure has two narrow stopbands; they can be controlled by changing the geometry parameters of the structure. Then, a bandpass filter with dual notched bands is designed by using the unit cell of S-D-CRLH-TL, and the designed filter is simulated, fabricated and measured, the measured and simulated results are in good agreement with each other, showing that the two notched bands centered at 3.60 GHz and 5.50 GHz, and the bandwidths are 9.7% and 7.3%. This designed filter can avoid the interference to UWB communication system effectively, which comes from the signals of WiMAX and WLAN. Besides, in comparison with the other bandpass filter with notched-bands, the designed filter has good electromagnetic performances.

1. INTRODUCTION

Since the theory of dual-composite right/left-handed transmission line (D-CRLH-TL) was first proposed by Christophe Caloz in 2006 [1, 2], as a novel special left-handed transmission line, D-CRLH-TL has been applied to design a lot of microwave components with good electromagnetic performances [3–6]. Ultra-wideband

Received 26 August 2013, Accepted 26 September 2013, Scheduled 26 September 2013

* Corresponding author: Guo-Cheng Wu (wgc805735557@163.com).

(UWB) communication system is one of the most important communication systems, and it develops very fast with the progress of microwave wireless communication technology [7]. The UWB Bandpass filters (BPFs) are very necessary and important microwave components in the UWB communication system, but the interference to UWB communication system, which comes from the signals of WiMAX (3.30 GHz–3.70 GHz) and WLAN (5.15 GHz–5.825 GHz), is a troublesome problem [8], so the UWB BPFs with notch-bands is emergently required, and many effective methods are used to realize notched bands in UWB BPFs: in [9–11], the ring resonator, the slow wave coplanar waveguide (CPW) multiple-mode resonator and the CPW detached-mode resonator are used to design UWB BPFs with one notched band; in [12–14], the simplified composite right/left-handed (S-CRLH) resonator, the asymmetric coupling strip line, and multiple-mode resonator are applied to realize multi notched bands in UWB BPFs.

In this article, a novel simplified dual-composite right/left-handed transmission line (S-D-CRLH-TL) is proposed and analyzed; the simulated results show that the stopband between the first right-handed passband and left-handed passband of D-CRLH-TL is destroyed; a new passband and two narrow stopbands are engendered, these two narrow stopbands can be controlled by changing the physical dimensions of the structure. Then, a bandpass filter with dual notched bands is designed; the BPF is designed by using the interdigital-coupled lines proposed in paper [15], the dual notched bands are realized by the unit cell of S-D-CRLH embedded in the BPF. The designed filter is fabricated and measured; the measured results are in good agreement with the simulated ones, showing that the passband is 3.10 GHz to 7.60 GHz, the two notched bands centered at 3.60 GHz and 5.50 GHz, the relative bandwidths are 9.7% and 7.6%, it can avoid the interference of WiMAX and WLAN signals effectively.

2. ANALYSIS OF THE S-D-CRLH

Figure 1 is the structure and equivalent circuit model of the proposed S-D-CRLH in this article. It is designed on a substrate with relative dielectric constant 2.2 and thickness 1 mm.

In the circuit model, where L_2 models the main transmission line inductance; L_R is realized by the narrow microstrip lines paralleled with the structure of spiral inter-digital; L_L models the left-handed inductance realized by the stub line; C_L represents the coupling of the structures of spiral inter-digital; C_1 and L_1 are realized by the self-coupling of the structures of spiral inter-digital. Compared

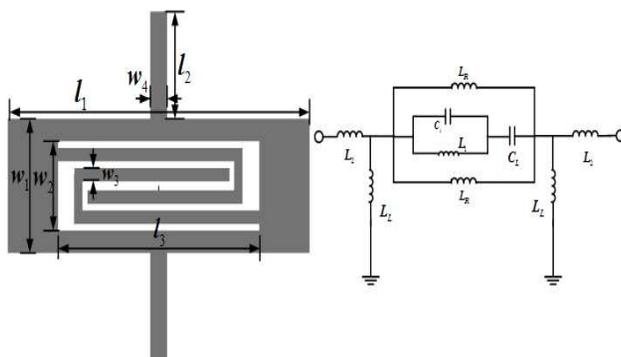


Figure 1. The structure and equivalent circuit model of the proposed S-D-CRLH.

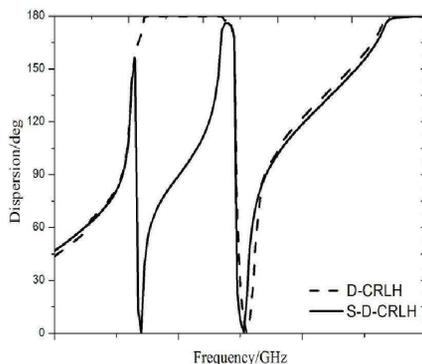


Figure 2. The comparison of dispersion between S-D-CRLH and D-CRLH.

with the equivalent circuit model of D-CRLH, there is no right-handed capacitance (C_R) in S-D-CRLH. Figure 2 shows the compared dispersion diagram of S-D-CRLH and D-CRLH.

In Figure 2, we can see that the stopband between the first right-handed passband and left-handed passband of D-CRLH-TL is destroyed, and a new passband and two narrow stopbands are engendered.

In order to obtain good performances, the physical dimensions of the S-D-CRLH are optimized, and the detailed dimensions are: $l_1 = 10$ mm, $l_2 = 2.5$ mm, $l_3 = 7$ mm, $w_1 = 2.2$ mm, $w_2 = 1.8$ mm, $w_3 = 0.2$ mm, $w_4 = 0.8$ mm. The value of elements in equivalent circuit model is $L_R = 1.5$ nH, $C_L = 0.85$ pF, $L_L = 6.24$ nH, $C_C = 8.9$ pF,

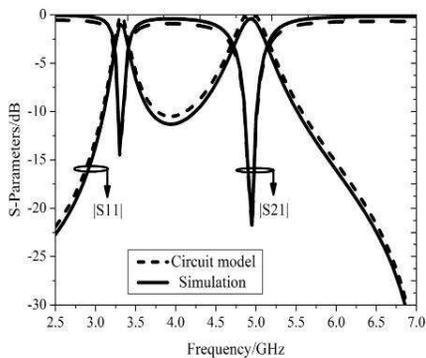


Figure 3. The simulated S -parameters of S-D-CRLH.

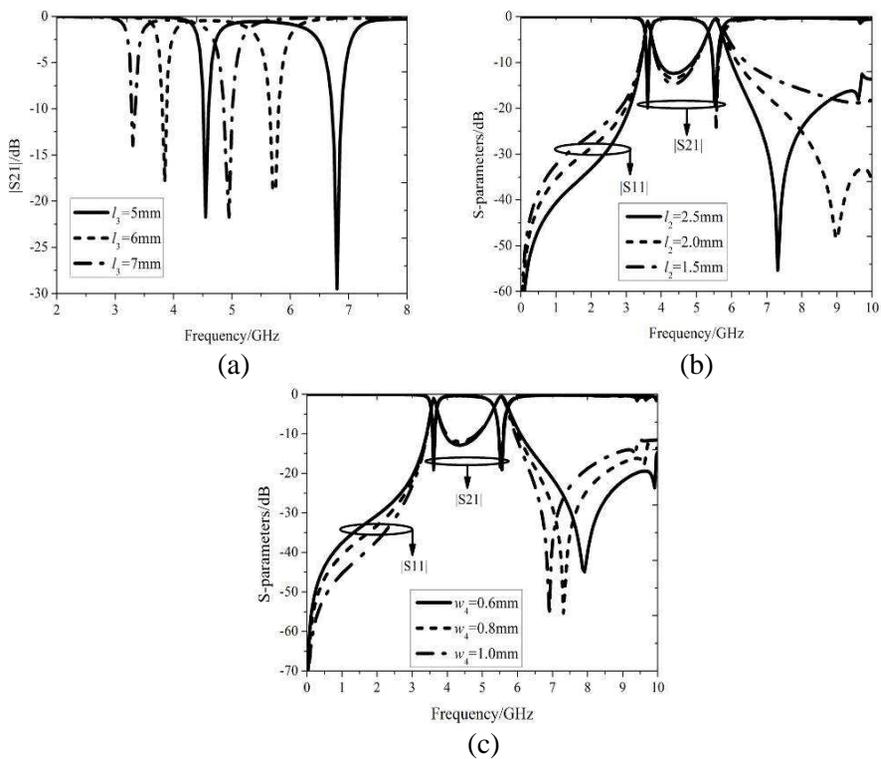


Figure 4. The effects of physical dimensions to the stopbands.

$L_1 = 0.24$ nH, $L_2 = 0.45$ nH, and the electromagnetic and equivalent circuit model simulated results are shown in Figure 3.

As shown in Figure 3, the electromagnetic and equivalent circuit model simulated S -parameters of the proposed S-D-CRLH are in good agreement with each other, showing that there are two narrow stopbands, and it has sharp transmissions at the edges of the two stopbands. This characteristic can be used to design the microwave components with notched bands.

In Figure 4, we can see that the electromagnetic performances of the proposed S-D-CRLH change with the change of its physical dimensions. Figure 4(a) indicates that the two transmission zeros will be shifted to lower frequency with the increase of length of spiral inter-digital; Figure 4(b) clearly observes that with the increasing length l_2 , the transmission characteristics at the two edges of the stopbands is becoming good, and it has no influence on the stopbands; Figure 4(c) shows that with the increasing width w_4 , the transmission characteristics at the two edges of the stopbands is also becoming good, and it has no influence on the two transmission zeros.

3. DESIGN AND MEASUREMENT OF THE BANDS NOTCHED FILTER

3.1. Design of the Bandpass Filter

In [15], the interdigital-coupled lines are used to design bandpass filter, and this method is used in this article. Figure 5 shows the structure of the designed bandpass filter.

In Figure 5, we can see that one of the outer coupled lines of each section is shorted to ground to allow this structure to generate new transmission zeros at the lower and upper edges of the desired passband. The width of the coupled lines and the gap between them are defined by w and g_1 , respectively. The length of main microstrip line and the shorted coupled lines is described by L_1 and L_2 . The gap between the main microstrip line and the coupled line is given by g_2 . The physical dimensions are shown in Table 1, and Figure 6 shows the simulated S -parameters of the designed bandpass filter.

Table 1. The physical dimensions of bandpass filter (mm).

L_1	L_2	g_1	g_2	w
11.1	10	0.1	0.15	0.5

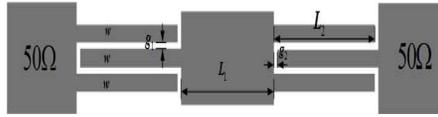


Figure 5. The structure of bandpass filter.

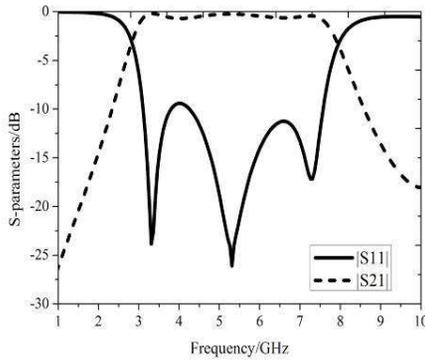


Figure 6. The simulated results of the designed bandpass filter.

In Figure 6, the passband of the filter is from 3.10 GHz to 7.60 GHz, the relative bandwidth 84.1%, and it will be interfered by the signals of WiMAX (3.30 GHz–3.70 GHz) and WLAN (5.15 GHz–5.825 GHz) which are undesired in UWB communication system.

3.2. Design of the Bandpass Filter with Dual Notched Bands

In order to avoid the interference of WiMAX and WLAN signals, a BPF with dual notched-bands is designed. Figure 7 shows the structure of the designed band-notched filter. The main microstrip line is replaced by the unit cell of S-D-CRLH-TL, and a photograph of this filter is shown in Figure 8. The fabricated filter is measured by Agilent Vector Network Analyzer, and Figure 9 shows the comparison of simulated and measured results.

In Figure 9, we can see that the measured and simulated results are in good agreement. There are two notched bands appeared in the passband due to the S-D-CRLH unit cell embedded in the structure of filter. The measured results show that the two notched-bands are centered at 3.60 GHz and 5.50 GHz with the rejection level of more than 15 dB, and the bandwidths of the notched bands are 9.7% and 7.3%, which can avoid the interference of WiMAX and WLAN effectively. The comparison of the designed band-notched filter in this article and

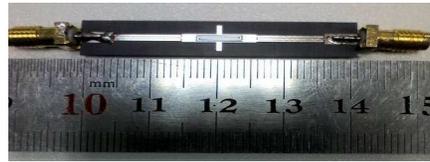
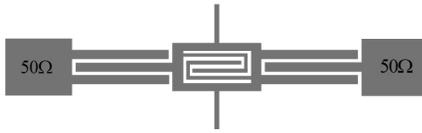


Figure 7. The structure of the designed band-notched filter.

Figure 8. The photograph of the designed band-notched filter.

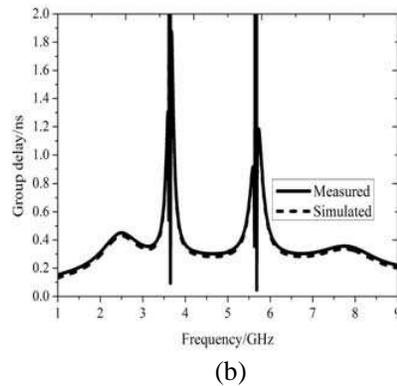
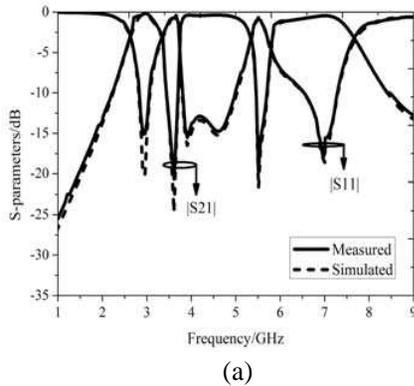


Figure 9. The measured and simulated results.

Table 2. Comparison with previous works.

<i>papers</i>	<i>notched frequency</i>	<i>relative bandwidth</i>	<i>rejection level</i>
[9]	5.41 GHz	3.5%	11.14 dB
[10]	5.65 GHz	2.1%	19.2 dB
[11]	5.80 GHz	2.06%	24.7 dB
[14]	5.85 GHz	7.9%	20 dB
[14]	8.05 GHz	6.4%	15 dB
[16]	5.2 GHz	3.8%	20 dB
[16]	5.8 GHz	5.5%	20 dB
this work	3.60 GHz	9.7%	20.6 dB
	5.50 GHz	7.3%	19.7 dB

the previous works in other papers is shown in Table 2.

It can be seen that the designed filter in this article not only shows good performances, but also has greater bandwidth at the dual notched-bands than the previous works in the references.

4. CONCLUSIONS

A bandpass filter with dual notched-bands based on the unit cell of S-D-CRLH-TL is proposed in this article. First, the proposed S-D-CRLH is analyzed, and its special characteristics are proved. Then, the band-notched bandpass filter is designed, fabricated and measured. The measured results show that the dual notched-bands are centered at 3.60 GHz and 5.50 GHz with the bandwidths of 9.7% and 7.3%, and the designed filter can avoid the interference of WiMAX and WLAN effectively. In addition, the proposed filter not only exhibits good performances, but also has greater bandwidth of each notched band than the previous works in the references.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China (Grant No. 60971118). The authors thank the China North Electronic Engineering Research Institute for the fabrication.

REFERENCES

1. Caloz, C., "Dual composite right/left-handed (D-CRLH) transmission line metamaterial," *IEEE Microwave and Wireless Components Letters*, Vol. 16, No. 1, 585–687, 2006.
2. Caloz, C. and H. V. Nguyen, "Novel broadband conventional and dual-composite right/left-handed (C/D-CRLH) metamaterials: Properties, implementation and double-band coupler application," *Applied Physics A — Materials Science & Processing*, Vol. 87, No. 2, 309–316, 2007.
3. Caloz, C., S. Abielmona, H. van Nguyen, and A. Rennings, "Dual composite right/left-handed (D-CRLH) leaky-wave antenna with low beam squinting and tunable group velocity," *Physica Status Solidi (b)*, Vol. 244, No. 4, 1219–1226, 2007.
4. Tong, W., Z. Hu, H. Zhang, C. Caloz, and A. Rennings, "Study and realization of dual-composite right/left-handed coplanar waveguide metamaterial in MMIC technology," *IET Microwaves, Antennas & Propagation*, Vol. 2, No. 7, 731–736, 2008.
5. Hu, X., P. Zhang, and S. He, "A novel dual-band balun based on the dual structure of composite right/left handed transmission line," *International Symposium on Biophotonics, Nanophotonics and Metamaterials*, 16–18, 2006.

6. González-Posadas, V., J. L. Jiménez-Martín, A. Parra-Cerrada, L. E. García-Muñoz, and D. Segovia-Vargas, "Dual-composite right-left-handed transmission lines for the design of compact diplexers," *IET Microwaves, Antennas & Propagation*, Vol. 4, No. 8, 982–990, 2010.
7. Shaman, H. and J. S. Hong, "Asymmetric parallel-coupled lines for notch implementation in UWB filter," *IEEE Microwave and Wireless Components Letters*, Vol. 17, No. 7, 516–518, 2007.
8. Hao, Z.-C. and J.-S. Hong, "Compact UWB filter with double notch-bands using multilayer LCP technology," *IEEE Microwave and Wireless Components Letters*, Vol. 19, No. 8, 500–502, 2009.
9. Kim, C. H. and K. Chang, "Ultra-wideband (UWB) ring resonator bandpass filter with a notched band," *IEEE Microwave and Wireless Components Letters*, Vol. 21, No. 4, 206–208, 2011.
10. Sekar, V. and K. Entesari, "Miniaturized UWB bandpass filters with notch using slow-wave CPW multiple-mode resonators," *IEEE Microwave and Wireless Components Letters*, Vol. 21, No. 2, 80–82, 2011.
11. Luo, X., J.-G. Ma, K. Ma, and K. S. Yeo, "Compact UWB bandpass filter with ultra narrow notched band," *IEEE Microwave and Wireless Components Letters*, Vol. 20, No. 3, 145–147, 2010.
12. Li, K., D. Kurita, and T. Matsui, "UWB bandpass filters with multi notched bands," *Proc. 36th EuMC*, 591–594, Sep. 2006.
13. Song, K. and Q. Xue, "Compact ultra-wideband (UWB) bandpass filters with multiple notched bands," *IEEE Microwave and Wireless Components Letters*, Vol. 20, No. 8, 447–449, 2010.
14. Wei, F., Q. Y. Wu, X. W. Shi, and L. Chen, "Compact UWB bandpass filter with dual notched bands based on SCRLH resonator," *IEEE Microwave and Wireless Components Letters*, Vol. 21, No. 1, 28–30, 2011.
15. Shaman, H. N., "New S-band bandpass filter (BPF) with wideband passband for wireless communication systems," *IEEE Microwave and Wireless Components Letters*, Vol. 22, No. 5, 242–244, 2012.
16. Mao, S.-G., Y.-Z. Chueh, C.-H. Chen, and M.-C. Hsieh, "Compact ultra-wideband conductor-backed coplanar waveguide bandpass filter with a dual band-notched response," *IEEE Microwave and Wireless Components Letters*, Vol. 19, No. 3, 149–151, 2009.