Progress In Electromagnetics Research Letters, Vol. 24, 35–42, 2011

A NOVEL COMPACT ULTRA-WIDEBAND BANDPASS FILTER WITH SIMULTANEOUS NARROW NOTCHED BAND AND OUT-OF-BAND PERFORMANCE IMPROVEMENT

J.-Z. Chen*, G.-C. Wu, and C.-H. Liang

Science and Technology on Antenna and Microwave Laboratory, Xidian University, Xi'an, Shaanxi 710071, China

Abstract—A compact ultra-wideband (UWB) bandpass filter (BPF) with simultaneous narrow notched band and out-of-band performance improvement is presented. The UWB BPF is built up using the hybrid microstrip and coplanar waveguide (CPW) structure. By employing the split-ring resonator (SRR) which is defected on the lower plane, the narrow notched band was introduced. The center and bandwidth of the notched band can be controlled by adjusting the length and width of the SRRs. A novel cross-shape patch is constructed to implement transmission stopband in the upper out-of-band so as to suppress the spurious passband. The novel UWB BPF is designed and fabricated. The measured insertion loss is less than 1.6 dB, the return loss is more than 13 dB and the variation of group delay is less than 0.12 ns. The width of narrow notched band is about 0.15 GHz and the attenuation is 18 dB at the center frequency of 5.76 GHz. The upper stopband is up to 15.2 GHz with rejection greater than 20 dB.

1. INTRODUCTION

In February 2002, the Federal Communications Commission (FCC) allocated a 3.1–10.6 GHz band for unlicensed use of ultra-wide band (UWB) systems [1]. Since then, considerable research efforts have been put into ultra-wideband (UWB) radio technology worldwide. For the indoor use, the UWB frequency band of 3.1 to 10.6 GHz may be interfered by the wireless local area network radio signals. So a communication system working in this UWB frequency band required

Received 23 March 2011, Accepted 19 May 2011, Scheduled 24 May 2011

* Corresponding author: Jian Zhong Chen (xjtucjz@gmail.com).

a bandpass filter (BPF) with a notched band to avoid being interfered by the WLAN radio signals.

As one of the essential component blocks, various UWB BPFs have been proposed via different methods and structures [2–15]. Compared with the UWB BPFs implemented by a direct cascade of the low- and high-pass filters [2], a UWB filter using multimode resonator (MMR) [3–7] has low insertion loss and occupies less circuit size. The first three resonant frequencies of MMR were properly adjusted to be placed quasi equally within the UWB. In [8], three interdigital edge coupled microstrip lines are used for coupling enhancement. Recently, broadside-coupled structures have received great attention. In [9, 10], microstrip-coplanar waveguide structures are be used to realize wideband filter or even UWB filter. The fork-form resonators [11] have been used to design UWB BPF with two transmission zeros near both passband edges of lower and higher frequency. In order to generate notched band, embedded open stubs were introduced in [12]. In [13], stepped impedance resonators are implemented to realize the notched band. Two different quarter-wavelength lines are arranged on the ground of UWB BPF to generate dual narrow stop bands [14]. For getting good out-of-band performance of the UWB filter, an interdigital coupled line with capacitive-ended loading is constructed in [15].

In this paper, we present a compact UWB BPF with notched band and improved out-of-band performance for the use in wireless systems. A UWB BPF is built up by the CPW multiple-mode resonator (MMR) and microstrip/CPW surface-to-surface coupling lines. For getting notched band, SRRs are embedded in the CPW MMR without enlarging the size of the filter. The center and bandwidth of the notched band can be controlled by adjusting the length and width of the stubs. A cross-shape microstrip is constructed to suppress the first spurious passband. Details of the UWB BPF design and parameter study are presented and discussed as follows.

2. UWB BPF DESIGN

The geometry of the proposed UWB BPF in this paper is shown in Figure 1. The UWB BPF is designed and fabricated on a substrate with dielectric constant of 9.6, thickness of 0.8 mm and loss tangent of 0.0025, and total area of $30 \times 6\,\text{mm}^2$. On the lower plane, SRRs are embedded on the two sides of the CPW MMR. On the upper plane, a cross-shape patch is constructed in the middle.

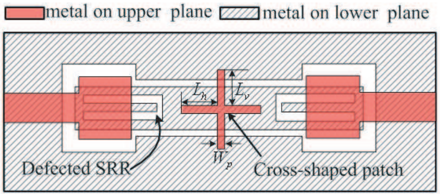
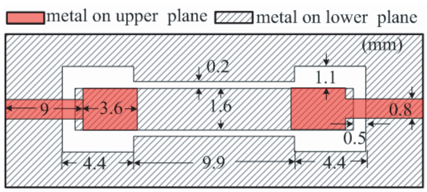
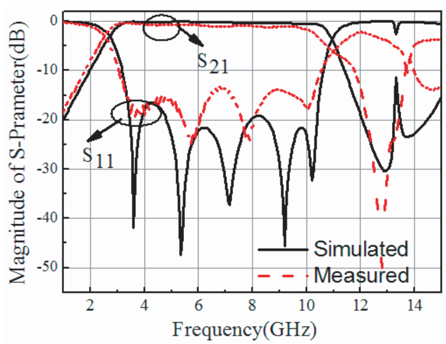


Figure 1. Geometry of the proposed UWB BPF.



(a)



(b)

Figure 2. (a) The structure of the proposed UWB BPF. (b) Simulated and measured S-parameter responses of the UWB BPF.

2.1. UWB BPF Using the Hybrid Microstrip and Coplanar Waveguide (CPW) Structure

Based on the design procedure which has been illustrated in [3–7], a UWB BPF using the multimode resonator (MMR) can be easily realized. The geometry of the filter is shown in Figure 2(a). A CPW non-uniform shape resonator is constructed to produce its first three resonant modes occurring around the lower end, center, and higher end of the UWB band. Then, a microstrip/CPW surface-to-surface coupled line is formed and modeled to allocate the enhanced coupling peak around the center of this UWB band. As such, a five-pole UWB

BPF is built up and realized with the passband covering the entire UWB band (3.1–10.6 GHz). Figure 2(b) shows the simulated and measured responses of the UWB BPF, the insertion loss and return loss are better than 1.0 dB and 15 dB in most pass band, respectively. The discrepancy between the simulated and measured results, mostly attributed to the tolerance in the relative dielectric constant and the loss tangent $\tan\delta$ of the substrate, manufacture and test environment, is tolerable.

2.2. Design of the Notched Band

As mentioned above, the problem of interference between UWB devices and systems is an important issue in developing a UWB radio module or system. To solve this problem, we implement a notched band which can be adjusted easily. The notched band is introduced by defecting two SRRs on the both sides of the CPW MMR as shown in Figure 3(a). Design of the notched band is flexible and the bandwidth can be controlled by changing dimensions of the SRR.

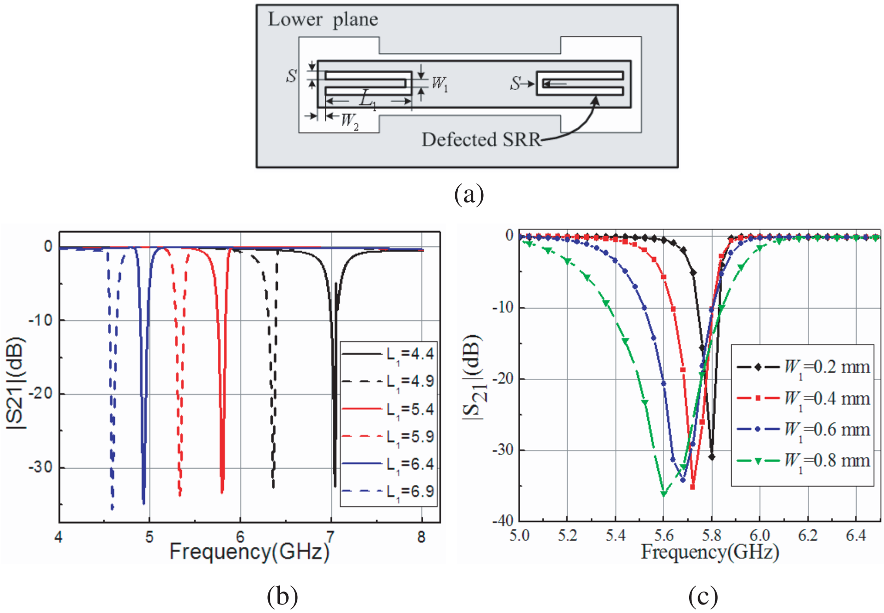
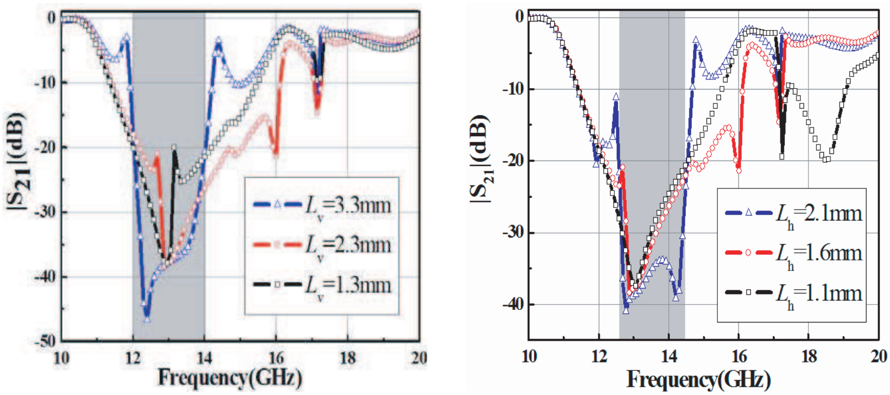


Figure 3. (a) Defected SRRs on the bottom of the proposed filter. (b) Full-wave simulation results sults with $W_1 = 0.2$ mm and variable L_1. (c) Full-wave simulation results with $L_1 = 5.4$ mm and variable W_1.

Some useful experiments have been done to find the notched band characteristic of the UWB BPF. We fix the dimensions $S = 0.2$ mm and $W_2 = 0.2$ mm. Other dimensions are shown in Figure 2(a). Figure 3(b) displays the transmission characteristic with the fixed $W_1 = 0.2$ mm and variable L_1. It should be noted that the position of the notched band moves to the higher frequencies due to the decrease of L_1. The notched band can be allocated at any desired frequency when letting L_1 be about a quarter-wavelength at the needed center frequency. The bandwidth of the notched band can also be controlled. Figure 3(c) depicts the full-wave simulation results with the fixed $L_1 = 5.4$ mm and variable W_1. It is found that small bandwidth requires narrow W_1 and the center of the notched band may shift slightly with different W_1. In this design, $W_1 = 0.2$ mm and $L_1 = 5.4$ mm are chosen to avoid interference from WLAN signals ranged from 5.725 to 5.825 GHz.

2.3. Out-of-band Performance Improvement

As seen from Figure 2(b), the upper out-of-band rejection is not so good due to the first spurious passband at about 13.4 GHz. In order to widen the upper–stopband performance, a novel cross shape patch with longitudinal length L_v and latitudinal length L_h is constructed in the middle of the top side of the proposed UWB BPF as shown in Figure 1. The cross shape patch is introduced to implement transmission stopband in the upper out-of-band so as to inhibit the spurious passband. The cross shape patch can be treated as a split half-wavelength resonator. So, the initial length ($L_v = L_h = L_1/2$) of the cross shape patch can be got from $f_s = c(2L_1\sqrt{\varepsilon_e})$, where c is the speed of the light in free space, ε_e denotes the effective dielectric constant of the substrate and f_s is center frequency of the first spurious passband. Compared with half-wavelength resonator, the cross shape patch has a wider transmission stopband with different L_v and L_h. The position of the transmission stopband is determined by L_v and L_h. Some study has been made with fixed $W_p = 0.4$ mm. Figure 4(a) shows the variation of transmission properties with fixed $L_h = 1.6$ mm and variable L_v and Figure 4(b) shows the variation of transmission properties with fixed $L_v = 2.3$ mm and variable L_h, respectively. From Figure 4, it is found when $L_v = 2.3$ mm and $L_h = 1.6$ mm the UWB BPF will have upper stopband up to 15.2 GHz with rejection better than 20 dB.



(a) (b)

Figure 4. (a) Transmission ission properties with fixed $L_h = 1.6\,\text{mm}$ and variable L_v. (b) Transmission properties with fixed $L_v = 2.3\,\text{mm}$ and variable L_h. (The gray shaded areas represent the transmission stopband).

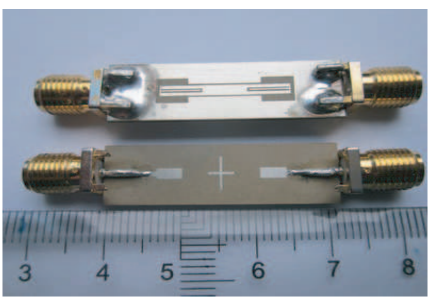


Figure 5. Photograph of the proposed filter.

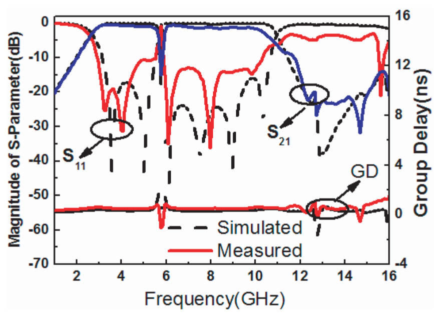


Figure 6. Simulated and measured results of the proposed UWB BPF. Dashed line: simulation results. Solid line: measurement results.

3. RESULTS AND DISCUSSION

Simulation and measurement are carried out using Zeland IE3D software and Agilent's 8719ES network analyzer, respectively. Figure 5 depicts the photographs of the fabricated UWB BPF, and the simulated and measured results are illustrated in Figure 6. It can be seen that the simulated and measured results are in good agreement.

The measured insertion loss is less than 1.6 dB, return loss is above 13 dB and the group delay is about 0.48–0.59 ns from 3.1–10.2 GHz except the frequency near the notched band 5.725–5.825 GHz. The width of the notched band is about 0.15 GHz and the attenuation is more than 18 dB at the center frequency of 5.76 GHz. The upper stopband is up to 15.8 GHz with rejection greater than 20 dB. The discrepancies between simulated and measured results may be caused by unexpected tolerances in fabrication, the loss tangent of the substrate and the parasitic effects of the SMA connectors.

4. CONCLUSION

In this paper, a compact UWB BPF with notched band and improved out-of-band performance is proposed and fabricated. The notched band of 5.725 to 5.825 GHz is introduced by embedding two SRRs in the CPW MMR. The attenuation is 18 dB in the center frequency. A cross shape patch is employed to get wider upper stopband. The harmonic passband is suppressed and the upper stopband is up to 15.8 GHz with rejection better than 20 dB. The measured insertion loss is less than 1.6 dB in operating band. Therefore, the proposed filter can be integrated in UWB wireless system due to their simple structure, compact size, and excellent performance.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China (NSFC) under project No. 60901031 and the Fundamental Research Funds for the Central Universities No. 72005477.

REFERENCES

1. "Revision of Part 15 of the commission's rules regarding ultra-wide band transmission systems," Federal Communications Commission, ET-Docket 98–153, 2002.
2. Lin, Y. S., W. C. Ku, C. H. Wang, and C. H. Chen, "Wideband coplanar-waveguide bandpass filters with good stopband rejection," *IEEE Microw. Wireless Compon. Lett.*, Vol. 4, No. 9, 422–424, Sep. 2004.
3. Zhu, L., S. Sun, and W. Menzel, "Ultra-wideband (UWB) bandpass filters using multiple-mode resonator," *IEEE Microw. Wireless Compon. Lett.*, Vol. 15, No. 11, 796–798, Nov. 2005.

4. Zhu, L. and H. Wang, "Ultra-wideband bandpass filter on aperture-backed microstrip line," *Electronics Lett.*, Vol. 41, No. 18, 1015–1016, Sep. 2005.
5. Wang, H., L. Zhu, and W. Menzel, "Ultra-wideband bandpass filters with hybrid microstrip/CPW structure," *IEEE Microw. Wireless Compon. Lett.*, Vol. 15, No. 12, 844–846, Dec. 2005.
6. Gao, S. S., X. S. Yang, J. P. Wang, S. Q. Xiao, and B. Z. Wang, "Compact ultra-wideband (UWB) bandpass filter using modified stepped impedance resonator," *Journal of Electromagnetic Waves and Applications*, Vol. 22, No. 4, 541–548, 2008.
7. Lee, C. H., I.-C. Wang, and L. Y. Chen, "MMR-based band-notched UWB bandpass filter design," *Journal of Electromagnetic Waves and Applications*, Vol. 22, No. 17–18, 2407–2415, 2008.
8. Singh, P. K., S. Basu, and Y.-H. Wang, "Planar ultra-wideband bandpass filter using edge coupled microstrip lines and stepped impedance open stub," *IEEE Microw. Wireless Compon. Lett.*, Vol. 17, No. 9, 649–651, Sep. 2007.
9. Thomson, N. and J.-S. Hong, "Compact ultra-wideband microstrip/coplanar waveguide bandpass filter," *IEEE Microw. Wireless Compon. Lett.*, Vol. 17, No. 3, 184–186, Mar. 2007.
10. Li, K., D. Kurita, and T. Matsui, "An ultra-wideband bandpass filter using broadside-coupled microstrip-coplanar waveguide structure," *2005 IEEE MTT-S Int. Microwave Symp. Dig.*, Jun. 2005.
11. Chen, H. and Y.-X. Zhang, "A novel and compact UWB bandpass filter using microstrip fork-form resonators," *Progress In Electromagnetics Research*, Vol. 77, 273–280, 2007.
12. Shaman, H. and J. S. Hong, "Ultra-wideband (UWB) bandpass filter with embedded band notch structures," *IEEE Microw. Wireless Compon. Lett.*, Vol. 17, No. 3, 193–195, Mar. 2007.
13. Shaman, H. and J.-S. Hong, "Ultra-widebadn (UWB) microstrip bandpass filter with narrow notched band," *Proc. 38th EuMC*, 857–860, Oct. 2008.
14. Huang, J.-Q., Q.-X. Chu, and C.-Y. Liu, "Compact UWB filter based on surface-coupled structure with dual notched bands," *Progress In Electromagnetics Research*, Vol. 106, 311–319, 2010.
15. Sun, S. and L. Zhu, "Capacitive-ended interdigital coupled lines for UWB bandpass filters with improved out-of-band performance," *IEEE Microwave Wireless Compon. Lett.*, Vol. 16, No. 8, 440–442, Aug. 2006.