

# Compact Microstrip UWB Bandpass Filter with Two Band-Notches for UWB Applications

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**Abstract**—A new microstrip ultra-wideband (UWB) bandpass filter (BPF) with dual sharply rejected notched bands based on E-shaped resonator is proposed in this paper. The basic UWB BPF is designed using two microstrip interdigital coupled lines and one rectangular patch multiple-mode resonator (MMR). Then, to achieve dual band-notched performance, the proposed dual-mode E-shaped resonator is investigated and coupled to the rectangular patch multiple-mode resonator of the basic UWB BPF. To validate the design theory, a microstrip UWB BPF with two notch-bands centered at the frequencies of 5.8 GHz and 8.0 GHz, respectively, is designed and fabricated. Both simulation and experimental results are provided with good agreement.

## 1. INTRODUCTION

In 2002, the U.S. Federal Communications Commission (FCC) authorized the unlicensed use of ultra-wideband (UWB, from 3.1 to 10.6 GHz) for a variety of applications, such as indoor and hand-held systems [1]. UWB BPFs, as one of the essential components of the UWB systems, have gained much attention in recent years. There are many methods presented to design UWB bandpass filters [2–10]. For instance, multiple-mode resonator (MMR) [2, 3], defected microstrip structure (DMS) [4], defected ground structure (DGS) [5, 6], multilayer coupled structure [7, 8], and the cascaded low-pass/high-pass filters [9, 10] have been widely used to achieve UWB characteristics.

However, the existing wireless networks such as 5.8 GHz WLAN signals and some 8.0 GHz satellite communication systems signals can interfere with UWB systems, thus compact UWB BPFs with multiple notched bands are emergently required to reject these interfering signals [11–21]. To achieve a notched band, a pair of radial impedance resonators are used in [11], and a stepped impedance resonator is employed in [12, 13]. On the other side, the embedding open-circuited stub is introduced in [14–16], and the wave's cancellation theory is proposed in [17, 18] to block unwanted existing radio signals. However, these methods can only achieve one notched band. Thus, a coupled simplified composite right/left-handed resonator is used in [19], and a novel E-shaped resonator [20, 21] to get two notched bands. However, these two designed methods are all that dual-mode resonator is coupled to the main transmission line of the initial UWB BPF to achieve dual notched bands. Additionally, double open-circuit stubs are embedded into broadside-coupled stepped impedance resonators on middle layer in [22], and folded stepped impedance resonators are vertically-coupled to the second layer in [23], two notched bands can also be introduced into an UWB BPF. However, they are based on a multilayer structure and hardly compatible with the existing microwave-integrated circuit.

In this paper, we present a new microstrip ultra-wideband (UWB) bandpass filter (BPF) with dual sharply rejected notched bands based on E-shaped resonator is proposed in this paper. The

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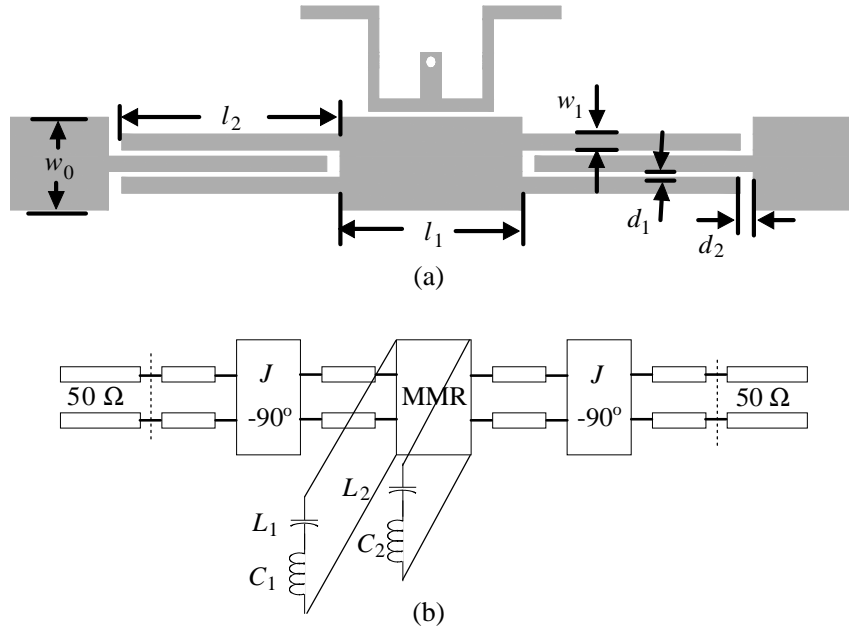
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design procedures are as following: the basic microstrip UWB BPF is designed using two microstrip interdigital coupled lines and one rectangular patch multiple-mode resonator (MMR). Then, two band-notched performance are achieved by coupling the dual-mode E-shaped resonator to the rectangular patch multiple-mode resonator of the basic UWB BPF. The dual-notched bands can be easily generated and realized by controlling the locations of even-odd modes resonance frequency of the dual-mode stepped impedance resonator. Finally, the proposed filter is designed, fabricated and measured. Good agreement between measured and simulated results is achieved.

## 2. DESIGN OF UWB BPF WITH NOTCHED BANDS

Figure 1 shows the layout and equivalent circuit network of the designed UWB BPF with dual sharply rejected notched bands. Figure 1(a) comprises of two microstrip interdigital coupled lines and one rectangular patch multiple-mode resonator (MMR) embedded an E-shaped resonator. By forming quarter-wavelength parallel coupled lines and employing a rectangular patch MMR in the input and output ports, six transmission poles are introduced in the UWB passband to help the constituted filter achieve deeper rejection skirts and wider bandwidths. The equivalent circuit network of the proposed filter is shown in Figure 1(b). The interdigital coupled lines can be equaled as two single transmission lines at two sides and a  $J$ -inverter susceptance in the middle. The E-shaped resonator coupled to the rectangular patch MMR section of the basic UWB BPF can be modeled as two shunt series resonant branches.



**Figure 1.** Layout and equivalent circuit network of the UWB BPF with dual notched bands. (a) Layout. (b) Equivalent circuit network.

To realize band-notched characteristics, we introduce an E-shaped resonator into the basic UWB BPF. It should be mentioned that the E-shaped resonator can be equivalent to two shunt-connected series resonance circuit when placed next to the microstrip line, i.e., it can result in dual band-notched performance. This structure is simple and flexible for blocking undesired narrow band radio signals that may appear in UWB band. The introduced E-shaped resonator is composed of a stepped impedance hairpin resonator with centrally loaded a short-ended stub. Figure 2 shows the layout of the E-shaped resonator coupled to the microstrip line and its corresponding equivalent circuit. Since the E-shaped structure is symmetrical to the  $A-A'$  plane, the resonance properties of E-shaped resonator can be analyzed by the even-odd modes analysis method. Under mode excitation, the resonator electrical field

distribution of the resonator exhibits either an even or an odd mode distribution property as shown in Figure 3. For the odd mode condition, the electrical fields exhibit an anti-symmetric distribution along the  $A-A'$  axis and there is no electrical field on the short-end stub as shown in Figure 3(a). While for the even mode, the electrical fields exhibit a symmetric distribution along the  $A-A'$  axis and the electrical fields distribute on both the open-end and the short-end stubs of the resonator as shown in Figure 3(b). Thus, based on the electrical field distribution property, the even-odd modes resonance

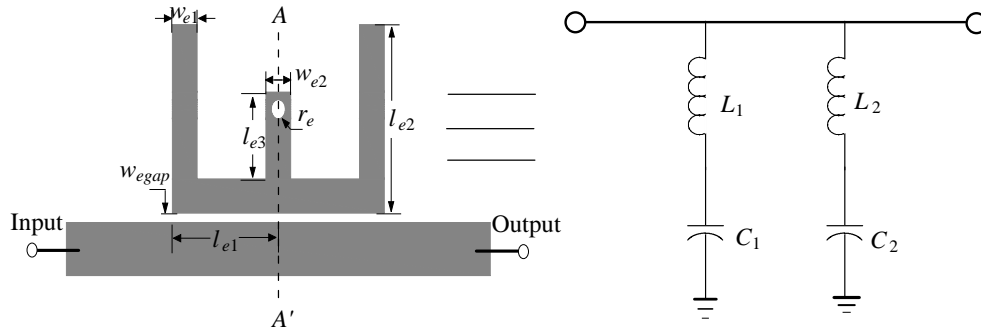


Figure 2. Layout and equivalent circuit of the coupled E-shaped resonator.

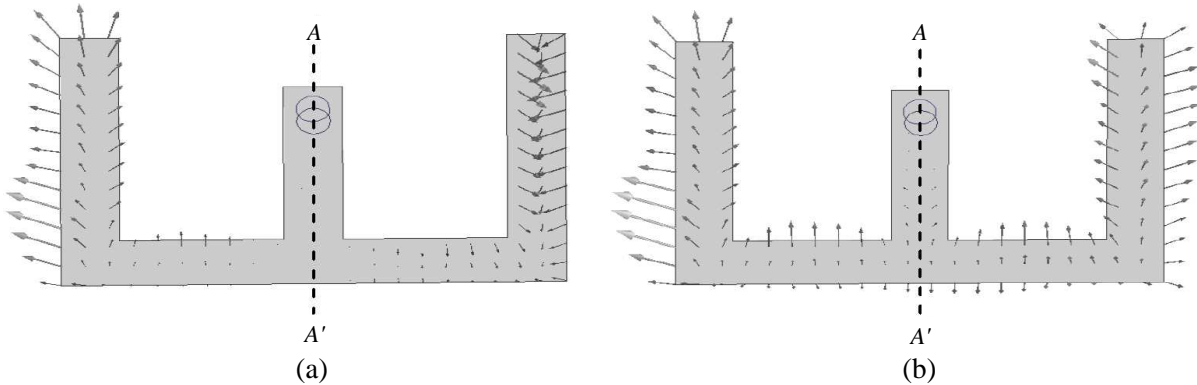


Figure 3. Electrical field distribution of the E-shaped resonator. (a) Odd mode. (b) Even mode.

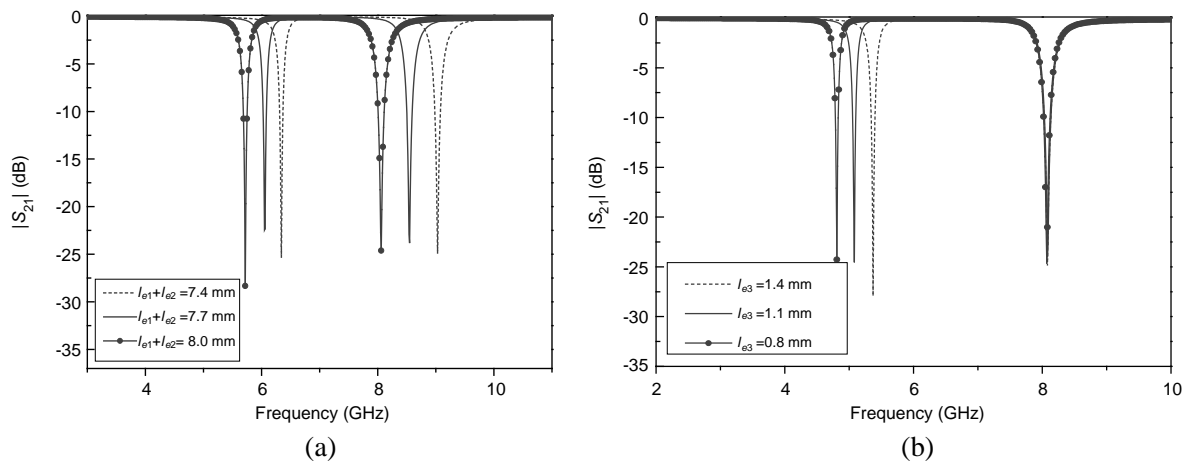


Figure 4. Simulated  $S$ -parameters of the coupled E-shaped resonator for various dimensions. (a)  $l_{e1} + l_{e2}$ . (b)  $l_{e3}$ .

frequencies can be expressed as:

$$f_{\text{notch-even}} = \frac{c}{\lambda_{\text{notch-even}}\sqrt{\varepsilon_{\text{eff}}}} = \frac{c}{4(l_{e1} + l_{e2} + l_{e3})\sqrt{\varepsilon_{\text{eff}}}} \quad (1)$$

$$f_{\text{notch-odd}} = \frac{c}{\lambda_{\text{notch-odd}}\sqrt{\varepsilon_{\text{eff}}}} = \frac{c}{4(l_{e1} + l_{e2})\sqrt{\varepsilon_{\text{eff}}}} \quad (2)$$

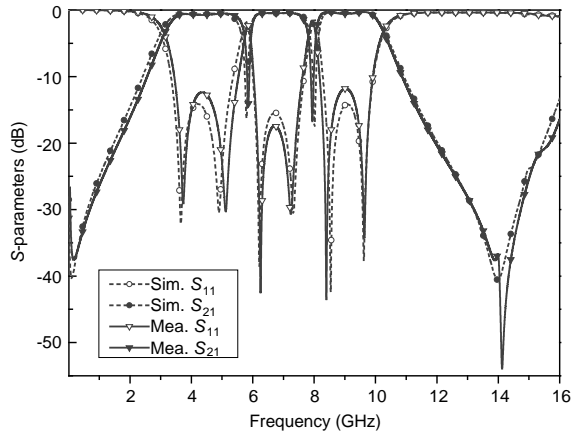
where  $\lambda_{\text{notch}}$  is the wavelength of the center frequency of the notched band,  $f_{\text{notch}}$  is the center frequency of the notched band,  $\varepsilon_{\text{eff}}$  is the effective dielectric constant, and  $c$  is the light speed in free space.

The frequency characteristics of the coupled E-shaped resonator with various dimensions are investigated to validate the dual-mode resonant property as shown in Figure 4. It can be seen that the frequency locations of the two notch-bands move down simultaneously as increase the dimensions of  $l_{e1}$ ,  $l_{e2}$ . This is because the electrical fields distribute on these two areas for both the even and the odd modes. When we decrease  $l_{e3}$ , only the frequency location of lower notch-band moves up. This is because there is no electrical fields distribute on the area of  $l_{e3}$  for the odd mode. Therefore, by appropriately adjusting the resonator dimensions, dual notched bands can be achieved at desired frequencies.

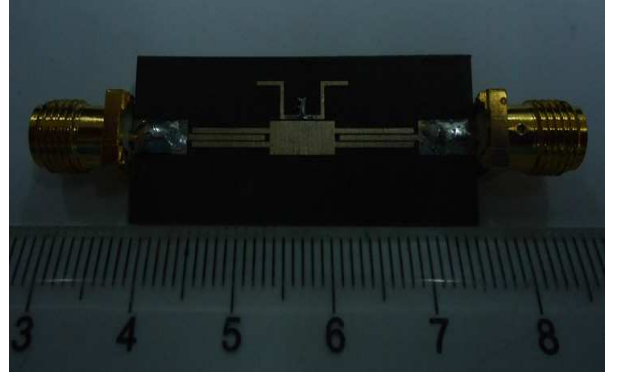
### 3. EXPERIMENTAL RESULTS

The UWB BPF has been designed on substrate Rogers RT/duroid 5880 with a dielectric constant of 2.2, thickness of 1.0 mm, and loss tangent of 0.0009. The structural parameters for the optimal UWB BPF circuit are selected as follows: (as illustrated in Figures 1 and 2):  $l_1 = 7.0$  mm,  $l_2 = 8.4$  mm,  $w_0 = 3.0$  mm,  $w_1 = 0.5$  mm,  $d_1 = 0.1$  mm,  $d_2 = 0.5$  mm,  $l_{e1} = 2.4$  mm,  $l_{e2} = 5.6$  mm,  $l_{e3} = 1.5$  mm,  $w_{e1} = 0.4$  mm,  $w_{e2} = 0.8$  mm,  $w_{\text{egap}} = 0.1$  mm, and  $r_e = 0.2$  mm.

Finally, the fabricated UWB BPF is measured with an Agilent N5244A vector network analyzer. Simulated and measured scattering parameters are described in Figure 5 with good agreement. Referring to Figure 5, the fabricated UWB BPF has a passband from 3.0 to 10.3 GHz and the upper-stopband with  $-10$  dB attenuation is up to 16 GHz. The return loss is under  $-15$  dB over most part of the passband. For the two highly rejected notched bands, the measured results show that a better 15 dB insertion loss at 5.8 and 8.0 GHz with the respective 3 dB FBW of 5.9% and 4.2% are achieved. It should be mentioned that the UWB BPF is built up with good insertion loss and return loss for achieving additional six transmission poles in the entire passband. The deviations of the measurements from the simulations are expected mainly due to the reflections from the connectors and the finite substrate. Figure 6 shows the photograph of the fabricated UWB BPF with dual sharply rejected notched bands. The overall size is about  $34 \times 14$  mm<sup>2</sup>.



**Figure 5.** Simulated and measured  $S$ -parameters of the designed UWB BPF with dual notched bands.



**Figure 6.** Photograph of the fabricated UWB BPF with dual notched bands.

#### 4. CONCLUSION

A new microstrip UWB BPF with dual highly rejected notched bands has been proposed in this letter. The basic UWB BPF is designed using two microstrip interdigital coupled lines and one rectangular patch MMR. Then, dual-mode E-shaped resonator is investigated and coupled to the rectangular patch multiple-mode resonator of the basic UWB BPF to achieved two notched bands. The two notched bands can be easily generated and realized by controlling the even-odd modes frequency locations of the E-shaped resonator. For demonstration, a microstrip UWB BPF is designed, simulated, and measured. Good agreement between the predicted and measured results is obtained. Therefore, the proposed filter is very useful for modern UWB wireless communication systems owing to its marked properties of simple topology, compact size, and excellent performance.

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#### REFERENCES

1. FCC, "Revision of Part 15, the Commission's rules regarding to ultra-wide-band transmission system," First Note and Order Federal Communication Commission, ET-Docket 98-153, 2002.
2. Zhu, H. and Q.-X. Chu, "Compact ultra-wideband (UWB) bandpass filter using dual-stub-loaded resonator (DSLRL)," *IEEE Microw. Wireless Compon. Lett.*, Vol. 23, No. 10, 572-579, 2013.
3. Qiang, L., Y.-J. Zhao, Q. Sun, W. Zhao, and B. Liu, "A compact UWB HMSIW bandpass filter based on complementary split-ring resonators," *Progress In Electromagnetics Research*, Vol. 11, 237-243, 2009.
4. Fallahzadeh, S. and M. Tayarani, "A new microstrip UWB bandpass filter using defected microstrip structures," *Journal of Electromagnetic Waves and Applications*, Vol. 4, No. 7, 893-902, 2010.
5. Shobeyri, M. and M.-H. Vadjed-Samiei, "Compact ultra-wideband bandpass filter with defected ground structure," *Progress In Electromagnetics Research*, Vol. 4, 25-31, 2008.
6. Naghshvarian-Jahromi, M. and M. Tayarani, "Miniature planar UWB bandpass filters with circular slots in ground," *Progress In Electromagnetics Research*, Vol. 3, 87-93, 2008.
7. Packiaraj, D., K.-J. Vinoy, and A.-T. Kalghatgi, "Analysis and design of two layered ultra wide band filter," *Journal of Electromagnetic Waves and Applications*, Vol. 23, Nos. 8-9, 1235-1243, 2009.
8. Wang, H., L. Zhu, and W. Menzel, "Ultra-wideband bandpass filter with hybrid microstrip/CPW structure," *IEEE Microw. Wireless Compon. Lett.*, Vol. 15, No. 12, 844-846, 2005.
9. Comez-Garcia, R. and J.-I. Alonso, "Systematic method for the exact synthesis of ultra-wideband filtering responses using high-pass and low-pass sections," *IEEE Trans. Microw. Theory Tech.*, Vol. 54, No. 10, 3751-3764, 2006.
10. Hao, Z.-C. and J.-S. Hong, "UWB bandpass filter using cascaded miniature high-pass and low-pass filters with multilayer liquid crystal polymer technology," *IEEE Trans. Microw. Theory Tech.*, Vol. 58, No. 4, 941-948, 2010.
11. Xu, J., W. Wu, W. Kang, and C. Miao, "Compact UWB bandpass filter with a notched band using radial stub loaded resonator," *IEEE Microw. Wireless Compon. Lett.*, Vol. 22, No. 7, 351-353, 2012.

12. Liu, C.-Y., T. Jiang, and Y.-S. Li, "A novel UWB filter with notch-band characteristic using radial-UIR/SIR loaded stub resonators," *Journal of Electromagnetic Waves and Applications*, Vol. 25, Nos. 2–3, 233–245, 2011.
13. Ghatak, R., P. Sarkar, R.-K. Mishra, and D.-R. Poddar, "A compact UWB bandpass filter with embedded SIR as band notch structure," *IEEE Microw. Wireless Compon. Lett.*, Vol. 21, No. 5, 261–263, May 2011.
14. Li, Q., C. H. Liang, W. Zhang, and W. F. Xu, "Novel compact UWB bandpass filter with notched band," *Microw. Opt. Technol. Lett.*, Vol. 52, No. 2, 280–283, 2010.
15. 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.
16. Wang, K., S. W. Wong, and Q. X. Chu, "A compact UWB bandpass filter with short-ended H-shaped resonator and controllable notched band," *Microw. Opt. Technol. Lett.*, Vol. 55, No. 7, 1577–1581, 2013.
17. Wong, S.-W. and L. Zhu, "Implementation of compact UWB bandpass filter with a notch-band," *IEEE Microw. Wireless Compon. Lett.*, Vol. 18, No. 1, 10–12, 2008.
18. Nosrati, M. and M. Daneshmand, "Compact microstrip ultra-wideband double/single notch-band band-pass filter based on wave's cancellation theory," *IET Microw. Antennas Propag.*, Vol. 8, No. 6, 862–868, 2012.
19. Wei, F., Q.-Y. Wu, X.-W. Shi, and L. Chen, "Compact UWB bandpass filter with dual notched bands based on SCRLH resonator," *IEEE Microw. Wireless Compon. Lett.*, Vol. 21, No. 1, 28–30, 2011.
20. Zhao, J.-D., J.-P. Wang, G. Zhang, and J.-L. Lin, "Compact UWB bandpass filter with dual notched bands using E-shaped resonator," *IEEE Microw. Wireless Compon. Lett.*, Vol. 23, No. 12, 638–640, 2013.
21. Zhao, J.-D., J.-P. Wang, and J.-L. Lin, "Design of UWB bandpass filter with dual notched bands based on E-shaped resonator," *IEEE MTT-S International Microwave Workshop Series*, Singapore, 2013.
22. Hao, Z.-C., J.-S. Hong, S. K. Alotaibi, J. P. Parry, and D. P. Hand, "Ultra-wideband bandpass filter with multiple notch-bands on multilayer liquid crystal polymer substrate," *IET Microw. Antennas Propag.*, Vol. 3, No. 5, 749–756, 2009.
23. Hao, Z.-C. and J. S. Hong, "Compact UWB filter with double notch-bands using multilayer LCP technology," *IEEE Microw. Wireless Compon. Lett.*, Vol. 19, No. 8, 500–502, 2009.