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COMPACT DUAL-PASSBAND FILTER USING SPIRAL RESONATORS

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Abstract—A novel compact dual-band bandpass filter using spiral resonators and input/output (source-load) direct coupling structure has been presented. Two different transmission paths are utilized to realize independently controllable central frequencies and bandwidths for each passband. In addition, three transmission zeros has been introduced to improve the frequency selectivity. A dual-passband filter centered at 2.41 GHz and 4.22 GHz is designed, simulated, and fabricated to demonstrate the performance of the proposed filter structure. The measured results show good agreement with the simulated ones.

1. INTRODUCTION

Filter is one of the key passive components in microwave communication systems and various kinds of structures have been proposed by previous researchers [1–13]. In [1–3], narrow band bandpass filters with wide upper stopband were proposed. In [4–6], some bandstop filters have been designed for signal suppression. The electric controllable filters are also popular. A switchable bandpass filter is proposed in [7]. By changing the status of the PIN diodes, the filter is switched from a single band bandpass filter to a dual-band bandpass filter. Moreover, dual-mode resonators such as stepped-impedance resonators (SIRs) and stub-loaded technique were utilized to generate two passbands [8–11].

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With the rapid development of dual- and multi-band wireless communication systems, dual-band filters are paid more and more attentions, which should be compact, low loss, and compatible with systems in package. Then, various of dual-band filters have been presented [12–22]. A dual-band filter was constructed by cascading two individual filters with two specified single passbands in [12], while a dual-band filter was constructed by cascading a wideband bandpass filter and a narrowband bandstop filter [13]. They may suffer from high insertion loss and large size. The source-load cross coupling is utilized in [14] to design a dual-band bandpass filter with good frequency selectivity, but since the structure is based on cascaded triplet (CT) unit, the final design suffers from large size. Moreover, the dual-mode resonators, such as stepped-impedance resonators (SIRs) and stub-loaded technique, are applied to introduce two passbands [15–19]. However, it is difficult to tune their passband bandwidths. Recently, the dual-band filters with controllable bandwidths have been studied [20, 21]. However, these dual-band filters have limited controllable bandwidth. The coplanar waveguide is also involved [22], combined with the microstrip split ring resonator, the authors constructed a dual-band bandpass filter the good out-of-band suppression, unfortunately only one transmission zero is generated. In [1], the author concentrated on stopband extension, though a deep wide stopband is realized, the frequency selectivity of the filter is not good.

In this paper, a compact dual-passband filter based on spiral resonators is presented. The source-load cross coupling structure is applied to realize the upper passband and improve the frequency selectivity. The presented dual-passband filter is designed, fabricated, and measured. The measured results validate the good performance of the fabricated dual-passband filter.

2. DESIGN OF DUAL-PASSBAND FILTER

The configuration of the dual-band bandpass filter is shown in Fig. 1. The presented dual-passband filter consists of two sets of half-wavelength spiral resonators and two input/output microstrip asymmetric parallel-coupled feed lines. Obviously, the presented filter has compact size because of the compact spiral resonators. In addition, the source-load cross coupling is implemented by the input/output feed lines. Then, the compact spiral resonators can be applied to generate the lower passband with the center frequency f_1, while the input/output direct coupling feed lines can be utilized to implement the upper passband operating at center frequency f_2.

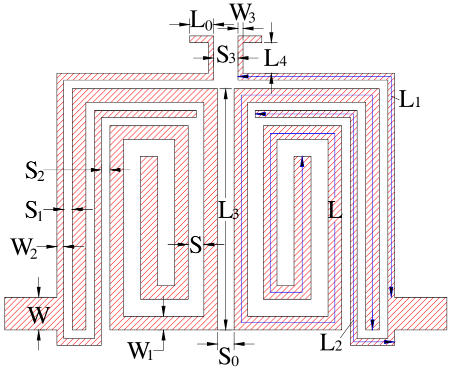
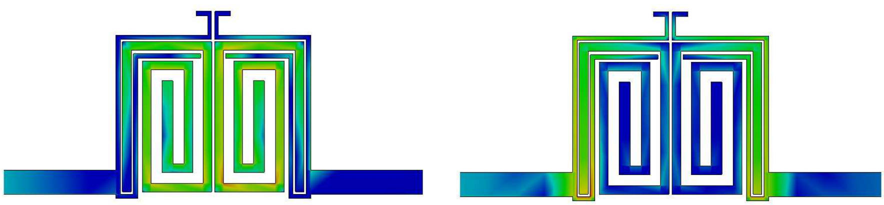


Figure 1. Configuration of the presented dual-passband filter.



(a) (b)

Figure 2. Current distribution, (a) at lower resonant frequency and (b) at upper resonant frequency.

Moreover, asymmetric parallel coupled feed lines can generate a transmission zero [23] and the transmission zero can be determined by the dimensions of the asymmetric parallel-coupled feed lines. In addition, the source-load cross coupling is implemented by using the input/output direct coupling feed lines, which can also generate two additional transmission zeros [24–27]. Then, three transmission zeros can generate and can be placed at the desired frequencies. The frequency selectivity and the out-of-band performance can be improved greatly after appropriate design of the three transmission zeros.

Figure 2 shows the simulated current distributions at lower and upper resonant frequencies. As shown in Fig. 2(a), the spiral resonators generate a RF signal path from source to load at the lower passband. In this case, the input/output direct coupling feed lines do not result in the lower-passband frequency response and can be ignored. The input/output direct coupling feed lines can provide another RF signal path from source to load at the upper passband, as shown in Fig. 2(b).

In this case, the two spiral resonators don't affect the upper-passband frequency response and can be neglected due to little contribution to the upper passband.

The operating bandwidth of the lower passband is mainly controlled by the coupling gaps S_0 and S_1 [3], as shown in Fig. 1. Meanwhile, the bandwidth of the upper passband is determined by the dimensions (S_2, L_4, W_3) of the input/output direct coupling structure. The length (L) of the spiral resonator is chosen to half wavelength of the center frequency of low passband, while the dimensions (L_0, L_1, L_2, W_2) of the asymmetric parallel coupled feed line can be determined according to [23]. In addition, the performance of the lower passband is almost independent with that of the upper passband. According to above analysis and design method, the initial dimensions of the presented dual-passband filter can be obtained. Then, the electromagnetic (EM) simulation tools (such as IE3D, HFSS, CST, etc.) can be used for simulations and optimizations of the designed dual-passband filter. Fig. 3 shows the simulated S_{21} comparison between the presented dual-passband filter in this paper and the bandpass filter in reference [3]. It can be seen that the low-passband frequency response of the presented dual-passband filter is almost the same as the bandpass-filtering frequency response in [3]. However, the frequency response between them is further different at more than 3 GHz, as shown in Fig. 3. The filter in [3] has a wide stopband from 3 to about 10 GHz, while the dual-passband filter in this paper has an upper passband and spurious bands over the same frequency range.

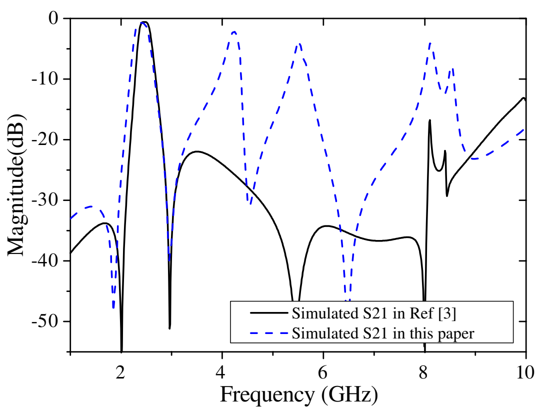


Figure 3. Simulated S_{21} comparison between the presented dual-passband filter in this paper and the bandpass filter in reference [3].

3. FABRICATION AND EXPERIMENT RESULTS

According to the above analysis and design method, a compact dual-passband filter using spiral resonators was designed. The EM simulations and optimizations about the dual-passband filter were performed by using a commercially available tool (IE3D). The dual-passband filter has been fabricated on a substrate Taconic RF-35 with a dielectric constant of 3.5 and a thickness of 0.508 mm by using print-circuit-board (PCB) technique. The fabricated dual-passband filter is shown in Fig. 4. Although a low dielectric constant has been used, the filter is extremely compact with a size of 8.8 mm × 8.6 mm. The dimensions for the dual-passband filter circuit are (as illustrated in Fig. 1): $L = 36.75\,\text{mm}$, $L_0 = 0.7\,\text{mm}$, $L_1 = 10.35\,\text{mm}$, $L_2 = 10.3\,\text{mm}$, $L_3 = 6.9\,\text{mm}$, $L_4 = 0.9\,\text{mm}$, $W = 1.1\,\text{mm}$, $W_1 = 0.4\,\text{mm}$, $W_2 = 0.2\,\text{mm}$, $W_3 = 0.15\,\text{mm}$, $S = 0.46\,\text{mm}$, $S_0 = 0.14\,\text{mm}$, $S_1 = 0.1\,\text{mm}$, $S_2 = 0.2\,\text{mm}$, $S_3 = 0.17\,\text{mm}$.

Figure 5 demonstrates the S-parameters of the fabricated dual-passband filter. It can be seen that the simulated and measured results are in reasonable agreement with each other. As can be observed, two passbands centered at 2.41 GHz and 4.22 GHz are realized. The measured return loss of the lower passband is about 20 dB, while that of the upper passband is more than 15 dB. The measured minimum insertion loss within the lower passband is about 0.8 dB, while the measured 3-dB insertion loss bandwidth of the lower passband is 300 MHz. Moreover, the measured minimum insertion loss within the upper passband is about 2.3 dB, while the measured 3-dB insertion loss bandwidth of the upper passband is about 300 MHz. The three transmission zeros are located at 1.9, 3, and 4.55 GHz. The measured insertion losses include the loss of SMA connectors, which is about 1 dB.

Figure 4. Photograph of the fabricated dual-passband filter.

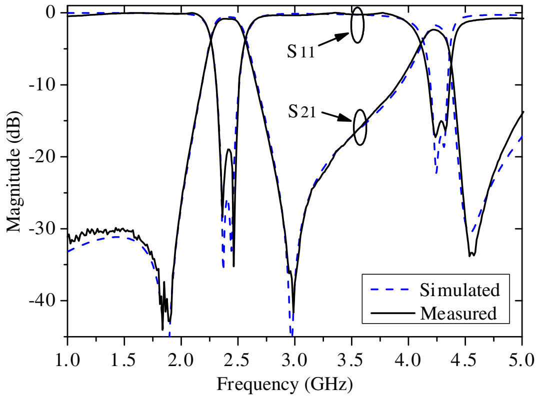


Figure 5. Simulated and measured frequency response of the fabricated dual-passband filter.

4. CONCLUSION

A novel compact dual-passband filter is presented. The presented filter is constructed by using the spiral resonators and input/output direct coupling structure. The proposed dual-passband filter has been designed, fabricated, and measured. The measured results demonstrate the reasonable performance of the fabricated dual-passband filter.

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REFERENCES

1. Kuo, J.-T., C.-Y. Fan, and S.-C. Tang, "Dual-wideband bandpass filters with extended stopband based on coupled-line and coupled three-line resonators," *Progress In Electromagnetics Research*, Vol. 124, 1–15, 2012.
2. Yang, R.-Y., C.-M. Hsiung, C.-Y. Hung, and C.-C. Lin, "A high performance bandpass filter with a wide and deep stopband

by using square stepped impedance resonators," *Journal of Electromagnetic Waves and Applications,* Vol. 24, Nos. 11–12, 1673–1683, 2010.

3. Ma, L., K. Song, C. ZhuGe, and Y. Fan, "Compact bandpass filter with wide upper-stopband based on spiral-shaped resonators and spur-lines," *Progress In Electromagnetics Research Letters,* Vol. 29, 87–95, 2012.
4. Chen, H., Y.-H. Wu, Y.-M. Yang, and Y.-X. Zhang, "A novel and compact bandstop filter with folded microstrip/CPW hybrid structure," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 1, 103–112, 2010.
5. Fallahzadeh, S., H. Bahrami, and M. Tayarania, "Very compact bandstop waveguide filters using split-ring resonators and perturbed quarter-wave transformers," *Journal of Electromagnetic Waves and Applications*, Vol. 30, No. 5, 482–490, 2010.
6. Xiao, J.-K. and X.-P. Zu, "Multi-mode bandstop filter using defected equilateral triangular patch resonator," *Journal of Electromagnetic Waves and Applications*, Vol. 25, No. 4, 507–518, 2011.
7. Abu-Hudrouss, A. M. and M. J. Lancaster, "Design of multiple-band microwave filters using cascaded filter elements," *Journal of Electromagnetic Waves and Applications,* Vol. 23, No. 16, 2109–2118, 2009.
8. Weng, M. H., C. H. Kao, and Y. C. Chang, "A compact dual-band bandpass filter with high band selectivity using cross-coupled asymmetric SIRs for WLANs," *Journal of Electromagnetic Waves and Applications*, Vol. 24, Nos. 2–3, 161–168, 2010.
9. Weng, M.-H., S.-K. Liu, H.-W. Wu, and C.-H. Hung, "A dual-band bandpass filter having wide and narrow bands simultaneously using multilayered stepped impedance resonators," *Progress In Electromagnetic Research Letters*, Vol. 13, 139–147, 2010.
10. Velazquez-Ahumada, M. D. C., J. Martel-Villagr, F. Medina, and F. Mesa, "Application of stub loaded folded stepped impedance resonators to dual band filter design," *Progress In Electromagnetic Research*, Vol. 102, 107–124, 2010.
11. Ma, D., Z. Y. Xiao, L. Xiang, X. Wu, C. Huang, and X. Kou, "Compact dual-band bandpass filter using folded SIR with two stubs for WLAN," *Progress In Electromagnetic Research*, Vol. 117, 357–364, 2011.
12. Miyake, H., S. Kitazawa, T. Ishizaki, T. Yamada, and Y. Nagatom, "A miniaturized monolithic dual band filter using

ceramic lamination technique for dual mode portable telephones," *IEEE MTT-S Int. Microw. Symp. Dig.*, 789–792, 1997.
13. Zhang, X. Y., J.-X. Chen, J. Shi, and Q. Xue, "Dual-band bandpass filter design using a novel feed scheme," *IEEE Microwave and Wireless Components Letters*, Vol. 19, No. 6, 350–352, 2009.
14. Chen, F.-C. and Q.-X. Chu, "Design of dual-band CT filter with sourceload coupling," *Journal of Electromagnetic Waves and Applications,* Vol. 25, No. 1, 15–22, 2011.
15. Chen, F. and Q.-X. Chu, "A compact dual-band bandpass filter using meandering stepped impedance resonators," *IEEE Microwave and Wireless Components Letters*, Vol. 18, No. 5, 320–322, 2008.
16. Chen, C.-F., T.-Y. Huang, and R.-B. Wu, "Design of dual- and triple-passband filters using alternately cascaded multiband resonators," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 54, No. 9, 3550–3558, 2006.
17. Deng, H.-W., Y.-J. Zhao, X.-S. Zhang, W. Chen, and J.-K. Wang, "Compact and high selectivity dual-band dual-mode microstrip BPF with single stepped-impedance resonator," *Electron. Lett.*, Vol. 47, No. 5, 326–327, 2011.
18. Wei, S. C. and Y. C. Chi, "Analytical design of microstrip short-circuit terminated stepped-impedance resonator dual-band filters," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 59, No. 7, 1730–1739, 2011.
19. Shi, J. and Q. Xue, "Novel balanced dual-band bandpass filter using coupled stepped-impedance resonators," *IEEE Microwave and Wireless Components Letters*, Vol. 20, No. 1, 19–21, 2010.
20. Lin, T.-W., U.-H. Lok, and J.-T. Kou, "New dual-mode dual-band bandpass filter with quasi-elliptic function passbands and controllable bandwidths," *IEEE MTT-S Int. Microw. Symp. Dig.*, 576–579, 2010.
21. Wu, X.-H., Q.-X. Chu, and L. Fan, "Compact dual-band bandpass filter with controllable bandwidths," *Proc. Int. Conf. Microwave and Millimeter Wave Technology*, 1305–1307, 2010.
22. Lin, H. J., X. W. Shi, X. Q. Chen, X. H. Wang, and Y. F. Bai, "Dual passband filter using hybrid microstrip split ring resonators and coplanar waveguide quarter wavelength resonators," *Journal of Electromagnetic Waves and Applications,* Vol. 25, No. 1, 39–48, 2011.
23. Shaman, H. and J. S. Hong, "Asymmetric parallel-coupled lines

for notch implementation in UWB filters," *IEEE Microwave and Wireless Components Letters*, Vol. 17, No. 3, 516–518, Jul. 2007.

24. Song, K. and Q. Xue, "Novel broadband bandpass filters using Y-shaped dual-mode microstrip resonators," *IEEE Microwave and Wireless Components Letters*, Vol. 19, No. 9, 548–550, 2009.
25. Shaman, H. and J.-S. Hong, "Input and output cross-coupled wideband bandpass filter," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 55, No. 12, 2562–2568, 2007.
26. Ma, K.-X., J.-G. Ma, M. A. Do, and K. S. Yeo, "Compact two-order bandpass filter with three finite zero points," *Electron. Lett.*, Vol. 41, No. 15, 846–848, 2005.
27. Jianxin, C., Y. Mengxia, X. Jun, and X. Quan, "Compact microstrip bandpass filter with two transmission zeros," *Electron. Lett.*, Vol. 40, No. 5, 311–313, 2004.