Progress In Electromagnetics Research Letters, Vol. 67, 47–51, 2017

Design of Asymmetric Dual-Band Microwave Filters

Zhongxiang Zhang[1, 2, *], Jun Ding[3], Shuo Wang[2], and Hua-Liang Zhang[3]

Abstract—This paper presents the design and implementation of dual-band filters. The proposed method works well for dual-band filters with asymmetric dual-passband, high selectivity, and pre-assigned in-band return loss levels (e.g., equal or un-equal at two frequency bands). To verify the design concept, a prototype dual-band filter using combline coaxial cavity-type resonators was designed, fabricated and tested. Good agreement has been achieved among the theoretical synthesis results, simulation results and measurement results.

1. INTRODUCTION

Microwave filters play important roles in high-frequency systems such as wireless communication systems, radar systems, and satellite systems. Recent rapid development in these fields has imposed stringent requirements for microwave filters. Especially, due to the proliferation of high-frequency systems operating at different frequency bands, it is highly desired to realize dual-band microwave filters with flexible in-band and out-of-band responses.

Up to now, most of existing dual-band filters are based on the conventional microstrip technology [1–15]. Due to the low-Q of the microstrip resonator, the insertion loss of resulting filters is high. Also an effective synthesis method is missing in these prior work. To address this issue, there are a few attempts which investigated the synthesis of dual-band microwave filters [16–20]. In [16, 17], frequency transformation techniques are applied to synthesize dual-band filters. However, the resulting dual-band filters cannot support asymmetric dual-passbands. In [18], asymmetric dual-band microwave filters are designed, where optimizations are needed to synthesize the filter prototype. In [19], an analytical method is proposed to synthesize asymmetric dual-band filters. But the in-band return-loss levels of designed filters are not equal at the two passbands. Another analytical method is presented in [20] to design asymmetrical dual-band filters. Even though it can achieve asymmetric dual-band filters with equal in-band return loss levels, it still suffers from limitations on transmission zero locations and other issues such as the interference among multiple passbands during the synthesis process.

To address these issues, a semi-analytical method is applied in this paper to design asymmetrical dual-band filters with equal in-band return loss levels. To verify the proposed method, a prototype filter working at around 887 and 932 MHz is synthesized. It is then implemented using combline coaxial-cavity resonators and experimentally characterized.

Received 5 February 2017, Accepted 31 March 2017, Scheduled 10 April 2017
* Corresponding author: Zhongxiang Zhang (zhzhx@mail.ustc.edu.cn).
[1] School of Electronic and Information Engineering, Hefei Normal University, Hefei, Anhui 230601, China. [2] Key Laboratory of Polarization Imaging Detection Technology Anhui Province, Hefei 230031, China. [3] Department of Electrical and Computer Engineering, University of Massachusetts Lowell, Lowell, MA 01854, USA.

2. DUAL-BAND FILTER SYNTHESIS

Assuming the designed dual-band filter has N resonators, its S-parameters can be expressed as:

$$S_{11}(\omega) = \frac{F_N(\omega)/\varepsilon_R}{E_N(\omega)} \tag{1}$$

$$S_{21}(\omega) = \frac{P_N(\omega)/\varepsilon}{E_N(\omega)} \tag{2}$$

where ω is the real frequency variable, and ε is related to the return loss level, $\varepsilon_R = 1$ or $\varepsilon_R = \frac{\varepsilon}{\sqrt{\varepsilon^2-1}}$ if the designed filter is fully canonical, and:

$$F(s) = \prod_{i=1}^{N} (s - jp_i) \tag{3}$$

$$P(s) = \prod_{k=1}^{N} (s - jz_k) \tag{4}$$

where p_i and z_k denote the poles and zeros of the filtering function, $s = j\omega$, and $E(s)$ is obtained by taking the roots of $\varepsilon_R P(s) + \varepsilon F(s)$ and mapping right half plane roots to the left half plane.

During the synthesis process, the analytical procedure described in [19] is initially applied to calculate the filter function. Typically, the return loss levels at the two passbands will be un-equal. To address this issue, the following techniques have been proposed. First, the positions of the transmission zeros (e.g., z_k) will be adjusted. Specifically, pushing the transmission zero towards the passband will lead to a smaller in-band return loss and vice versa. Therefore, depending on the return loss levels obtained during the initial phase of the synthesis (larger or smaller than the desired return loss levels), the transmission zeros can be correspondingly moved (towards or away from the passband) to tune the in-band return loss levels. Second, additional transmission zeros can be assigned to further tune the in-band return loss levels. Typically, more finite transmission zeros will lead to a smaller in-band return loss. By combining these two techniques and after some optimizations, we can effectively achieve equal return loss levels at the two passbands, as well as maintain the desired out-of-band rejection levels (i.e., selectivity).

3. PROTOTYPE DESIGN

To demonstrate the effectiveness of the proposed design method, an asymmetric dual-band microwave filter with equal in-band return loss levels and good out-of-band rejection levels is synthesized. Without loss of the generality, it follows the following arbitrarily chosen specifications:

- Band 1 (Passband: 885 $\sim$ 889 MHz)
  In-band return loss level: 21 dB
  Number of poles: 5
- Band 2 (Passband: 930 $\sim$ 934 MHz)
  In-band return loss level: 21 dB
  Number of poles: 7
- Out-of-band rejection levels
  20 dB @ 880 MHz
  40 dB @ 915 MHz
  40 dB @ 935 MHz

The synthesis results of the designed dual-band filter are plotted in Fig. 1. As desired, the first band has 5 poles and the second band has 7 poles. Four finite transmission zeros at 893.5 MHz, 900.5 MHz, 926.9 MHz, and 935 MHz are asymmetrically allocated near the two passbands to achieve the required out-of-band rejections. Most importantly, it is observed that even though the frequency response of the synthesized filter is not symmetric about the central frequency of the two passbands, the return loss levels at the two passbands are both 21 dB.

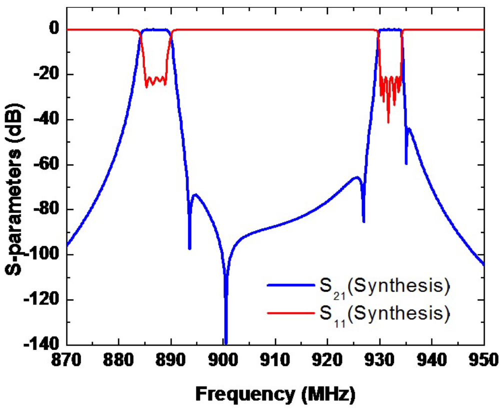

Figure 1. The synthesized performance of the dual-band filter.

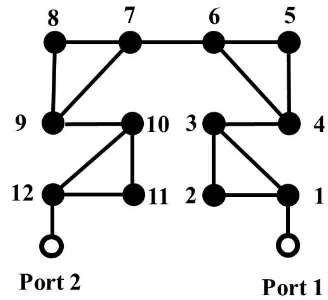

Figure 2. The general topology of the designed dual-band filter.

Next, based on the synthesis results, a prototype dual-band filter is designed. Its general topology is shown in Fig. 2 with 12 resonators, where the solid black circles represent resonators.

By applying the general parameter conversion equations presented in [21] and following the topology in Fig. 2, the key design parameters (including the coupling coefficients between resonators ($k_{i,j}$), the external Q at the input and output ports, and the resonant frequencies of resonators) of the designed filter are calculated and listed as follows:

- Main path coupling coefficients ($k_{1,2}, \ldots, k_{11,12}$):
  [0.04233, −0.02044, 0.01175, 0.02871, 0.0036, 0.04918, 0.00214, −0.01822, 0.01538, 0.01856, 0.03542]
- Cross-coupling coefficients:
  $k_{1,3} = 0.0251$, $k_{4,6} = 0.0052$, $k_{7,9} = 0.0066$, $k_{10,12} = 0.03218$
- External Q:
  $Q_1 = 87.04$, $Q_2 = 82.26$.
- Resonant frequency of each resonator (MHz):
  [905.64, 909.07, 892.11, 926.95, 891.57, 908.79, 909.69, 929.61, 890.02, 922.51, 925.52, 901.98]

From the above parameters, the designed dual-band filter can be physically implemented.

4. EXPERIMENTAL VERIFICATION

To experimentally validate the performance of the designed dual-band filter, a combline-coaxial-cavity-resonator based filter with the design parameters listed above was designed, implemented and characterized. The performance of the prototype filter (resonator dimensions: 42 mm × 42 mm × 42 mm) is numerically simulated using the full-wave electromagnetic simulator HFSS.

In the real implementation, tuning screws have been used to finely tune the resonant frequencies of resonators and couplings between adjacent resonators. The photo of the fabricated prototype is shown in Fig. 3. The overall dimension of the fabricated dual-band filter is around 190 mm × 150 mm. The simulated and measured responses of the prototype dual-band filter are shown in Fig. 4.

It is observed that the two desired passbands have been achieved. Also, the simulated return loss levels at the two passbands are almost equal. The prescribed transmission zeros (in the synthesis results) are well maintained in the simulation results.

The measured insertion loss level at the first passband is around 1.85 dB. And the measured insertion loss level at the second passband is around 2.25 dB. Due to the physical implementation of the fabricated filter, the measured return loss levels at the two passbands are affected. But they still agree with the theoretical results and are around 18 dB at both passbands. Similarly, the transmission zeros in the measurement results are shifted, which do not degrade the out-of-band rejection performance too much.

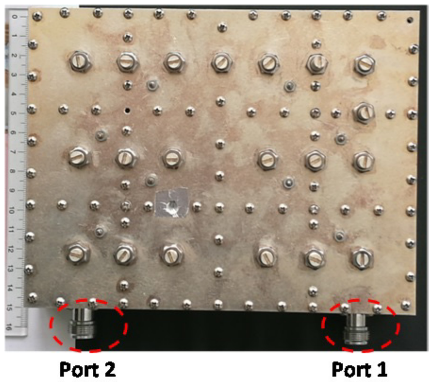

Figure 3. The photo of the fabricated prototype.

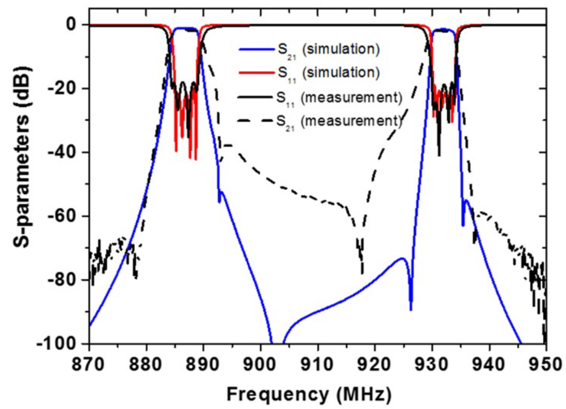

Figure 4. The simulation and measured performance of the designed dual-band filter.

Overall, both the simulation and measurement results are in good agreement with the synthesis results, which clearly validate the proposed design method of asymmetric dual-band filters.

5. CONCLUSIONS

A semi-analytical design method for dual-band microwave filters is presented in this paper. The proposed technique allows the design of dual-band filters with flexible bandwidths, return loss levels, and out-of-band rejections at two passbands. An experimental prototype filter is synthesized, designed, fabricated, and measured. The simulation and measurement results agree well with the synthesis ones, which verify the proposed design technique.

ACKNOWLEDGMENT

This work is supported by the Foundation of Key Laboratory of Polarization Imaging Detection Technology Anhui Province (2016-KFJJ-005), China.

REFERENCES

1. Luo, S., L. Zhu, and S. Sun, "A dual-band ring-resonator bandpass filter based on two pairs of degenerate modes," *IEEE Trans. Microw. Theory Tech.*, Vol. 58, No. 12, 3427–3432, Dec. 2010.
2. Yang, L., W.-W. Choi, K.-W. Tam, and L. Zhu, "Balanced dual-band bandpass filter with multiple transmission zeros using doubly short-ended resonator coupled line," *IEEE Trans. Microw. Theory Tech.*, Vol. 63, No. 7, 2225–2232, Jul. 2015.
3. Peng, Y., L. Zhang, J. Fu, Y. Wang, and Y. Leng, "Compact dual-band bandpass filter using coupled lines multimode resonator," *IEEE Microw. Wirel. Compon. Lett.*, Vol. 25, No. 4, 235–237, Apr. 2015.
4. Zhou, M., X. Tang, and F. Xiao, "Compact dual band bandpass filter using novel E-type resonators with controllable bandwidths," *IEEE Microw. Wirel. Compon. Lett.*, Vol. 18, No. 12, 779–781, Dec. 2008.
5. Liu, H., B. Ren, X. Guan, J. Lei, and S. Li, "Compact dual-band bandpass filter using quadruple-mode square ring loaded resonator (SRLR)," *IEEE Microw. Wirel. Compon. Lett.*, Vol. 23, No. 4, 181–183, Apr. 2013.
6. Chen, F. C., Q. X. Chu, Z. H. Li, and X. H. Wu, "Compact dual-band bandpass filter with controllable bandwidths using stub-loaded multiple-mode resonator," *IET Microw. Antennas Propag.*, Vol. 6, No. 10, 1172, 2012.

7. Sun, S. and L. Zhu, "Compact dual-band microstrip bandpass filter without external feeds," *IEEE Microw. Wirel. Compon. Lett.*, Vol. 15, No. 10, 644–646, Oct. 2005.
8. Yan, J.-M., L.-Z. Cao, J. Xu, and R.-S. Chen, "Design of a fourth-order dual-band bandpass filter with independently controlled external and inter-resonator coupling," *IEEE Microw. Wirel. Compon. Lett.*, Vol. 25, No. 10, 642–644, Oct. 2015.
9. Chen, J., K. Deng, S. Yang, C.-H. Liang, and L. Lin, "Design of compact dual-band bandpass filter using dual-mode stepped-impedance stub resonators," *Electron. Lett.*, Vol. 50, No. 8, 611–613, Apr. 2014.
10. Kuo, J.-T., T.-H. Yeh, and C.-C. Yeh, "Design of microstrip bandpass filters with a dual-passband response," *IEEE Trans. Microw. Theory Tech.*, Vol. 53, No. 4, 1331–1337, Apr. 2005.
11. Zhang, X. Y., J.-X. Chen, Q. Xue, and S.-M. Li, "Dual-band bandpass filters using stub-loaded resonators," *IEEE Microw. Wirel. Compon. Lett.*, Vol. 17, No. 8, 583–585, Aug. 2007.
12. Zhang, X. Y., C. H. Chan, Q. Xue, and B.-J. Hu, "Dual-band bandpass filter with controllable bandwidths using two coupling paths," *IEEE Microw. Wirel. Compon. Lett.*, Vol. 20, No. 11, 616–618, Nov. 2010.
13. Lee, H.-M. and C.-M. Tsai, "Dual-band filter design with flexible passband frequency and bandwidth selections," *IEEE Trans. Microw. Theory Tech.*, Vol. 55, No. 5, 1002–1009, May 2007.
14. Zhang, Y. P. and M. Sun, "Dual-band microstrip bandpass filter using stepped-impedance resonators with new coupling schemes," *IEEE Trans. Microw. Theory Tech.*, Vol. 54, No. 10, 3779–3785, Oct. 2006.
15. Kim, C. H. and K. Chang, "Independently controllable dual-band bandpass filters using asymmetric stepped-impedance resonators," *IEEE Trans. Microw. Theory Tech.*, Vol. 59, No. 12, 3037–3047, Dec. 2011.
16. Macchiarella, G. and S. Tamiazzo, "Novel approach to the synthesis of microwave diplexers," *IEEE Trans. Microw. Theory Tech.*, Vol. 54, No. 12, 4281–4290, Dec. 2006.
17. Lee, J. and K. Sarabandi, "A synthesis method for dual-passband microwave filters," *IEEE Trans. Microw. Theory Tech.*, Vol. 55, No. 6, 1163–1170, Jun. 2007.
18. Lenoir, P., S. Bila, F. Seyfert, D. Baillargeat, and S. Verdeyme, "Synthesis and design of asymmetrical dual-band bandpass filters based on equivalent network simplification," *IEEE Trans. Microw. Theory Tech.*, Vol. 54, No. 7, 3090–3097, Jul. 2006.
19. Zhang, Y., K. A. Zaki, J. A. Ruiz-Cruz, and A. E. Atia, "Analytical synthesis of generalized multi-band microwave filters," *IEEE/MTT-S International Microwave Symposium*, 1273–1276, 2007.
20. Kuo, Y.-T., J.-C. Lu, C.-K. Liao, and C.-Y. Chang, "New multiband coupling matrix synthesis technique and its microstrip implementation," *IEEE Trans. Microw. Theory Tech.*, Vol. 58, No. 7, 1840–1850, Jul. 2010.
21. Cameron, R. J., C. M. Kudsia, and R. R. Mansour, *Microwave Filters for Communication Systems Fundamentals, Design, and Applications*, 1st Edition, Wiley, NJ, 2007.