Open access • Journal Article • DOI:10.1109/LMWC.2010.2042550

Design of Dual-Passband Microstrip Bandpass Filters With Multi-Spurious Suppression — Source link

Meshon Jiang, Li-Ming Chang, Albert Chin

Institutions: National Chiao Tung University

Published on: 01 Mar 2010 - IEEE Microwave and Wireless Components Letters (IEEE)

Topics: Passband, Band-pass filter, Stopband, Microstrip and Bandwidth (signal processing)

Design of Dual-Passband Microstrip Bandpass Filters With Multi-Spurious Suppression

Meshon Jiang, Li-Ming Chang, and Albert Chin, *Senior Member, IEEE*

***Abstract*—A systematic design method for microstrip bandpass filters with both dual-passband response and multi-spurious suppression is proposed in this letter. The filter is composed of stepped impedance resonators (SIRs). A novel asymmetric SIR structure is proposed to effectively increase the degree of freedom in the dual-passband bandwidth design. As a consequence, the transmission zero of the coupling stage could be used to suppress the unwanted higher order spurious responses. A complete design procedure considering both the synthesis of passband responses and the suppression of spurious responses is also depicted in detail. A fifth order filter is designed and fabricated to demonstrate this idea. The measured results show that the upper stopband can have an attenuation level near 30 dB up to more than 20 GHz (8.16 f_0).**

***Index Terms*—Dual-passband filter, microstrip, spurious response, stepped impedance resonator (SIR).**

I. Introduction

DUAL-BAND, even tri-band, operation for RF devices has become a widespread tendency in recent wireless communication systems for enhancing the system functionality. In recent years, multi-band filters used as key components in the front end of a wireless communication system have been proposed and investigated extensively in the related academic community [1]–[5]. All these multi-band filters discussed above suffer from the unwanted higher order spurious responses, which deteriorates the rejection levels and bandwidth of the upper stopband and can greatly limit their applications. Many techniques have been proposed to tackle this problem for the single-passband filter [6]–[8], but very little has been done for the dual-band one. In the previous work [9], the idea in [10] is adopted to suppress the higher order spurious responses. However, the rejection level is obviously degraded due to the limited tuning ranges of the higher order resonant frequencies of the constitutive SIRs.

A novel asymmetric SIR is proposed in this letter to increase the degree of freedom when designing the bandwidth of a dual-passband filter. Therefore, the over-coupled structure in [7] can be suitably used to suppress the unwanted higher order spurious responses. Section II will introduce the asymmetric structure of SIR and depict the overall design process. The measured responses of the fabricated filter will be shown and compared with the simulation ones in Section III, and the conclusion will be drawn in Section IV.

Manuscript received October 08, 2009; revised January 07, 2010. First published March 01, 2010; current version published April 07, 2010. This work was supported in part by National Nano Project NSC 97-2120-M-009-005 and NSC 97-2221-E-233-002 of Taiwan.

M. Jiang is with the Department of Computer and Communications Engineering, Ta Hwa Institute of Technology, Hsinchu 307, Taiwan (e-mail: u8913563@gmail.com).

L.-M. Chang and A. Chin are with the Department of Electronics Engineering, National Chiao Tung University, Hsinchu 300, Taiwan. (e-mail: universalagape@gmail.com; achin@cc.nctu.edu.tw).

Color versions of one or more of the figures in this letter are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/LMWC.2010.2042550

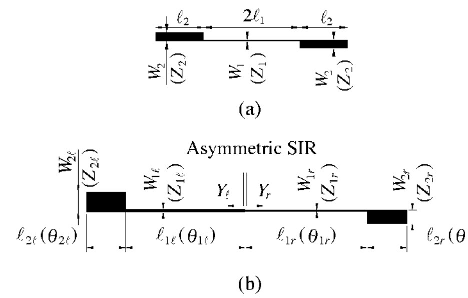

Fig. 1. Circuit layouts. (a) The traditional SIR. (b) The proposed asymmetric SIR.

II. Asymmetric SIR and Filter Design Procedure

A. Asymmetric SIR

The proposed asymmetric SIR is plotted in Fig. 1(b). The input impedance $Z_{\rm in} = 1/Y_{\rm in} = 1/(Y_\ell + Y_r)$ seen at the center of the SIR in Fig. 1(b) can be derived. The resonant conditions for odd mode ($Z_{\rm in} = 0$) and even mode ($Z_{\rm in} = \infty$) can be collated as

$$\begin{cases} \tan\theta_{1\ell}\cdot\tan\theta_{2\ell} = R_\ell \\ \tan\theta_{1r}\cdot\tan\theta_{2r} = R_r \end{cases} \quad \text{odd mode} \tag{1}$$

$$\begin{cases} \cot\theta_{1\ell}\cdot\tan\theta_{2\ell} = -R_\ell \\ \cot\theta_{1r}\cdot\tan\theta_{2r} = -R_r \end{cases} \quad \text{even mode} \tag{2}$$

where $R_\ell = Z_{2\ell}/Z_{1\ell}$ and $R_r = Z_{2r}/Z_{1r}$. If let $\theta_{1\ell} = \theta_{1r} = \theta_1, \theta_{2\ell} = \theta_{2r} = \theta_2$ and $R_\ell = R_r = R$, (1) and (2) can be simplified to the form of the resonance conditions for traditional SIRs as in [8]. In other words, as long as the above conditions are held, the line widths of the asymmetric SIR can be arbitrarily changed without affecting the SIR resonant characteristics. Hence, the degree of freedom in the bandwidth design of the filter can be effectively increased.

B. Filter Design Procedure

First, the SIR parameters, including impedance ratio R and length ratio u, must be determined. In Fig. 2, the design curves show all the possible solutions for SIRs with $f_1/f_0 = 5.8$ GHz/2.45 GHz = 2.367. An impedance ratio

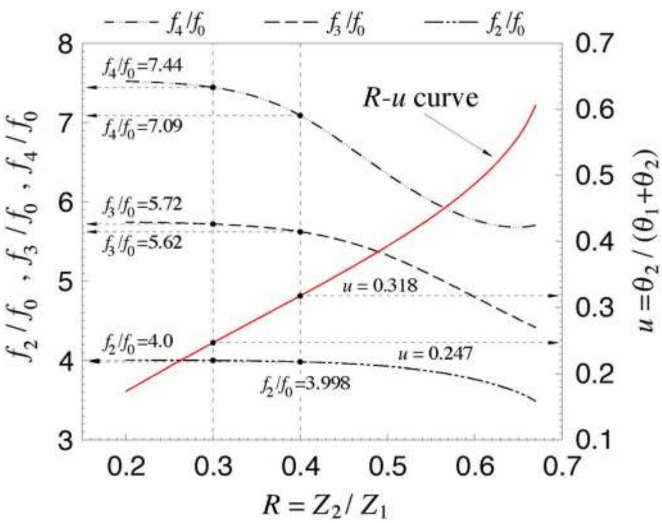

Fig. 2. Design curves for determining R and u values of SIR with $f_1/f_0 = 2.367$.

$R = 0.3$ was chosen, and the corresponding values of $u, f_2/f_0, f_3/f_0$ and f_4/f_0 can be found to be 0.247, 4.0, 5.72 and 7.44 respectively in Fig. 2. A fifth-order dual-passband filter as shown in Fig. 3(c) is designed and fabricated to demonstrate the proposed ideas in this letter. The filter has five resonators (SIR_1–SIR_5) and four coupled stages (CS_1–CS_4), and is symmetrical at the center. CS_1 and CS_4 are expected to suppress the spurious response at f_2 while CS_2 and CS_3 are used to cope with the unwanted harmonic at f_3. The transmission zeros of CS_1 and CS_4 are located at f_2, and those of CS_2 and CS_3 are at f_3. Then, the fractional bandwidth design graph can be established as shown in Fig. 4. The passband ripples for the first and second passband are 0.01 dB and 0.1 dB respectively. If $g_{i,j}$ represents the ith element value of the low-pass filter prototype of the jth passband, $g_{1,1} = g_{5,1} = 0.7563, g_{2,1} = g_{4,1} = 1.3049, g_{3,1} = 1.5773, g_{1,2} = g_{5,2} = 1.1468, g_{2,2} = g_{4,2} = 1.3712$ and $g_{3,2} = 1.975$ for the Chebyschev filter. The bandwidth design graph can be divided into two portions. The dash line is for CS_2 and CS_3 while the solid one is for CS_1 and CS_4. The shadow region represents the realizable fractional bandwidth for both bands in the given circuit size range of W_1/h and S/h. The range of Δ_1 is from 7.24% to 19.35%, and that of Δ_2 is between 5.63% and 12.39%. The scope of the shadow region can be adjusted by the element values of the low-pass filter prototype. Based on Fig. 4, Δ_1 and Δ_2 are chosen to be 10% and 7% respectively. The corresponding coupled stage circuit sizes $(W_1/h, S/h)$ for CS_1 and CS_4 are (0.5777, 0.7843), and those for CS_2 and CS_3 are (0.2487, 0.9655). The last step is to complete the design of tapped-line input/output as plotted in Fig. 3(b). By the method similar to that in [5], appropriate values of $x/(2\ell_1 + 2\ell_2)$ for $\Delta_1/\Delta_2 = 0.1/0.07 = 1.429$ can be 0.317 or 0.683, and the load impedances at the input/output points have an identical value of 164.35 Ω. Based on [11], the dual-band frequency transformer with dimensions $Z_a = 79.8\ \Omega, Z_b = 103\ \Omega$ and $\ell_a = \ell_b = 13.62$ mm can satisfy this demand. The parameters, W_a and ℓ_a, in Fig. 3(b) refer to the line width and line length of the 50 Ω line which is connected to the SMA connector for measurement. The

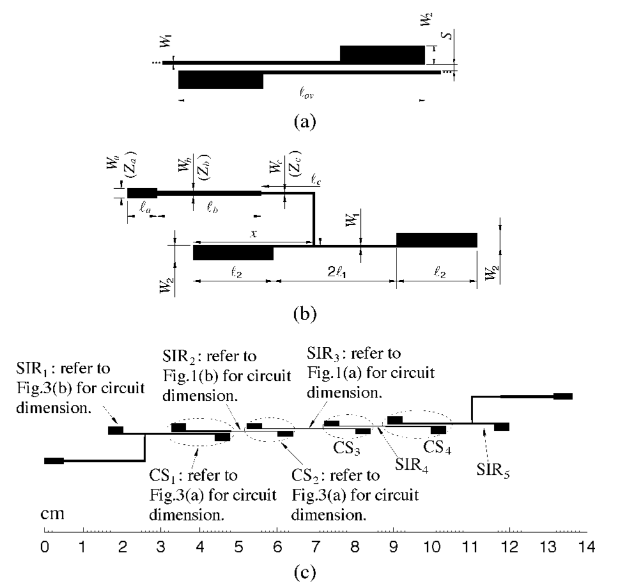

Fig. 3. Circuit layouts. (a) The coupled stage. (b) The tapped input/output resonator. (c) The fifth-order dual-passband bandpass filter (BPF). (SIR_1: $W_a = 1.561, W_b = 0.715, W_c = 0.419, W_1 = 0.294, W_2 = 1.965, \ell_a = 5.0, \ell_b = 13.62, \ell_c = 13.62, \ell_1 = 11.843, \ell_2 = 3.875, x = 9.505$. SIR_2: $W_{1\ell} = 0.294, W_{2\ell} = 2.13, W_{1r} = 0.126, W_{2r} = 1.426, \ell_{1\ell} = 11.715, \ell_{2\ell} = 3.833, \ell_{1r} = 11.946, \ell_{2r} = 3.908$. SIR_3: $W_1 = 0.126, W_2 = 1.372, \ell_1 = 12.035, \ell_2 = 3.938$. CS_1: $\ell_{ov} = 15.181, S = 0.398$. CS_2: $\ell_{ov} = 11.92, S = 0.497$. unit: mm.)

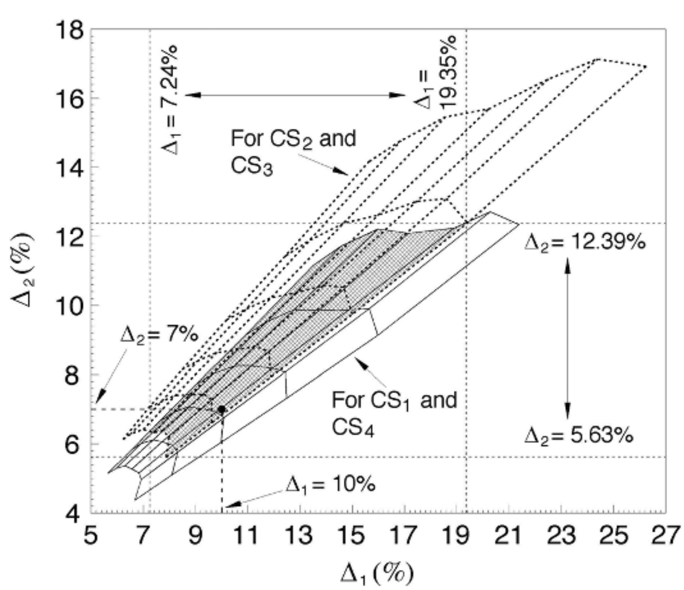

Fig. 4. Fractional bandwidth design graphs for a fifth-order dual-passband filter with suppression of spurious responses. Substrate: $\varepsilon_r = 2.2$, thickness $h = 0.508$ mm.

systematic design process mentioned above can be applied to the design of even higher order filters.

III. Simulation and Measurement

The fifth-order filter is simulated by the full-wave commercial EM simulator IE3D and fabricated on a high frequency laminate RT/duroid® 5880 with $\varepsilon_r = 2.2$ and $h = 0.508$ mm. The simulation and measured frequency responses are plotted

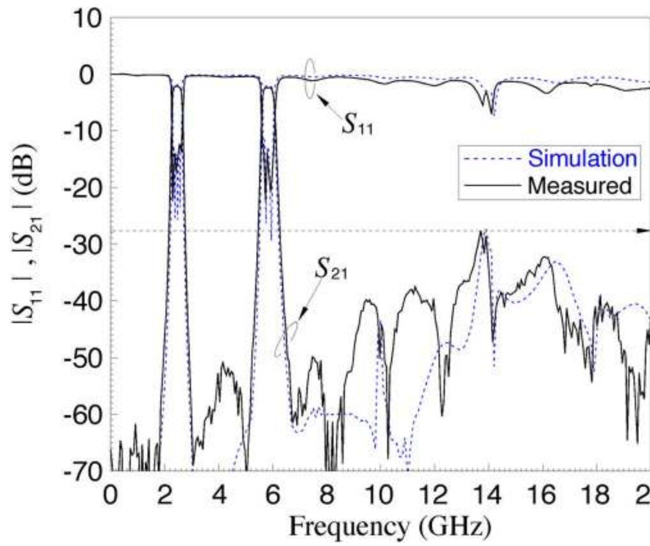

Fig. 5. Simulation and measured frequency responses of the experimental dual-passband filter with order $N = 5$.

in Fig. 5, and the circuit layout with detailed circuit dimensions noted in the figure legend is shown in Fig. 3(c). The measured results agree well with the simulation ones. The insertion losses at f_0 and f_1 are 2.12 dB and 2.33 dB respectively, and both return losses are greater than 12 dB. It can be shown that the spurious responses at f_2 $(4.0f_0 = 9.8$ GHz) and f_3 $(5.72f_0 = 14.01$ GHz) are effectively suppressed. The upper stopband can have an attenuation level near 30 dB up to more than 20 GHz $(8.16f_0)$.

IV. Conclusion

This letter brings up a complete design methodology for spurious-free microstrip line dual-passband filters. A novel idea of asymmetric SIR is proposed herein. One can arbitrarily change the line widths of the SIR without affecting its resonant characteristics. This particular feature can effectively increase the degree of freedom in the dual-passband bandwidth design and facilitate the structure of over-coupled stage in [7] to become an appropriate choice for spurious responses suppression. A fifth-order filter is designed and fabricated to demonstrate the proposed ideas. The measured and simulation responses agree well with each other and show that good inband responses and upper stopband attenuation can be achieved simultaneously.

Acknowledgment

The authors wish to thank Dr. J.-T. Kuo and Dr. S.-J. Chung, Department of Electrical Engineering, National Chiao Tung University, Taiwan, for generously providing help on circuit fabrication and measurement.

References

[1] J. Lee and K. Sarabandi, "A synthesis method for dual-passband microwave filters," *IEEE Trans. Microw. Theory Tech.*, vol. 55, no. 6, pp. 1163–1170, Jun. 2007.

[2] H.-M. Lee and C.-M. Tsai, "Dual-band filter design with flexible passband frequency and bandwidth selections," *IEEE Trans. Microw. Theory Tech.*, vol. 55, no. 5, pp. 1002–1009, May 2007.

[3] J. Lee, M. S. Uhm, and I.-B. Yom, "A dual-passband filter of canonical structure for satellite applications," *IEEE Microw. Wireless Compon. Lett.*, vol. 14, no. 6, pp. 271–273, Jun. 2004.

[4] C.-Y. Chen and C.-Y. Hsu, "A simple and effective method for microstrip dual-band filters design," *IEEE Microw. Wireless Compon. Lett.*, vol. 16, no. 5, pp. 246–248, May 2006.

[5] J.-T. Kuo, 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, pp. 1331–1337, Apr. 2005.

[6] C.-F. Chen, T.-Y. Huang, and R.-B. Wu, "Design of microstrip bandpass filters with multiorder spurious-mode suppression," *IEEE Trans. Microw. Theory Tech.*, vol. 53, no. 12, pp. 3788–3793, Dec. 2005.

[7] M. Jiang, M.-H. Wu, and J.-T. Kuo, "Parallel-coupled microstrip filters with over-coupled stages for multispurious suppression," in *IEEE MTT-S Int. Dig.*, Long Beach, CA, Jun. 12–17, 2005, pp. 687–690.

[8] J.-T. Kuo and E. Shih, "Microstrip stepped impedance resonator bandpass filter with an extended optimal rejection bandwidth," *IEEE Trans. Microw. Theory Tech.*, vol. 51, no. 5, pp. 1554–1559, May 2003.

[9] M. Jiang, H.-P. Lin, and J.-T. Kuo, "Design of quasi-elliptic function filters with dual-passband responses and multi-spurious suppression," in *Proc. Asia-Pacific Microw. Conf.*, Bangkok, Thailand, Dec. 11–14, 2007, pp. 2365–2368.

[10] C.-F. Chen, T.-Y. Huang, and R.-B. Wu, "Design of microstrip bandpass filters with multiorder spurious-mode suppression," *IEEE Trans. Microw. Theory Tech.*, vol. 53, no. 12, pp. 3788–3793, Dec. 2005.

[11] C. Monzon, "A small dual-frequency transformer in two sections," *IEEE Trans. Microw. Theory Tech.*, vol. 51, no. 4, pp. 1157–1161, Apr. 2003.