

A miniaturized dual-band bandpass filter using composite resonators with flexible frequency ratio

Pin Wen^{1,2,3}, Zhewang Ma^{1a)}, Haiwen Liu^{3b)}, Shuangshuang Zhu³,
Baoping Ren^{1,2}, Xiaolong Wang¹, and Masataka Ohira¹

¹ Graduate School of Science and Engineering, Saitama University,
255 Shimo-Okubo, Sakura-ku, Saitama 338–8570, Japan

² College of Information Engineering, East China Jiaotong University,
Nanchang 330013, People's Republic of China

³ School of Electronic and Information Engineering, Xi'an Jiaotong University,
Xi'an 710049, People's Republic of China

a) ma@ees.saitama-u.ac.jp

b) haiwen_liu@hotmail.com

Abstract: A miniaturized dual-band bandpass filter (DBPF) using a pair of composite resonators is proposed in this letter. The composite resonator consists of two vertical short-circuited microstrip lines and a short transversal microstrip line, and its resonant characteristics are analyzed by using the even- and odd-mode method. The even- and odd-mode of the resonator can be controlled individually readily, and hence the DBPF can be designed with a flexible frequency ratio. The DBPF has a compact size of $0.06\lambda_g \times 0.14\lambda_g$. To verify the design, a compact DBPF with 3-dB fractional bandwidths of 6% and 7% is designed and fabricated. The measured response is in good agreement with the simulated result.

Keywords: dual-band bandpass filter (DBPF), composite resonator, flexible frequency ratio

Classification: Microwave and millimeter-wave devices, circuits, and modules

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1 Introduction

To meet the growing requirement for multi-service in wireless communications, dual-band bandpass filters (DBPFs) having simple design, low cost, compact size and independent control of the frequency ratio of its dual-passbands are required. In recently years, a number of approaches to realize DBPFs had been proposed [1, 2, 3, 4, 5, 6, 7, 8]. In [1], a multiple orders DBPF was presented with two types of resonators having different resonant frequencies but common input and output feed lines. A ring resonator and a pair of strong coupled I/O feeding structure were introduced to configure a DBPF with a reduced circuit size was proposed in [2]. DBPFs are also realized using stepped-impedance resonators (SIRs) [3, 4] and stub-loaded resonators (SLRs) [5, 6, 7], which have dual or multiple non-degenerate modes and easy control of the frequency ratio of the dual-passbands. Moreover, substrate integrated waveguide (SIW) [8, 9], composite right-/left-handed (CRLH) structures [10], and other novel types of resonators were also used to design DBPFs. Nevertheless, the independent controllable of dual-passband performance and a compact circuit size are still strongly demanded in the DBPFs design.

In this Letter, a miniaturized DBPF is analyzed and realized with two cascaded composite resonators, and a flexible frequency ratio of its dual-passband is easily achieved. Moreover, by introducing a mixed electric and magnetic coupling, a good frequency selectivity and out-band rejection performance of the DBPF is realized.

2 Proposed composite resonator

Fig. 1a depicts the transmission line mode of the proposed composite resonator. It consists of two short-circuited microstrip lines and a short transversal connecting line. The characteristic impedances of these lines are all the same, and are indicated by Z . The electrical lengths of these lines are indicated by θ_1 , θ_2 and $2\theta_3$,

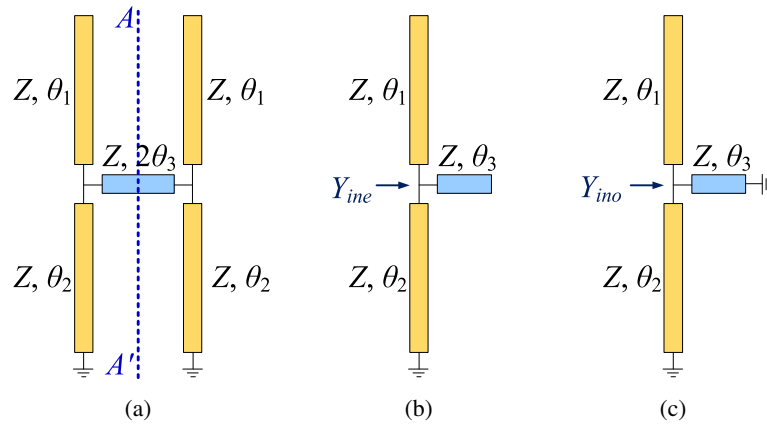


Fig. 1. (a) Transmission line model of the proposed composite resonator; (b) Even-mode equivalent circuit; (c) Odd-mode equivalent circuit.

respectively. Since the resonator is a symmetrical structure, the even- and odd-mode method is good candidate for analyzing the proposed resonator. Under the even-/odd-mode excitation, the symmetrical plane AA' behaves as a perfect magnetic wall or electric wall, respectively, and the even-/odd-mode equivalent circuit of the resonator are shown in Fig. 1b and Fig. 1c, respectively. As illustrated in Fig. 1b, Y_{ine} represent the input admittance under the even-mode excitation and is given by

$$Y_{ine} = jY_0(\tan \theta_1 - \cot \theta_2 + \tan \theta_3) \quad (1)$$

At resonance, the input admittance $Y_{ine} = 0$, thus the resonant condition is derived as

$$\tan \theta_1 - \cot \theta_2 + \tan \theta_3 = 0 \quad (2)$$

Similarly, under the odd-mode excitation, the Y_{ino} is express as

$$Y_{ino} = jY_0(\tan \theta_1 - \cot \theta_2 - \cot \theta_3) \quad (3)$$

and the resonant condition is derived as

$$\tan \theta_1 - \cot \theta_2 - \cot \theta_3 = 0 \quad (4)$$

Therefore, the resonant frequencies at the even-mode (f_{even}) and odd-mode (f_{odd}) can be calculated by solving (2) and (4). It can be seen from (2) that when θ_1 is fixed and θ_3 is very small compare with θ_2 , θ_3 will has little effect on the even-mode frequency f_{even} . Under the same constraint, it can be seen from (4) that θ_2 has less influence on the odd-mode frequency f_{odd} . Therefore, f_{even} and f_{odd} , can be independently tuned by changing θ_2 and θ_3 , respectively, with θ_1 fixed.

To verify the analysis, EM simulation results of the resonator under a weak coupling with $Z = 98 \text{ Ohm}$, $\theta_1 = 54^\circ$, $\theta_2 = 36.7^\circ$, and $\theta_3 = 4^\circ$ are illustrated in Fig. 2a. The proposed composite resonator has two resonant modes, f_{even} and f_{odd} . Moreover, two potential transmission zeros (TZs), TZ_{VG1} and TZ_{VG2} , are observed at the lower and upper sides of two resonant modes, respectively, they are mainly produced by the virtual grounds existed in composite resonator (when Y_{ine} and Y_{ino} are equal to ∞), and the phases reversal ($\Delta\phi = 180^\circ$) at the TZs. The variation of

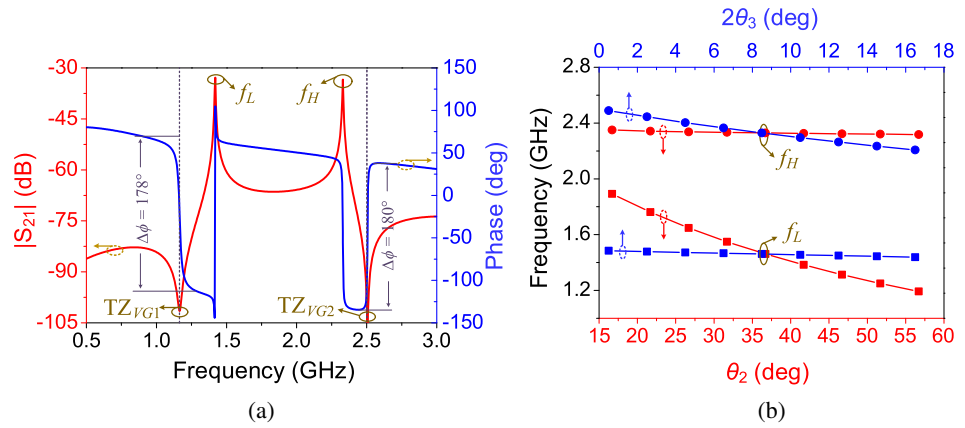


Fig. 2. (a) Simulated amplitude and phase of S_{21} , and (b) Variation of the even- and odd-mode resonant frequencies with θ_2 and $2\theta_3$.

resonant frequencies with θ_2 and $2\theta_3$ is illustrate in Fig. 2b, which verify that f_{even} and f_{odd} can be independently controlled by changing θ_2 and θ_3 , respectively.

3 Design of the dual-band bandpass filter

The configuration of the DBPF is illustrated in Fig. 3. It consists of two composite resonators and a pair of side feeding lines. To realize the required coupling coefficients, the geometrical parameters g_1 , g_{ic} , and L_{ic} are determined by simulated extraction. On the other hand, the side feeding structures with dimension L_{f1} , L_{f2} , and g_0 are adjusted to meet the demanded external quality factors. Furthermore, for purpose of enhance the selectivity of the DBPF, the common ground via-hole and interdigital capacitor structures are introduced to form a mixed electric and magnetic coupling (MEMC), which, together with the inherent transmission zeros of the composite resonators, results in three transmission zeros (TZ_1 , TZ_2 , and TZ_3), as shown in Fig. 4.

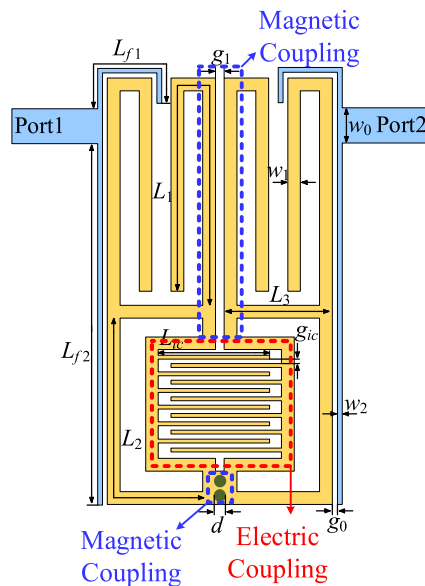


Fig. 3. Configuration of the proposed DBPF.

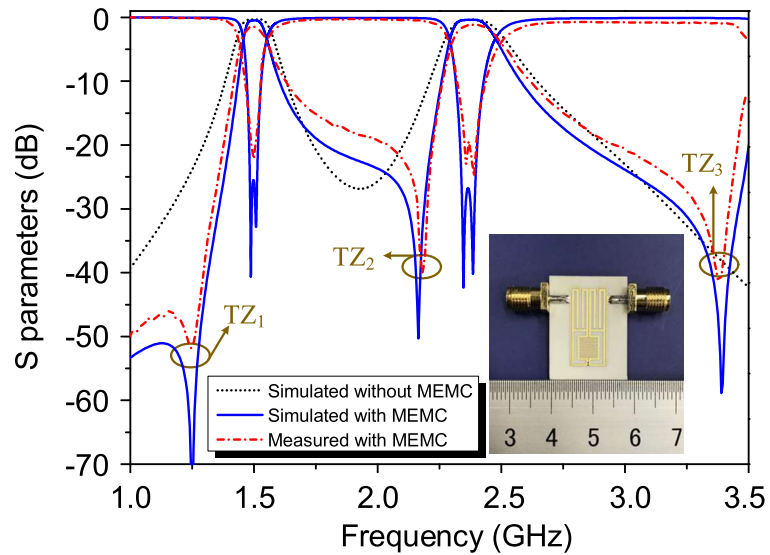


Fig. 4. Simulated and measured results and photograph of the fabricated DBPF.

4 Results and discussion

The DBPF is fabricated on Rogers RO 4003C substrate with a relative permittivity $\epsilon_r = 3.38$, loss tangent $\tan \delta = 0.0027$, and a thickness $h = 0.813$ mm, and the overall circuit size is $0.06 \lambda_g \times 0.14 \lambda_g$, where λ_g is the guided wavelength at the center frequency of the lower passband. The final dimensions of the DBPF are: $L_{f1} = 6$, $L_{f2} = 15.2$, $g_0 = 0.2$, $L_1 = 20$, $L_2 = 13.5$, $L_3 = 3$, $L_{ic} = 3.95$, $w_0 = 1.8$, $w_1 = 0.5$, $w_2 = 0.2$, $g_1 = 0.15$, $g_{ic} = 0.2$, and $d = 0.4$ (Unit: mm). The measured results and photograph of the DBPF are shown in Fig. 4. As shown in Fig. 4, the two passbands are centered at near 1.5 GHz and 2.35 GHz, with a 3-dB fractional bandwidth of 5.96% and 7.19%, respectively. The measured minimum in-band insertion losses are 1.43 dB and 1.15 dB at the two center frequencies, respectively. Both the return losses of the two passbands are greater than 20 dB. Moreover, the three TZs are located at 1.25 GHz, 2.19 GHz, and 3.39 GHz, respectively, which improve significantly the out-of-band suppression performance of the DBPF. Finally, Table I gives a comparison of the proposed DBPF with other reference works. It is seen that our DBPF has merits like low insertion loss and very compact circuit size.

Table I. Compared with previous DBPFs

Ref.	Center Freq. (GHz)	3-dB FBWs (%)	Insertion Loss (dB)	Return Loss (dB)	TPs/TZs	Circuit Size ($\lambda_g \times \lambda_g$)
[1]	2.4/5.2	6.4/5.8	1.4/1.76	15/19	8/4	0.21×0.35
[2]	2.4/5.2	9.2/9.5	1.2/2.7	15/11	4/4	0.18×0.18
[5]	1.63/2.73	7.5/5.1	1.5/2.15	17/23	8/7	0.25×0.25
[6]	2.4/5.8	4.63/3.6	1.35/1.97	17/15	4/2	0.39×0.25
This work	1.5/2.35	5.96/7.19	1.43/1.15	22/20	4/3	0.06×0.14

5 Conclusion

A miniaturized dual-band bandpass filter using composite resonators with flexible frequency ratio is developed. Three transmission zeros are produced by introduced a mixed electric and magnetic coupling, which improves significantly the selectivity and out-band rejection performance. With the features of compactness, flexible design, and high performance, the proposed dual-band filter is attractive for dual-band wireless communication applications, such as the GPS and the TD-LTE system.

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