Progress In Electromagnetics Research C, Vol. 14, 45–52, 2010

A NOVEL COUPLING METHOD TO DESIGN A MICROSTRIP BANDPASS FILER WITH A WIDE REJECTION BAND

R.-Y. Yang, J.-S. Lin, and H.-S. Li

Department of Materials Engineering
National Pingtung University of Science and Technology
No. 1, Syuefu Rd., Neipu Township, Pingtung County 91201, Taiwan

Abstract—In this paper, we present a novel method to design a microstrip bandpass filter (BPF) with high selectivity and upper rejection band. The proposed coupling structure mainly composes of half-wavelength input/output (I/O) microstrip lines and open-loop ring resonators. By properly selecting the coupling position between the I/O lines and resonators, the spurious response of the BPF can be well suppressed. A filter example centered at 2.4 GHz achieves a high band selectivity and a wide upper-stopband rejection greater than 20 dB from 2.7 to 6 GHz. Experimental results show a good agreement with the simulated ones.

1. INTRODUCTION

Planar microstrip bandpass filters (BPFs) are a key component in radio frequency (RF) front end of the wireless communication systems. The challenges to circuit designers when designing a BPF are to achieve high band selectivity [1] and a wide stopband simultaneously. In the past, parallel coupled BPF is widely used due to its planar configuration and easy integrated procedure. However, the difference between the even and odd mode phase velocities on the lines causes spurious responses at twice the passband frequency of half-wavelength resonators. In order to avoid the interference to the RF performance of the active circuits such as the low noise amplifier (LNA) or the power amplifier (PA), a BPF having high band selectivity and a wide stopband simultaneously is necessary.

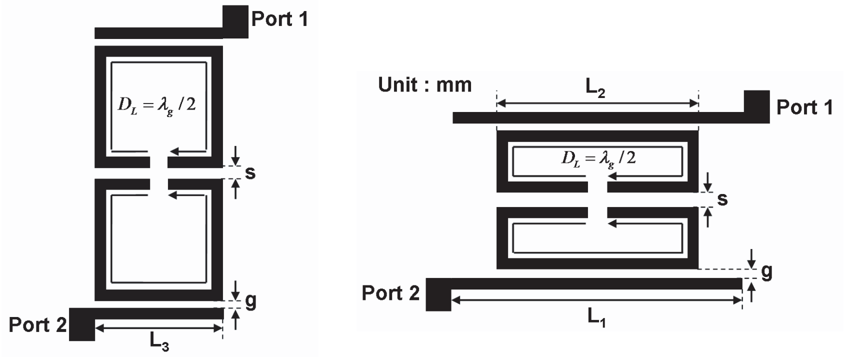
Corresponding author: R.-Y. Yang (ryyang@mail.npust.edu.tw).

Several methods have been proposed to suppress the spurious responses, such as the techniques of over-coupled end stages [2], substrate suspension [3], wiggly-line [4], stepped impedance resonators (SIRs) [5, 6], tapping additional line [7, 8], spur-line [9], discriminating coupling [10], or complementary split ring resonator [11]. However, the above solutions often suffer from extend overall size, extra complicated design processes and poor selectivity. In [12], Dai et al. first investigated special coupling regions to suppress the harmonics by using the combination of open- and short-ended resonators.

In this paper, a novel concept to design a microstrip BPF having a high band selectivity and a wide stopband is proposed by using a new coupling structure. The aim of this paper focuses on the design and method of selecting the coupling region between resonators and microstrip-line for harmonics elimination. A filter example using this design concept is designed, fabricated and measured. The proposed coupling structure mainly composes of half-wavelength input/output (I/O) microstrip lines and open-loop ring resonators. By properly selecting the length of the coupling structure for the desired coupling strength, spurious responses can be eliminated, and required passband performance is obtained. The design procedure is presented in detail in the following sections. It is found that experimental results show a good agreement with the simulated ones.

2. DESIGN PROCEDURES

Figure 1 illustrates the schematic diagram of the conventional and proposed microstrip BPF with an upper rejection band. Two designs both mainly compose of half-wavelength I/O microstrip lines and open-loop ring resonators. The difference is that the conventional bandpass filter uses $\lambda_g/8$ microstrip lines as the I/O ports, while the proposed design uses $\lambda_g/2$ microstrip lines as the I/O ports. In the paper, we shall point out that the resonators are not limited as the open-loop ring resonators. Other types of the resonators can be also used in the design to extend the design freedom when satisfying the proposed design concept. Firstly, the variation of the characteristic impedance in the coupled line is analyzed, and a pair of resonators are coupled to the zero characteristic impedance in the coupled line to have a strong coupling.



(a) (b)

Figure 1. Geometrical diagram of the (a) conventional and (b) proposed BPF with an upper rejection band. Two are both designed and fabricated on Duroid 5880 substrate having a thickness of 0.787 mm, a dielectric constant ε_r of 2.2, and a loss tangent of 0.0009. λ_g is the guided wavelength at the central frequency.

2.1. Variation of Characteristic Impedance in the Microstrip Lines

Figure 2(a) shows the general configuration of the parallel microstrip lines, each having characteristic impedance Z_{01} with electrical length θ_1 and characteristic impedance Z_{02} with electrical length θ_2, respectively. The voltage and current waves on the parallel microstrip lines are expressed as follows [1, 3]

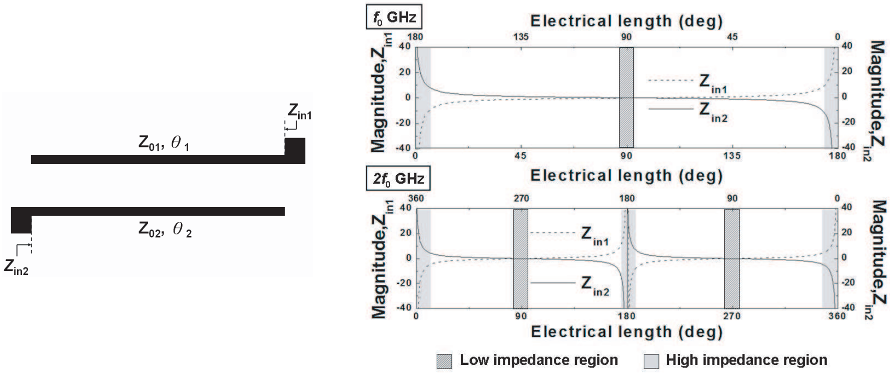
$$V(\ell) = 2V_0^+ \cos\theta \tag{1a}$$

$$I(\ell) = \frac{-2jV_0^+}{Z_0} \sin\theta. \tag{1b}$$

Due to the same uniform strip width of input/output (I/O) microstrip lines, the characteristic impedance $Z_{01} = Z_{02} = Z_0$ and electrical length $\theta_1 = \theta_2 = \theta$ are set to simplify formula (1). It is deserved to be mentioned that the θ_1 and θ_2 have the same magnitude but opposite phases. When the parallel microstrip lines are considered as open-circuited, the input impedance can be defined as

$$Z_{in} = -jZ_0 \cot\theta. \tag{2}$$

Therefore, the varied values of the characteristic impedance in different positions of the parallel coupled line can be calculated and shown in Fig. 2(b) according to formula (2).



(a) (b)

Figure 2. (a) Schematic diagram and (b) the varied values of the characteristic impedance in different position of the parallel coupled line when the resonances occurs at f_0 and $2f_0$, respectively.

It is observed that the input impedance, Z_{in1} or Z_{in2}, has a magnitude of zero at the open-circuited quarter-wavelength location (or $n \times \lambda_g/4$, $n = 1, 3, 5, \ldots$, λ_g: Guided wavelength at the central frequency f_0) when the electrical length θ is set as half-wavelength at f_0. In other words, there are a null impedance value, maximum current density and maximum coupling strength in the centre of the parallel microstrip lines at frequency of f_0. Otherwise, the middle section of the parallel coupled line has high impedance value, low current density and thus low coupling strength in the centre of the parallel microstrip lines at frequency of $2f_0$. It is then expected that when the resonators are set and coupled to the maximum coupling strength of the microstrip lines, the resonant mode can be passed and created. Otherwise, when the resonators are set and coupled to the low coupling strength of the microstrip lines, the resonant mode might be suppressed.

2.2. Filter Example Design

Based on the above discussion, the I/O microstrip lines have electrical length of the half-wavelength at 2.4 GHz and the same uniform line width of 0.5 mm. A pair of identical open-loop ring resonators having the same electrical length of the half-wavelength at 2.4 GHz and the same uniform line width of 0.5 mm are set to couple to the center of the parallel microstrip lines.

To establish actual coupling between the resonators, spacing s is varied to have the desired coupling strength for the desired passband performance. The calculated coupling coefficient k between the resonators can be specified by the two dominant resonant frequencies, which are split off from the resonance condition, and coupling coefficient k can be calculated as [1, 4]

$$k = \pm \frac{f_{p2}^2 - f_{p1}^2}{f_{p2}^2 + f_{p1}^2} \tag{3}$$

where f_{p2} and f_{p1} are the two resonance frequencies of the split mode respectively. The coupling coefficients K calculated by a full-wave EM simulator [1, 5] are shown in Fig. 3, and the spacing s of 1.3 mm is obtained to achieve the minimum ripple response over the passband.

Figure 4 depicts the frequency response for conventional design and the proposed design. It is clearly observed that the second harmonic response appears in the conventional design but it is eliminated in the proposed design. By selecting the coupling region between resonators and coupled-line, the harmonics is eliminated.

Figure 5 shows current density of the BPF example when the resonant modes are at (a) 2.4 GHz and (b) 4.8 GHz, respectively. It is clear that the middle section has the maximum magnetic field distribution and strong coupling effect between the resonators, and the coupled I/O lines can be obtained at 2.4 GHz. However, the spurious response of 4.8 GHz cannot be well transmitted from the input line to the output line since the magnetic field distribution between the resonators and coupled I/O lines is weak. Thus, the spurious response of 4.8 GHz might be suppressed.

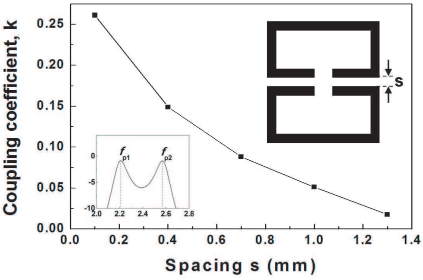


Figure 3. Coupling coefficient of the proposed parallel coupled BPF as shown in Fig. 1.

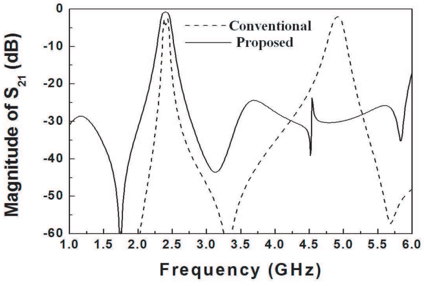
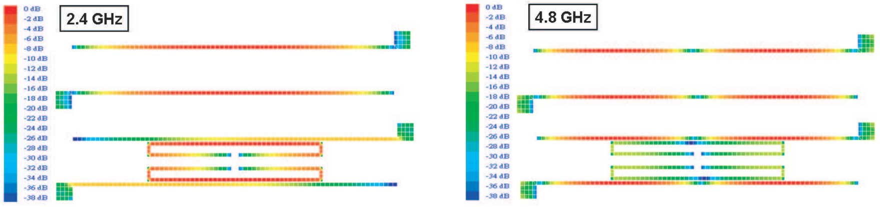


Figure 4. The simulated frequency responses for conventional and proposed design.

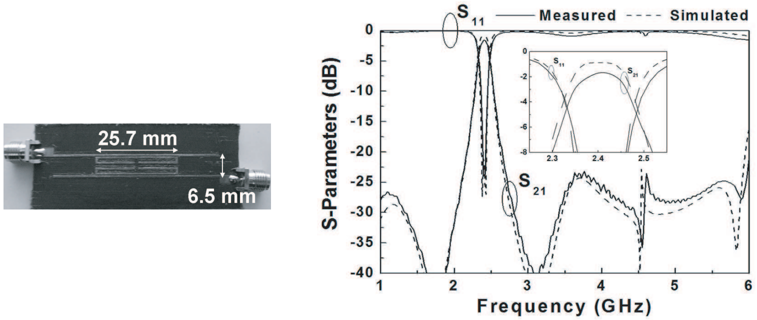


(a) (b)

Figure 5. Current density of the BPF example when the resonant modes are at (a) 2.4 GHz and (b) 4.8 GHz, respectively.

3. RESULTS AND DISCUSSION

The designed filter example was fabricated and then measured by an HP8510C Network Analyzer. Fig. 6(a) shows the photograph of the fabricated layout. Fig. 6(b) shows the simulated and measured results of the proposed BPF example using the proposed design concept. The structural parameters of the designed filter example at center frequency $f_0 = 2.4\,\text{GHz}$ are $L_1 = 47.4\,\text{mm}$, $L_2 = 25.7\,\text{mm}$, $s = 1.3\,\text{mm}$, $g = 0.1\,\text{mm}$, and two feed ports are 2.42 mm wide corresponding to a $50\,\Omega$ microstrip. The whole size of the fabricated filter is about $47.4\,\text{mm} \times 6.5\,\text{mm}$, i.e., approximately $0.5\lambda_g$ by $0.07\lambda_g$, where λ_g is the guided wavelength at the center frequency. The measured characteristics have an insertion loss of $-2.0\,\text{dB}$, a return loss of $-25\,\text{dB}$, and the fractional bandwidth of 6.2% that is slightly less than



(a) (b)

Figure 6. (a) Photograph and (b) simulated and measured frequency responses of the fabricated parallel coupled BPF. Insert is the passband filter performance in detail.

the simulated value of 6.5%. The transmission zero can be obviously introduced at the low frequency side of passband to improve the band selectivity. Furthermore, a wide out-of-band with a rejection level greater than 20 dB is verified from 2.7 to 6 GHz. In general, there is a good agreement between the experimental and the simulated results.

4. CONCLUSION

In this paper, we have presented a novel method to design a microstrip BPF that can have a high band selectivity and an upper rejection band. By analyzing the varied values of the characteristic impedance in different positions of the parallel microstrip lines, the position having null or high impedance values can be found, thus the coupling position between the coupling lines and resonators can be carefully chosen to achieve the desired passband and suppress the spurious response. The filter example using this design concept was designed at center frequency $f_0 = 2.4\,\text{GHz}$, and fabricated and measured. The measured results actually verified the predicted results, showing a wide stopband of 2.7–6 dB. It is noted that the proposed design concept is useful for designing a diplexer or multiband BPF.

REFERENCES

1. Dai, G. L. and M. Y. Xia, "Novel miniaturized bandpass filters using spiral-shaped resonators and window feed structures," *Progress In Electromagnetics Research*, Vol. 100, 235–243, 2010.
2. Kuo, J. T., S. P. Chen, and M. Jiang, "Parallel-coupled microstrip filters with over-coupled end stages for suppression of spurious responses," *IEEE Microw. Wireless Compon. Lett.*, Vol. 13, 440–442, 2003.
3. Kuo, J. T., M. Jiang, and H. J. Chang, "Design of parallel-coupled microstrip filters with suppression of spurious resonances using substrate suspension," *IEEE Trans. Microw. Theory Tech.*, Vol. 52, 83–89, 2004.
4. Lopetegi, T., M. A. G. Laso, J. Hernández, M. Bacaicoa, D. Benito, M. J. Garde, M. Sorolla, and M. Guglielmi, "New microstrip 'wiggly-line' filters with spurious passband suppression," *IEEE Trans. Microwave Theory Tech.*, Vol. 49, 1593–1598, 2001.
5. Chang, Y. C., C. H. Kao, M. H. Weng, and R. Y. Yang, "Design of the compact dual-band bandpass filter with high isolation

for GPS/WLAN applications," *IEEE Microw. Wireless Compon. Lett.*, Vol. 19, 780–782, 2009.

6. Zhang, J., J. Z. Gu, B. Cui, and X. W. Sun, "Compact and harmonic suppression open-loop resonator bandpass filter with tri-section SIR," *Progress In Electromagnetics Research*, Vol. 69, 93–100, 2007.
7. Zhu, Y. Z., Y. J. Xie, and H. Feng, "Novel microstrip bandpass filters with transmission zeros," *Progress In Electromagnetics Research*, Vol. 77, 29–41, 2007.
8. Zhang, X. Y. and Q. Xue, "Novel centrally loaded resonators and their applications to bandpass filters," *IEEE Trans. Microw. Theory Tech.*, Vol. 56, 913–921, 2008.
9. Griol, A., J. Marti, and L. Sempere, "Microstrip multistage coupled ring bandpass filters using spur-line filters for harmonic suppression," *Electron. Lett.*, Vol. 37, 572–573, 2001.
10. Zhang, X. Y. and Q. Xue, "Harmonic-suppressed bandpass filter based on discriminating coupling," *IEEE Microw. Wireless Compon. Lett.*, Vol. 19, 695–697, 2009.
11. Karthikeyan, S. S. and R. S. Kshetrimayum, "Harmonic suppression of parallel coupled microstrip line bandpass filter using CSRR," *Progress In Electromagnetics Research Letters*, Vol. 7, 193–201, 2009.
12. Dai, G. L., X. Y. Zhang, C. H. Chen, Q. Xue, and M. Y. Xia, "An investigation of open- and short-ended resonators and their applications to bandpass filters," *IEEE Trans. Microw. Theory Tech.*, Vol. 57, 2203–2210, 2009.
13. Pozar, D. M., *Microwave Engineering*, 2nd edition, Wiley, New York, 1998.
14. Hong, J. S. and M. J. Lancaster, *Microstrip Filters for RF/Microwave Applications*, Wiley, New York, 2001.
15. IE3D, *Simulator*, Zeland Software, Inc., Fremont, CA, 1997.