Progress In Electromagnetics Research, PIER 100, 235–243, 2010

NOVEL MINIATURIZED BANDPASS FILTERS USING SPIRAL-SHAPED RESONATORS AND WINDOW FEED STRUCTURES

G.-L. Dai and M.-Y. Xia

School of Electronics Engineering and Computer Science
Peking University
China

Abstract—In this paper, we present a new class of miniaturized microstrip bandpass filters with low-insertion loss, sharp-rejection and narrow-band performance. The proposed filters are composed of two spiral-shaped resonators and rectangle window feed structures. Both back-to-back and interdigital combinations of the resonators are adopted to obtain the miniaturized filter size. Compared to the traditional square loop bandpass filter, the sizes are reduced by 82% and 80%. It is also found that there is a pair of transmission zeros located on each side of the passbands, resulting in high selectivity. To validate the proposed idea, two demonstration filters with back-to-back and interdigital spiral-shaped resonators are implemented. The measured results exhibit good agreement with the full-wave simulation results.

1. INTRODUCTION

As one of the most important components in wireless communication system, bandpass filter with low cost and high performance are highly desired [1–4]. Since most mobile devices become smaller and leave limited space for the placement of the filters, it is of importance to miniaturize the required filter size. Recently, much research work on miniaturized microstrip bandpass filter has been performed and various kinds of resonators have be presented [5–15]. Among them, dual-mode resonators are most widely used in the miniaturized filters designs [5–11]. In [5–8], square loop resonators with different loaded structures such as capacitive open-loop arms [5], distributed capacitors [6], tree-shaped patches [7] and slow-wave open loop arms [8] are utilized to

Corresponding author: G.-L. Dai (dglwmq@hotmail.com).

obtain size reduction. In [9], the authors present the perturbed dual-mode ring resonators to miniaturize the areas. Slotted patch [10, 11] is another choice to reduce the fundamental resonant frequency with the same dimensions. However, some dual-mode filters proposed above occupy still a fairly large circuit area. On the other hand, compact microstrip resonant cell (CMRC) structure [12], stepped-impedance ring [13], capacitive-loaded open loop [14] and meander loop resonators [15] are also proposed to design small-sized bandpass filters.

In this paper, we present a new class of miniaturized microstrip bandpass filters with low-insertion, sharp-rejection and narrow-band performance. The two proposed filters are both composed of rectangle window feed structures and two spiral-shaped resonators. The back-to-back and interdigital combinations of the resonators are utilized to obtain the size reduction, which are only about 18% and 20% of the traditional square loop bandpass filter [16], respectively. The novel rectangle window feed structures are introduced to provide cross coupling scheme between source/load and resonators. It is found that the two proposed filters generate a pair of transmission zeros, which locate at each side of the passbands, resulting in high selectivity. To validate the proposed idea, filter A with back-to-back spiral-shaped resonators and filter B with interdigital spiral-shaped resonators are implemented in the following sections. The measured results exhibit good agreement with the full-wave simulation results.

2. MINIATURIZED BANDPASS FILTER A WITH BACK-TO-BACK SPIRAL-SHAPED RESONATORS

In this section, miniaturized bandpass filter A with back-to-back spiral-shaped resonators is designed. The configuration of the proposed filter A is shown in Fig. 1. It consists of rectangle window feed structure and two spiral-shaped resonators.

Figure 2 depicts the procedure to obtain the filter A. Fig. 2(a) shows two conventional short-ended half-wavelength coupled microstrip lines. I/O ports are directly connected to the other ends of the lines. At the operation frequency, electromagnetic field along the line exhibits standing wave. Then, these two short-ended microstrip lines can be regarded as two shalf-wavelength resonators with series resonant responses [17].

By folding the lines, two back-to-back spiral-shaped half-wavelength resonators can be obtained as shown in Fig. 2(b). At the end of the spirals, there are two metalized vias connected to the ground. It is found that the coupling between these two resonators is

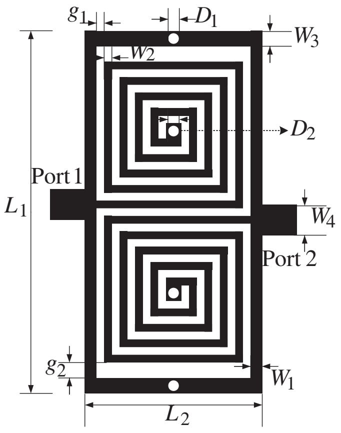

Figure 1. Configuration of the proposed filter A.

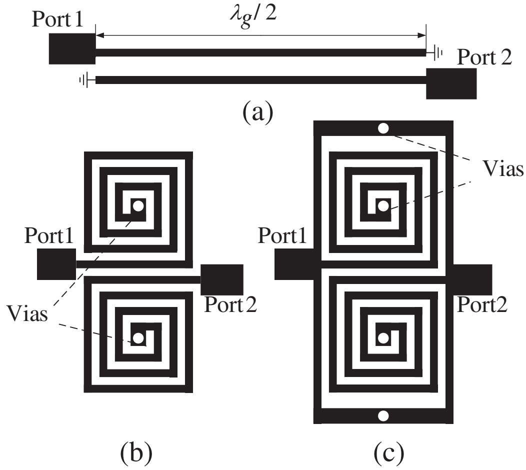

Figure 2. (a) Conventional half-wavelength coupled microstrip lines, (b) meandered half-wavelength coupled microstrip lines, (c) structure of the proposed filter A.

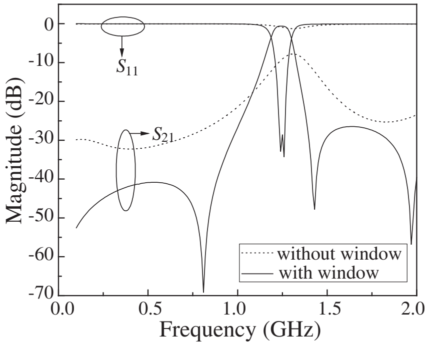

Figure 3. Simulated S-parameters of the proposed filter A with and without window.

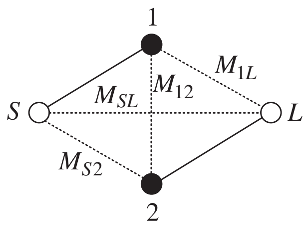

Figure 4. Feed and coupling scheme of the proposed filter A.

weak due to the limitation of the small coupling region. Therefore, a rectangle window feed structure is employed to provide the novel feed and coupling scheme. Combining the window feed structure and two back-to-back spiral-shaped resonators together, the proposed filter A is obtained as shown in Fig. 2(c). There locate two shared ground vias at the centers of the rectangle window, which not only provide the isolation of the out-of-band frequencies between I/O ports, but also control the strength of the source-load coupling [18]. To validate the effect of the novel feed structure, the simulation results with and without the window are compared in Fig. 3.

The proposed feed and coupling scheme is illustrated in Fig. 4. The black nodes represent spiral-shaped resonators and the hollow ones represent the source or load. M_{S2} and M_{1L} denote the coupling coefficients between source/load and spiral-shaped resonators, respectively. And M_{12} represents the coupling coefficient between the back-to-back spiral-shaped resonators, while M_{SL} denotes the source-load coupling. The operation frequency is determined by the electrical length of the spiral-shaped resonators. The coupling coefficients between the resonators and source/load can be easily tuned to the desired value by changing the widths of the microstrip lines and the gaps between them. Source-load coupling can also be tuned by changing ground via diameter of the window, which controls the magnetic coupling strength [18]. Fig. 5 shows the simulated S parameters under different ground via diameter, the transmission zeros can be adjusted effectively due to changed source-load coupling.

To validate the previous analysis, an experimental filter is designed. The proposed filter A is fabricated on the substrate with a relative dielectric constant of 2.33 and thickness of 0.787 mm. The dimensions are determined as follows: $L_1 = 30\,\text{mm}$, $L_2 = 12\,\text{mm}$, $W_1 = 0.65\,\text{mm}$, $W_2 = 0.3\,\text{mm}$, $W_3 = 1.6\,\text{mm}$, $W_4 = 2.3\,\text{mm}$, $g_1 = 0.7\,\text{mm}$, $g_2 = 3.75\,\text{mm}$, $D_1 = 0.9\,\text{mm}$, $D_2 = 0.9$ mm. The photograph of the fabricated filter A is shown in Fig. 6.

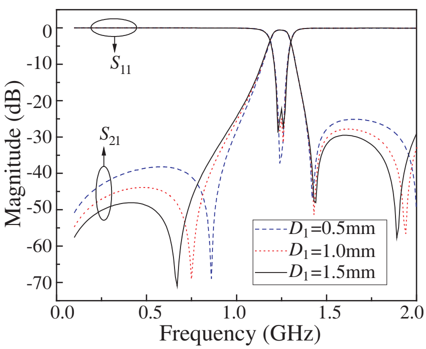

Figure 5. Simulated S-parameters of the proposed filter A under different ground via of the window.

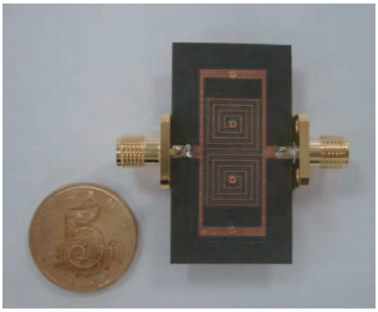

Figure 6. Photograph of the fabricated filter A.

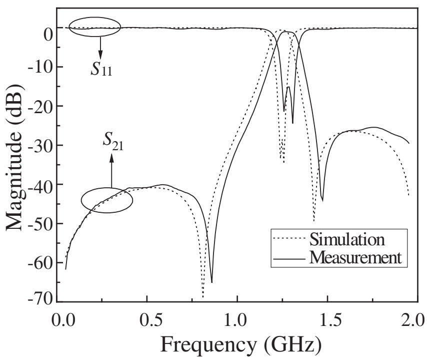

Figure 7. Simulated and measured S-parameters of the proposed filter A.

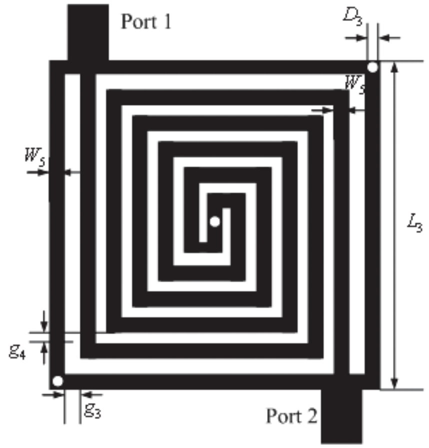

Figure 8. Configuration of the proposed filter B.

The simulation of this design is accomplished by using Ansoft designer. The fabricated prototype is measured by an Agilent 8753ES network analyzer. Fig. 7 depicts the simulated and measured results, which show good agreement. The passband is centered at 1.27 GHz with the 3 dB bandwidth from 1.21 GHz to 1.33 GHz, featuring the fractional bandwidth of 9.4%. The insertion loss, including the loss from SMA connectors, is measured to be 1.0 dB. Two transmission zeros on the both sides of the passband are located at 0.86 GHz and 1.47 GHz, resulting in high selectivity. The total circuit size is only $0.167\lambda_g \times 0.0667\lambda_g$ with the size reduction of 82% as compared to the traditional square loop bandpass filter [16].

3. MINIATURIZED BANDPASS FILTER B WITH INTERDIGITAL SPIRAL-SHAPED RESONATORS

In this section, another miniaturized bandpass filter B with the similar feed and coupling scheme is presented. The proposed filter B is also composed of rectangle window feed structure and two spiral-shaped resonators, which are realized to reduce the circuit size. However, the combination of the two resonators is quite different from the proposed filter A. The configuration of the proposed filter B is illustrated in Fig. 8. Interdigital coupling is used between the two spiral-shaped resonators. Furthermore, the common ground via at the center of the spirals provide magnetic coupling between the two resonators [18].

The window feed structure with two shared ground vias at its corners is located outside. To validate the effect of the novel feed structure, the simulation results with and with the window are compared in Fig. 9.

The feed and coupling scheme of the proposed filter B is the similar to that of the proposed filter A shown in Fig. 4. Here, coupling coefficients M_{S2} and M_{1L} are determined by the microstrip line width W_5 and the gap g_3, M_{12} is related to W_5 and the gap g_4 as well as the dimensions of the ground via.

A demonstration filter B is also implemented. The experimental filter is also fabricated on the substrate with a relative dielectric constant of 2.33 and thickness of 0.787 mm. The dimensions are as follows: $L_3 = 19.8$, $W_5 = 0.8\,\text{mm}$, $g_3 = 1.2\,\text{mm}$, $g_4 = 0.7\,\text{mm}$,

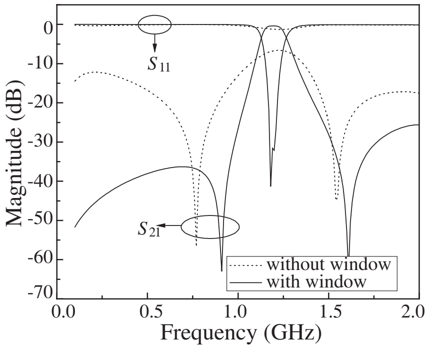

Figure 9. Simulated S-parameters of the proposed filter B with and without window.

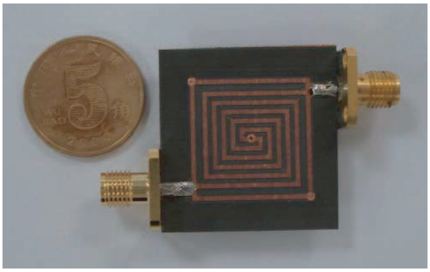

Figure 10. Photograph of the fabricated filter B.

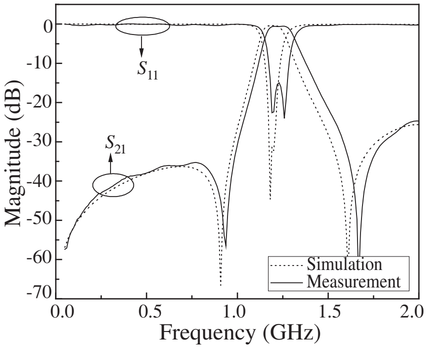

Figure 11. Simulated S-parameters of the proposed filter B with and without window.

$D_3 = 0.9$ mm. The photograph of the fabricated filter B is shown in Fig. 10.

The simulation of this design is accomplished by using Ansoft designer. The fabricated prototype is also measured by an Agilent 8753ES network analyzer. Fig. 11 depicts the simulated and measured results, which show good agreement. Center at 1.25 GHz, the passband has 3 dB bandwidth of 160M or 12.7%. The measured insertion loss, including the loss from SMA connectors, is only to be 0.55 dB. Two transmission zeros on the both sides of the passband are located at 0.94 GHz and 1.66 GHz, resulting in high selectivity. The total circuit size of the proposed filter B is only $0.11\lambda_g \times 0.11\lambda_g$ with the size reduction of 80% as compared to the traditional square loop bandpass filter [16].

4. CONCLUSION

In this paper, a new class of miniaturized microstrip bandpass filters with low-insertion loss, sharp- rejection and narrow-band performance is presented. The proposed filters are composed of window feed structure and two spiral-shaped resonators, which are used to reduce the overall circuit sizes. The novel rectangle window feed structures are introduced to provide novel cross coupling scheme between source/load and resonators. Two experimental filters using back-to-back and interdigital combination of the resonators are implemented. The measured results show that the circuit sizes of the designed filters are only about 18% and 20% of the traditional square loop bandpass filter. It is also found that there is a pair of transmission zeros located at each side of the passbands, resulting in high selectivity. The proposed filters are simple in structure and easy to fabricate. They will be very useful in wireless communication systems due to their low-insertion loss, sharp-rejection and narrow-band performance.

ACKNOWLEDGMENT

This work is supported by NSFC projects 60771001 and 60825102. The authors would like to thank Xiu Yin Zhang, City University of Hong Kong, Kowloon, Hong Kong, for his valuable discussions.

REFERENCES

1. Dai, G. L., X. Y. Zhang, C. H. Chan, Q. Xue, and M. Y. Xia, "An investigation of open- and short-ended resonators and their

applications to bandpass filters," *IEEE Trans. Microw. Theory and Tech.*, Vol. 57, No. 9, 2203–2210, Sep. 2009.

2. Mo, S.-G., Z.-Y. Yu, and L. Zhang, "Design of triple-mode bandpass filter using improved hexagonal loop resonator," *Progress In Electromagnetics Research*, PIER 96, 117–125, 2009.
3. Wang, R., L.-S Wu, and X.-L. Zhou, "Compact folded substrate integrated waveguide cavities and bandpass filter," *Progress In Electromagnetics Research*, PIER 84, 135–147, 2008.
4. Mo, S.-G., Z.-Y. Yu, and L. Zhang, "Compact dual-mode bandpass filters using hexagonal meander loop resonators," *Journal of Electromagnetic Waves and Applications*, Vol. 23, No. 13, 1723–1732, 2009.
5. Goaur, A., C. Karpuz, and M. Akpinar, "A reduced-size dual-mode bandpass filter with capacitively loaded open-loop arms," *IEEE Microw. Wireless Compon. Lett.*, Vol. 13, No. 9, 385–387, Sep. 2003.
6. Wang, J.-P., L. Wang, Y.-X. Guo, Y. X. Wang, and D.-G. Fang, "Miniaturized dual-mode bandpass filter with controllable harmonic response for dual-band application," *Journal of Electromagnetic Waves and Applications*, Vol. 23, No. 11–12, 1525–1533, 2009.
7. Wang, Y. X., B.-Z. Wang, and J. P. Wang, "A compact square loop dual-mode bandpass filter with wide stop-band," *Progress In Electromagnetics Research*, PIER 77, 223–228, 2007.
8. Gorur, A., "A novel dual-mode bandpass filter with wide stopband using the properties of microstrip open-loop resonator," *IEEE Microw. Wireless Compon. Lett.*, Vol. 12, No. 10, 386–388, Oct. 2002.
9. Tan, B. T., J. J. Yu, S. T. Chew, M.-S. Leong, and B.-L. Ooi, "A miniaturized dual-mode ring bandpass filter with a new perturbation," *IEEE Trans. Microw. Theory and Tech.*, Vol. 53, No. 1, 343–348, Jan. 2005.
10. Tu, W.-H. and K. Chang, "Miniaturized dual-mode bandpass filter with harmonic control," *IEEE Microw. Wireless Compon. Lett.*, Vol. 15, No. 12, 838–840, Dec. 2005.
11. Liu, H., T. Fu, Y. Yang, and X. Li, "Miniaturized dual-mode filter using fractral slot and snaky-shape spur-line," *Journal of Electromagnetic Waves and Applications*, Vol. 22, No. 13, 1775–1782, 2008.
12. Shum, K. M., T. T. Mo, Q. Xue, and C. H. Chan, "A compact bandpass filter with two tuning transmission zeros using a CMRC

resonator," *IEEE Trans. Microw. Theory Tech.*, Vol. 53, No. 3, 895–900, Mar. 2005.

13. Kuo, J.-T. and C.-Y. Tsai, "Periodic stepped-impedance ring resonator (PSIRR) bandpass filter with a ministurized area and desirable upper stopband characteristics," *IEEE Trans. Microw. Theory Tech.*, Vol. 54, No. 3, 1107–1112, Mar. 2006.
14. Zhang, X. Y., J.-X. Chen, and Q. Xue, "Compact bandpass filter using open-loop resonators with capacitive loading," *Microwave and Optical Technology Letters*, Vol. 49, No. 1, 83–84, Jan. 2007.
15. AlHawari, A. R. H., A. Ismail, M. F. A. Rasid, R. S. A. R. Abdullah, B. K. Esfeh, and H. Adam, "Compact microstrip bandpass filter with sharp passband shirts using square spiral resonators and embedded-resonators," *Journal of Electromagnetic Waves and Applications*, Vol. 23, No. 5–6, 675–683, 2009.
16. Hong, J.-S. and M. J. Lancaster, "Bandpass characteristics of new dual-mode microstrip square loop resonators," *Electronics Letters*, Vol. 31, No. 11, 891–892, May 1995.
17. Pozar, D. M., *Microwave Engineering*, 3rd edition, 307–310, Wiley, New York, 2005.
18. Ma, K. X., J.-G. Ma, K. S. Yeo, and M. A. Do, "A compact size coupling contronllable filter with separate electric and magnetic coupling paths," *IEEE Trans. Microw. Theory Tech.*, Vol. 54, No. 3, 1113–1119, Mar. 2006.