

Novel Quasi-Elliptic Function Bandpass Filter Using Hexagonal Resonators with Capacitive Loading

Changtao Wang, Wenming Li, Feng Liu, and Haiwen Liu

ABSTRACT—A novel and compact elliptic-function bandpass filter is proposed in this letter. The techniques of slot etching and the addition of open stubs are applied to enhance the self-inductance and self-capacitance of hexagonal open-loop resonators. Thus, size reduction and improved transmission performance are obtained. Compared to the performance of the conventional design, the central frequency and insertion loss are reduced by 28% and 3.1 dB, respectively. Measurements show that the proposed filter has a fraction bandwidth of 23% at the central frequency of 1.84 GHz, and its insertion loss in the passband is less than -1.5 dB. The bandpass filter occupies only 12 mm×21.2 mm (approximately $0.24\lambda_g \times 0.14\lambda_g$).

Keywords—Hexagonal open-loop resonator; elliptic-function bandpass filter (BPF), slot, open stub.

I. Introduction

Modern mobile systems have high requirements for a bandpass filter (BPF) with many advantages, such as small size, high selectivity, wide upper stopband, low insertion loss, and low cost. The planar microstrip elliptic-function BPF is a good choice in this regard. Advances in BPFs based on circular, square, and triangular patch/ring resonators are reported widely. For example, Hong proposed an elliptic-function BPF using meander square resonators for size reduction [1], while Zhang presented another elliptic-function BPF with capacitive loading for compactness and sharp rejection performance [2].

Recently, there has been a growing interest in planar hexagonal resonators/filters because of their small size and high electric coupling [3]. In 2002, Chang provided a high-selectivity quasi-elliptical BPF with five hexagonal resonators [4], and Mao described a dual-mode BPF using hexagonal resonators in 2006 [5]. However, the circuit sizes are large and occupy at least $0.83\lambda_g \times 0.71\lambda_g$ (λ_g is the guided wavelength of the central frequency in the passband). To make the circuit size compact and enhance the coupling between resonators, Ni reported a hexagonal filter with a source-load coupling structure in [6]. The filter requires a size of $0.32\lambda_g \times 0.21\lambda_g$.

In this letter, we propose a novel and small elliptic-function

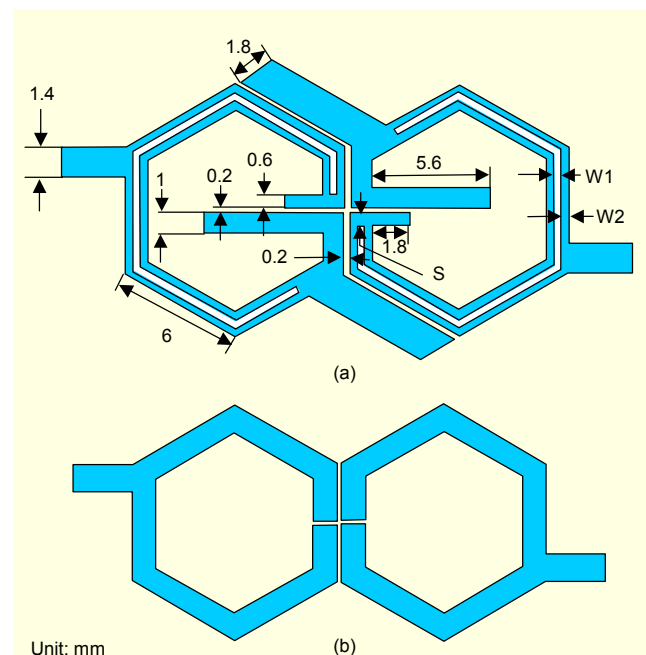


Fig. 1. Layout of hexagonal resonator filters: (a) proposed and (b) conventional.

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hexagonal BPF. The design techniques of slot etching and the addition of open stubs are analyzed and verified by simulation and measurement. Compared to the reported hexagonal filter, the proposed filter exhibits size reduction and improved transmission performance. This filter occupies only $21.2 \text{ mm} \times 12 \text{ mm}$ which is equal to a size of $0.24\lambda_g \times 0.14\lambda_g$.

II. Hexagonal Filter Design

Figure 1(a) shows the proposed microstrip bandpass filter. The electric coupling structure is chosen for this filter, and elliptical frequency response is achieved by using two skew-symmetric transmission feed lines [7], [8]. The proposed filter consists of two hexagonal open-loop resonators with slots and three pairs of open stubs as capacitive loading. After etching one slot on each resonator, an extra transmission zero may occur, which could be adjusted by changing the slot's length leading to improved stopband performance [9], [10]. Moreover, the inner open stubs increase the resonator's self-capacitance, while the outer open stubs enhance the electric coupling between resonators. Because of its limited size, a filter with reduced central frequency and low insertion-loss performance in the passband can be realized.

III. Results and Discussion

To demonstrate the use of the proposed design, the filters were simulated by Ansoft HFSS 8.0. The insertion loss performance is presented in Fig. 2. The substrate for simulation and measurement was a 0.8 mm thick FR4 layer with a dielectric constant ϵ_r of 4.5. The input/output lines are chosen for the characteristic impedance of a 50Ω microstrip line. The physical parameters of the filters are given in Fig. 1.

The proposed filters show improvement over the

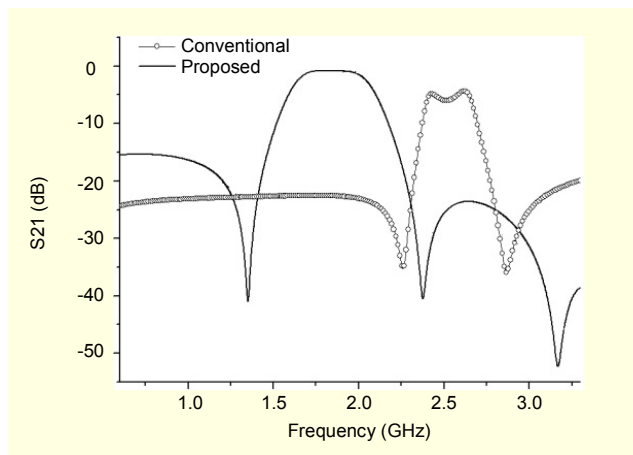


Fig. 2. Comparison of insertion loss performance of the filters: $W1=0.4 \text{ mm}$, $W2=0.8 \text{ mm}$, and $S=0.6 \text{ mm}$.

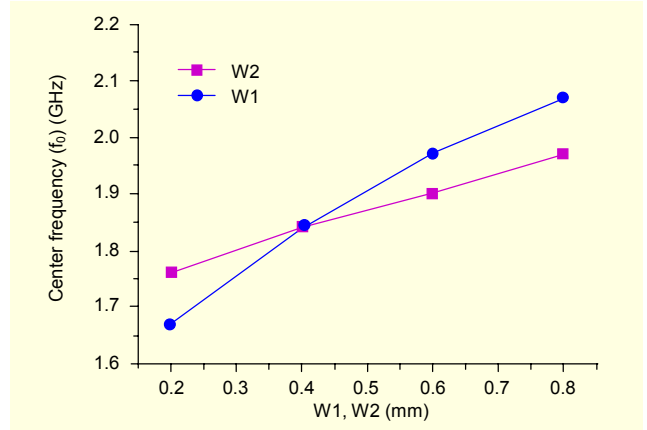


Fig. 3. Parameters $W1$ and $W2$ versus the central frequency of the proposed filter. When $W1$ ($W2$) changes, $W2$ ($W1$) keeps constant at 0.4 mm . $S=0.6 \text{ mm}$.

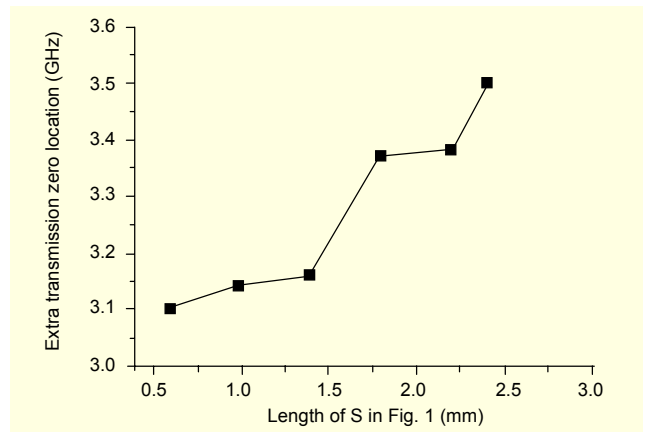


Fig. 4. Parameter S versus extra transmission zero location of the proposed filter. $W1=0.4 \text{ mm}$ and $W2=0.4 \text{ mm}$.

conventional filter as seen in Fig. 2. The central frequency of the passband changes from 2.5 GHz to 1.8 GHz and the insertion loss in the passband decreases from -4.2 dB to -1.1 dB . The central frequency and insertion loss are reduced by 28% and -3.1 dB , respectively. Moreover, the central frequency in the passband decreases when $W1$ ($W2$) becomes smaller, shown in Fig. 3. Design parameter S is in a positive proportional relationship with the extra transmission zero location shown in Fig. 4. The proposed filter (Fig. 1(a)) was fabricated, and its photograph is shown in Fig. 5. Its physical parameters are the same as those shown in Fig. 1(a): $W1=0.4 \text{ mm}$, $W2=0.4 \text{ mm}$, and $S=0.6 \text{ mm}$. Measured results are given in Fig. 6. Measurements verify that the proposed filter has a fractional bandwidth of 23% at the center frequency of 1.84 GHz . The filter has a return loss of more than -15 dB from 1.71 GHz to 1.98 GHz . The insertion loss in the passband is less than 1.5 dB . There are two transmission zeros on both sides of the passband. They are -41 dB and -38 dB at 1.35 GHz

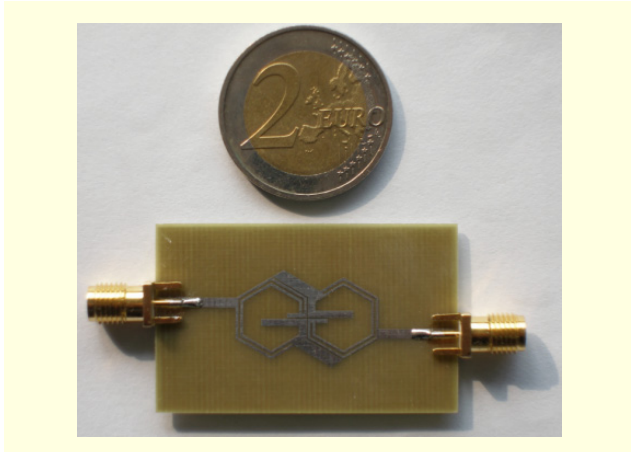


Fig. 5. Photograph of the proposed filter.

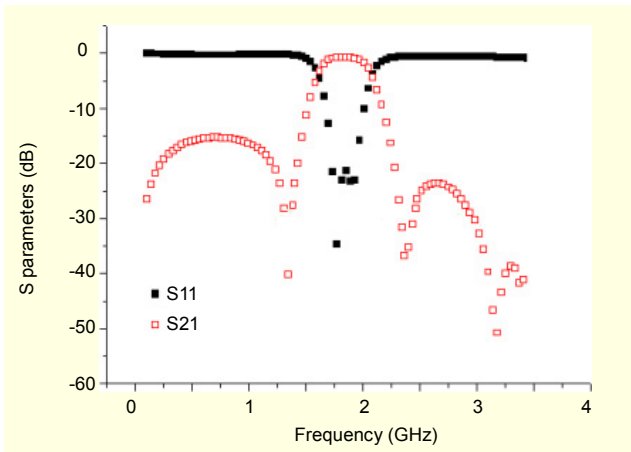


Fig. 6. Measured results of the proposed filter.

and 2.37 GHz, respectively. Another transmission zero is -51 dB at 3.20 GHz. There is good agreement between simulated and measured results. The circuit size is 21.2 mm×12 mm. A comparative study with the size of the reported hexagonal BPFs ($0.32\lambda_g \times 0.21\lambda_g$) in [6] demonstrates that the proposed filter ($0.24\lambda_g \times 0.14\lambda_g$) is 50% more compact. Measurements were carried out on an Agilent 8722 vector network analyzer.

IV. Conclusion

A novel hexagonal BPF design was introduced. Slot etching and the addition of open stubs were applied to enhance the self-inductance and self-capacitance of the hexagonal open-loop resonators to achieve a compact filter with low insertion loss. Extra transmission zeros occur, which leads to wide upper rejection performance. Finally, this filter was designed, fabricated, and measured. Results demonstrate that the compact BPF achieves good transmission performance and has potential for future microwave circuit

applications [11].

References

- [1] J.S. Hong and M.J. Lancaster, "Compact Microwave Elliptic Function Filter Using Novel Microstrip Meander Open-Loop Resonators," *Electro. Lett.*, vol. 32, no. 6, Mar. 1996, pp. 563-564.
- [2] X.Y. Zhang, J.X. Chen, and Q. Xue, "Compact Bandpass Filter Using Open-Loop Resonators with Capacitive Loading," *Microw. Optical.Tech. Lett.*, vol. 49, no. 1, Jan. 2007, pp. 83-84.
- [3] Y.Z. Zhu and Y.J. Xie, "New $\lambda/2$ Microstrip Bandpass Filters Using Skew-Symmetric Feed Structure," *Microw. Optical.Tech. Lett.*, vol. 50, no. 2, Feb. 2008, pp. 440-442.
- [4] K.F. Chang et al., "Novel Quasi-elliptic Microstrip Filter Configuration Using Hexagonal Open-Loop Resonators," *Proc. IEEE Int'l Symp. Circuits Syst.*, vol. 3, Arizona, USA, 2002, pp. 863-866.
- [5] R.J. Mao and X.-H. Tang, "Novel Dual-Mode Bandpass Filters Using Hexagonal Loop Resonators," *IEEE Trans. Microwave Theory Tech.*, vol. 54, no. 9, Sept. 2006, pp. 3526-3533.
- [6] D. Ni, Y. Zhu, and Y. Xie, "Design of Hexagonal Filter with Source-Load," *Electron. Lett.*, vol. 42, no. 23, Nov. 2006, pp. 1355-1357.
- [7] J.S. Hong and M.J. Lancaster, "Couplings of Microstrip Square Open-Loop Resonators for Cross-Coupled Planar Microwave Filters," *IEEE Trans. Microwave Theory Tech.*, vol. 44, no. 12, Dec. 1996, pp. 2099-2109.
- [8] C.M. Tsai, S.Y. Lee, and C.C. Tsai, "Performance of a Planar Filter Using a 0° Feed Structure," *IEEE Trans. Microwave Theory Tech.*, vol. 50, no. 10, Oct. 2002, pp. 2362-2367, Oct. 2002.
- [9] C.-F. Chen, T.-Y. Huang, and R.-B. Wu, "Miniaturized Microstrip Quasi-Elliptical Bandpass Filters Using Slotted Resonator," *IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 2, San Francisco, USA, 2006, pp. 1185-1188.
- [10] H.W. Liu, R.H. Knoechel, and K.F. Schuenemann, "Miniaturized Bandstop Filter Using Meander Spurline and Capacitively Loaded Stubs," *ETRI Journal*, vol. 29, no. 5, Oct. 2007, pp. 614-618.
- [11] Z.G. Shi, and L.X. Ran, "Microwave Chaotic Colpitts Oscillator: Design, Implementation and Applications," *Journal of Electromagnetic Waves and Applications*, vol. 20, no. 10, Oct. 2006, pp. 1335-1349.