# A Miniaturized Surface Mount Compatible Quasi-elliptic Response Bandpass Filter Using Multilayer Substrates

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***Abstract*—In this paper, a miniaturized UHF band second-order quasi-elliptic response bandpass filter (BPF) is proposed. Traditional UHF transmission line filter suffers from large circuit size and large footprint area. For the purpose of miniaturization, spiral quarter-wavelength short-circuited resonators is used in this BPF filter design. For further footprint reduction, the proposed filter is implemented by stacking multilayer substrates. Coplanar waveguide (CPW) transmission lines are used as input and output ports on the same layer, which can be compatible with surface mounting technology (SMT) effectively. It is observed from simulation and measured results that the return loss and insertion loss at a center frequency of 433 MHz are about 15 dB and 0.7 dB, respectively, with a fractional bandwidth of 19%. Two transmission zeros are located on both sides of the passband. A good agreement is obtained between the simulated and measured results.**

***Index Terms*—spiral short-circuited resonators, bandpass filter, multilayer substrates, surface mounting technology.**

## I. Introduction

With the rapid development of wireless communication system, bandpass filter (BPF) plays an important role as part of RF front-end. The demand for high-performance filters is also growing, including low insertion loss, compact size, high selectivity and easy fabrication. A lot of works of planar miniaturized bandpass filter has been reported, but the size of filter is still large, especially in VHF and UHF band. For the further miniaturization, multilayer technology has emerged and is widely used in microwave BPFs. These multilayer technologies include Low Temperature Co-Fired Ceramic (LTCC) technology and multilayer printed circuit board (PCB) substrate stacking technology. In [1] and [2], although LTCC technology is used to design highly compact bandpass filters with two transmission zeros, the insertion losses of these two filters are more than 2 dB. Moreover, LTCC technology is more expensive than multilayer PCB substrate technology. A lot of BPF using multilayer PCB substrate technology has been reported in [3]-[6]. In [3], a fourth-order BPF with two transmission zeros is proposed and the filter achieve a compact size by using folded quarter-wavelength short-circuited resonators. In [4], a fourth-order BPF with more than two transmission zeros is proposed. Although the filters in [3] and [4] have high selectivity, their size is quite large. In [5], a third-order BPF using multilayer organic substrate is proposed. However, it is large in size and also has no transmission zero.

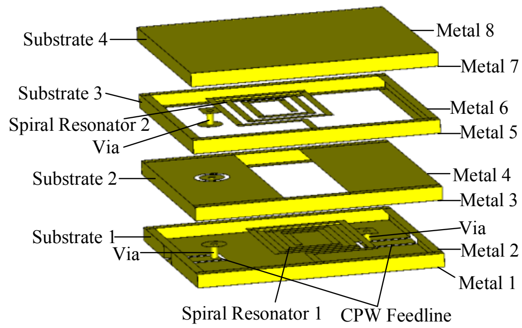

Fig. 1. 3-D-view of the proposed BPF.

In [6], a second-order multilayer self-packaged BPF with surface-mounted packaging is proposed. It achieves a compact size but has no transmission zero and with large insertion loss. At present, most reported BPFs using multilayer PCB substrates technology do not consider the connection of feedline so that the BPFs cannot be compatible with surface mounting technology (SMT) effectively.

In this paper, a miniaturized quasi-elliptic second-order BPF with two transmission zeros is proposed. Spiral quarter-wavelength short-circuited resonators are used to reduce the size of the proposed filter. In order to achieve compact size and smaller footprint, the proposed filter is implemented by stacking multilayer PCB substrates. The coupling strength between adjacent resonators can be controlled by coupling windows on the middle layer. Coplanar waveguide transmission lines are used as input and output ports to be compatible with SMT.

## II. Geometry, Analysis and Design

Fig. 1 shows the 3-D view of the proposed BPF, which consists of four-layer of substrates and eight-layer of metals. For better understanding the metal structure, the substrates in Fig. 1 are hidden. Two spiral quarter-wavelength short-circuited resonators are located on the metal 2 layer and the metal 6 layer, respectively. A coupling window which can control the coupling strength between adjacent resonators is located on the metal 5 layer. Each resonator is connected to the feed structure of the metal 1 layer through a via so that the BPF can be compatible with SMT. Fig. 2 shows some important parameters of the proposed BPF. $L$ and $w$ represent the length and width of each substrate, respectively. $W_s$ and $g$ represent the width and gap of each spiral resonator as shown in Fig. 2(a).

The operating frequency is changed by the total length of the spiral resonator. Fig. 2(b) shows the CPW feeding lines of input and output ports. $W_f$ and $g_f$ represent the physical size of the feed-lines. Fig. 2(c) shows the coupling window in metal 4 layer between two spiral resonators in metal 2 and metal 6 layers. $W_C$ and $l_c$ indicate the width and length of coupling window, respectively. The coupling coefficient ($k_{12}$) between adjacent resonators is controlled by the values of $w_c$ and $l_c$. Fig. 2(e) shows the spiral resonator in metal 6 layer. Fig. 2(d) and Fig. 2(f) show the via connecting the spiral resonator in metal 6 layer with the CPW port at metal 1 layer.

A second-order BPF with center frequency ($f_0$) of 433 MHz, fractional bandwidth (FBW) of 19% and return loss 15 dB with two TZs at 223 MHz and 910 MHz is designed as an example. The coupling mechanism is given in Fig. 3. According to [7], the normalized coupling matrix of the filter is given in (1), and the generalized coupling matric is denormalized by using the (2) and (3) [8]. According to (2) and (3), the theoretical $Q_e$ and $k_{12}$ are 7.28 and 0.165, respectively. According to [9], the external quality factor ($Q_e$) and coupling coefficient ($k_{12}$) between adjacent resonators can be extracted. Fig. 4(a) shows that as the value of $p$ increases, the external quality factor ($Q_e$) decreases. Fig. 4(b) shows that as the values of $w_c$ and $l_c$ increases, the value of $k_{12}$ increases.

$$M = \begin{bmatrix} 0 & 0.85 & -0.04 & -0.011 \\ 0.85 & 0 & 0.87 & -0.04 \\ -0.04 & 0.87 & 0 & 0.85 \\ -0.011 & -0.04 & 0.85 & 0 \end{bmatrix} \quad (1)$$

$$\mathrm{k}_{12} = \mathrm{FBW} \cdot \mathrm{M}_{12} \quad (2)$$

$$\mathrm{Q}_{\mathrm{e}} = \frac{1}{\mathrm{FBW} \cdot \mathrm{M}_{\mathrm{S1}}^2} \quad (3)$$

## III. Simulated and Measured Results

Based on above theoretical analysis, the proposed BPF is designed by using electromagnetic simulation software CST. The optimized parameters are given: $w = 25$, $l = 28$, $w_s = 0.8$, $g = 0.8$, $p = 13.9$, $r = 0.4$, $w_c = 7.2$, $w_f = 2.4$, $g_f = 0.5$, $l_c = 23$ (all in mm). Fig. 5 shows that EM simulation result is consistent with the coupling matrix response. There are two transmission zeros at the lower and upper-stopband to form a quasi-elliptic filtering response. Fig. 6 (a) shows a 3-D view of the proposed BPF with a testing CPW PCB board. Finally, as shows in Fig. 6 (b), the proposed BPF is fabricated on the substrate with a relative permittivity of 3.48, a loss tangent of 0.0037, and a thickness of 1.524 mm for each substrate layer. Fig. 6(c) shows an example of SMT using proposed BPF. The BPF module only occupies 0.075λg×0.067λg×0.016λg, where λg is guided wavelength. Fig. 7 shows the simulated and measured results. It can be seen that with or without the testing PCB board, the simulation results are almost unchanged except that the transmission zeros move slightly. Measurement results show

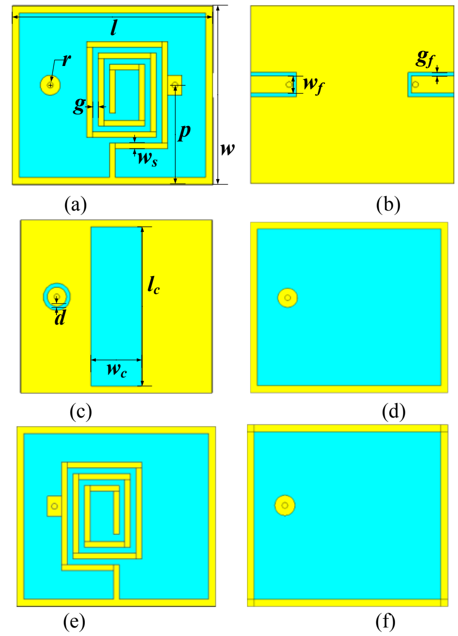


Fig. 2. Views of substrate 1, substrate 2 and substrate 3 layers. (a) Metal 2 Layer. (b) Metal 1 Layer. (c) Metal 4 layer. (d) Metal 3 layer. (e) Metal 6 layer. (f) Metal 5 layer.

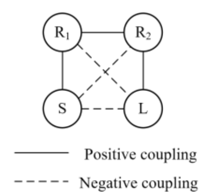


Fig. 3. Schematic topology of filter.

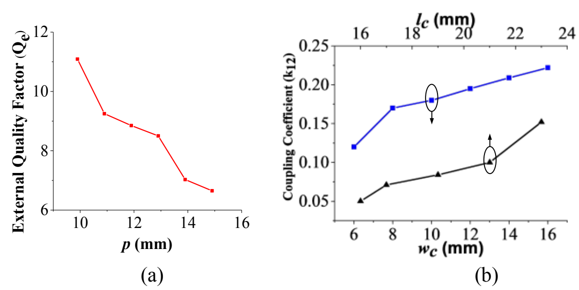


Fig. 4. Extracted external quality factor and coupling coefficient. (a) Variation of $Q_e$ under different $p$. (b) Variation of $k_{12}$ under different $w_c$.

that the operating frequency and two transmission zeros have some slight changes because of the fabrication error. At the center frequency of 433 MHz, the return loss and insertion loss are about 15 dB and 0.7 dB with a fractional bandwidth of 19%. The proposed BPF has a good selectivity due to the existence of two transmission zeros on both sides of the passband. Table I shows the comparison between the proposed BPF and other BPFs mentioned in the reference. Compared with the filters in [3], [4] and [5], the proposed BPF is more compact, whereas compared with the filters in [5] and [6], the proposed BPF has a good selectivity due to the existence of two transmission zeros. Though the [6] has smaller size, but the insertion loss is 2 times of the proposed filter. It is noteworthy that the proposed work has the smallest insertion loss among the BPFs in Table I.

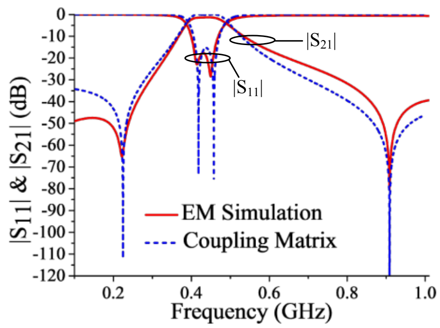

Fig. 5. Comparison of EM simulation and coupling matrix response.

TABLE I
COMPARISON WITH OTHER MULTILAYER PCB BPFS

| Reference | Order | $f_0$/FBW (GHz/%) | RL/IL (dB) | NO. of TZ | Size ($\lambda_g^3$/10^5) |
|---|---|---|---|---|---|
| [3] | 4 | 2.25/31 | 15/1 | 2 | 46.8 |
| [4] | 4 | 0.81/15.8 | 25/1.13 | >2 | 38 |
| [5] | 3 | 0.96/8 | 10/4 | 0 | 27.4 |
| [6] | 2 | 0.8/15 | 18/1.48 | 0 | 1.37 |
| **This work** | **2** | **0.433/19** | **15/0.7** | **2** | **8.24** |

$f_0$: the center Frequency; FBW: Fractional Bandwidth; RL: Return Loss; IL: Insertion Loss; TZ: Transmission Zero.

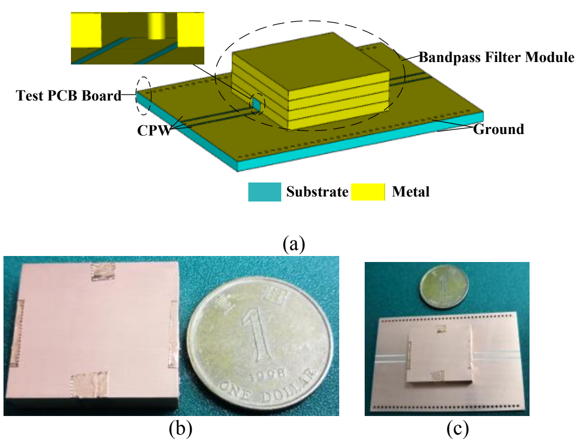

Fig. 6. (a) 3-D view of the proposed BPF with test PCB board. (b) Photograph of the fabricated BPF. (c) SMT implementation with CPW transmission line testing PCB board.

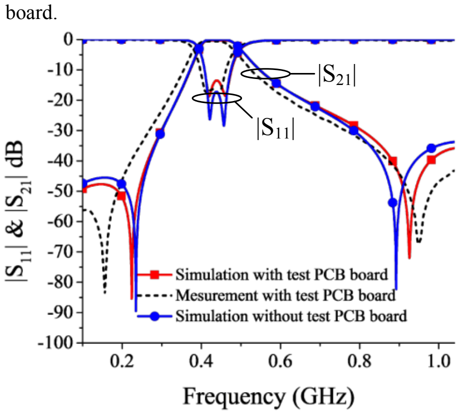

Fig. 7. Simulated and measured results of the proposed BPF.

## IV. CONCLUSION

In this paper, a miniaturized second-order quasi-elliptic response BPF by using spiral short-circuited resonators is proposed. It is implemented by using multilayer PCB substrate. Moreover, the proposed BPF can be compatible with surface mounting technology (SMT). At the center frequency of 433 MHz, the measured return loss and insertion loss are about 15 dB and 0.7 dB, respectively, with a fractional bandwidth of 19%. In addition, the proposed BPF has a good selectivity.

## ACKNOWLEDGMENT


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