Miniaturized dual-bandpass filter based on dual-mode ring and CPW feeding

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Abstract. In this paper, a miniaturized dual-bandpass filter based on dual-mode ring and
and CPW feeding is proposed. The filter is composed of two square dual-mode rings embedded with each other, and the inner ring adopts an arrow structure to realize capacitance loading to achieve miniaturization. Compared with the parallel coupling feeding structure, the CPW feeding method has design structure flexibility and better electrical performance. The designed dual-band filter is fabricated and measured to validate the present approach.

1. Introduction
To meet the requirements in the recent development of advanced multi-band wireless system, the dual-band BPF also becomes a good candidate. Microstrip filter is characterized by a high level of miniaturization, easy process characteristics such as widely used in microwave integrated circuits. In the development of multi-frequency technology, many synthetic design methods of dual-bandpass filter emerged. Multi-layer dual-mode ring resonator is used to realize dual-bandpass filter [1] and [2], which achieves miniaturization but also brings complicated design structure. In the same way, the form of stub-loaded can be used to independently design wide-bandpass dual-bandpass filter [3]. Two capacitance loaded dual-mode ring resonator are cascaded to realize dual-bandpass filter [4] and its disadvantage is its large size. To overcome size problems, several dual-band dual-ring bandpass filters were proposed on a single substrate such as coplanar-waveguide (CPW) feed network [5].

2. Square dual-mode resonator
In this paper, the resonator is adopted as a square double-mode resonator, as shown in figure.1. The structure of the resonator (a) is composed of a square ring and a small square patch. L1 is used to represent one arm length. The relation of waveguide wavelength can be expressed approximately as:

\[
\lambda_g = \frac{c}{\sqrt{\varepsilon_{\text{eff}}}} \tag{1}
\]

Where \(c\) is the light speed of vacuum, \(\varepsilon_{\text{eff}}\) is the effective dielectric constant, and \(f\) is the resonant frequency of \(L1 \approx \lambda_g/4\). The small square patch in the upper right corner is used to excite and coupling a pair of degenerate modes \(f_{01}\) and \(f_{02}\). The resonator (b) is based on the resonator (a) using an arrow structure to realize capacitive loading to reduce the size of the resonator and realize the miniaturization function.
Take (c) and (e) as an example to extract the resonant frequency $f_{01}$ and $f_{02}$ of the degenerate mode in the case of weak coupling feed, the change curves of the two resonant frequencies with $L_1$ and $L_c$ are obtained, as shown in the figure 2.

It can be seen from the figure 2, the resonant frequency $f_{01}$ and $f_{02}$ decreases as $L_1$ increases. According to the frequency extraction, the coupling coefficient of the degenerate mode can be obtained and the appropriate bandwidth filter can be designed. The resonant frequency $f_{01}$ and $f_{02}$ also decreases as $L_c$ increases, which is helpful to control the size of the resonator and realize miniaturization.

As can be seen from figure 3 and figure 4, the coupling strength of the two frequencies can be adjusted by changing the size of the perturbed patch of the dual-mode ring. The coupling strength increases with the increase of perturbation patch size.

In figure 1 (c) and (d), parallel coupling feeding and CPW feeding can be used to obtain two sets of different quality factor ($Q_e$) value change curves in figure 3. It can be seen from figure 3, the value of the quality factor of two feeding structure decreases as the coupling length $L$ increases.
From the figure 5, the CPW feeding structure obtains a wider range of \( Q_e \), and it can be used to design filters with wide or narrow bandwidths. Conversely, parallel coupling has high within a limited range and, thus, can only be applied to narrowband filter design. Therefore, the CPW feeding method has design structure flexibility and better electrical performance.

3. CPW feeding dual-bandpass filter

In the above section, the resonance characteristics of the proposed dual-mode resonator are theoretically explained, and the relationships between the modal frequencies and physical dimensions are described clearly. In this section, a dual-band bandpass filter utilizing the proposed dual-mode resonator will be designed. Figure 6 illustrates the layout of the designed filter, the capacitance loaded dual-mode ring resonator be embedded in a double-mode ring resonator, which are square patch_2 and square patch_1 respectively.

Figure 4. Parameter analysis of the \( p_o \). (The value of the main parameter: \( L1=30\text{mm}, W1=1.1\text{mm}, S1=0.5\text{mm}, L3=7\text{mm} \))

Figure 5. External quality factors parallel- and CPW coupling. (The value of the main parameter: \( L1=30\text{mm}, W1=1.1\text{mm}, L3=5\text{mm}, S1=0.15\text{mm}, L4=3\text{mm} \))

Figure 6. (a) Structure of the proposed dual-band filters by CPW feeding. (b) Structure of feeding structure.
The specific structure and size are shown in figure 6 and figure 7. The value of the main parameter is: L1=30, L2=20, W1=1.1, W2=1.1, W_p_0=1.1, p_0=0.6, W_p=1.13, p=0.63, S1=0.4, L_c=6.1, W_c=0.5, L4=9.2, L5=9.61, L6=19.49, L7=19, W3=2.2, W4=2.59, W5=2.2, W6=2.61, g1=1.7, g2=0.1. All units are in millimeters.

FEKO was used for all the simulation. According to the results shown in figure 8, the 3 dB bandwidth of the first bandpass was from 1.41 GHz to 1.48 GHz, and the 3 dB bandwidth of the second bandpass was from 1.83 GHz to 1.92 GHz. Through the I/O coupling structure, four transmission zeros (TZs) are formed in 1.22 GHz, 1.53 GHz, 1.7 GHz and 2.12 GHz respectively greatly increase the out-of-band rejection. It can be seen from figure 8 that the first bandpass is two transmission poles and the return loss is -20 dB. The second bandpass also has transmission two poles and the return loss is also about -20 dB.

### TABLE I COMPARISON WITH OTHER CIRCUIT TOPOLOGIES

|      | FBW₁ | FBW₂ | SIZE       |
|------|------|------|------------|
| [2]  | 2.9% | 2.3% | 1.1λ × 0.83λ |
| [4]  | 7.5% | 5.43%| > 0.3λ × 0.3λ |
| [5]  | 10.6%| 3.6% | 0.25λ × 0.25λ |
| This work | 4%   | 4.2% | 0.17λ × 0.17λ |
4. Fabrication and measurement
To verify our proposal, a dual-mode dual-band bandpass filter by CPW feeding is designed and implemented on Rogers RO4350 substrate with a dielectric constant of 3.66 and a thickness of 0.508 mm.

![Figure.10. Photograph of the proposed filter. (a) Top layer. (b) Bottom layer.](image)

It can be observed that a shift in the center frequencies of the two passbands is between the simulated and measured results in the figure.9, which maybe attributed to the fabrication tolerances. The measured center frequency of the lower passband is 1.43 GHz, whereas the upper passband is center at 1.88 GHz. In the dual passbands, the measured 3 dB fractional bandwidths (FBWs) of the lower and the upper passbands are about 4.9 and 3.7%, respectively. Both of the return losses of the two passband are >20 dB. In addition, five transmission zeros appear at 1.2, 1.52, 1.7, 2.17 and 2.35 GHz, which improve the out-of-band performance of the filter. Table 1 compares the circuit size between the previous designs and our proposed filter. Distinctly, the total size of the proposed filter is compact.

5. Conclusion
In this letter, a miniaturized dual-band BPF centred at 1.41 and 1.48 GHz has been proposed and studied. The relationship between the frequency and the arrow structure double-mode ring is analyzed. It has the function of equivalent capacitance loaded to achieve miniaturization. By comparing CPW feeding with parallel coupled feeding, CPW feeding has a wider quality factor range. Good agreement has been realised between the measured and simulated results, showing great potential in high-quality and integrated dual-band communication applications.

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