Novel bandpass filter with high selectivity and very wide stopband using open stub loaded and DGS

Guoan Wu, Xiang Zhang, and Wenguang Li
School of Optical and Electronic Information, Huazhong University of Science and Technology, NO. 1037, Luoyu Road, Wuhan, 430074, China
a) 13006133089@163.com

Abstract: A novel bandpass filter (BPF) based on half-wave-length (λ/2) stepped-impedance resonators (SIRs) is proposed in this paper. By properly designing the impedance ratios of the SIRs, the spurious harmonics of the filter can be pushed to upper frequency. With several bandstop structures such as open stubs and defected ground structures (DGSs) applied to the BPF, a good stopband performance is obtained. Moreover, 0° feed structure is used to improve the selectivity of the BPF. Then a BPF which has high selectivity and wide stopband is implemented. Measured results show good agreement with the simulated results.

Keywords: BPF, widestopband, high selectivity, DGS

Classification: Microwave and millimeter-wave devices, circuits, and modules

References

1 Introduction

Microstrip bandpass filters (BPFs) with low insertion loss, compact size, high-frequency selectivity and wide stopband are key components of wireless communication systems. The BPFs with excellent out-of-band rejection are necessarily required in order to eliminate the unwanted interference or noise in the stopband. Several measures are taken to improve the rejection of stopband. A direct way for stopband suppression is to cascade the bandstop [1, 2, 3, 4, 5] structures into the BPFs. But these extra structures will enlarge the circuit size and the insertion loss. SIRs are now widely used to minimize the spurious response of the filter [6]. By using SIRs, the lower spurious harmonics can be shifted away from the fundamental frequency, but has a limited rejection at upper stopband. Other methods to suppress spurious were also proposed. By employing a different perturbation in coupled-line section [7] is an effective method to realize spurious rejection. Photonic-bandgap (PBG) [8] structures and defected ground structures (DGSs) [9] are recently adopted to extend the stopband. All above these methods present limited rejection and BPFs with wide stopband is still challenging.

In this letter, a novel ultra-wide-stopband BPF based on two $\lambda/2$ SIRs and several bandstop structures is proposed. The split-end SIRs are used to push the spurious harmonics to the upper frequency and overcome the coupling surface limitation, the rectangular open stubs, stepped-impedance stubs, double U-shaped DGSs are designed to suppress spurious harmonics, so that a BPF with an ultra-wide stopband can be achieved. What’s more, the use of $0^\circ$ feed structure improves the selectivity of the BPF. Simulated and measured results are given and show good agreements.

2 Filter design and analysis

The proposed ultra-wide-stopband BPF is based on a second-order BPF with several bandstop structures loaded. Fig. 1(a) and (b) show the layout of the filter. In order to get a BPF with a better stopband performance, $\lambda/2$ SIRs [6] are adopted in the design. Moreover, in order to enhance interstage coupling, the ends of $\lambda/2$ SIRs can
be split and folded as shown in Fig. 1(a), thus more coupling area is available between two resonators.

Based on the above theory model and the synthesis method of coupling matrix, a BPF is designed. The BPF has a center frequency of 1.3 GHz and a 3 dB bandwidth with a relative value of 6%. Thus the normalized coupling matrix including source coupling and load coupling can be derived and show in (1):

\[
M = \begin{bmatrix}
0 & 1.22 & 0 & 0 \\
1.22 & 0 & 1.66 & 0 \\
0 & 1.66 & 0 & 1.22 \\
0 & 0 & 1.22 & 0 \\
\end{bmatrix}.
\]

Thus the coupling coefficients and external Q can be figured out by using the follow expressions (2):

\[
m_{ij} = \text{FBW} \cdot M_{ij}, \quad Q = \frac{1}{\text{FBW} \cdot M_{s1}^2}.
\]

For the proposed filter: \( Q_s = Q_l = 11.0, \ k_{12} = 0.1 \). Furthermore, the 0° feed structure [10] is applied to the proposed BPF. When the filter is designed with different tapped-line feed points as shown in Fig. 1, meanwhile the electrical delay of the lower coupling paths is same as the upper ones at the fundamental resonant frequency. This not only will not change the passband response but also improves the selectivity since two transmission zeros are created near the passband. EM simulation software is employed to evaluate and adjust the frequency responses of the BPF. So far the basic BPF design is finished. The analysis is verified by the simulated results of the BPF as Fig. 2 shows. The stopband characteristics are improved at the lower stopband, but the rejection level from 3 to 5 GHz and 9 to 12 GHz remain to be improved.

The stopband characteristics are improved at the lower stopband, but get worse at the higher stopband. In order to get a better stopband performance, several
bandstop structures are applied to the basic BPF. The step-impedance stub (SIS) structure is used to improve rejection level of the stopband from 3 to 5 GHz as shown in Fig. 3(a). Two SISs with different sizes are placed at the appropriate places and by tuning the parameters shown in Fig. 3(a) of each structure, the transmission zeros can be moved to the desired position. Meanwhile, in order to suppress the spurious passbands in the vicinity of 10 GHz, open stubs shown in Fig. 3(b) with different sizes are applied in this study. By placing a \( \lambda/4 \) open stub in parallel with the tapped-line, one transmission zero can be generated due to the inherent resonant characteristics of \( \lambda/4 \) transmission line, where \( \lambda \) is the wavelength at resonant frequency. By tuning the parameter, two transmission zeros can be relocated around 10 GHz to improve the stopband performance.

![Fig. 2. Simulated S-parameters of the basic BPF](image)

Fig. 2. Simulated S-parameters of the basic BPF

![Fig. 3. Simulated S-parameters of several bandstop structures with dimensions (all units are in mm) (a) step-impedance stub (SIS: \( s_{l3} = 3.2, s_{l4} = 4.3, s_{w3} = 2, s_{w4} = 7.8; \) SIS1: \( s_{l3} = 3.6, s_{l4} = 3.5, s_{w3} = 2, s_{w4} = 6 \)). (b) open stub (Stub1: \( a = 5, b = 2, \) Stub2: \( a = 4.6, b = 1.9 \)). (c) double U-shaped DGS (DGSU: \( d_{w1} = 0.7, d_{w2} = 0.7, d_{w3} = 0.7, d_{w4} = 0.7, d_{l1} = 10.2, d_{l2} = 4.8, d_{l3} = 5.4, d_{l4} = 2.8, d_{s1} = 1.7, d_{s2} = 1.3; \) DGSU1: \( d_{w} = 0.7, d_{w2} = 0.7, d_{w3} = 0.8, d_{w4} = 0.8, d_{l1} = 7.6, d_{l2} = 4.3, d_{l3} = 4.6, d_{l4} = 3.5, d_{s1} = 0.8, d_{s2} = 1.4 \)).](image)
With several bandstop structures applied to the BPF, the spurious harmonics at certain frequencies can be suppressed. In order to further improve the rejection level of the whole upper stopband, the double U-shaped DGSs modified from CSRR in [11] has been used. Fig. 3(c) shows the characteristics of the proposed structure. As Fig. 3(c) shows, the double U-shaped DGS offers more transmission zeros than CSRR and distribute in a wide band. By tuning the parameters shown in Fig. 3(c), these transmission zeros can be redistributed, thus the stopband performance can be improved effectively.

Several measures have been taken to improve the stopband performance, the double U-shaped DGSs can improve the stopband performance without influencing the passband, but other two structures may lead a higher insertion loss and bad mismatching. By using the DGST and DGST1 shown in Fig. 1(b) can change the equivalent capacitance due to the distribution of the field is changed. Fig. 4 shows the influence of these two structures on the passband responses. Obviously a good match is obtained.

![Simulated passband frequency responses of the BPF influenced by DGST&T1](image)

Fig. 4. Simulated passband frequency responses of the BPF influenced by DGST&T1

### 3 Implementation and measurement

Based on the above analyses, a wide stopband BPF is implemented on Rogers RT 5880 with dielectric parameter of 2.2, conductor thickness of 17 um and substrate thickness of 0.76 mm. Its overall circuit size occupies 0.36 $\lambda_g \times 0.3 \lambda_g$. Fig. 5 shows the photograph and the S-parameters of the BPF. As shown in Fig. 5(a), the measured center frequency is located at 1.32 GHz, the minimum insertion loss in the passband is about 1.1 dB and the fractional 3 dB bandwidth is 6.0%. The return loss within the passbands is better than 23 dB. Two transmission zeros located at 1.16 GHz and 1.71 GHz are generated to improve the frequency selectivity. Fig. 5(b) shows the spurious harmonics are suppressed from 1.46 up to 26.5 GHz with a rejection level better than 20 dB. As the listed insertion loss and return loss shown in Table I, the proposed BBF has a better in-band performance. The center frequency and rejection level give the certain stopband range, and the designed BPF presents a better stopband performance.
In this letter a second-order BPF based on the $\lambda/2$ SIRs and several bandstop structures has been proposed, analysed and implemented. Due to the use of SIRs and several bandstop structures, the proposed filter has an ultra-wide stopband to above 20 times of the center frequency. The measurements shows low insertion loss, high return loss and high selectivity. With these good characteristics, the proposed filter is applicable for modern wireless communication systems.

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