Design of Dual-Band Bandpass Filter with Controllable Bandwidths

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1. Introduction

Dual-band operation for RF systems has been widespread in modern wireless communication systems to enhance the functionality and capacity. In these systems, high-performance dual-band bandpass filters (BPFs) are heavily demanded to suppress unwanted signals. In response to this requirement, much research work has been conducted and various design approaches have been proposed [1]-[7]. Among them, two kinds of methods are very popular. The first category is to combine two sets of resonators with common input and output ports [1]-[3]. The passband frequencies can be easily tuned by changing the dimensions of the corresponding resonators. Using proper configurations, the required external quality factors and coupling coefficients can be simultaneously obtained at two passbands and hence the bandwidths can be independently controlled. Although it is easy to meet the performance requirement, the structures are relatively complex and the size is bulky. The second category is to make use of resonators' fundamental resonant frequency and the second harmonic to generate two passbands [4]-[7]. A typical example is to use stepped-impedance resonators (SIRs) to design dual-band filters. By controlling the impedance and length ratios of SIRs, desirable operating frequencies can be obtained. However, it is difficult to control the bandwidth of each passband.

In this letter, a novel method for designing dual-band BPFs with controllable bandwidths is proposed. The filters utilize stub-loaded resonators. The stubs, loaded at the center of open-ended microstrip lines, affect only the upper passband performance and have no impact on the lower passband behavior. Hence, the coupling path formed between the stubs only deliver signals at the upper passband frequency. The other coupling path can be used to adjust the coupling strengths at both passband frequencies. By properly controlling the coupling strength at each path, the desirable coupling coefficients at both passbands can be obtained and hence the bandwidths can be controlled. Furthermore, by using the stub-loaded resonators [7], the passband frequencies can be easily tuned. Therefore, both the frequency and bandwidth of each passband can be easily controlled. Based on the proposed idea, two BPFs are implemented. The design methodology and experimental results are presented.

2. Filter Design

The proposed BPFs are designed using stub-loaded resonators with two coupling paths. The filter topology and design methodology are addressed as follows.

2.1 Filter Topology

Fig. 1 shows the configuration of the proposed microstrip dual-band BPF. This is a second-order filter utilizing two stub-loaded resonators [7]. The open stub is loaded at the center of the stepped-impedance line and the line is symmetric with respect to the stub. The two open stubs are coupled to each other, forming a coupling path denoted by path 1. The other coupling path, path 2, is near the open ends of the stepped-impedance lines. Two 50 Ω lines are tapped at the resonators, acting as the input and output ports.

The fundamental odd- and even-mode resonant frequencies of the stub-loaded resonators are used to determine the lower and upper passband frequencies. As analyzed in [7], the voltage at the line center is zero at the odd-mode resonant frequencies. Hence, the lower passband frequency is not affected by the open stubs and only determined by the length and impedance of the line. The open stub affects only the even-mode resonant frequencies and can be used to control the upper passband frequencies.

The bandwidths of the proposed dual-band BPFs are affected by the two coupling paths. As stated above, the voltage at the line center is zero at the lower passband frequency. Hence, path 1 cannot deliver signals at lower passband frequency. This is indicated by the simulated current distribution as illustrated in Fig. 2. As can be seen, the current goes through the stubs only at the upper frequency. Hence, path 1 affects the coupling strength at the upper frequency and has no impact on that at the lower frequency. In contrast, path 2 can couple signals at both lower and upper passband frequencies. Hence this path will affect the coupling strengths at both frequencies. By properly controlling the coupling strengths at the two paths, the desirable coupling coefficients at both passbands can be achieved. Besides coupling coefficients, the external quality factor, Q_e, also affects the bandwidths. In this design, Q_es at the two passbands are mainly determined by the tap position of the ports and the line widths of various resonator sections [8]. Hence, Q_es at the two passbands can be tuned to desirable values within a certain range. As a result, the bandwidths can be controlled by tuning the coupling coefficients and Q_es at the two passbands.

2.2 Design Methodology

To design the proposed filter, the first step is to tune the passband frequencies to desirable values. As stated above, the open stub will not affect the lower passband frequency. Therefore we first determine the lower frequency by changing the lengths and widths of two sections of the stepped-impedance line. The electric length of the line is half guided wavelength at the lower frequency. Then, the stub length is determined based on the required upper passband frequency.

The second step is to determine the dimensions of the coupling regions and tap position of the ports. As can be seen from Fig. 2, the dimension of coupling path 1 does not affect the upper passband behavior. When the length LC of coupling path 1 is tuned, the upper passband bandwidth can be controlled whereas the lower passband remains unaltered. Hence, we firstly meet the bandwidth requirement of the lower passband.

This can be achieved by changing the dimensions of coupling path 2 and the tap position of the ports. The detailed method is described in [8]. After this, the dimensions of coupling path 1 are tuned to fit the coupling coefficient requirement at the upper passband frequency. As for the Qe, we can fine tune the tap position and the line width of different resonator sections to control it. Since these parameters will affect the performance at both passbands, optimization is then followed to fulfill the requirements of both passbands.

3. Experiments

Following the design methodology, two dual-band BPFs, denoted as Filters I and II, are implemented with different bandwidths. Both the two filters are fabricated on a substrate with a relative dielectric constant of 6.15 and thickness of 0.635 mm. The simulation and measurement are accomplished using IE3D and 8753ES network analyzer, respectively.

Filter I is designed with narrower lower passband and wider upper passband, i.e., $\Delta 1$=4.5% and$\Delta 2$=5.5%. The dimensions are tabulated in Table 1. Fig. 3(a) plots the simulated and measured results. The lower passband is centered at 1.6 GHz, with the 3 dB fractional bandwidth (FBW) of 4.5%. The insertion loss is measured at 1.46 dB. The upper passband has the center frequency of 2.45 GHz and 3 dB FBW of 5.6%. The measured insertion loss is 1.16 dB. The measured return loss in the two passbands is greater than 12 dB. Two transmission zeros are generated near the passband edges, resulting in high selectivity. There are some slight discrepancies between simulated and measured results, which are primarily due the fabrication tolerance.

Filter II is designed with the bandwidths: Δ1=5.5% and Δ2=4.5%. The results are illustrated in Fig. 3(b). Similar to Filter I, this filter has the two passbands are centered at 1.6 GHz and 2.45 GHz. The lower and upper passbands have the 3 dB FBW of 5.6% and 4.6%, respectively. The measured insertion loss of both passbands is around 1.33 dB and the return loss is greater than 12 dB.

For comparison, the bandwidths of the two filters are compared in Table 1. It is seen that various FBWs have been obtained, indicating that the bandwidths can be controlled.

4. Conclusion

This paper has presented a novel method for designing dual-band filters with controllable bandwidths. Two coupling paths are adopted between the two esonators. One path is for controlling the coupling strengths at both passbands whereas the other path is only for the upper passbands. Using these two paths, the bandwidths of both passbands can be tuned to desirable values. The design methodology has been described and two example filters have been implanted. The results have been presented to verify the proposed method.

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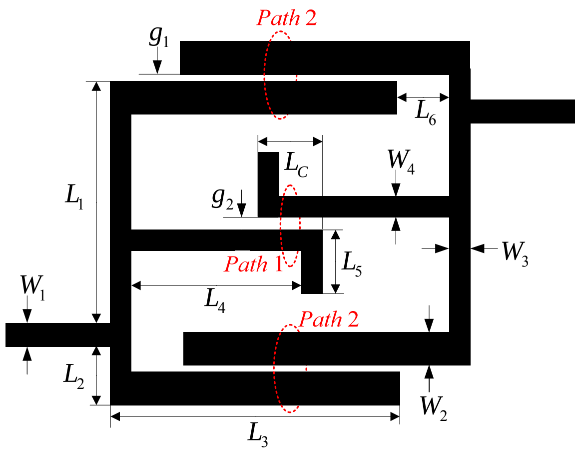


Figure 1. The configuration of the proposed microstrip filter.

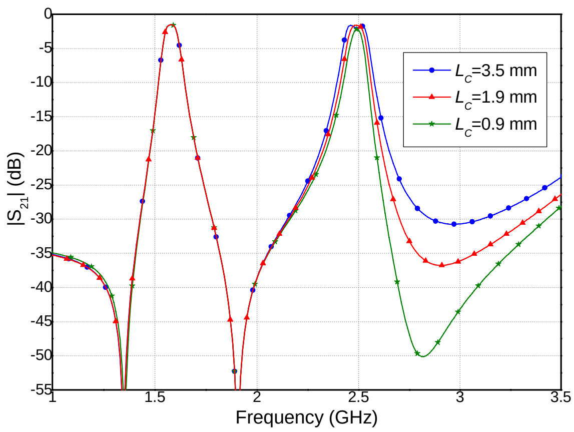
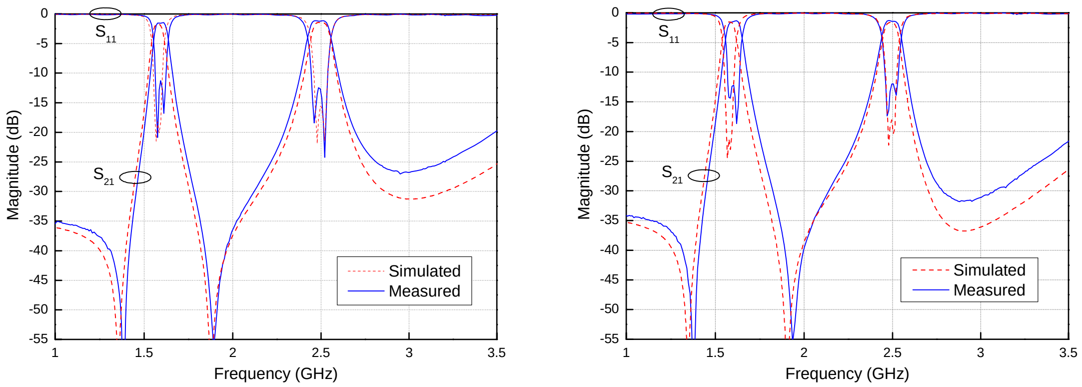


Figure 2: Bandwidths versus coupling length LC.



(a) (b)

Figure 3: Simulated and measured responses. (a) Filter I. (b) Filter II.

Table 1
Bandwidth Comparison of the Implemented Filters

Filter	Lower passband	Upper passband
Filter I	4.5%	5.6%
Filter II	5.6%	4.6%

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