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THIRD-ORDER DUAL-BAND BANDPASS FILTER WITH CONTROLLABLE BANDWIDTHS USING SHORT STUB-LOADED RESONATORS

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Abstract—A compact microstrip-line dual-band bandpass filter using a short stub-loaded resonator is presented. The resonator is formed by loading one short stub in shunt to a simple uniform impedance line. A key merit of the filter configuration is that the center frequency and bandwidth of the first passband can be conveniently controlled by properly adjusting the lengths of the short stubs and the coupling between the short stubs, whereas those of the second passband are fixed. To illustrate the concept, a third-order dual-band filter is designed, fabricated and measured. Simulated and measured results are found to be in good agreement with each other.

1. INTRODUCTION

In recent years, various dual-band bandpass filters have been extensively studied and developed to meet requirements in modern multiband wireless communication systems [1]. Much research work was conducted, and various design approaches were proposed. Lately, it is popular to design the dual-band filters using stepped impedance resonators [2–10] and stub-loaded resonators [11–20] mainly because of their easily controlled resonant frequencies.

The dual-band (or tri-band) filters were designed using centrally loaded resonators proposed in [11–16], where only the second-order filters were considered. In [17], the open-loop resonators loaded by the shunt stubs were proposed to design the compact high-order dual-band filters, but the bandwidths of the two passbands can't be controlled independently. The dual-band filters with controllable bandwidths

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were designed using the stub loaded resonators proposed in [18, 19], this design is much more flexible, but can hardly extend to high-order filters with controlled bandwidths. In [20], a novel multi-stub loaded resonator suitable for high-order dual-band filter applications was proposed, however, these filters are of a larger size because open stubs were used.

In this letter, a third-order dual-band filter with controllable bandwidths is proposed. The filter utilizes three short stub-loaded resonators [13, 16] and the passband frequencies can be easily tuned. Two coupling routes are utilized. One route delivers only the signals at the lower passband frequency and the other is able to transfer signals at both passbands. By properly tuning the coupling strength at each route, the desirable coupling coefficients at both passbands can be obtained, and thus the bandwidths of both passbands can be controlled. Based on the concept, a third-order dual-band filter is implemented. The design methodology and experimental results are presented.

2. FILTER DESIGN

Recently, the authors have presented a cascaded triplet (CT) filter using $\lambda/4$ resonators [15]. Figure 1 shows the structure of the CT filter, three $\lambda/4$ resonators are combined together to form a special CT unit. The via hole that connects the microstrip line and the ground plane is denoted by a circle. The input and output feeding lines are coupled at the edge of the resonators.

In [15], the bandwidth of the CT filter can be changed by tuning

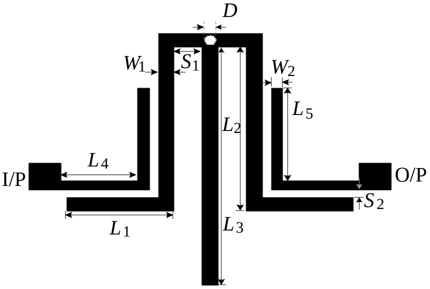


Figure 1. Structure of the CT filter. $L_1 = 6.8$, $L_2 = 12.5$, $L_3 = 21.15$, $L_4 = 4.9$, $L_5 = 7.05$, $S_2 = 0.2$, $W_1 = 1$, $W_2 = 0.7$, $D = 0.9$, all are in millimeter.

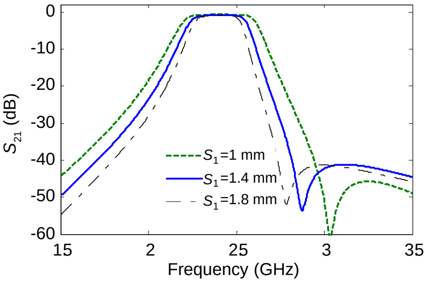


Figure 2. Simulated S_{21} of the CT filter under different coupling space S_1.

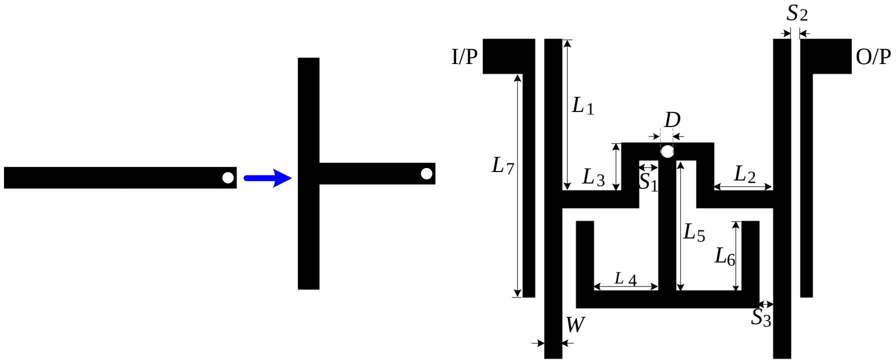
the ground via diameter. Similarly, the bandwidth of the filter can be changed by tuning the coupling space between resonators. Figure 2 shows the simulated insertion loss responses under different S_1, the bandwidth can be adjusted effectively by tuning S_1, meanwhile the port coupling should be changed to accommodate the bandwidth.

To obtain a dual-passband response, a short stub-loaded resonator is introduced to replace the $\lambda/4$ resonator, as shown in Figure 3(a). The short stub is loaded at the center of the uniform impedance line. The resonator is symmetrical and thus odd- and even-mode analysis can be used to characterize it, as detailed in [13, 16].

The first two resonant frequencies of the short stub-loaded resonators are used as the lower and upper passband frequencies, f_1 and f_2, namely. Following the analysis in [13, 16], it is found that f_2 is only determined by the uniform-impedance line and the short stub only affects f_1.

Figure 3(b) shows the configuration of the third-order dual-band bandpass filter. The filter utilizes three short stub-loaded resonators as illustrated in Figure 3(a). The three short stubs are coupled with each other, forming an additional coupling path to tune the bandwidths of the dual-band filter. The coupled-line structure is employed to realize the input/output coupling because it has more degrees of freedom in the design process as illustrated in [20].

The dual-band filter is to be designed on a substrate with dielectric constant $\varepsilon_r = 2.55$, loss tangent $\delta = 0.0029$, and thickness $h = 0.8\,\text{mm}$. Let the designed frequencies be at 2.4 and 5.7 GHz and both passbands have 0.1-dB ripple level.



(a) (b)

Figure 3. (a) Resonator transformation. (b) Layout of the third-order dual-band filter.

The starting dimensions of the dual-band filter can be obtained from the frequency ratio (f_2/f_1), the optimized parameters of the filter are: $L_1 = 8.9$, $S_1 + L_2 = 4.7$, $L_3 = 2.8$, $L_4 = 3.85$, $L_5 = 7.7$, $L_6 = 4.1$, $L_7 = 13.2$, $S_2 = 0.2$, $W = 1$, $D = 0.9$, all are in millimeter.

The center frequency of the first passband can be tuned conveniently by adjusting the short stub length. As shown in Figure 4, by changing the short stub length L_5 (L_2 and L_3 should be varied accordingly), the first passband frequency can be shifted within a wide range, whereas the second passband frequency remains fixed.

There are two kinds of coupled sections among the dual-band filter, the coupling between the short stub (S_1) and the coupling between the uniform impedance lines (S_3). As detailed in [19, 20], the required bandwidth of the first passband is codetermined by the coupling between the short stubs and the coupling between the uniform-impedance line, and the bandwidth of the second passband is

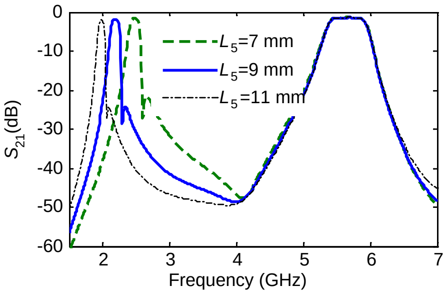
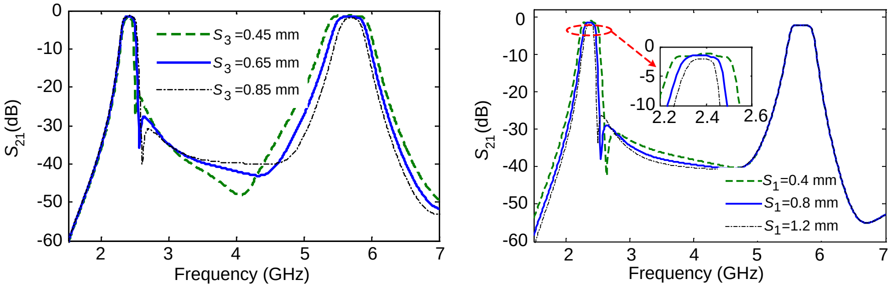


Figure 4. Simulated S_{21} of the dual-band filter under different short stub length L_5.



(a) (b)

Figure 5. Simulated S_{21} of the dual-band filter under different coupling space. (a) S_3. (b) S_2.

dominated by the coupling between the uniform-impedance line. To verify the above analysis, different coupling parameters are presented for demonstration. When S_3 varies from 0.45 mm to 0.85 mm (with all the other parameters are fixed), the bandwidth of the second passband decreases obviously (10.9%–6%), while the bandwidth of the first passband varies a little, as shown in Figure 5(a) When S_1 varies from 0.4 mm to 1.2 mm (with all the other parameters are fixed), the bandwidth of the first passband decreases obviously (11.9%–6%), while the bandwidth of the second passband stays fixed (6.6%), as shown in Figure 5(b).

According to the discussion, the design procedure of this kind of dual-band filter can be summarized as follows. Firstly, deduce the short stub length of the resonator according to the frequency ratio (f_2/f_1). Secondly, tune the coupling between the uniform impedance lines to satisfy the bandwidth of the second passband. Thirdly, tune the coupling between the short stubs to satisfy the bandwidth of the first passband. Finally, select proper input/output coupled-line to meet the required Q_e (external quality factor) of each passband. Based on this procedure, a compact dual-band filter of third-order is designed in Section 3.

3. MEASUREMENTS

A dual-band filter with a third-order Chebyshev frequency response and 0.1-dB ripple level is designed with the following specifications: the center frequencies of the two bands (f_1, f_2) are 2.4, 5.7 GHz. The fractional bandwidths are 0.045 and 0.045, respectively.

The coupling coefficients and Q_e can be deduced based on the specifications: $K_1 = K_2 = 0.04132$, $Q_{e1} = Q_{e2} = 22.92$, where K_1 denotes the coupling coefficient between the first and second resonators at f_1, and K_2 denotes the coupling coefficient between the first and second resonators at f_2.

As the physical parameters of the resonator have been obtained in the previous Section, the coupling space between the uniform-impedance lines should be determined firstly according to K_2. $S_3 = 0.45$ mm (the coupling length L_6 is set as 3.7 mm) can be obtained quickly using full wave simulations. Then determine the coupling space between short stubs according to K_1 : $S_1 = 0.65$ mm. Finally, select proper input/output coupled-line parameters according to Q_{e1} and Q_{e2}. The optimized parameters of the dual-band filter are: $L_1 = 8.9$, $L_2 = 4.05$, $L_3 = 2.55$, $L_4 = 4.25$, $L_5 = 7.5$, $L_6 = 3.7$, $L_7 = 11.7$, $S_2 = 0.2$, $W = 1$, $D = 0.9$, all are in millimeter.

Figure 6 presents a photograph of the fabricated filter, and the

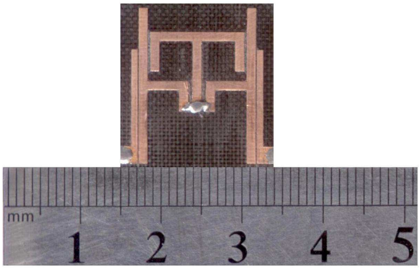


Figure 6. Photograph of the fabricated dual-band filter.

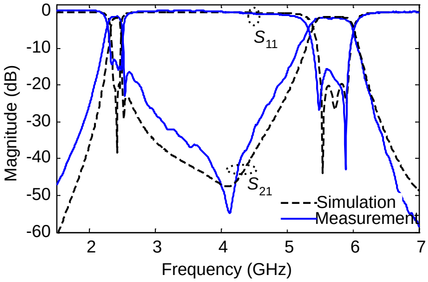


Figure 7. Simulated and measured results of the dual-band filter.

size of the filter is about 19 mm × 18.5 mm, approximately $0.22\lambda_g$ by $0.215\ \lambda_g$, where λ_g is the guided wavelength on the substrate at the center frequency of the first passband. The third-order filter size is reduced greatly compared with the dual-band filter using open stub-loaded resonators (33 mm × 24 mm) proposed in [20] with the similar specifications and same substrate.

The measured frequency responses of the proposed dual-band bandpass filter were obtained using a HP N5230A vector network analyzer. Figure 7 shows the simulated and measured S-parameters. The measured S-parameters agree well with those obtained from the simulation. The measured 3 dB bandwidths for the two passbands centered at 2.4, 5.7 GHz are found to be 2.263 to 2.496 GHz, 5.315 to 5.996 GHz, respectively. The minimum insertion losses measured for the two passbands in the same sequence are 1.37 and 1.73 dB. The two passbands are separated by a 30-dB stopband extending from 3.1 to 4.56 GHz.

4. CONCLUSION

In this paper, a short stub-loaded resonator suitable for third-order dual-band filter application is proposed, analyzed and verified experimentally. The passband frequencies of the proposed filter are flexibly controlled, and the bandwidth of the first passband can be tuned conveniently by adjusting the coupling between the short stubs while that of the second passband remains the same. The experimental results have shown that the proposed resonators will be useful for dual-band bandpass filter applications of compact size.

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