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A novel tri-band filter realization via band-splitting technique

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Abstract: This letter presents a novel microstrip tri-band filter in which a shunt-stub bandpass filter and a dual-band bandstop filter are integrated into a single structure of short length. The two stopbands of the bandstop filter are allocated within the wideband passband of the bandpass filter, resulting in a filter having three passbands. Good return loss is obtained using an optimization routine. This technique has high flexibility on setting the bandwidths and center frequencies of passbands. A prototype filter is designed and fabricated. Good agreements between simulation and measurement in respect of low insertion loss and high isolation are demonstrated.

Keywords: shunt stub filter, dual-band bandstop filter, tri-band filter, band-splitting technique.
Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

Recently with the fast development of various communication systems, multi-mode or multi-band hardwares that can support two or more systems simultaneously with good isolation between bands are becoming popular. Tri-band filters are one kind of key components in these systems. Various configurations have been proposed to realize tri-band filters. [1] arranged three sets of resonators for realizing three passbands with high complexity and large dimension. To reduce circuit size, the number of resonator sets are decreased to two, one set of dual-mode resonators operate at two passbands and one set of single mode resonators at the third [2, 3]. Tri-mode resonators are adopted to tri-band filter design for higher circuit efficiency [4, 5, 6]. In [4] tri-section stepped impedance resonators (SIR) technique is utilized to design tri-band filter with compact dimension. A kind of stub-loaded tri-mode resonator is proposed to construct tri-band filter with transmission zeroes between the passbands [5]. T-shape tri-mode resonators connected by transmission lines are used to realize tri-band filters with good features such as wide bandwidths and configurable bandwidth ratios [6].

A band-splitting technique was firstly implemented with a serial combination of bandpass filter and bandstop filter for realizing two widely spaced passbands with features of flexible bandwidths but at the expense of large dimension [7]. This technique was improved by directly embedding the elements of a bandstop filter into a bandpass filter, which results in dual-band filter with half length [8]. This letter extends the technique to realize a tri-band filter by integrating a dual-band bandstop filter (DBBSF) inside the circuit of a stub bandpass filter with the help of optimization technique. The novel tri-band filter has the same length as the stub bandpass filter with advantages of high circuit efficiency and design flexibility.

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2 Schematic of the Tri-band Filter

Fig. 1 (a) shows the topology of a wideband shunt-stub BPF, in which, several short-circuited stubs are cascaded by $\lambda/4$ transmission lines [9]. The short-circuited stubs act as resonators and the connecting lines are used to implement admittance or J inverters, realizing tight couplings between resonators. The fractional bandwidth of a short-circuited stub filter can be over 100% as the characteristic impedances of the stubs are becoming high enough.

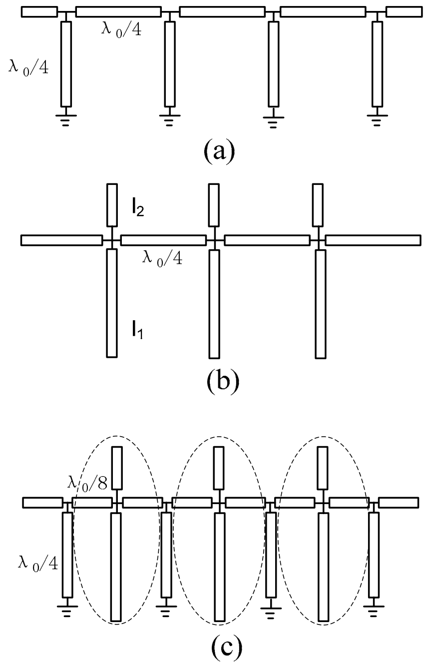

Fig. 1. Filter topologies: (a) Shunt stub bandpass filter; (b) Dual-band bandstop filter; (c) Tri-band filter.

Fig. 1 (b) is the circuit of a dual-band bandstop filter where composite resonators are connected by 90 degree transmission lines at a frequency between the two bands [10, 11]. Each composite resonator contains two open-circuited stubs whose lengths decide the frequencies of the stop bands:

$$f_{sn} = \frac{c}{4l_n\sqrt{\varepsilon_{reff}}} \qquad n = 1, 2 \tag{1}$$

Here c is light velocity and ε_{reff} is effective dielectric constant of transmission lines.

Fig. 1 (c) is a mixture circuit of Fig. 1 (a) and Fig. 1 (b) in which the composite resonators of the DBBSF are loaded to the centers of the connecting lines of the BPF. The DBBSF and BPF are integrated into one structure, sharing the same main line and the wide passband of BPF is split by the two stopbands of DBBSF into three passbands. An explanation is given below.

A $\lambda/4$ connecting line in Fig. 1 (a) can be approximately regarded as a wideband J inverter. Being loaded with two open-stubs of different lengths as shown within the dotted ellipse, the connecting line becomes dual-defected J

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inverter that signal transmission is forbidden at two bands. It is because the input impedances of the two open stubs respectively reach zero at one band and the loading point of the composite resonator is equivalent grounded, which results in full reflection of signal and thus transmission zeros. At frequencies with enough distance from the two stopbands, signal transmission is only weakly affected and passband can be maintained. As a result, the wide passband of BPF is tailored and three passbands achieved.

Due to circuit complexity and mutual affection between BPF and DBBSF parts, theoretical synthesis approach to the tri-band filter is difficult and optimizing method is used for the design. BPF with proper bandwidth covering all the three passbands of a tri-band filter should be designed, thus decide the initial dimensions of the short-circuited stubs and the connecting lines; According to frequencies of the notch bands, we can give initial lengths for the open-stubs and set the initial characteristic impedances to be high enough that the initial notch widths are small. All lengths and widths are then extracted by optimization.

3 Experiment results and discussion

A prototype tri-band filter with three passbands located at 1.05-1.3, 1.85-2.05 and 2.75-2.9 GHz is worked out by a gradient optimization tool which is integrated in Ansoft Serenade 8.7. The passbands are set by requiring the corresponding return loss to be low enough in the optimization goals. Optimization goals also specify the rejections outside of the passbands. The optimization is based on circuit model analysis thus much faster than using EM simulation. Due to the numbers of goals and unknowns are big, suitable optimization strategy and sequence are needed. At the beginning we emphasis on making the center frequencies and bandwidths to be as specified while the isolations between bands are of minor care. Then optimization goals are modified with the isolations strengthened. It is better to tune the goal data gradually, ensuring the responses being improved smoothly. Good simulation results of the example tri-band filter are achieved after several hours of circuit optimization.

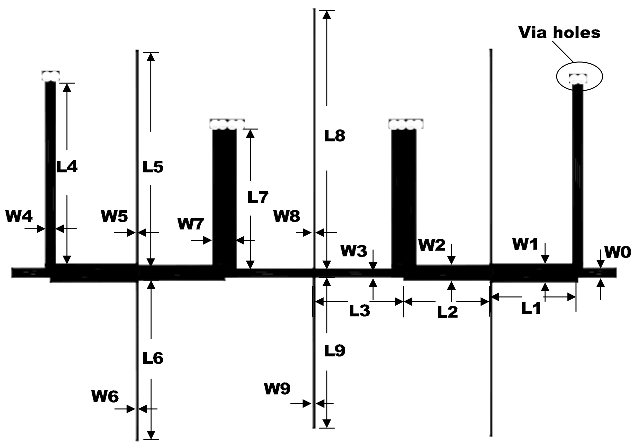

Fig. 2. Circuit dimensions of the proposed tri-band filter.

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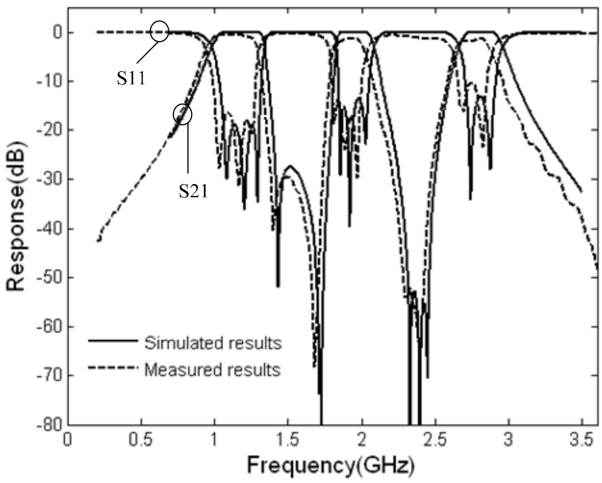
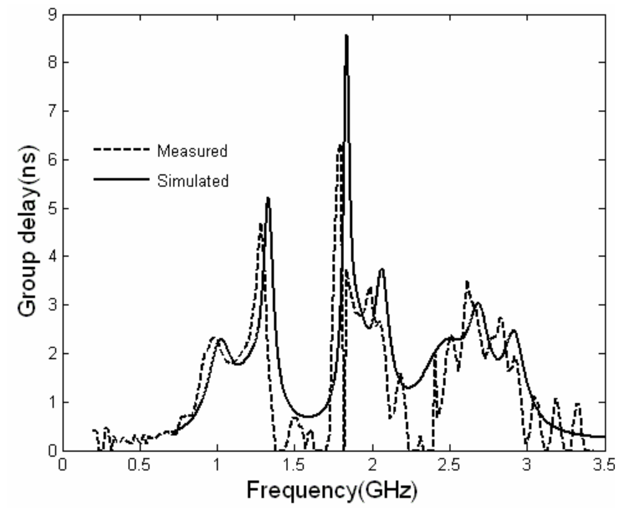
This filter is fabricated on a substrate with a thickness of 0.508 mm and a dielectric constant ε_r of 3.38. To minimize the number of unknowns and reduce optimization time, the circuit shown in Fig. 2 is arranged symmetrically. All the dimensions are listed below: W0 = 1.16; W1 = 2.36; W2 = 1.95; W3 = 1.07; W4 = 1.31; W5 = 0.24; W6 = 0.18; W7 = 3.09; W8 = 0.18; W9 = 0.25; L1 = 11.16; L2 = 11.24; L3 = 11.47; L4 = 23.74; L5 = 27.8; L6 = 20.73; L7 = 18.13; L8 = 33.63; L9 = 19.53 (All in mm).

The total dimension is $78.3 * 64.7\,mm^2$. The measured results, compared by the circuit simulation results are shown in Fig. 3 with good agreement observed. The lowest insertion losses of the three passbands are 0.5 dB, 1.3 dB and 1.3 dB, respectively. The resturn loss of each are 15 dB, 15 dB and 10 dB. High isolations of more than 28 dB and 50 dB are achieved between the three passbands. As an optimization result, the short-circuited stubs are non-uniform in length. The upper three open-stubs are use to realize



(a)



(b)

Fig. 3. Simulated and measured responses of the prototype tri-band filter: a) S parameters; b) Group delay.

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the stop band between the 1st and 2nd passbands, and the three open-stubs of shorter lengths below realize the higher stop band. The allocations and bandwidths of the stopbands efficiently affect those of the three passbands. Small frequency shift between the simulation and measurement plots is due to fabrication tolerances.

4 Conclusion

A novel tri-band filter topology, in which a dual-band bandstop filter is embedded in a wideband shunt-stub filter, is proposed. Three passbands are achieved by a band-splitting behavior. A prototype filter is designed by optimization method, fabricated and measured. Good features such as low insertion loss and high isolation are obtained. The design of passband center frequencies and bandwidths are more flexible compared to many other solutions.

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