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Compact dual-band bandpass filter using open loop resonator loaded by in-line beeline for wideband applications

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Abstract: In this paper, a dual-band bandpass filter with low insertion loss in the pass bands and compact size is designed using only two open-loop microstrip resonators loaded by in-line beelines. The in-line beelines, are loaded to achieve two passbands with high performance. By adjusting the stub lengths and widths and also the tap line position, the harmonics above the second band are suppersed. The minimum insertion loss is 0.9 and 0.2 dB at the first and second passbands respectively. The minimum attenuation above the second passband is −19.5 dB from 5.4 up to more than 20 GHz, so it can be used for wideband applications. This filter is then fabricated and measured. The measured and simulated results are in good agreement.

Keywords: dual-band filter, stepped impedance, stub, ultra wideband.

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

Microstrip dual-band bandpass filters are important components of radio transceivers in modern wireless communication systems such as wireless code-division multiple-access WCDMA, wireless local area network WLAN and global systems for GSM. A good microstrip dual-band bandpass filter has low insertion loss in both passbands as well as compact size. In [1], a new dual-band filter using net-type resonators is proposed to operate at two resonant frequencies and is applied to implement a dual-band microstrip bandpass filter using extra coupled resonator. Although the proposed structure has high rejection in mid-band but it has large implementation area and high insertion loss in the first and second pass bands. In [2], due to utilization of the SIRs for the dualband bandpass filter, the circuit size of the filter has been increased. Open loop resonators are loaded by open stubs in [3], in order to synthesize a two-order dual-band bandpass filter. Large insertion loss and large implementation area are the main drawbacks of this structure. In [4], a balanced dual-band bandpass filter, based on $\frac{\lambda}{2}$ SIRs and open-loop resonators is presented. This filter achieves acceptable common-mode suppression at the two passbands but it has large insertion loss in the first and second passbands. In [5], open-loop resonators with electric coupling, magnetic coupling and mixed coupling are implemented to realize dual-band filter. The problem of this filter is it's large implementation area. In [6] and [7] the stepped-impedance resonator are used to achieve dual-band bandpass filters that have high insertion loss. The proposed filter in [8] has good skirt attenuation rate on the edge of the first and the second pass bands and its stopband is relatively wide, but the complex filter structure is needed to achieve good selectivity and wide stopband, at the same time. In [9], open-loop resonators are implemented to achieve, dual-band characteristic, using magnetic and electric coupling structures. In this filter, above the second passband, the stopband performance is undesired and between the two

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passbands, some harmonics exist, also the filter size is large.

In this paper, a compact size and low insertion loss dual band, bandpass filter, is designed and fabricated. In this filter, open loop resonators that are loaded by in-line beelines are used. By tuning the stub lengths, widths and tap line position, the harmonics above the second band can be attenuated and wide stopband can be achieved.

2 Design and study of the proposed filter structure

For a symmetrical step, the capacitance and inductances of the equivalent circuit that are indicated in Fig. 1a, may be approximated by the following formulation [10]:

$$C = 0.00137h\left(1-\frac{w_2}{w_1}\right)\left(\frac{\varepsilon_{re1}+0.3}{\varepsilon_{re1}-0.258}\right)\left(\frac{\sqrt{\varepsilon_{re1}}}{Z_{c1}}\right)\left(\frac{\frac{w_1}{h}+0.264}{\frac{w_1}{h}+0.2}\right) \quad (pF) \tag{1}$$

$$L_1 = \frac{L_{W1}}{L_{W1}+L_{W2}}L \tag{2}$$

$$L_2 = \frac{L_{W2}}{L_{W1}+L_{W2}}L \tag{3}$$

$$L_{wi} = Z_{ci}\sqrt{\frac{\varepsilon_{re}}{C}} \tag{4}$$

$$L = 0.000987h\left(1-\frac{Z_{c1}}{Z_{c2}}\sqrt{\frac{\varepsilon_{re1}}{\varepsilon_{re2}}}\right)^2 (nH) \tag{5}$$

Fig. 1b, presents a four-section stepped impedance resonator with an equivalent circuit as shown in Fig. 1c. In this circuit C represents, equivalent capacitance of the symmetrical step and L_1 and L_2 are it's equivalent inductances.

Therefore, the capacitance and inductances are related to the stubs length and width, and the resonant frequency of the in-line beeline resonator, is related to the capacitance and inductances, so the in-line beeline resonator can resonate at the desired frequency by adjusting its lengths and widths. The open loop resonator, that is loaded by in-line beeline resonator, is shown in Fig. 2. The electrical length θ_s is increased when the stub length is increased. The input admittance of the open end (shown by θ_1) is:

$$Yin = jY\frac{\sum_{i=1}^{15}(tan\theta_i)}{1-tan\theta_1\sum_{i=2}^{15}(tan\theta_i)} \tag{6}$$

Where $Y_S = Y_R = Y$ and Y_R and Y_S are the characteristic admittances of the resonator and the stub, respectively. The resonance condition can be obtained when:

$$\sum_{i=1}^{15}(tan\theta_i) = 0 \tag{7}$$

parameter θ is related to the length and width of the stub, thus the second resonance frequency can be created by adjusting the in-line beeline lengths and widths.

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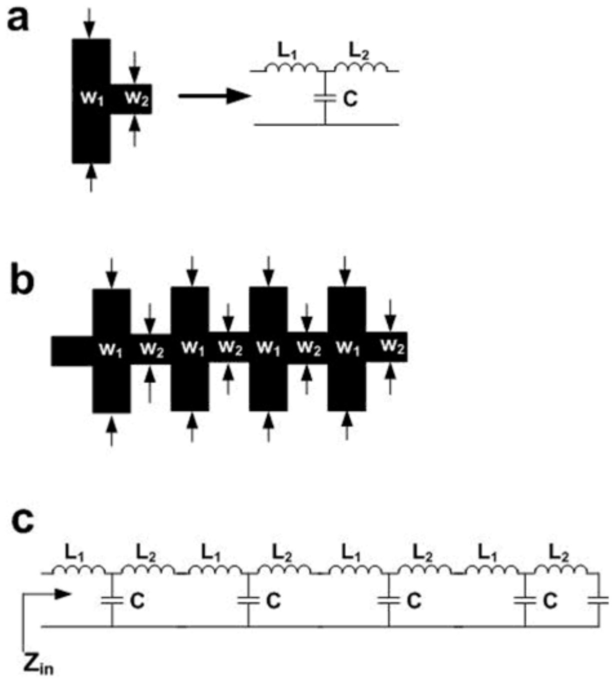

Fig. 1. (a) Stepped impedance resonator and its equivalent circuit (b) In-line beeline (c) Equivalent circuit for the stepped impedance resonator.

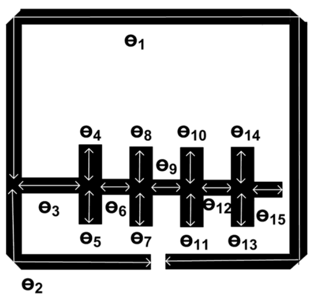

Fig. 2. Open loop resonator that loaded by in-line beeline.

Two similar open-loop resonators are connected together, using mixed coupling. These resonators are loaded by in-line beeline, shown in Fig. 1b to achieve dual-band bandpass filter as shown in Fig. 3a. The tapped line, feed structures are used to connect input/output ports. So based on in-line beeline loaded open-loop resonator, a dual-band microstrip filter is designed. Each of open loops that loaded by two in-line beeline cells help to reduce size in comparison with stub loaded open loop resonator in [5]. In the proposed structure a novel coupling structure are been used that consist of three different coupled lines cells, which are connected in series to improve filter performance. Also in the proposed filter a small tap line is used for impedance matching for reduction of insertion loss, where in [5] a large impedance transformer is used for impedance matching. The in-line beelines, 1 and 4, resonate at the center frequency of the first band, as shown in Fig. 3b. This figure, presents the frequency response of the filter of Fig. 3a, at the absence of the in-line

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beelines, 2 and 3. The in-line beelines 2 and 3 resonate at the second band. The insertion loss at the first and second pass bands is reduced by using the in-line beelines, 2 and 3. The frequency response of the filter of Fig. 3a is shown in Fig. 3c. The harmonics can be changed, using different L_4 values as shown in Fig. 3d. It can be observed that, when L_4 value is nearest to 3 mm, the harmonics level above the second band is most attenuated. The photograph of the fabricated filter is shown in Fig. 3e.

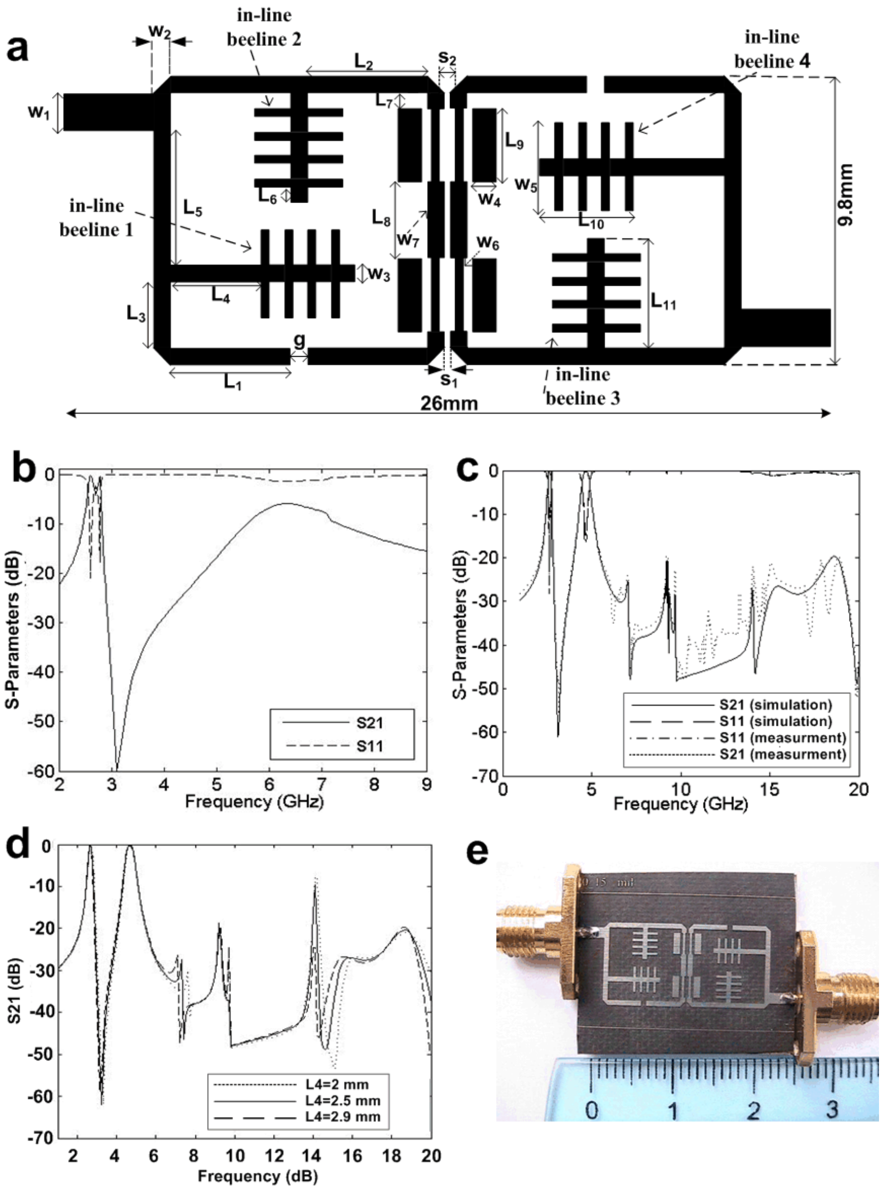

Fig. 3. (a) Two open loop resonators with mixed coupling (b) Frequency response of the structure of Fig. 3a without in-line beelines, 2 and 3 (c) The frequency response of the structure of Fig. 3a (d) Frequency response of the structure of Fig. 3a, for different L_4 values (e) Photograph of the fabricated filter.

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3 Simulation and measurement

The dual-band bandpass filter is fabricated on RT Duroid 5880 substrate having dielectric constant $\varepsilon_r = 2.22$, 15 mil thickness and loss tangent equal to 0.0009. The proposed filter is simulated by the full-wave EM simulator, ADS. The values of dimensions of this filter are: $L_1 = 4$ mm, $L_2 = 4$ mm, $L_3 = 2.2$ mm, $L_4 = 3$ mm, $L_5 = 4.5$ mm, $L_6 = 0.5$ mm, $L_7 = 0.5$ mm, $L_8 = 2.6$ mm, $L_9 = 2.5$ mm, $L_{10} = 3.2$ mm, $L_{11} = 3.7$ mm, $w_1 = 1.3$ mm, $w_2 = 0.6$ mm, $w_3 = 0.6$ mm, $w_4 = 0.8$ mm, $w_5 = 3$ mm, $w_6 = 0.3$ mm, $w_7 = 0.6$ mm, $S_1 = 0.2$ mm, $S_2 = 0.3$ mm, g = 0.6 mm.

This filter has cut off frequencies at 2.55 GHz, 2.75 GHz in the first passband and 4.46 GHz, 4.89 GHz in the second passband. Below the first passband, minimum attenuation is −20 dB from DC to 2.1 GHz. Between the two pass bands, minimum attenuation is −20 dB from 3.9 to 4 GHz. Minimum attenuation above the second pass band from 5.5 to 20 GHz is −19.6 dB. So this filter can be used for ultra wideband applications. The insertion loss at 2.65, 4.67 GHz is better than 0.7 and 0.2 dB respectively and the insertion loss at the first and second band, is better than 0.9 and 0.2 dB respectively.

The filter size is 26 mm $*$ 9.8 mm. In comparison with the previous works, the filter size and insertion loss are improved. The filter size reduction is equal to 80%, 86%, 23% and 80% in comparison with the structures of [1, 2, 3] and [4] respectively. The insertion loss improvement in the first band is 64%, 57%, 18% and 89% in comparison with the works of [1, 2, 3] and [4] respectively. The improvement of this parameter in the second band is 91%, 91%, 80% and 89% in comparison with the works of [1, 2, 3] and [4] respectively. BWR in the first and second band is equal to 7.6%, 9.2% respectively. In comparison with filter I [5], filter II [5] and filter III [5] the filter size is reduced more than 53%, 51%, and 63% respectively. The insertion loss in the first pass band in comparison with filter I and filter II and filter III is improved more than 69%, 74%, and 51% respectively. The insertion loss in the second pass band in comparison whit filter I and filter II and filter III is improved more than 94%, 94%, and 88%.

4 Conclusion

A new dual-band bandpass filter with low insertion loss and very compact size is designed and fabricated for ultra wideband applications. In this structure, two open loop resonators and stepped impedance resonators are used simultaniously to achieve dual-band bandpass filter with high performance. This filter has wide stopband and the harmonics are almost attnuated. The minimum attenuation level above the second passband is −19.5 dB from 5.4 to 20 GHz. The insertion loss at the center frequencies of the first and second band is equal to 0.7 and 0.2 dB, respectively.

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