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A NEW APPROACH OF DUAL-BAND FILTERS BY STEPPED IMPEDANCE SIMPLIFIED CASCADED QUADRUPLET RESONATORS WITH SLOT COUPLING

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Abstract—This paper presents novel approaches for dual-band bandpass filter design utilizing stepped impedance simplified cascaded quadruplet resonators (SI-SCQRs) with slot coupling. A pair of SI-SCQRs forms a cross coupled dual-band filtering path to provide high selectivity passband response, and a slot coupling structure provides SI-SCQRs with another filtering path for improving and controlling the performances of the dual-band filter such as insertion loss and bandwidth. Measured insertion losses are 0.26 dB and 1.2 dB, and return losses are better than 16.3 dB and 15.2 dB at the first and second

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passband frequencies, respectively, with a mid-stopband attenuation around 30 dB.

1. INTRODUCTION

Recently, the subject of dual-band bandpass filters is generating great interest in the design of dual-band bandpass filters with compact size and high selectivity performance [1–9]. Conventional microwave filter design procedures suitable for wideband passband and narrowband stopband operation have been discussed in previous studies [1]. Unfortunately, this solution suffers from large overall size due to extra cascaded circuits. Different design procedures have been proposed in [2–9]. In [7] and another general approach [5], dual-mode dual-band bandpass filters were initially reported. Unfortunately, this solution suffers from high insertion loss and none high selectivity near the passband. Moreover, there has been improved insertion loss [9, 10]. Stepped impedance resonator (SIR) can control second passband by adjusting the impedance ratio and electric lengths of SIRs. By properly selecting the relevant impedance or strip width ratio, the dual-band filters using stepped-impedance resonators can be created [2, 3]. In addition, in order to build up the high selectivity of the passband frequency, some researchers adopted an asymmetrical feeding structure [3, 7]. However, these approaches may cause some problematic issues, such as extra insertion loss and poor circuit size [4, 6, 8]. For considerations of improving insertion losses and selectivity in both dual passbands, a dual-band filter can be designed by using cascaded quadruplet (CQ) filter with stepped impedance resonator (SIR) to obtain a high selectivity performance [9]. But, large size due to a fourth-order design has become the key problematic issue in this approach. Moreover, the insertion loss in the passband is not good enough [8].

As a consequence, the implementation of a dual-band bandpass filter with high selectivity and low insertion loss requires a sufficiently large coupling coefficient to cover the complete set of dual passbands. Besides utilizing the general multi-order or cascaded quadruplet (CQ) filter technique, a dual-band bandpass filter with high selectivity and low insertion loss is difficult to implement in second-order. Furthermore, the conventional second-order techniques always face a tradeoff between the performance of the first and second passbands, which leads to limited insertion loss and narrow bandwidth.

For considerations of improving insertion loss and selectivity in both dual passbands, a novel approach to design dual-band bandpass filter in second-order is constructed and implemented in this paper. A pair of SI-SCQRs forms a cross coupled dual-band filtering passage to provide high selectivity in both dual passbands, and a slot coupling structure provides SI-SCQRs with another filtering passage for controlling the performances of the dual-band filter such as insertion loss and bandwidth.

2. SIMPLIFIED CASCADED QUADRUPLET RESONATOR (SCQR) STRUCTURE

Referring to the lowpass prototype filter for the filter synthesis as shown in Fig. 1(a) [10], where the rectangular boxes represent ideal admittance inverters with characteristic admittance J, the item m is equal to $n/2$, where n denotes the order number, and g-values present as the lowpass prototype parameters.

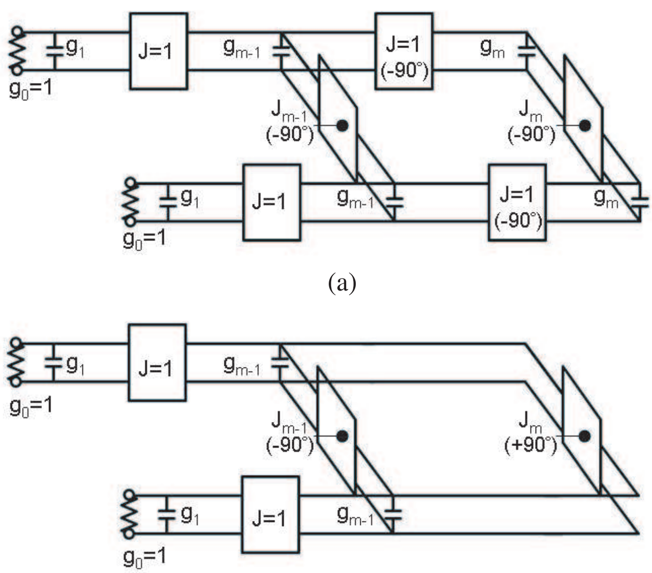


Figure 1. Equivalent circuits of (a) the traditional 4th-order CQ structure and (b) the proposed 2nd-order SCQR structure with phase shift in $J_m = +90°$.

In order to introduce high selectivity, the items of J_{m-1} and J_m are required (requires a sufficiently large coupling coefficient to cover the complete set of electric and magnetic coupling mechanisms). For

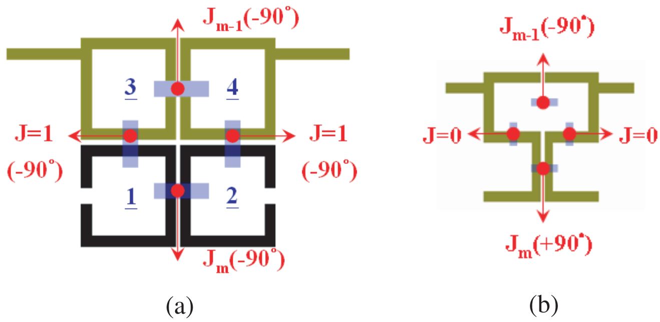


Figure 2. Geometries of (a) the traditional 4th-order CQ structure and (b) the proposed 2nd-order SCQR structure with phase shift in J_m.

total phase delay results of 180°, unit elements $J = 1$ present as some phase delay only; J_m of the upper route constructs phase delay of $-270°$, the same as $+90°$. Likewise, the mixed couplings (both the unit elements $J = 1$) exist for constructing magnetic-coupling (J_m) with a phase delay of $-270°$. As a result, unit elements can be ignored when J_m has a phase shift as $+90°$ by itself, as shown in Fig. 1(b). It is observed that the geometry in second-order also has the possibility of high selectivity when both electric and magnetic coupling mechanisms obtain a sufficiently large coupling coefficient.

Geometries of the traditional fourth-order CQ structure and the proposed second-order SCQR structure with phase shift in $J_m = +90°$ are shown in Figs. 2(a) and 2(b), respectively. The proposed SCQR structure simplified from the traditional 4th-order CQ structure not only keeps the possibility of high selectivity but also reduces the order number to two.

3. STEPPED IMPEDANCE SIMPLIFIED CASCADED QUADRUPLET RESONATOR (SI-SCQR) STRUCTURE

Furthermore, the proposed SI-SCQRs consist of SIR technique and simplified cascaded quadruplet resonators. Stepped-impedance resonators are utilized to realize the dual-band characteristics and reduce size. The synthesis method is developed. Geometrical diagram of SIR is shown in Fig. 3. Resonance condition of $\lambda_g/2$ type SIR at resonator length $(L_n) < 1$ is shown in Fig. 4, $L_n = 2\theta_1/\pi$ [11]. For practical application it is preferable to choose $\theta_1 = \theta_2$. It is evident from Fig. 4 that the electrical length has minimum value

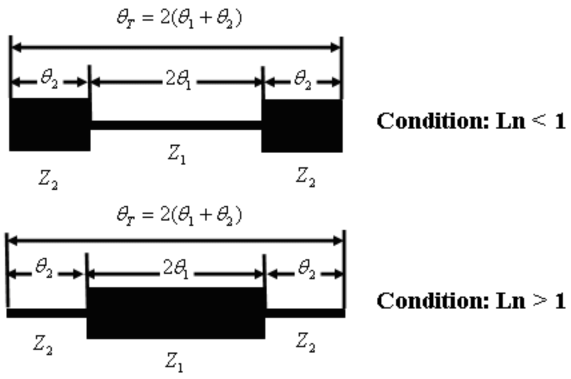


Figure 3. Geometrical diagrams of the stepped impedance resonator.

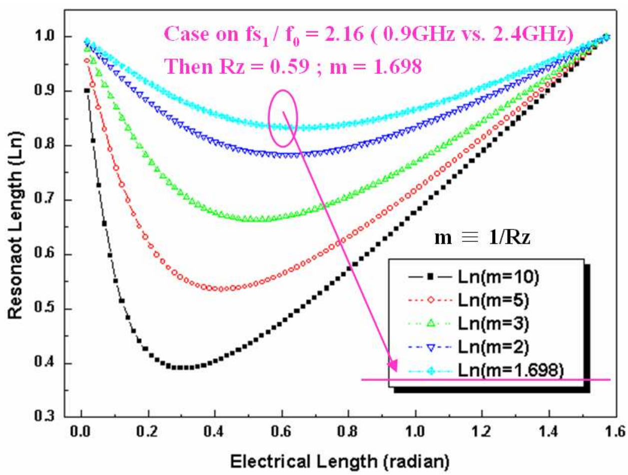


Figure 4. Resonance condition of $\lambda_g/2$ type SIR, the resonator length $(L_n) < 1$.

in condition as $L_n < 1$. In these ways, the dual-band passband frequencies of the filter are dependent on the length and impedance ratios of the SIRs. Then, the parameters of the designed dual-band bandpass filter with a first frequency (f_1) 0.9 GHz and second frequency (f_2) 2.4 GHz are: frequency ratio $(f_2/f_1) = 2.16$, impendence ratio $(RZ \equiv Z_2/Z_1) = 0.59$, related constant m $(m \equiv 1/RZ) = 1.698$, sub-parameters chosen as $Z_2 = 22.3$, $Z_1 = 50$, $\theta_1 = \theta_2 = 33.75°$. The selected substrate has a permittivity of 10.2 and a thickness of

1.27 mm.

On the other hand, the feeding location affects the insertion loss of the two passbands simultaneously. Consequently, the second-order filter faces a tradeoff between the performance of the first and second passbands. For considerations of improving insertion loss and selectivity in both passbands, this paper adopts the slot coupling at the lower plane to enhance the problems, configuration and geometric parameters of the proposed dual-band filter shown as Fig. 5.

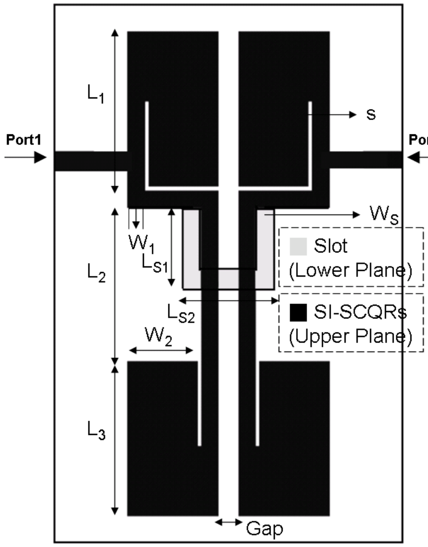
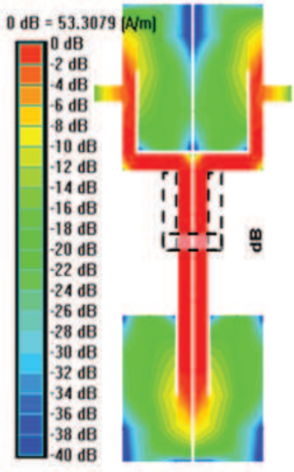


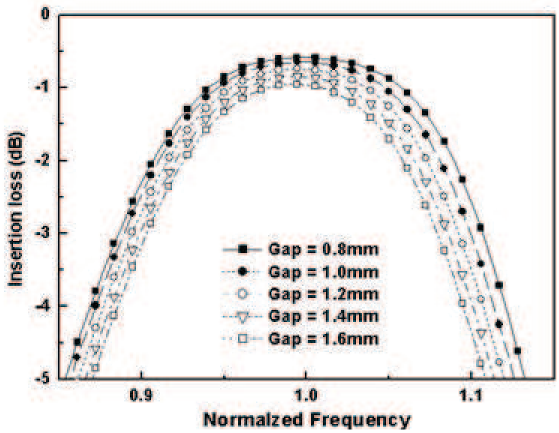
Figure 5. Configuration and geometric parameters of the proposed dual-band filter constructed from the 2nd-order SI-SCQRs and slot coupling structure.

Simulation and measurement are carried out using Zeland IE3D software and Agilent's E8364A network analyzer, respectively. Fig. 6 presents the diagrams of (a): simulated current distribution at 0.9 GHz (for determining the location of the slot structure to apply both passbands having strong coupling) and relationship between the slot coupling gap and bandwidth in both passbands (b): normalized frequency at 0.9 GHz and (c): normalized frequency at 2.4 GHz. It can be seen that the slot coupling structure provides SI-SCQRs with another filtering passage for improving and controlling the performances of the dual-band filter such as insertion loss and bandwidth.

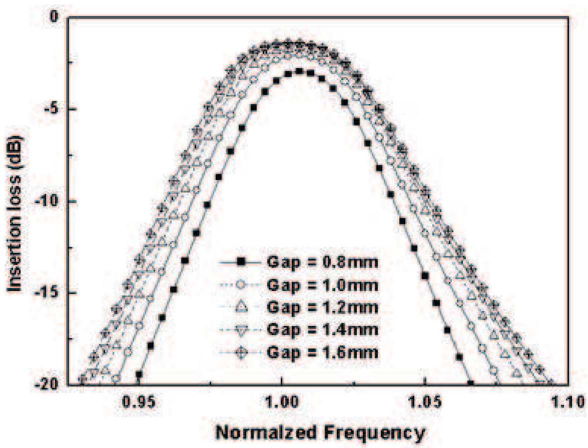
The simulated and measured frequency responses of the proposed



(a)



(b)



(c)

Figure 6. Diagrams of (a): simulated current distribution at 0.9 GHz (Dash line shows the area of the slot structure in lower plane.) and relationship between the slot coupling gap and bandwidth in both two passbands (b): normalized frequency at 0.9 GHz and (c): normalized frequency at 2.4 GHz.

dual-band filter are shown in Fig. 7. The dual-band bandpass filter is realized and simulated by full-wave EM simulation. Experimental results of the fabricated filter were in agreement with the design

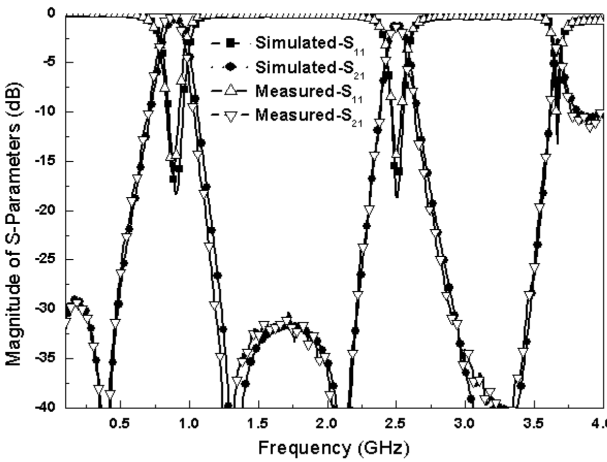


Figure 7. Simulated and measured frequency responses of the proposed dual-band filter. Geometric parameters of the filters are $W_1 = 1.15$; $W_2 = 4.5$; $L_1 = 10.1$; $L_2 = 9.71$; $L_3 = 9.89$; $W_S = 1.15$; $L_{S1} = 5.15$; $L_{S2} = 5.8$; Gap = 1.2. All are in mm.

specification. Measured insertion losses are 0.26 dB and 1.2 dB, and return losses are better than 16.3 dB and 15.2 dB at the first and second passband frequencies, respectively, with a mid-stopband attenuation around 30 dB. Moreover, the proposed microstrip filter is 30 mm×12 mm in size.

4. CONCLUSION

In this paper, a simple and effective method for designing microstrip dual-band filters utilizing SI-SCQRs with slot coupling has been investigated. The proposed filter realizes the two passbands (0.9 GHz and 2.4 GHz) in good controllability and has good performances just like low insertion loss within passbands, high selectivity, and compact size. The measurement results are found to be in good agreement with the simulation results.

ACKNOWLEDGMENT

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