A Tri-band Bandpass Filter with Compact Circuit Size and High Passband Selectivity

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***Abstract* –In this paper, a new resonator configuration to design a compact triple-passband filter with high passband selectivity is proposed. The filter includes three propagation paths within single stepped impedance resonator (SIR) and connecting with magnetically coupling by via hole to ground at the symmetric plane of the filter. The multipath-embedded SIR is designed to have three resonant paths at 1.575 GHz, 2.45 GHz and 5.8 GHz. The resonant frequencies can be easily controlled by tuning impedance ratio Ki and length ratio α_i (where i = 1, 2 and 3) for each resonant paths in the multipath-embedded SIR. The measured results are in good agreement with the full-wave electromagnetic (EM) simulation results.** [1]

***Index Terms*— triple-passband, bandpass filter, stepped impedance resonator.**

I. INTRODUCTION

Recently, multi-passband bandpass filters (BPFs) are the important and essential components in RF front-end. Rapid progress in multi-band filters with compact size and high performance has more increased the need in modern wireless communication systems. Triple-passband filters play an important role in nowadays.

Multi-band filter using stepped impedance resonators (SIRs) technique has been a popular method to achieve compact size of planar circuits and multi-band performance [1]–[5]. Recently, triple-passband filters have been implemented by using the SIRs [1]-[4]. Stub-loaded resonators (SLRs) are the newly structure for developing the triple-passband filters [3]-[5]. However, the uniform impedance resonators (UIRs) are used that the design freedom is limited when choosing the every passband frequencies. Besides, circuit size and wide stopband are an issue and needed to further improve. The dual-band filter using embedded open-loop ring resonators was proposed in [6]. The filter without using the external impedance transformer can further miniaturize the circuit size. However, the passband selectivity should be improved. This idea is good and inspired us to further study this issue.

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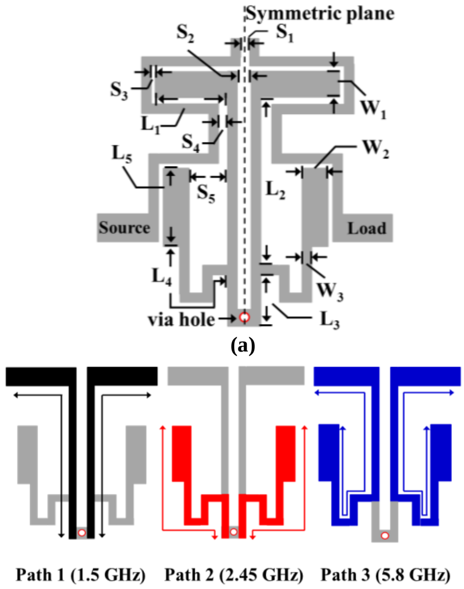


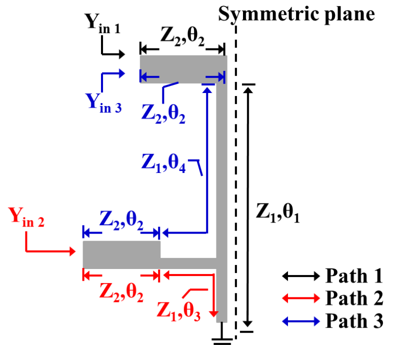
(b)

Fig 1. (a) Configuration and (b) each propagation path of the proposed filter.

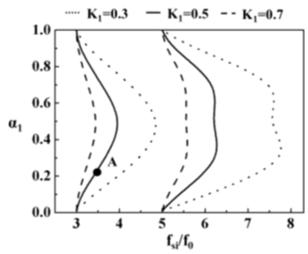
In this paper, a triple-passband bandpass filter using multipath-embedded stepped impedance resonators is proposed. The filter includes two multipath-embedded SIRs and connecting with magnetically coupling by via hole to ground at symmetric plane of the filter. The multipath-embedded SIR is designed to have three resonant paths (path 1 for 1.575 GHz, path 2 for 2.45 GHz and path 3 for 5.8 GHz) in single circuit configuration. Each resonant path can be easily controlled to very close or far away for highly design freedom. In comparison of conventional multi-band filters, the filter is only using two coupled resonators to form three passbands with low insertion loss and high passband selectivity. The filter realized on a printed circuit board occupies an area of only 26.3 × 14 mm^2. The measured results are in good agreement with the full-wave electromagnetic (EM) simulation results [7].

II. FILTER DESIGN

Fig. 1(a) shows configuration of the proposed filter. The filter consists of two multipath-embedded stepped impedance resonators and connected by via hole to ground plane along symmetric plane of the filter. The source-loaded coupling are able to control simultaneously the performance of three passbands.



(a)



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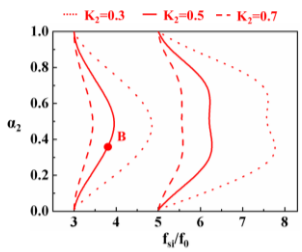

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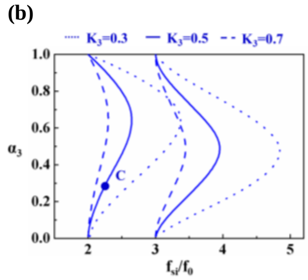
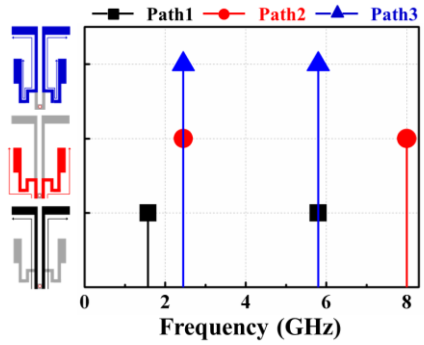


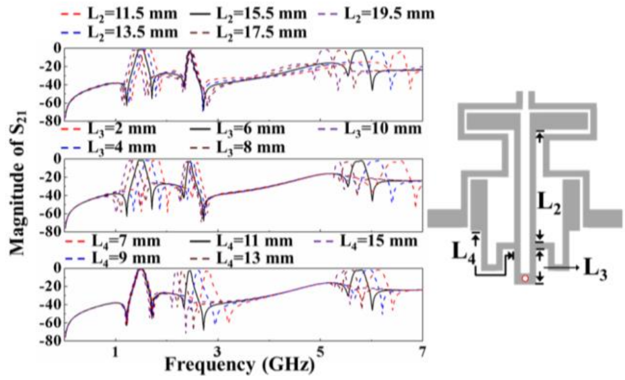
(d)

Fig 2. (a) Transmission line model of the proposed multipath-embedded stepped impedance resonator and relations between the normalized f_{si}/f_0 and (b) [K_1, α_1], (c) [K_2, α_2] and (d) [K_3, α_3].

The multipath-embedded SIR includes three resonant paths as shown in Fig. 1(b). Path 1 (indicated by black) is designed at 1.575 GHz by using the quarter-wavelength SIR and to be a main structure in the filter. Path 2 and path 3 (indicated by red and blue) is designed at 2.45 GHz and 5.8 GHz respectively by using quarter-wavelength (path 2) and conventional SIRs (path 3). Path 2 and path 3 is embedded in path 1 so as to reduce the circuit size. Three passbands are able to generate and control individually by tuning the impedance ratio (K) and length ratio (α_1, α_2 and α_3) of each path. The filter is only using two coupled resonators to generate three passbands and producing the transmission zeros at each passband skirt by multipath propagation of cross coupling effects in the filter. Fig. 2(a) shows transmission line model of the multipath-embedded SIR. In this work, multipath-embedded SIR is composed of a quarter-wavelength SIR ([(Z_1, θ_1), (Z_2, θ_2)] of path 1 at 1.575 GHz) and embedded quarter-wavelength SIRs ([(Z_1, θ_3), (Z_2, θ_2)] of path 2 at 2.45 GHz and half- wavelength SIRs [(Z_1, θ_4), 2(Z_2, θ_2)] of path 3 at 5.8 GHz). By properly tuning the dimension of each resonant path, such as impedance ratio of $K_1 = K_2 = K_3 = Z_1 / Z_2$ and length ratio of $\alpha_1 = \theta_2/(\theta_1+\theta_2)$, $\alpha_2 = \theta_2/(\theta_2+\theta_3)$ and $\alpha_3 = 2\theta_2/(2\theta_2+\theta_4)$ for each path, the arrangements of every resonant modes become more flexible. The resonant modes of the multipath-embedded SIR can be derived by setting $Y_{in} = 0$ and expressed as



(a)



(b)

Fig 3. Simulated (a) resonant peaks and (b) frequency response of each path of the proposed filter.

$$Y_{in1} = Y_2 \frac{Z_2 - Z_1 \tan\theta_1 \tan\theta_2}{jZ_1 \tan\theta_1 + jZ_2 \tan\theta_2} \quad \text{for path 1} \quad (1)$$

$$Y_{in2} = Y_2 \frac{Z_2 - Z_1 \tan\theta_3 \tan\theta_2}{jZ_1 \tan\theta_3 + jZ_2 \tan\theta_2} \quad \text{for path 2} \quad (2)$$

$$Y_{in3} = Y_2 \frac{Z_2 + Z_1 (\tan\theta_4/2) \tan\theta_2}{-jZ_1 (\tan\theta_4/2) + jZ_2 \tan\theta_2} \quad \text{for path 3} \quad (3)$$

Fig. 2(b) shows relations between the normalized f_{si}/f_0 and length ratios of α_1, α_2 and α_3 with impedance ratios of K_1, K_2 and K_3 for each path. It is found that each resonant path can be designed individually by using the multipath-embedded SIR. The appropriate design parameters of multipath-embedded SIRs in this work are indicated as marked point A, B and C in Fig. 2(b), (c) and (d). Using multipath-embedded SIRs, design of multi-band filter with very close (and/or faraway) passbands can be easily achieved and having the high passband selectivity of each passband.

TABLE I.
COMPARISONS WITH OTHER PROPOSED FILTERS.
(λg IS THE GUIDED WAVELENGTH OF THE 1ST CENTER PASSBAND FREQUENCY)

Ref.	[2]	[3]	[4]	[5]	**This study**
Number of resonators	5	4	2	4	**2**
1st / 2nd / 3rd Passbands (GHz)	2.3 / 3.7 / 5.3	2.45 / 3.5 / 5.25	1.575 / 2.4 / 3.5	1.84 / 2.45 / 3	**1.575 / 2.45 / 5.8**
$\|S_{11}\|$ $\|S_{21}\|$ (dB)	25 / 35 / 31 2.5/1.9/2.9	37 / 15 / 15 0.9/1.7/2.1	9 / 19 / 13.5 1.6/1.5/2.3	20 / 15 / 15 0.9/1.6/0.8	**23 / 22 / 34 1.3/1.9/2**
Passband selectivity	fair	low	fair	fair	**high**
Circuit Size (mm^2) (λ_g * λ_g)	1239 (0.68*0.28)	1264 (0.43 * 0.53)	2793 (0.72 * 0.82)	700 (0.22 * 0.27)	**369 (0.19 * 0.1)**

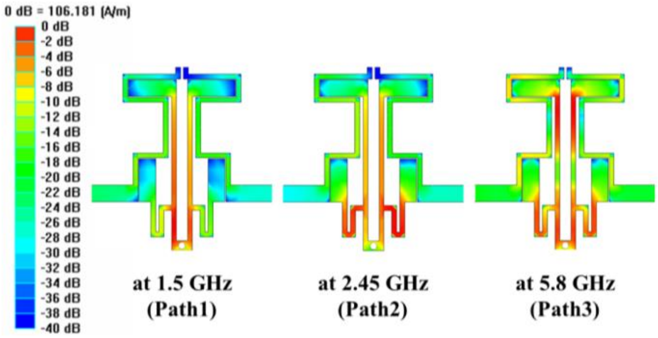


Fig 4. Current distribution of the proposed filter.

In this work, path 1 as [(Z_1, θ_1), (Z_2, θ_2)] for 1.575 GHz (K_1 = 0.5, α_1 = 0.21), path 2 as [(Z_1, θ_3), (Z_2, θ_2)] for 2.45 GHz (K_2 = 0.5, α_2 = 0.36) and path 3 as [(Z_1, θ_4), 2(Z_2, θ_2)] for 5.8 GHz (K_3 = 0.5, α_3 = 0.29) are chosen in the proposed filter. Fig 3 shows simulated resonant peaks and frequency response of each path of the proposed filter. In Fig. 3(a), the resonant peaks of (1.575 GHz and 5.8 GHz), (2.45 GHz and 8 GHz) and (2.45 GHz and 5.8 GHz) are determined by quarter-wavelength SIRs as path 1 and path 2 and path 3, respectively. To determine each passband, only to change the lengths of L_2, L_3 and L_4 for evaluating the effects of triple passband performance. 1st passband (1.575 GHz) and 3rd passband (5.8 GHz) is shifted to lower frequency with maintaining response for 2nd passband (2.45 GHz) when L_2 is increased. Similarly, the resonant frequencies of 2nd passband is shifted to lower frequency when L_4 is increased. Each path is created by the quarter-wavelength (and/or a conventional half-wavelength) SIR. The resonant frequencies of each path can be tuned in wide frequency range. Therefore, each passband can be implemented individually by using the proposed SIRs. Fig. 4 shows current distribution of the proposed filter. It is clearly observed that 1st, 2nd and 3rd

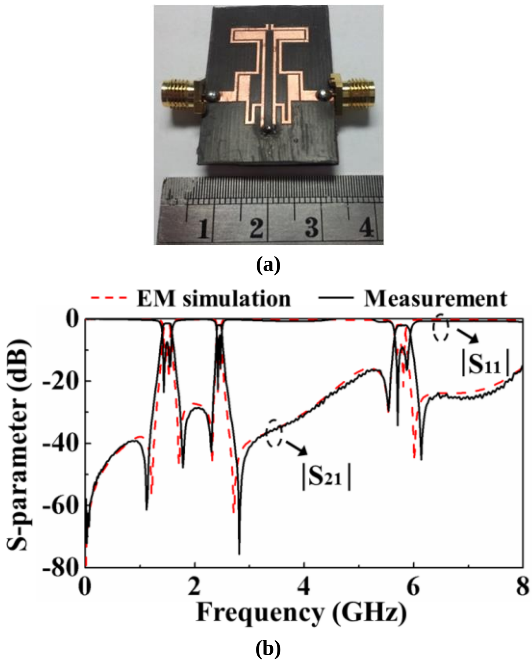


Fig. 5 (a) Photograph and (b) measured results of the fabricated filter. (L_1 = L_5 = 6.2, L_2 = 15.5, L_3 = 6, L_4 = 11 , W_1 = W_2 = 2.4, S_1 = 0.4, S_2 = 1.6, S_3 = 0.12, S_4 = 0.5 and S_5 = 2.3. All are in mm.)

passband at 1.575, 2.45 and 5.8 GHz are generated by three resonant paths of the multipath-embedded SIRs and no interactions produced to interfere the performance of each passband. Each passband can be implemented individually, therefore, low insertion loss triple-passband performance can be well achieved.

III. RESULTS

Fig. 5 shows the photograph and measured results of the fabricated dual-band BPF. Overall size is 26.7 × 14 mm^2, i.e., approximately 0.19λ_g by 0.1λ_g (where λ_g is the guided wavelength at center frequency of 1st passband). The filter is measured on an HP8510C Network Analyzer. The filter has measured center frequencies at 1.5, 2.45 and 5.8 GHz, the 3-dB fractional bandwidth (FBW) of 8.5%, 3% and 3.6%, the minimum insertion loss (-20 log $|S_{21}|$) of 1.3, 1.9 and 2 dB and the return losses (-20 log $|S_{11}|$) are around 20 dB at three passbands. The transmission zeros near the each passband edge are generated due to the multipath propagation induced from cross coupling effect in the filter. The multipath-embedded SIR essentially helps not only to create the transmission zeros by multipath propagation, but also to reduce the overall circuit size. Moreover, it is noted that the insertion losses for three passbands are very low. It might be that the filter is only using two resonators to produce three passbands, this is a significant characteristic compared with conventional multi-passband filters. Table I summarized the comparison of the proposed filter with other reported triple-passband filters [2]-[5].

IV. Conclusion

In this paper, a new compact triple-passband filter using the multipath-embedded stepped impedance resonators has been presented. The multipath-embedded stepped impedance resonators can generate three resonant paths at 1.575, 2.45 and 5.8 GHz in single filtering structure and no interaction produced between each path. The transmission zeros are generated by induced multipath propagations from cross-coupling effect in the filter. The filter has a small circuit size, high passband selectivity and low insertion loss. The proposed method of the triple-passband filter is effectively useful for multi-band wireless communication systems.

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