Compact Dual-Band Bandpass Filter Using Two-Path Embedded Asymmetric Stub Stepped Impedance Resonators

Tzu-Chun Tai[1], Hung-Wei Wu[2]*, Yung-Wei Chen[1], Ping-Tun Huang[3] and Chuan-Wang Chang[*4]

ABSTRACT

This paper presents a compact dual-band bandpass filter that involves using the embedded asymmetric stepped impedance resonators (SIRs) for achieving simultaneously compact circuit size and good dual-band performance. The embedded asymmetric SIR is designed to have two resonant paths at 2.4 GHz and 3.5 GHz. The resonant frequencies can be easily controlled by tuning impedance ratio (K_1 and K_2) and length ratio (α_1 and α_2) for each resonant path in the embedded asymmetric SIR. This study is showing simple configuration, effective design method and compact circuit size. The measured results are in good agreement with the simulation results.[1]

Keywords: dual-band, bandpass filter, stub stepped impedance resonators, embedded asymmetric resonator.

I. INTRODUCTION

Recent developments in microwave dual-band bandpass filters (BPFs) have been gaining much attention for multi-service wireless communication systems [1]. Dual-band filters became important building blocks and deeply demanded. To design a dual-band filter with low insertion loss, compact size, good passband selectivity and wide stopband is a challenge for the circuit designers.

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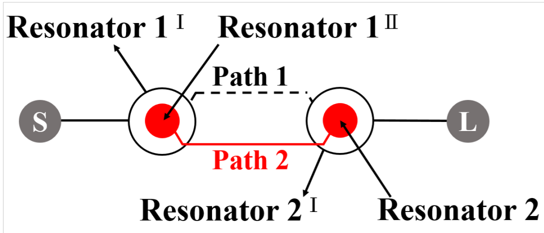


Figure 1. Coupling structure of the proposed filter. (The superscripts of I and II, indicate first passband and second passband.)

Some previous works for the dual-band filters are proposed [2]-[5]. In [2], the multi-layered filter consists of the stub-loaded stepped-impedance resonator on the top layer and the stub-loaded uniform-impedance resonator on the bottom layer that can provide the multi-path propagation to enhance the filter performance and compact circuit size. In [3], the filter using multi-stub loaded resonator contains six symmetric stubs, which can provide sufficient coupled sections between adjacent resonators, it is realizable to build the high-order dual-band filters using the proposed resonators. In [4], the dual-band filter using net-type resonator is designed to simultaneously operate at two closely specified passbands.

In [5], the dual-band filter using the short-circuited stepped-impedance resonator to easily control the first and second resonances by adjusting its structural parameters is proposed. However, the spurious response of these works needs to suppress at higher passband frequency range. Besides, the circuit size of previous works are a little bit large because the resonators are arranged by the

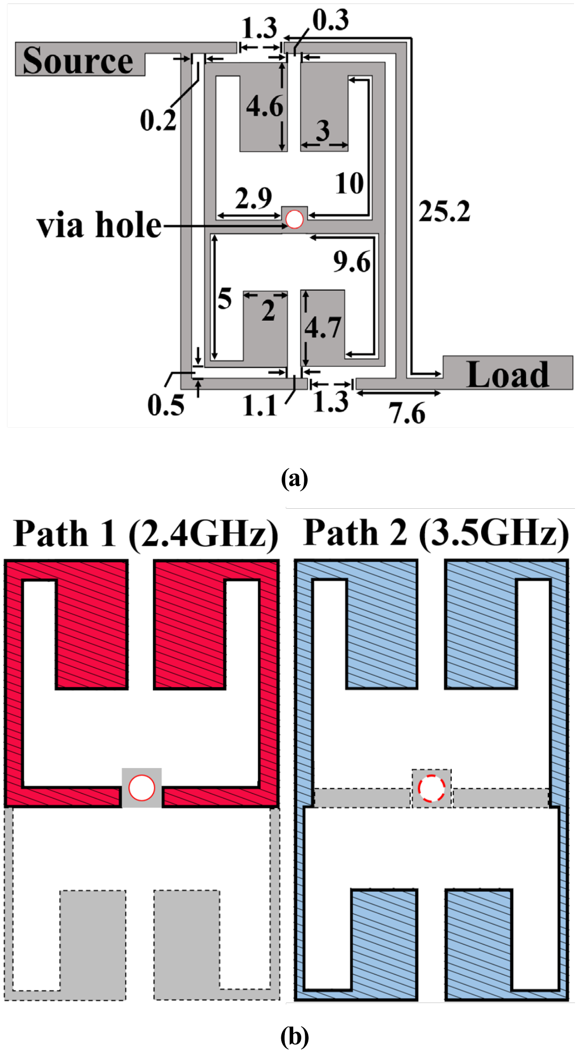


Figure 2. (a) Configuration and (b) two embedded resonant paths of the proposed filter. All are in mm.

direct-coupling or cross-coupling structures.

This paper presents a compact dual-band bandpass filter that involves using the embedded asymmetric stepped impedance resonators (SIRs) for achieving simultaneously compact circuit size and good dual-band performance. The embedded asymmetric SIR is designed to have two resonant paths at 2.4 GHz and 3.5 GHz. The resonant frequencies can be easily controlled by tuning impedance ratio (K_1 and K_2) and length ratio (α_1 and α_2) for each resonant path in the embedded asymmetric SIR. The design procedure of the filter is simple and may be followed easily. This study provides a simple and effective method to design a low-loss compact dual-band BPF without complex design and fabrication process.

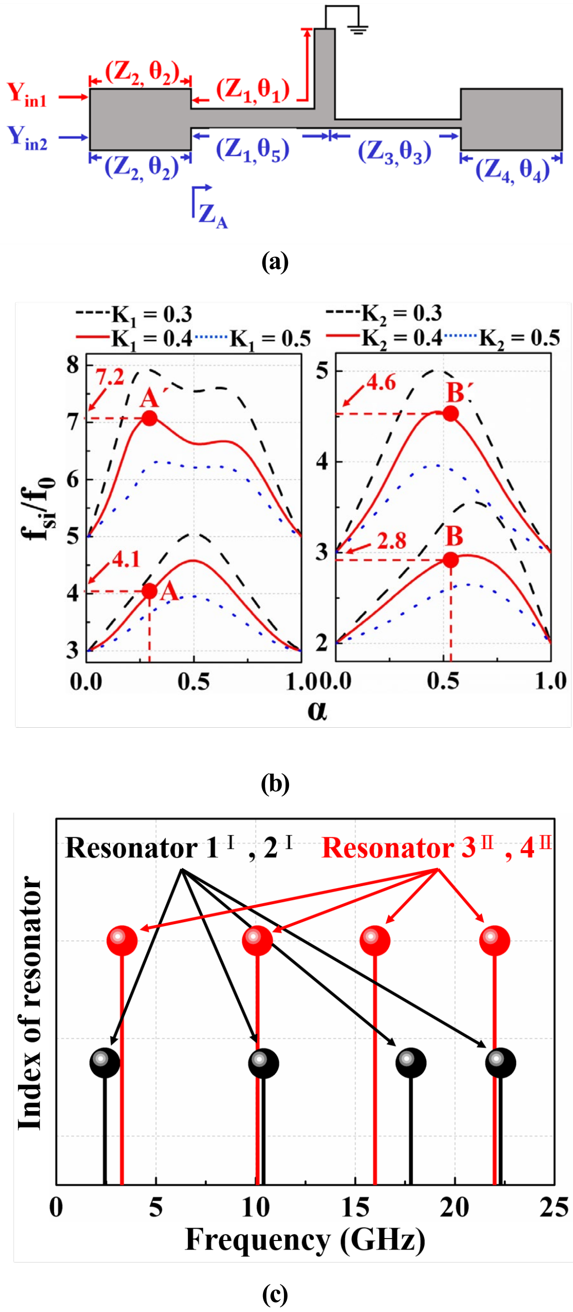


Figure 3. (a) Structure, (b) relations of the normalized f_{si}/f_0 versus length ratio α with different impedance ratio K ($K_1 = Z_2 / Z_1$, $K_2 = ((Z_2+Z_4)/2) / ((Z_1+Z_3)/2)$, $\alpha_1 = \theta_2 / (\theta_1+\theta_2)$ and $\alpha_2 = (\theta_2+\theta_4) / \theta_T$) and (c) distribution of fundamental and higher order resonant modes of the proposed SIRs.

II. FILTER DESIGN

Fig. 1 shows coupling structure of the proposed filter. In comparison of conventional multi-passband filters, the filter is only using two coupled resonators to generate dual passband with high passband selectivity. Each resonator includes two resonant paths operated at 2.4 and 3.5 GHz as indicated superscript of I and II shown in Fig. 1. The filter is designed, simulated and fabricated on the substrate of Duroid 5880 with dielectric constant $\varepsilon_r = 2.2$, loss tangent $\delta = 0.0009$ and thickness of 0.787 mm. The filter consists of two embedded asymmetric stepped impedance resonators connected each other by via hole (magnetically coupling) The source-loaded lines are able to control simultaneously the performance of the two passbands. The filter configuration and the two resonant paths by the embedded asymmetric SIR are shown in Fig. 2. Path 1 (indicated by red) is designed at 2.4 GHz by using the quarter-wavelength SIRs. Path 2 (indicated by blue) is designed at 3.5 GHz, by using c-shape asymmetric half-wavelength SIRs. Path 2 is embedded in a quarter-wavelength SIR (as path 1) so as to reduce the circuit size. Two passbands are generated and controlled individually by tuning the structure parameters of each path. The filter is not only using two coupled resonators to generate two passbands, but also producing the transmission zeros at each passband skirt. The transmission zeros are generated based on multipath propagation of cross coupling effects in the filter. Fig. 3(a) shows the structure of the embedded asymmetric SIR. The embedded asymmetric SIR is composed of a quarter-wavelength SIR ([(Z_1, θ_1), (Z_2, θ_2)] as path 1 at 2.4 GHz) and embedded half-wavelength SIRs [(Z_2, θ_2), (Z_1, θ_5), (Z_3, θ_3), (Z_4, θ_4)] as path 2 at 3.5 GHz). By properly tuning the dimension such as impedance ratio of $K_1 = Z_2/Z_1$, $K_2=((Z_2+Z_4)/2)/((Z_1+Z_3)/2)$ and length ratio of $\alpha_1 = \theta_2 / (\theta_1+\theta_2)$, $\alpha_2 = (\theta_2+\theta_4) / \theta_T$, the arrangements of every resonant mode become more flexible. The resonant modes of the multipath-embedded SIR can be derived by setting $Y_{in} = 0$, expressed as Fig. 3(b) shows relations between the

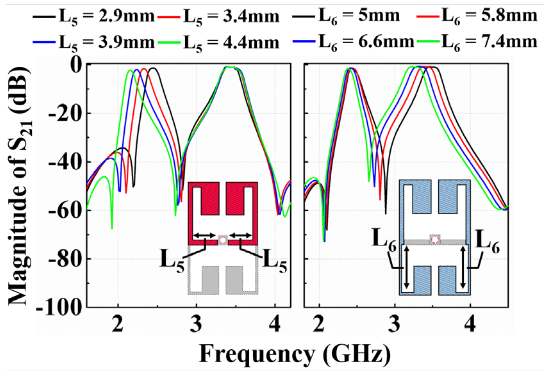


Figure 4. Simulated frequency responses of different length L_5 and L_6 for each resonant path. (Changing L_5 with fixed L_6 = 5 mm and Changing L_6 with fixed L_5 = 2.9 mm.)

normalized f_{si}/f_0 and length ratios of α_1 and α_2 with Fig. 4. impedance ratios of K_1 and K_2.

$$Y_{in1} = \frac{K_1 \text{ - } \tan\theta_1 + \tan\theta_2}{jK(\tan\theta_1 + k\tan\theta_2)} \quad \text{for path 1} \qquad (1)$$

$$Y_{in2} = Z_2 \frac{Z_A + jZ_2 \tan\theta_2}{Z_2 + jZ_A \tan\theta_2}$$

where

$$Z_A = \frac{(\ \ jZ_1Z_3Z_4\cot\theta_4 + jZ_1Z_3^{\,2}\tan\theta_3 + jZ_1\tan\theta_1)(Z_3 + Z_4\cot\theta_4\tan\theta_3)}{Z_1(Z_3 + Z_4\cot\theta_4\tan\theta_3) + (Z_3Z_4\cot\theta_4 \quad Z_3^{\,2}\tan\theta_3)}$$

for path 2 (2)

for each path. Path 1 shows resonant mode of a quarter-wavelength SIR. Path 2 shows resonant modes of the asymmetric half-wavelength SIR. It is found that each resonant path can be designed individually by using the embedded asymmetric SIR. The appropriate design parameters of multipath-embedded SIRs are indicated as marked point A and B in Fig. 3(b). Using embedded asymmetric SIR, 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. Fig. 3(c) shows the fundamental and higher order resonant modes of the embedded asymmetric SIR. The arrangements of fundamental and higher order resonant modes are critical for the dual passband with very wide stopband. Fig. 4 shows simulated frequency responses of different lengths L_5 and L_6 for each resonant path. To

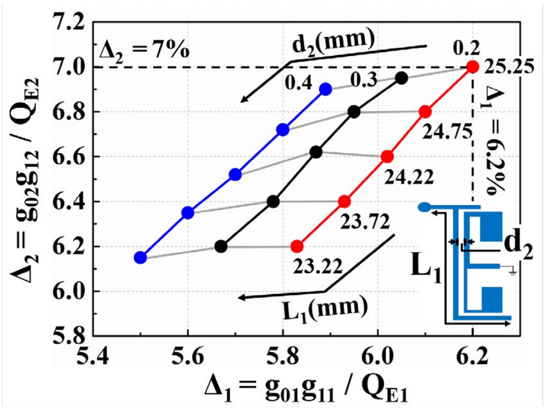


Figure 5. Relations between the FBW (Δ_1 and Δ_2), source-load line length L_1 and the coupling gap d_2 at 2.4 and 3.5 GHz for the proposed filter.

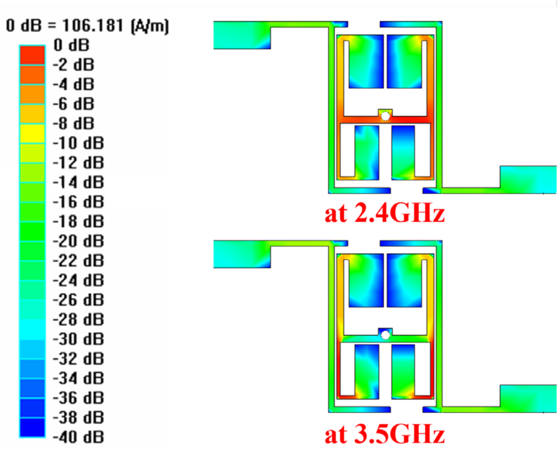
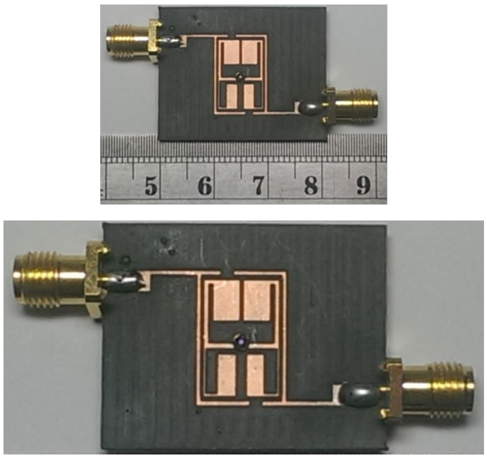
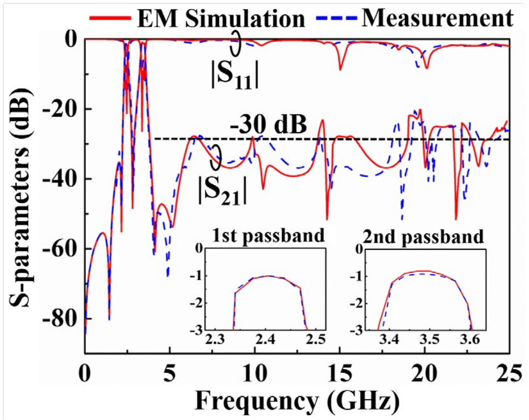


Figure 6. Current distribution of the proposed filter.

simplify the design, the parameters of sections of (Z_2, θ_2) and (Z_4, θ_4) are fixed, only to change the lengths of (Z_1, θ_1) as L_5 and (Z_3, θ_3) as L_6 for evaluating the effects of passband performance. For an example as path 1, 1st passband (2.4 GHz) is shifted to lower frequency with maintaining response for path 2 when L_5 is increased. Similarly, the resonant frequencies of path 2 (3.5 GHz) is shifted to lower frequency when L_6 is increased. Each path is created by the quarter-wavelength (and/or a asymmetric half- wavelength) SIR. The resonant frequencies of each path can be tuned in wide frequency range without



(a)



(b)

Figure 7. (a) Photograph and (b) measured results of the dual-band filter.

affecting another passband performance. Therefore, each passband can be implemented individually very well by using the embedded asymmetric SIR. Fig. 5 shows the relations between the 3-dB fraction bandwidth (FBW), source-load coupling lines length L_1 and the coupling gap d_2 at 2.4 GHz and 3.5 GHz of the proposed filter.

The extraction of quality factor (Q_{E1} and Q_{E2}) can be found as follows [6]

$$Q_{Ei} = f_{0i} / (\Delta f \pm 90°),\ i = 1 \text{ or } 2 \qquad (3)$$

where f_0 and $\Delta f \pm 90°$ represent the resonant frequency (at 2.4/3.5 GHz) and the absolute bandwidth between the ±90° points of S_{11} phase response for the coupling gap d_2 between the I/O ports. The subscript i indicates 1st passband to 2nd passband. The corresponding realizable

Table 1. COMPARISONS WITH OTHER PROPOSED FILTERS. (λ_g IS THE GUIDED WAVELENGTH OF THE 1ST CENTER PASSBAND FREQUENCY

	Ref. [2]	Ref. [8]	Ref. [9]	**This study**
Substrate height (mm)/ ε_r	0.787/2.2	0.635/6.15	0.8/4.4	**0.787/2.2**
1st / 2nd passband (GHz)	2.4 / 5.2	1.6 / 2.45	1 / 1.5	**2.4 / 3.5**
$\|S_{11}\|$ (dB)	20 / 20	12 / 12	16 / 15.2	**20 / 25**
$\|S_{21}\|$ (dB)	0.4 / 0.58	1.46 / 1.16	1.58 / 1.54	**1/ 0.8**
FBW (%)	20 / 10	4.5 / 5.6	3 / 3	**6.2 / 7**
30-dB Wide Stopband	×	×	×	**10f_0**
Circuit Size (mm^2) (λ_g* λ_g)	868 (0.25*0.22)	342 (0.24*0.25)	1453 (0.3*0.24)	**295 (0.23*0.17)**

3-dB fractional bandwidths (Δ_i) for dual-passbands are as follows.

$\Delta i = g_{0i}g_{1i} / Q_{Ei}$, i = 1 or 2 (4)

where g_{0i} and g_{1i} are element values of the filter response function and Q_{Ei} is the extracted external quality factor by using the full-wave electromagnetic (EM) simulation [7]. Fig. 6 shows the current distribution of the filter. It is clearly observed that 1st and 2nd passband at 2.4 and 3.5 GHz are generated by the inductive-coupled SIRs and no interactions produced to interfere the dual passband performance. The dual-band bandpass filter with low insertion loss is well achieved. It is noted that the size of filter is around 19.8 × 14.9 = 295 mm^2 (only approximately 0.23 λ_g × 0.17 λ_g, where λ_g is guided wavelength at 2.4GHZ.

III. RESULTS

Photograph of the fabricated BPF is shown in Fig. 7(a). The measured frequency response is characterized using an R&S ZVA40 network analyzer. Fig. 7(b) shows the measured results of the filter. The filter has measured center frequencies at 2.4 and 3.5 GHz, the 3-dB fractional bandwidth (FBW) of 6.2 % and 7 %, the minimum insertion loss (-20 log $|S_{21}|$) of 1 and 0.8 dB and the wide stopband under 30 dB over around 10 f_0 (at 1st passband) is well achieved. The transmission zeros at 2.1, 2.8 and 4.1 GHz are clearly observed, resulting in high passband selectivity. The comparison of the filter with other reported works is summarized in Table 1. The proposed resonators essentially help not only to create the multi-path propagation, but also to reduce the overall circuit size. Good agreement between measurement and simulation validates the feasibility of the configuration.

Ⅳ. CONCLUSIONS

This paper presents a dual-band passband filter using the embedded asymmetric SIR. Good dual-band performance and high passband selectivity are well designed and implemented. The dual-band response is generated by properly choosing the impedance ratio and length ratio of the SIRs. The transmission zeros are generated by multipath propagations from cross-coupling effects in the filter. The circuit size is reduced greatly compared with the other reported works. Measured results reveal that the filter achieves a compact circuit size, low insertion loss and good passband selectivity at each passband. The proposed method of the dual band passband filter is effectively useful for multi-band wireless communication systems.

V. ACKNOWLEDGEMENT

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