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Compact Dual-Band Bandpass Filter Based on Quarter Wavelength Stepped Impedance Resonators

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***Abstract*—**This paper presents a compact dual-band bandpass filter that involves using the quarter wavelength stepped impedance resonators (SIRs) for achieving simultaneously compact circuit size and good dual-band performance. The filter is designed at 2.4 / 3.5 GHz and constructed by two pairs of quarter wavelength SIRs and source-load lines. By properly tuning the impedance ratio, length ratio and radius of via hole of the SIRs, dual-passbands performance can be easily determined. To improve the passband selectivity, the use of source-load lines is to increase coupling energy between the resonators. The filter is showing simple configuration, effective design method and small circuit size. The measured results are in good agreement with the simulation results.

***Keywords*—**Dual-band, bandpass filter, stepped impedance resonators, SIR.

I. Introduction

In recent years, the developments in multi-passband bandpass filters (BPFs) have been getting more attention for advanced wireless communication systems [1]. To design a dual-band filter with low insertion loss, compact size, good passband selectivity, and wide stopband is needed for fitting the requirements of current wireless communication systems.

Several works of designing the dual-band filters are presented [2]-[8]. 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. In [6], the filters are using the two coupling paths to control the bandwidth of each passband. In [7], the filter is developing with two stepped impedance resonators. Two ends of both resonators are mutually coupled. In [8], the dual-band filter of high isolation between two closely-positioned adjacent bands. The reconfigurable fourth-order bandpass filter (BPF) prototype consists of two individual filters and a double-diplexer configuration, which enables independent synthesis of BPF on each band. The previous works are showing the good idea and results, however, the passbands with low-loss, transmission zeros and closed adjacent with needed to further study.

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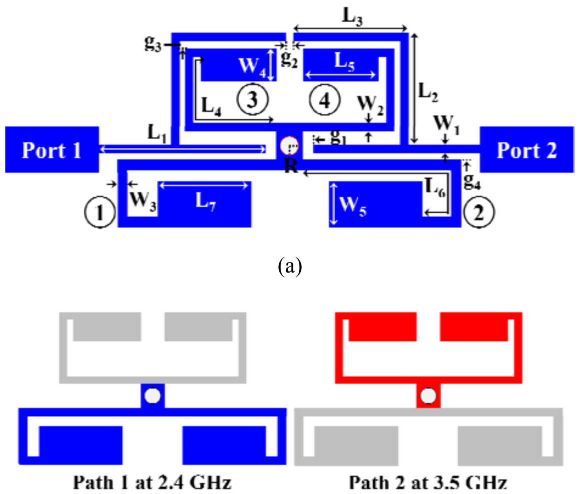
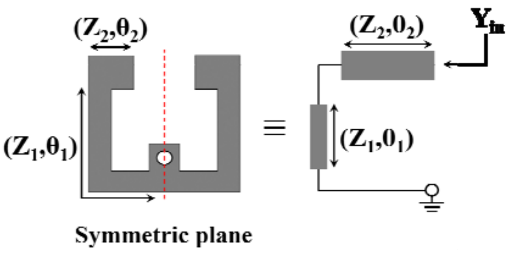


(a)

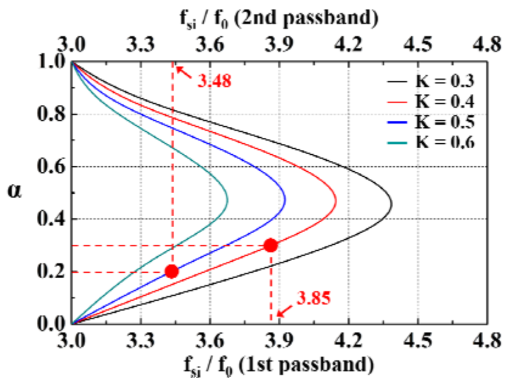
(b)

Fig. 1 (a) Configuration and (b) each resonant path of the proposed filter. L_1 = 8.5, L_2 = 5.8, L_3 = 14.7, L_4 = 9.2, L_5 = 4.1, L_6 = 13.4, L_7 = 5.1, W_1 = 0.5, W_2 = 0.5, W_3 = 0.6, W_4 = 1.8, W_5 = 2.5, g_1 = 0.3, g_2 = 0.3, g_3 = 0.2, g_4 = 0.25 R = 0.5. (All are in mm)

In this paper, the compact dual-band bandpass filter by using the stepped impedance resonators with quarter wavelength is proposed. The filter features simultaneously compact circuit size and good dual-band performance. The filter consists of two pairs of quarter wavelength SIRs and the source-load lines operated at 2.4 / 3.5 GHz. Each pair of the resonators is designed on magnetically coupling by via hole to ground at symmetric plane of the resonator. By using the combination of the quarter wavelength SIRs and source-load lines, the filter with compact circuit size and the wide stopband are well achieved. 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 quad-band BPF without complex design and fabrication process.



(a)



(b)

Fig. 2 (a) Transmission line model of the proposed filter and (b) Relations between the normalized fsi / f_0 and length ratios of α with impedance ratios of K

II. Filter Design

Fig. 1 (a) shows the configuration of the proposed filter. The filter consists of two quarter wavelength stepped impedance resonators connected each other by via hole (magnetically coupling) technique along symmetric plane of the filter. The source-loaded lines are able to control simultaneously the performance of two passbands. The quarter wavelength SIR includes two resonant paths as shown in Fig. 1 (b). 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 quarter-wavelength SIRs. 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 filter is simulated, designed and fabricated on the substrate Duroid 5880 with dielectric constant εr = 2.2, loss tangent δ = 0.0009 and thickness of 0.787 mm. Fig. 2 (a) shows the proposed short-ended quarter wavelength SIR. The impedance ratio (K) and the length ratio (α) are defined as $K = Z_2 / Z_1$ and $\alpha = \theta_2 / (\theta_1+\theta_2)$ for 1st passband and 2nd passband, respectively. The input admittance Y_{in} of the SIR is derived as

$$Y_{in} = \frac{K_1 - 1\tan\theta_1 + \tan\theta_2}{jK(\tan\theta_1 K\tan\theta_2)} \quad \text{for 1st and 2nd passband} \qquad (1)$$

The resonant conditions of the quarter wavelength SIR occur while $Y_{in} = 0$. Several solutions for θ_1 and θ_2, and are dependent on the choice of K and α. Compared with the conventional SIRs [9], higher resonant modes of the quarter wavelength SIR can be easily shifted to far away to the fundamental resonant mode. By properly tuning the dimension of each resonant path, such as impedance ratio K and physical length ratio α, the arrangements of every resonant mode become more flexible. Fig. 2 (b) shows relations between the normalized f_{si} / f_0 curves for a quarter wavelength SIRs with different K and α. The curves would be very useful for achieving the desired dual-passbands. The f_{s3} / f_0 can be achieved by choosing α value with specific K value. Using the quarter wavelength SIRs, design of multi-band filter with very close (or faraway) passbands can be easily achieved and having the high passband selectivity of each passband. Fig. 3 shows simulated frequency responses of different lengths L4 and L_6 for each resonant path. To simplify the design, the parameters of sections of L_5 and L_7 are fixed, only to change the lengths of L_4 and 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 1 when L_4 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 SIR. The resonant frequencies of each path can be tuned in wide frequency range without affecting another passband performance. Therefore, each passband can be implemented individually very well by using the quarter-wavelength SIR. The three passbands can also be designed individually, therefore, a single band filter design can be applied based on the knowledge of the coupling coefficients, as shown in Fig. 4 the center frequencies and fractional bandwidths are f_1 = 2.4 GHz, f_2 = 3.5 GHz, and Δ_1 = 4.3%, Δ_2 = 3.9%, respectively. The lumped circuit element values of the low-pass prototype filter are found to be $g_0 = 1$, $g_1 = 0.94982$, $g_2 = 1.35473$, $J_1 = -0.12333$, and $J_2 = 1.0181$. The required coupling coefficients and external quality factors are found to be $M_{12}=M_{21} = 0.0379$ at 2.4 GHz and $M_{34}= M_{43} = 0.0349$ at 3.5 GHz. The coupling coefficients (M_{ij}) can be obtained by using the full-wave electromagnetic (EM) simulation [14]. Fig. 5 shows the current distribution of the proposed filter. It is clearly observed that 1st and 2nd passbands at 2.4 and 3.5 GHz are generated by the quarter wavelength SIRs and no interactions produced to interfere the dual passband performance. The dual-band bandpass filter with low insertion loss is well achieved.

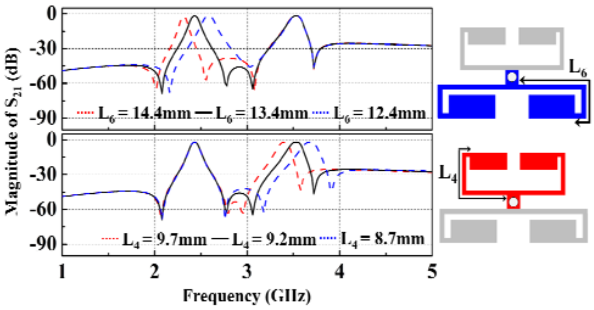


Fig. 3 Simulated frequency responses of different length for each resonant path: The positions of the transmission zeros depending on the lengths L4 and L6

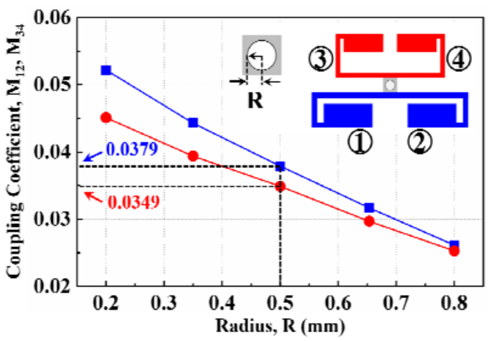


Fig. 4 Coupling coefficients at 1st and 2nd passband of the proposed filter

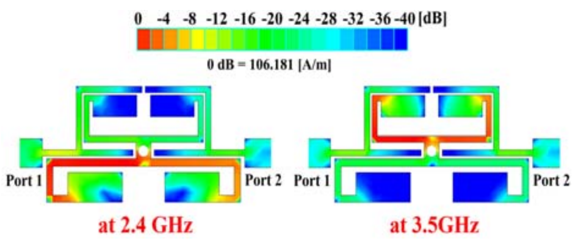


Fig. 5 Current distribution of the proposed filter

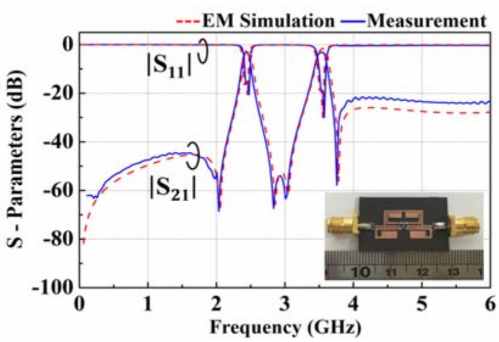


Fig. 6 Photograph and measured results of the dual-band filter

III. Results

Fig. 6 shows the photograph and measured results of the fabricated dual-band BPF. The filter is measured on an R&S Network Analyzer. The overall size is 19 × 10.1 mm^2, i.e., approximately 0.22λ_g by 0.12λ_g (where λ_g is the guided wavelength at center frequency of 1st passband). The filter has measured center frequencies at 2.4 and 3.5, the 3-dB fractional bandwidth (FBW) are of 4.3% and 3.9%, the minimum insertion loss (-20 log |S21|) of 1 and 2 dB and the return losses (-20 log |S11|) are around 20 dB near each passband. The transmission zeros near each passband edge are generated due to the multipath propagation induced from cross coupling effect in the filter. The quarter wavelength 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 loss of each passband is very low. It can be due to the fact 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
COMPARISONS WITH OTHER PROPOSED FILTERS, (λ_g IS THE GUIDED WAVELENGTH OF THE 1ST CENTER PASSBAND FREQUENCY)

Ref.	Substrate height (mm)/ ε_r	1st/2nd Passbands (GHz)	$\lvert S_{11}\rvert$ $\lvert S_{21}\rvert$ (dB)	FBW (%)	Size (mm^2) (λg * λg)
[2]	0.787/ 2.2	2.4/5.2	20/20 0.4/0.58	20/10	1327 (0.28 x 0.38)
[3]	0.508/ 33.8	1/2	12/12 2.7/2.7	4.6/4.8	680 (0.26 x 0.16)
[4]	0.8 / 2.45	2.4 / 3.5	13 / 10 2.8 / 4.5	8 / 5	1760 (0.64 x 0.18)
[6]	0.635/6.15	1.6 / 2.45	12 / 12 1.46 / 1.16	4.5 / 5.6	342 (0.24 x 0.25)
[7]	0.8/4.4	1 / 1.5	16 / 15.2 1.58 / 1.54	3 / 3	1453 (0.3 x 0.24)
[8]	0.508/3.55	1.5/2	23/23 3/3	11/10	4590 (0.57 x 0.7)
[10]	0.787/2.2	2.5/4.5	-3/-3 -10.3/-10.3	15.6/6.4	150 (0.18 x 0.13)
[11]	1.6/4.4	2.4/3.6	18/24 0.46/0.52	6.1/7.3	409.5 (0.35 x 0.32)
[12]	1/2.45	1.5/3.52	19.0/21 1.1/0.84	9.5/13.1	223.4 (0.13 x 0.11)
This study	0.787/ 2.2	**2.4 / 3.5**	**20 / 25** **1/ 2**	**4.3 / 3.9**	**192** **(0.22 x 0.12)**

IV. Conclusion

This paper presents a dual-band filter using the quarter wavelength SIRs. Good dual-band performance at 2.4 / 3.5 GHz and high passband selectivity are well designed and implemented. The dual-band response is generated by properly choosing the impedance ratio and physical length 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 design procedure of the proposed filter is simple and may be followed easily.

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