Design of Compact Triplexer based on Short-Ended Stepped Impedance Resonators (SIRs)

Yung-Wei Chen[1], Hung-Wei Wu*[2], Tzu-Chun Tai[1], and You-Sian Chen[3]

ABSTRACT

A compact microstrip triplexer using the semi-lumped short-ended stepped impedance resonators is proposed. The triplexer is designed at 2.4 / 3.5 / 5.2 GHz. The triplexer is composed of three pairs of semi-lumped short-ended stepped impedance resonators and the source-load coupling lines. By properly tuning the impedance ratio (R), length ratio (α) and inductive via hole of the semi-lumped short-ended stepped impedance resonators, three channels (passbands) frequencies can be easily determined. To improve the passband selectivity, the source-load coupling lines are designed to correspond to the quarter-wavelength at the center frequency for each channel. The proposed triplexer is showing a simple configuration, an effective design method and a small circuit size.

Keywords: triplexer, stepped impedance resonators, source-load coupling, circuit size.

I. INTRODUCTION

Recently, multi-band components are more demanded in the multi-service wireless communication systems. Multiplexers play a key role in the RF front ends of the wireless communication systems. To date, design of the multiplexer such as compact circuit size, low insertion loss, high in-band isolation, and ease to implement are more required to satisfy the requirements of the modern systems. Some previous works for the microstrip triplexers are proposed [1]-[5]. In [1], the new matching circuits for triplexers are proposed based on half-wavelength tapped-connected stepped-impedance resonators. In [2], the new triplexer using the compact composite right/left-handed (CRLH) quarter-wave type resonators is proposed. The very compact triplexer is implemented successfully. In [3], the triplexer with a common resonator is proposed. By exploiting the variable frequency response of stepped-impedance resonator, the common resonator can be shared by three filter channels of a triplexer. In [4], the authors proposed a high-isolation triplexer using multiple-mode resonators. The triplexer composed of the stepped impedance resonators, stepped-impedance resonators, and distributed coupling technique. In [5], the triplexer is composed of three pairs of bandpass filters and a star-junction. The passbands will be generated and having a wideband insertion loss. However, these works show the increasing circuit size and a little high insertion loss due to using the high-order coupled resonators needs to be further modified. These works provide very good idea and inspired us to further study these issues.

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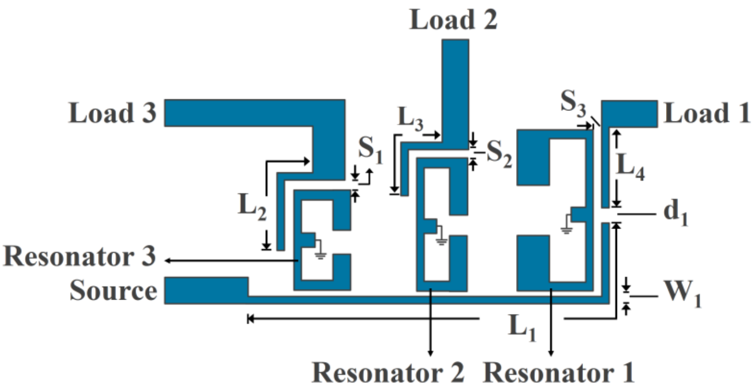


Figure 1. Configuration of the proposed triplexer. (Number 1, 2 and 3 indicate the index of bandpass filter in this work)

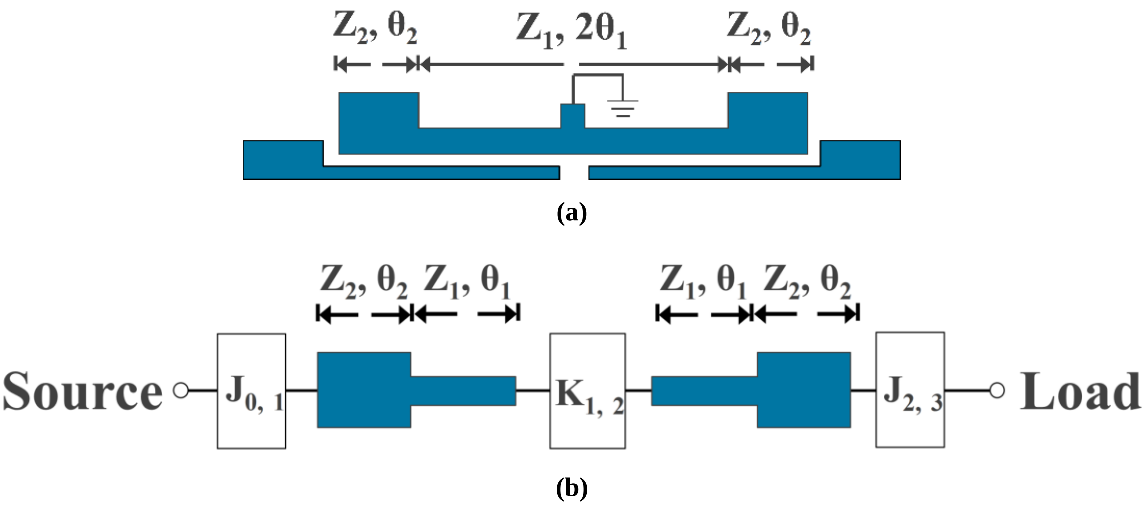
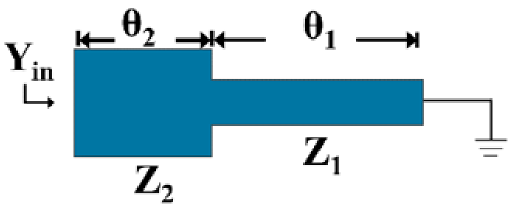


Figure 2. (a) 2-order filter structure and (b) alternative J and K inverters.

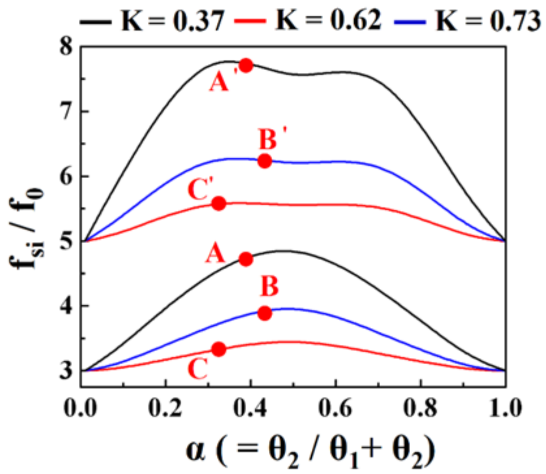
Table 1. Parameters of the Proposed Triplexer

	K	α	θ_1	θ_2	Z_1	Z_2
Filter 1	0.37	0.35	8.8	5.2	100	37
Filter 2	0.62	0.4	7.3	5.2	100	62
Filter 3	0.73	0.3	6	2.5	115	84

In this paper, we proposed the new triplexer with compact size, low insertion loss, and high in-band isolation. The triplexer includes three pairs of the semi-lumped short-ended stepped impedance resonators (SIRs). Each pair of the resonators is designed on magnetically coupling by via hole to ground at symmetric plane of the resonator. The triplexer is designed to have three passbands as 2.4 GHz, 3.5 GHz and 5.2 GHz by properly tuning the impedance ratio (K) and length ratio (α) of the



(a)



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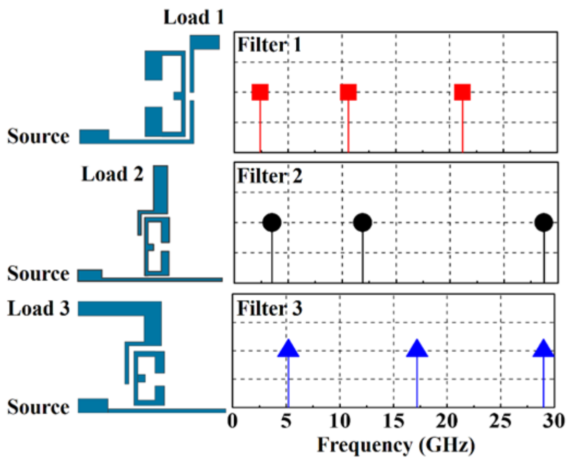


(c)

Figure 3. (a) Configuration of the proposed SIR, (b) the relations of the normalized f_{s1}/f_0 versus length ratio α with impedance ratio K

semi-lumped short-ended stepped impedance resonators. The short-ended sections of each resonator by via-hole grounding can determine the

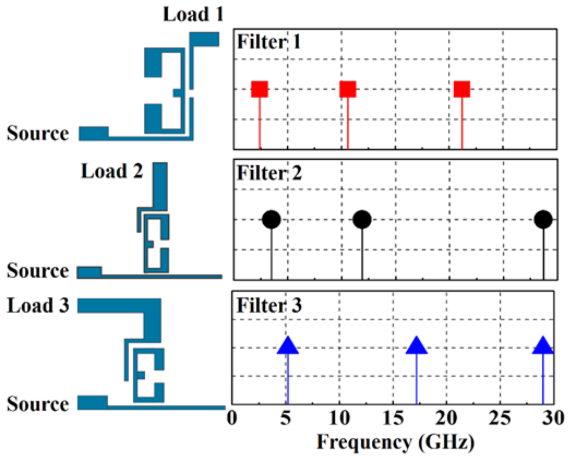


Figure 4. The distribution of fundamental and higher order resonant frequencies of the proposed SIRs for each channel.

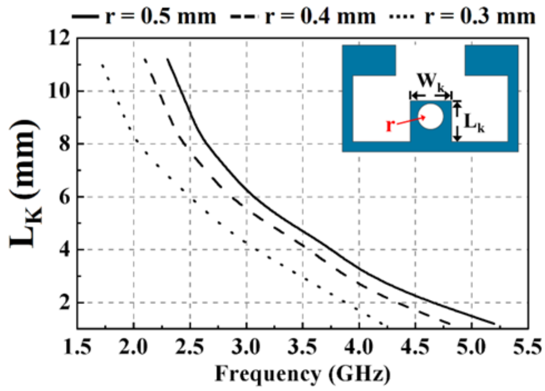


Figure 5. Relations between the short-circuited stub length L_K and size of via hole for passband frequencies tuning. (r indicates the radius of the via hole)

resonant peak without enlarging the circuit size. To improve the passband selectivity, the source-load line to corresponded to quarter-wavelength at center frequency of each passband are used. The design procedure of the proposed triplexer is simple and may be followed easily. The proposed triplexer should have many applications in multi-service and multi-band wireless communication systems.

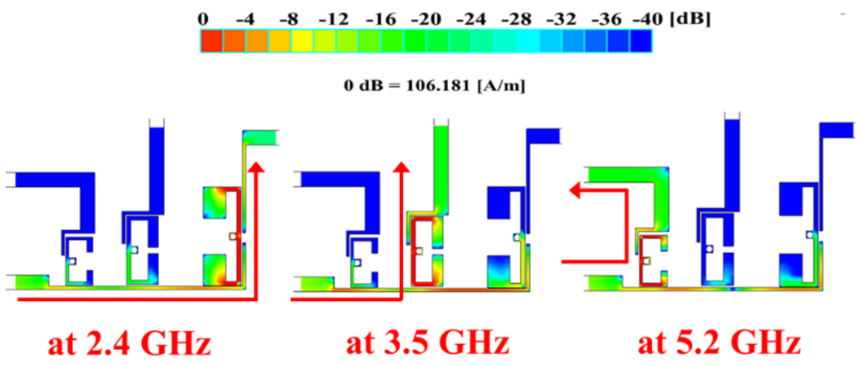


Figure 5. Current distribution of the proposed triplexer.

TABLE 2. Comparisons with other proposed triplexer (O/C: output ports / channels, IL: insertion loss)

Ref.	O/C	Substrate ε_r / height (mm)	Passbands (GHz)	IL (dB)	Isolation (dB)	Circuit size (mm^2 / λ_g^2)
[1]	3/3	2.2/ 0.787	1.48/1.75/2	3.38/2.9/3.2	> 32	9043/075
[2]	3/3	2.2/ 0.787	1.75/2.4/3.6	1.7/2.2/1.2	> 35	321/0.02
[3]	3/3	2.2/ 0.25	1.47/ 2.25/3	2.9/ 2.3/ 2	> 35	2370/0.15
[4]	3/3	3.38/ 0.508	3.2/3.7/4.4	2.7/2.5/1.8	> 35	430/0.15
[5]	3/3	3.55 /0.508	3.2/3.7/4.2	1.2/2.5/1.1	> 20	292/0.03
This work	**3/3**	**2.2/ 0.787**	**2.4/3.5/5.2**	**1.2/ 1.2/ 1.1**	**> 40**	**483/0.06**

II. TRIPLEXER DESIGN

Fig. 1 shows the configuration of the proposed lines corresponded to quarter-wavelength at center frequency of each passband are used. The design procedure of the proposed triplexer is simple and may be followed easily. The proposed triplexer should have many applications in multi-service and multi-band wireless communication systems. triplexer. The proposed triplexer composed of three pairs of the semi-lumped short-ended stepped impedance resonators (SIRs) to generate the triple-passband at 2.4 / 3.5 / 5.2 GHz, respectively. Each pair of the resonators (equal to a 2-order filter) is designed on magnetically coupling by via hole to ground at symmetric plane of the resonator. For an example to design the source-load coupling lines at channel 1 (2.4 GHz), the source-load coupling line is designed under the conditions of no reflection at 2.4 GHz for channel 1 and total reflections at 3.5 GHz for channel 2 and 5.2 GHz for channel 3. Therefore, designing the source-load coupling lines

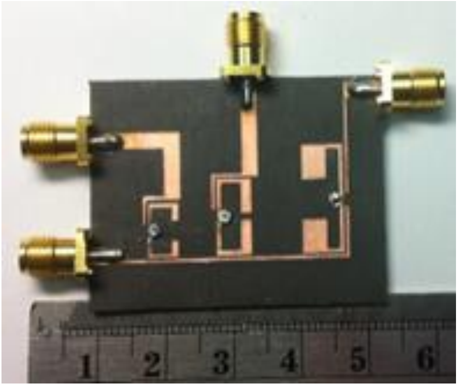
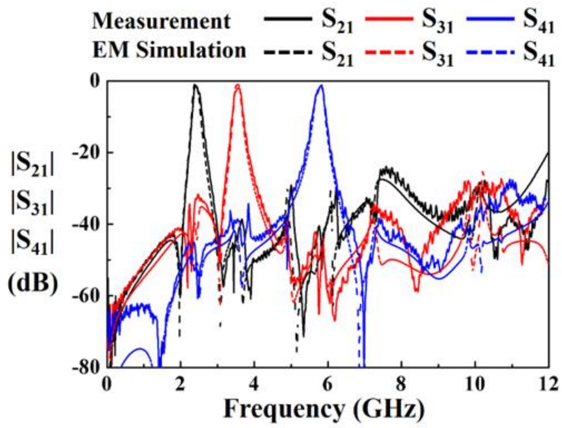
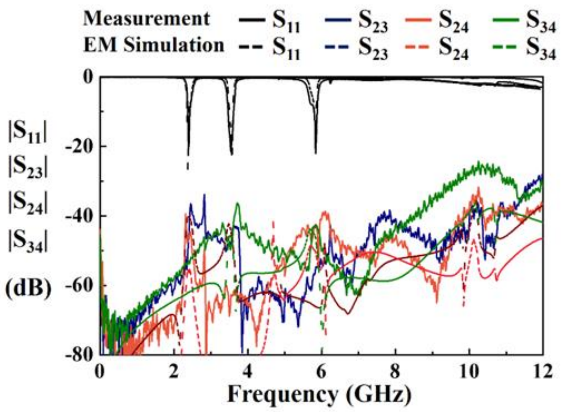


Figure 6. Photograph of the fabricated triplexer.



(a)



(b)

Figure 7. Simulated and measured results of (a) return loss, (b) insertion loss and in-band isolation of the proposed triplexer. The dimensions are L_1 = 40, L_2 = 12.1, L_3 = 9.6, S_4 = 0.3, S_1 = 0.2, S_2 = 0.2, S_3 = 0.2, W_1 = 0.5. (All are in mm).

corresponded to the quarter-wavelength transmission lines at first channel (passband) frequency to fulfill the above-mentioned conditions would be a good choice. The fabricated filter is simulated and implemented on the Duroid 5880 substrate with the relative dielectric constant $\varepsilon_r = 2.2$, loss tangent tan $\delta = 0.0009$ and thickness h = 0.787 mm. Fig. 2 shows the 2-order filter structure by using the semi-lumped short-ended stepped impedance resonators and alternative J and K inverters. The 2-order filter structure is consisting of two quarter-wavelength SIRs by connecting with semi-lumped short-ended via hole grounding. Fig.2(b) shows the equivalent circuit model of the resonators under ignoring the parasitic coupling effects for narrowband filter design. In past, designing the multiplexers with three passbands should be constructed by at least 4-order bandpass filter for forming each passband, however, the disadvantages of complex design parameters, higher spurious response and larger circuit size should be further modified. Therefore, the proposed compact triplexer shows a small circuit size and the triple-passband response with high passband selectivity. By using the matching network is needed for the triplexer design. The schematic of a SIR, which consists of two impedance sections as Z_1 and Z_2 with electrical lengths of θ_1 and θ_2, respectively. The left-end of Z_1 section is short circuited; therefore, we can find Y_{in} is formulated as

$$Y_{in} = -jY_1 \frac{K\tan\theta_2 + \tan\theta_1}{K\tan\theta_1\tan\theta_2 - 1} \qquad (1)$$

where the impedance ratio K is defined as Z_1/Z_2.

The resonant conditions of the proposed SIR occur while $Y_{in} = 0$. Several solutions for θ_1 and θ_2 are dependent on the choice of K and α. Fig. 3(b) shows the normalized f_{S1}/f_0 and f_{S2}/f_0 curves for a SIR with different K and α. The curves would be very useful for achieving the desired passbands of the triplexer without influencing each other. The marked points of A, B, and C at f_{S1}/f_0 and A', B', and C' at f_{Si}/f_0 are chosen for the optimal design parameter in this work. fundamental and higher order resonant modes are critical for the triplexer with very wide stopband. The designed parameters of each resonator in this work are summarized in Table 1. The center frequencies and fractional bandwidths are f_1 = 2.4 GHz, f_2 = 3.5GHz, f_3 = 5.2GHz, and Δ_1 = 3%, Δ_2 = 3%, Δ_3 = 3.5%, 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 $M_{12} = M_{21} = 0.070$ at 2.4GHz, $M_{23} = M_{32} = 0.034$ at 3.5GHz and $M_{13} = M_{31}$ = 0.024 at 5.2GHz. The coupling coefficients (M_{ij}) can be obtained from the two resonant modes as M_{ij} = $(f_H^2 - f_L^2) / (f_H^2 + f_L^2)$ through full-wave EM simulation. 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. Fig. 4 shows the relations between the short-circuited stub length L_K and size of via hole for the passband frequencies tuning. The short-circuited stub is formed to serve as the inverter, as shown in Fig. 2. By changing the length of L_k with different size of via hole, the frequencies of each passband can be verified in a wide range. The short-circuited stub could be characterized using the lumped/distributed model [6], and the resultant is valid for the narrowband case. To keep the circuit size without change, the passband frequencies can be easily controlled by only tuning the short-circuited stub length L_K and size of via hole in this work. Fig. 5 shows the current distribution of the proposed triplexer at 2.4 / 3.5 / 5.2 GHz. It is clearly observed that the EM waves are transmitted in the diplexer from source to load 1, load 2 and load 3 Each passband can be implemented individually, and low insertion loss and high passband selectivity of each passband can be well achieved.

III. RESULTS

Photograph of the fabricated triplexer is shown in Fig. 6. The overall size of the fabricated triplexer is about 15 × 31 = 465 mm^2 (around 0.18 λ_g × 0.36 λ_g, where λ_g is the guided wavelength at the center frequency of the 1st passband), as summarized in Table 2. The measured frequency response is characterized using an HP 8510C network analyzer. Fig. 7 shows the simulated and measured results of return loss $|S_{11}|$, insertion loss $|S_{21}|$, $|S_{31}|$, $|S_{41}|$ and in-band isolation of the proposed triplexer. The measured results have insertion losses of 1.2 dB, 1.2 dB and 1.1 dB, return losses are 20 dB, 25 dB and 35 dB corresponding to 2.4 GHz, 3.5 GHz and 5.2 GHz, respectively. The 3-dB fractional bandwidths (FBW) are 3%, 3% and 3.5%. The losses of the triplexer can be evaluated from the conductor line and dielectric substrate. The isolation values of $|S_{23}|$, $|S_{24}|$ and $|S_{34}|$ are averaged to be around 41 dB, 37 dB and 52 dB. The slightly mismatch between the simulated and measured results due to the fabrication errors or the variation of material properties. The comparison of the proposed triplexer with other reported works is summarized in Table 2. The measured and simulated results of the three passbands are still in close agreement. Good agreement between measurement and simulation validates the feasibility of the configuration.

IV. Conclusion

The triplexer based on the semi-lumped short-ended stepped impedance resonators has been investigated through the EM simulation and experiment. By using the proposed resonators and the source-load coupling lines, the triple-passbands with high passband selectivity and high in-band isolation (> 30 dB) can be well achieved. Measured results reveal that the triplexer achieves a compact circuit size, low insertion loss and good passband selectivity at each passband. The design procedure of the proposed triplexer is simple and being followed very easily.

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