Progress In Electromagnetics Research Letters, Vol. 73, 69–75, 2018

Wide Stopband Compact Microstrip Quadruplexer Using Common Crossed Resonator

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Abstract—A compact size and wide stopband microstrip quadruplexer with a common crossed resonator is proposed in this paper. The resonator mentioned is theoretically analyzed and proved to be able to resonate at three different frequencies. The resonant frequencies can be easily modified by changing the length of the corresponding stub of the resonator. This tri-mode resonator is proved to have the capacity of being shared by three different bandpass filters in a quadruplexer in this paper. Then an additional channel is designed to be coupled to the other side of the feed line of the common input port. Compared to conventional ones, the proposed quadruplexer has a more compact structure, since no extra matching network is needed, and the number of resonators is reduced effectively. Moreover, a wide stopband is obtained by making the resonators work at the same fundamental frequencies but different higher order frequencies. Besides, open circuit stubs are also used to suppress the harmonic frequencies. To demonstrate the design procedure, a quadruplexer with a third order Chebyshev response in each channel is fabricated and measured. The measured result is in good agreement with the simulated one, showing an attenuation of 20 dB up to 10.2 times of the first channel frequency.

1. INTRODUCTION

Multiplexers play an important role in modern communication system for signal separation or combination in both receivers and transmitters. To satisfy the strict modern communication system requirement, high isolation, compact size, easy realization and wide stopband multiplexers are always required. A conventional multiplexer usually consists of several bandpass filters and an impedance matching network for realizing the isolation between channels [1–4]. The common approach to synthesize multiplexers is to design each channel bandpass filter individually and then using a matching network to connect them. However, this type of design procedure usually leads to an unacceptable size and a complex geometry which limits its flexibility of being put into use. The limitation of space usually requires the size of the multiplexer small enough to be put into application in which the size of the device comes to have a higher priority. Besides, it is difficult to find an impedance matching network for multiplexers operating more than three channels.

For multiplexers, distributed coupling technique is widely used [5–8]. By properly locating the channels along the distributed common feed line, a good impedance matching in each channel can be gained, and isolation obtained can also meet the requirement sometimes. However, involving the common feed line unavoidably leads to a too long structure, and the high frequency responses of those multiplexers are always not very good, which is indeed important in some applications. Nevertheless, replacing the long common feed line or the matching network with a multi-mode resonator will make the structure more compact with easy fabrication. And usually wide stopband can be obtained in these designs. In [9], a diplexer using a dual-mode T-shaped resonator which can provide two extremely close

Received 22 November 2017, Accepted 30 January 2018, Scheduled 6 February 2018
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resonance frequencies as a common resonator is presented. The diplexer realizes an isolation of more than 35 dB in each channel and a stopband up to 5.26 times of the first channel frequency with a quite simple structure. Among various resonators, the most popular common resonator is step impedance resonator (SIR) for its controllable multi-mode operation. By properly designing the length and width of the SIR, it can work at two or more different frequencies. In [10, 11], a SIR was used as a common resonator to form a diplexer. Both the diplexers have a wide stopband because of the different high order resonance frequencies of those resonators involved [14]. A triplexer using SIR as a common resonator was presented in [12], but the wideband performance is not given. To the authors' knowledge, most of the literatures about common resonator are focused on diplexers, and works on multiplexers are much fewer.

In [13], a novel cross-shaped resonator was presented and proved to be able to resonate at three controllable frequencies. Based on this work, a quadruplexer based on a common crossed resonator is designed and measured. The quadruplexer has a third order Chebyshev response in each channel. Compared to conventional ones, the proposed quadruplexer has a compact structure and wide stopband. An experimental prototype is designed and measured, and predicted by the full-wave model.

2. CROSSED RESONATOR

The crossed resonator is shown in Figure 1. It constitutes a conventional half-wavelength resonator (Z, $\theta_0 = 90°$) with an open circuited stub (Z_2, θ_2) and a short circuited stub (Z_1, θ_1) loaded in the center. For design convenience, all the stubs have the same characteristic impedance ($Z_1 = Z_2 = Z = 1/Y$). To obtain the first three resonance frequencies (f_1, f_2, f_3) of the crossed resonator, the input impedance of the crossed resonator can be calculated as follows

$$Y_{in} = jY\frac{2\tan\theta_0 + \tan\theta_2 - \cot\theta_1}{1 - \tan\theta_0(2\tan\theta_0 + \tan\theta_2 - \cot\theta_1)} \tag{1}$$

When $\theta_0 = 90°$,

$$Y_{in} = \lim_{\theta_0 \to 90°} jY\frac{2\tan\theta_0 + \tan\theta_2 - \cot\theta_1}{1 - \tan\theta_0(2\tan\theta_0 + \tan\theta_2 - \cot\theta_1)} = 0 \tag{2}$$

And this corresponding frequency has been proved to be the second resonant frequency (f_2) of the crossed resonator [13]. The design curve for the other two resonance frequencies (f_1, f_3) can be plotted according to Eq. (1), which is shown in Figure 2. The second resonance (f_2) of the proposed cross resonator is dominated by the central half wavelength resonator ($2\theta_0$). When the resonance characteristic of the central resonator is fixed, the frequency rates of the first and third resonance frequencies to second resonance frequency can be adjusted easily by changing the length of the short circuited stub and open circuited stub. According to Figure 2, by tuning the short circuited stub length

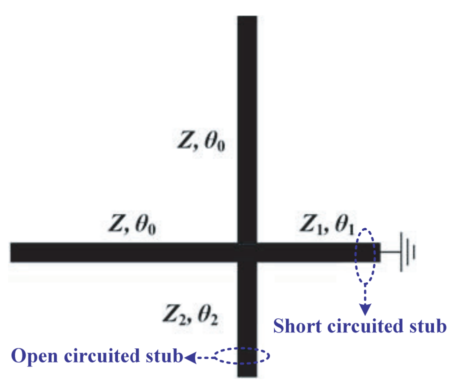


Figure 1. Configuration of the proposed crossed resonator.

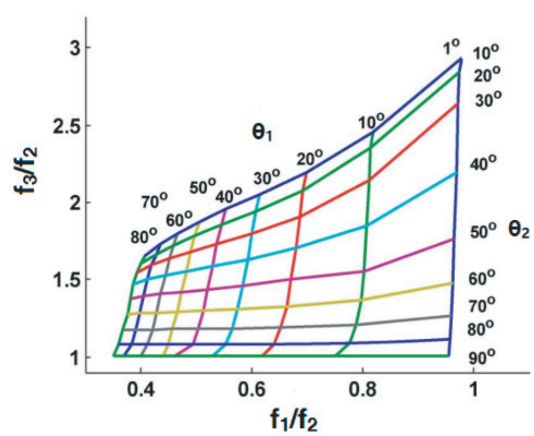


Figure 2. Design curve for crossed resonator.

from 1° to 80°, f_1/f_2 can vary from 0.97 to 0.35. Similarly, f_3/f_2 has a tuning range from 2.8 to 1.01 when the open stub varies from 10° to 90°. Therefore, the crossed resonator can be used as a common resonator of the triplexer. In the following design, three resonance frequencies are selected as 2.4 GHz, 3.5 GHz and 5.2 GHz. The frequency ratios can be calculated as $f_1/f_2 = 0.686$ and $f_3/f_2 = 1.486$. Then according to Figure 2, θ_1 and θ_2 can be determined as 20° and 52°, respectively.

3. DESIGN OF THE QUADRUPLEXER USING COMMON CROSSED RESONATOR

To verify the application of crossed resonator in quadruplexer design, a quadruplexer using crossed resonator as common resonator is designed and fabricated in this section.

Figure 3 illustrates the structure of the proposed quadruplexer with all the channels numbered. The quadruplexer in this paper is designed on a conventional substrate of 0.8 mm thickness with a dielectric constant of 2.55 and loss tangent of 0.0029. The full wave simulation is carried out by Zeland IE3D. The central frequencies of four channels are chosen at 2.4 GHz, 3.5 GHz, 4.5 GHz and 5.2 GHz, respectively. As shown in Figure 3, the first, second and fourth bandpass channels share a common cross resonator. The first bandpass channel is composed of a quarter-wavelength uniform impedance resonator (UIR) and a half-wavelength UIR. The via that connects the microstrip line and the ground plane is denoted by a circle with a radius of 0.25 mm. Similar to the first channel, different types of resonators (quarter-wavelength and half-wavelength UIRs) are also involved for the second channel. For these passband filters, wide stopbands are expected for their different resonators involved. As for the third channel, SIRs and UIR are used to improve the wideband performance. Cross coupling is introduced in the third channel to improve the upper skirt roll-off ratio. Open-loop UIRs are involved to constitute the fourth bandpass channel. Besides, open circuit stubs with high characteristic impedance are involved to introduce multiple transmission zeros in the upper stopband [15]. The simulated S_{41} of the proposed quadruplexer with/without stubs is shown in Figure 4. It can be seen that the original S_{41} is suppressed by the multiple transmission zeros introduced by these stubs.

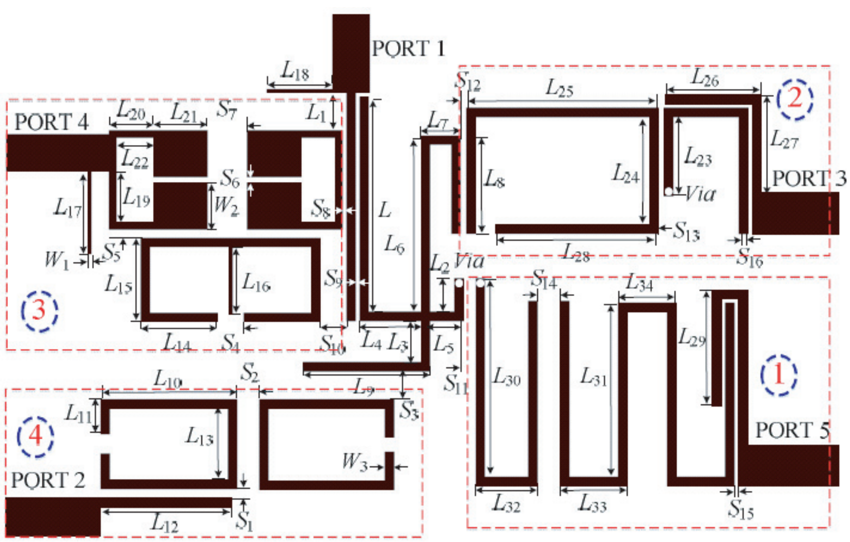


Figure 3. Layout of the quadruplexer using crossed resonator.

Here the first channel filter is presented for example to analyze the spurious frequencies suppression feature of the quadruplexer. The distributions of the resonance frequencies of the three different resonators are plotted in Figure 5. All the resonators have the same fundamental frequency at 2.4 GHz, which is the central frequency of the first passband. As can be observed, the spurious frequencies of these three different resonators stagger well. As a consequence, an improved high frequency rejection level will be gained.

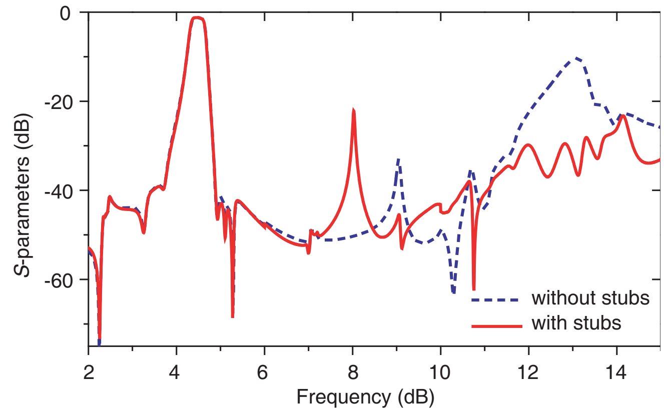


Figure 4. Simulated S parameters of the third passband with/without loading stubs.

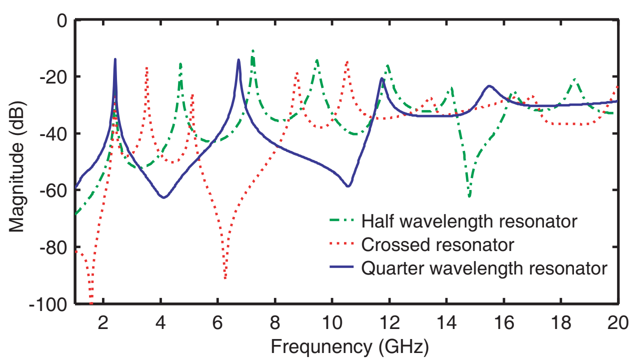


Figure 5. S parameters of three different test resonators.

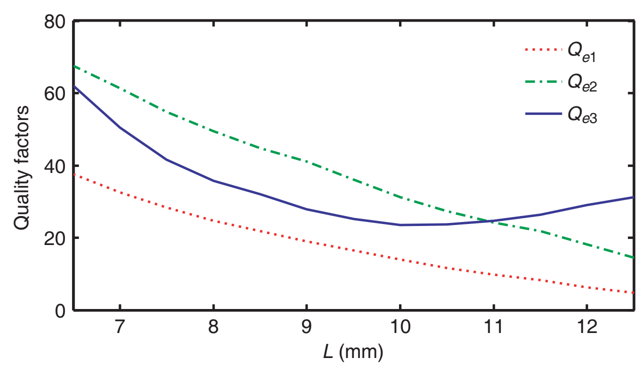


Figure 6. Extracted external quality factors at different channel.

It should be noted that the coupling strength between input port (Port 1 in Figure 3) and the common resonator influences the external quality factors (Q_e) at all the three channels, which will lead to a limitation of realizable bandwidth of each channel. Figure 5 shows the extracted Q_e of different channels while L varies from 6.5 mm to 12.5 mm, where Q_{e1}, Q_{e2}, Q_{e3} are the external quality factors of the three channels, respectively. Obviously, Q_{e2} is always smaller than Q_{e1} and Q_{e3}, which means that the bandwidth of the second channel will be wider than that of the first and fourth channels.

The design procedure of the proposed quadruplexer is outlined as follows:

(a) Given the central frequency of the second channel, the length of the θ_0 can be calculated as:

$$\theta_0 = \frac{f_2}{4 \cdot c\sqrt{\varepsilon_r}} \tag{3}$$

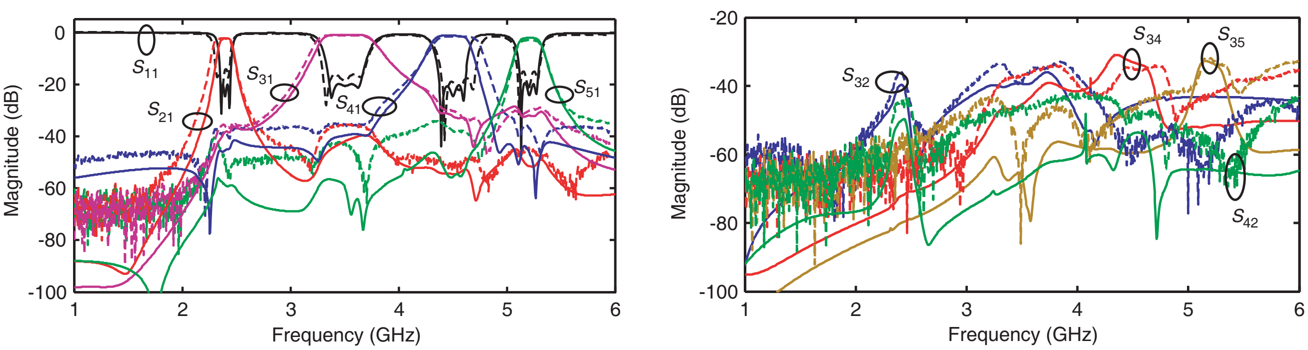
where c is the speed of light in free space, and ε_r denotes the effective dielectric constant. Then with frequency ratios f_1/f_2 and f_3/f_2 calculated, the length of the stubs of the cross resonator can be determined according to Figure 2. Herein the dimension of the cross resonator is decided.

(b) For harmonic suppression, quarter- and half-wavelength resonators are used simultaneously in the first, second and fourth channel filters. For the third channel filter, the dimension of the SIRs can be obtained by referring to the designing curves commonly found in the literature. Then all the four passband filters can be designed according to the filter design theory [16].

(c) Finally, for harmonic suppression, some quarter-wavelength open-circuit stubs are placed on the feedlines and resonators. Then these points are virtually shorted according to the transmission line theory, and as a consequence, the signals are blocked. After some proper optimization, the quadruplexer with wide stopband is achieved.

Following the procedure provided above, a qaudruplexer is designed and fabricated for validation. According to the corresponding quality factors in Figure 6, the fractional bandwidths (0.04321 dB ripple level) of the first, second and fourth channels can be obtained to be 3.5%, 8.7% and 3.6%, respectively. According to Figure 5, we choose $L = 11.5$ mm for the required specifications. The optimized parameters of the quadruplexer in Figure 3 are: $L = 11.50$, $L_1 = 1.80$, $L_2 = 1.77$, $L_3 = 2.19$, $L_4 = 3.27$, $L_5 = 1.79$, $L_6 = 9.42$, $L_7 = 2.11$, $L_8 = 5.25$, $L_9 = 6.80$, $L_{10} = 7.30$, $L_{11} = 1.84$, $L_{12} = 7.20$, $L_{13} = 3.78$, $L_{14} = 4.05$, $L_{15} = 4.50$, $L_{16} = 3.60$, $L_{17} = 4.20$, $L_{18} = 3.50$, $L_{19} = 2.70$, $L_{20} = 2.33$, $L_{21} = 2.90$, $L_{22} = 1.93$, $L_{23} = 4.22$, $L_{24} = 5.72$, $L_{25} = 10.25$, $L_{26} = 5.10$, $L_{27} = 5.25$, $L_{28} = 8.70$, $L_{29} = 6.20$, $L_{30} = 10.60$, $L_{31} = 9.3$, $L_{32} = 3.23$, $L_{33} = 3.60$, $L_{34} = 3.11$, $W_1 = 0.20$, $W_2 = 2.50$, $W_3 = 0.50$, $S_1 = 0.50$, $S_2 = 1.17$, $S_3 = 1.50$, $S_4 = 1.45$, $S_5 = 0.45$, $S_6 = 0.30$, $S_7 = 2.09$, $S_8 = 0.20$, $S_9 = 0.2$, $S_{10} = 1.32$, $S_{11} = 0.63$, $S_{12} = 0.31$, $S_{13} = 0.29$, $S_{14} = 1.2$, $S_{15} = 0.20$ (unit: mm).

Figure 7 shows the simulated and measured results of the quadruplexer while the measurement is carried out on HP 5320A vector network analyzer. The measured 3 dB bandwidths of three channels are 2.28 GHz to 2.45 GHz (7%), 3.23 GHz to 3.78 GHz (15.7%), 4.32 GHz to 4.75 GHz (9.5%) and 5.09 GHz to 5.33 GHz (4.6%), respectively. The measured insertion losses are 2.26 dB, 1.07 dB, 1.57 dB and 2.88 dB, respectively, while the measured passband return losses at all bands are below 15 dB, and isolations are better than 30 dB between 1 and 6 GHz. To save place, only S_{32}, S_{34}, S_{35}, and S_{42} are given in Figure 6(b). Furthermore, the simulated and measured results of the wideband responses of the quadruplexer are shown in Figure 8. The proposed quaduplexer has a wide measured stopband suppression of 20 dB up to $10.2f_1$ where f_1 is the central frequency of the first channel. Figure 9 presents



(a) (b)

Figure 7. Simulated (solid lines) and measured (dash lines) results of the proposed quadruplexer. (a) S_{11}, S_{21}, S_{31}, S_{41}, S_{51}. (b) Isolations of the quadruplexer.

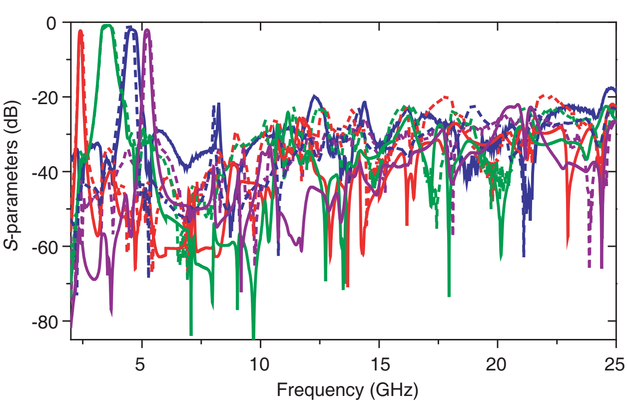


Figure 8. Simulated (solid line) and measured (dash line) wideband responses of the quadruplexer.

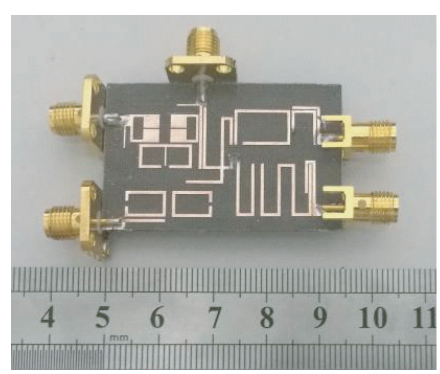


Figure 9. Photograph of the fabricated quadruplexer.

Table 1. Performance comparison among different multiplexers.

	Order	Passbands	Size (λ_g^2)	Isolations (dB)	20 dB stopband
[3]	4	3	0.39*0.34	50	NA
[5]	2	4	0.39*0.4	40	NA
[7]	2	3	0.34*0.35	40	$5.45f_1$
[8]	2	4	0.59*0.31	25	$11.4f_1$
[11]	2	2	NA	36	$2.7f_1$
This work	3	4	0.46*0.28	30	$10.2f_1$

a photograph of the fabricated quadruplexer. The size of the quadruplexer is 35.94 mm × 22.07 mm, approximately $0.46\lambda_g \times 0.28\lambda_g$, where λ_g is the guided wavelength on the substrate at f_1. The measured results are in good agreement with the simulated ones. The comparison with presented works is shown in Table 1. The proposed quadruplexer achieves a good performance in terms of high isolation, compact size and wide stopband.

4. CONCLUSION

This letter presents a novel quadruplexer using common crossed resonator with a wide stopband. Appropriately adjusting the structure of the crossed resonator enables it to be shared by three channels. Moreover, a wide stopband can be observed as resonators with staggered spurious frequencies are involved, and stubs introducing multiple transmission zeros are used. For validation, a quadruplexer is designed, fabricated and measured. Good agreement between the simulated and measured results validates the performance of the proposed microstrip quadruplexer.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China (61571194), Project of the Pearl River Young Talents of Science and Technology in Guangzhou, the Science and Technology Planning Project of Guangdong Province (2014A010103013), and the Natural Science Foundation of Guangdong Province (2015A030313203).

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