

Design of Compact Quad-Channel Diplexer Using Quad-Mode Stub-Loaded Resonators

Lei Lin^{*}, Yu-Tong Zhao, Bian Wu, and Chang-Hong Liang

Abstract—In this paper, a compact quad-channel diplexer utilizing quad-mode stub-loaded resonators (QMSLRs) is proposed. The proposed quad-channel diplexer is composed of two dual-band bandpass filters (BPFs) based on QMSLRs and source-load coupling lines. Due to the symmetry of the proposed quad-mode resonator, its resonance characteristics are analyzed by using the even-odd-mode method twice. All four modes equivalent circuits of the resonator are quarter wavelength resonators, so the circuit size can be very compact, and the first resonance frequencies is three times of the fundamental ones. Stub-to-stub coupling is introduced to split two identical resonance modes, which is in favor of implementing dual-band BPF by using a single quad-mode resonator. By tuning the corresponding physical dimensions of the stubs, the resonant modes can be individually adjusted. The source-load coupling lines are properly designed to provide appropriate external coupling for the passbands and high isolation level between channels. For demonstration, a quad-channel diplexer (0.9/1.2 GHz at Load 1 and 1.5/1.8 GHz at Load 2) using the quad-mode resonator is designed, fabricated and measured. The simulated and measured results with good agreement are presented.

1. INTRODUCTION

In modern wireless communication systems, diplexer plays an important role, and quad-channel diplexer becomes a good candidate. So far, a variety of configurations were proposed to implement diplexers [1–17]. A well designed diplexer should have compact circuit size, low cost and high performance. Microstrip diplexers attract much attention due to the advantages of low cost, flexible design of circuit layout, and they can be easily mounted on the dielectric substrate. So, much effort has been made to design them. In [1], a microstrip diplexer operating for broadband and wireless local area network (WLAN) application is designed, the bandpass filter (BPF) for broadband channel is formed by three-coupled-line structure and the BPF for WLAN channel is constructed by quarter-wavelength resonators. In [2], microstrip electromagnetic band gap structure is used to get wide stopband of the diplexer, but the selectivity is not good. In [3, 4], dual-mode stripline ring resonators and folded coupled-line structure are employed to produce transmission zeros to improve the selectivity of the diplexer. Microstrip diplexers and filters were realized based on modified stepped-impedance resonators [5, 6], dual-mode stepped-impedance resonators [7] and defected ground structure [8, 9] to achieve good selectivity, high isolation and wide stopband. In [10], a diplexer was proposed by utilizing common resonator sections. It composed of five resonators, and the circuit size could be improved further more. In [11], a diplexer employing a T-shape resonator as the common resonator and frequency selective splitter was presented, and the two bands are extremely close. To improve the out-of-band rejection level, a diplexer based on slot-line hairpin stepped impedance resonator structure was proposed in [12]. To reduce the circuit size, some diplexers are designed without distribution networks in the recent literatures [13–16]. A

Received 9 January 2015, Accepted 3 February 2015, Scheduled 5 February 2015

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new topology of the diplexer with the common port directly connected to two filters was proposed and synthesized in [16], although no design example was provided. A double-sided parallel-strip line with an inserted conductor plane was utilizing to design a diplexer in [17]. A novel dual-mode split microstrip resonator was proposed in [18], its even- and odd-modes can be varied independently in a wide range and the two lower resonant frequencies maybe arbitrary close to each other. Based on the split microstrip resonator, a variety of compact high performance filters [19, 20] and diplexer [21] were designed to prove the merits of the resonator. Recently, multi-channel diplexer attracts more and more attention, it can largely improve the density of integration for microwave systems. A six-channel diplexer based on parallel-coupled BPF was developed in [22]. The use of high-order coupled resonators leads to an increased insertion loss and circuit size. This is the first time to design a compact quad-channel diplexer using only one kind of quad-mode resonator.

In this paper, a compact quad-channel diplexer using the proposed quad-mode stub-loaded resonator is presented. Through the analysis, all the four modes equivalent circuits of the resonator are quarter-wavelength ($\lambda/4$) resonators. By using the proposed resonator, two compact dual-band BPFs with controllable passband frequencies and bandwidths were then constituted. Combining the two dual-band BPFs and the properly designed source-load coupling lines, a good performance quad-channel diplexer was then designed, fabricated, and measured. The measured results of the fabricated quad-channel diplexer are in good agreement with the simulated ones.

2. ANALYSIS OF THE PROPOSED QUAD-MODE RESONATOR

Figure 1 depicts the schematic of the proposed quad-mode stub-loaded resonator, which contains two identical T-shape stubs loaded at the two sides of square ring. $A-A'$ indicates the symmetry line of the resonator. Due to its symmetry, even-odd-mode method can be applied to analyze the characteristics of the resonator.

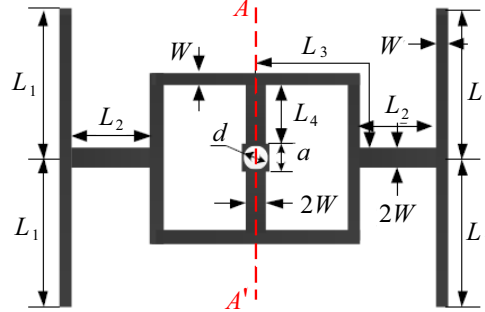


Figure 1. Schematic of the proposed quad-mode stub-loaded resonator.

Under even-mode excitation, the symmetry line $A-A'$ can be modeled as a magnetic wall, and the short-ended stub loaded at the middle of the square ring is bisected with the width is half what it was. The even-mode equivalent circuit is shown in Figure 2(a). Under odd-mode excitation, the symmetry line $A-A'$ behaves as an electric wall, and the short-ended stub is ignored. The odd-mode equivalent circuit is shown in Figure 2(b). It can be observed from Figure 2(a) and Figure 2(b) that the even- and odd-mode equivalent circuits are still symmetrical, and then even-odd-mode method is applied once again to analyze their operating mechanism. Figure 2(c) shows the even- and odd-mode equivalent circuits of Figure 2(a), and Figure 2(d) shows the even- and odd-mode equivalent circuits of Figure 2(b). Four modes named mode $E1$, $E2$, $O1$, and $O2$ are obtained from Figure 2(c) and Figure 2(d). Obviously, all the four mode equivalent circuits are $\lambda/4$ resonators, and their fundamental frequencies are named as f_{E1} , f_{E2} , f_{O1} , and f_{O2} , with the relationship of $f_{E1} < f_{O1} < f_{E2} = f_{O2}$.

Because all the four mode equivalent circuits of the resonator are $\lambda/4$ resonators, these four frequencies can be expressed as follows:

$$f_{E1} = \frac{c}{4(L_1 + L_2 + L_3 + L_4)\sqrt{\epsilon_{eff}}} \quad (1)$$

$$f_{E2} = \frac{c}{4L_1\sqrt{\epsilon_{eff}}} \tag{2}$$

$$f_{O1} = \frac{c}{4(L_1 + L_2 + L_3)\sqrt{\epsilon_{eff}}} \tag{3}$$

$$f_{O2} = \frac{c}{4L_1\sqrt{\epsilon_{eff}}} \tag{4}$$

where c is the speed of the light in free space, and ϵ_{eff} denotes the effective dielectric constant of the substrate. It can be seen from Figure 2(c) and Figure 2(d) that the stubs L_2 and L_3 only exist in modes $E1$ and $O1$, and that the stub L_4 only exists in mode $E1$, the same conclusions can be drawn from Equations (1)–(4). So the mode frequencies can be tuned by changing the lengths of corresponding stubs. Figure 3 describes the resonant frequencies against $L_2 + L_3$ and L_4 . As it is shown in Figure 3(a), the variation of $L_2 + L_3$ changes f_{E1} and f_{O1} , while f_{E2} and f_{O2} keep constant. From Figure 3(b), it can be observed that L_4 only relates to f_{E1} , while there is no influence on other frequencies.

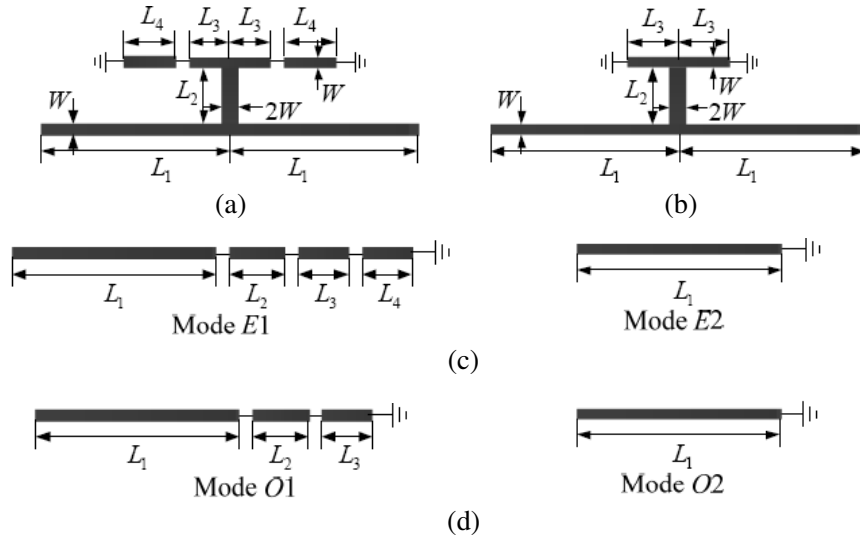


Figure 2. (a) Even-mode equivalent circuit of the quad-mode resonator, (b) odd-mode equivalent circuit of the quad mode resonator, (c) even- and odd-mode equivalent circuits of Figures 2(a) and (d) even- and odd-mode equivalent circuits of Figure 2(b).

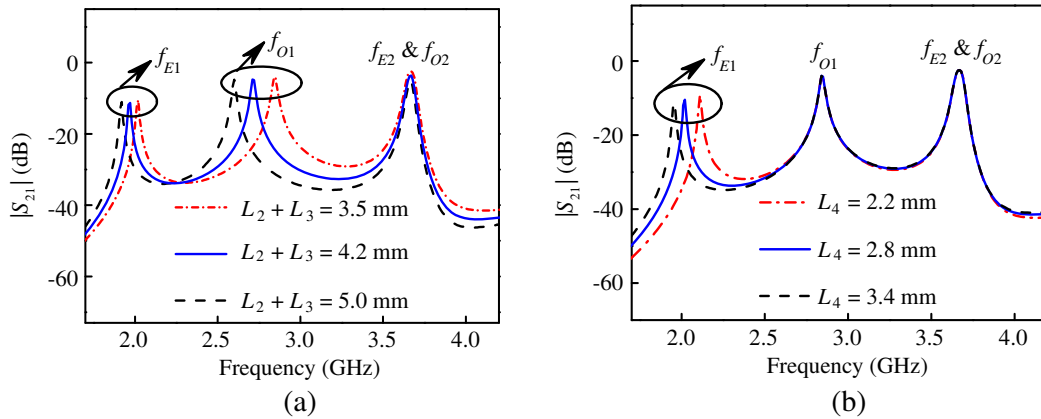


Figure 3. (a) Resonant frequencies with varied $L_2 + L_3$ and (b) resonant frequencies with varied L_4 .

3. DIPLEXER DESIGN, FABRICATION AND MEASUREMENT

In the above section, the resonance characteristics of the proposed quad-mode resonator were theoretically analyzed. Using this, a quad-channel diplexer was designed in this section. To design a quad-channel diplexer using the proposed quad-mode resonator, two dual-band BPFs need to be constructed. Here, stub-to-stub coupling was introduced, which splits two identical frequencies f_{E2} and f_{O2} , and produces two transmission zeros (TZs) due to out-of-phase cancellation [23]. As shown in Figure 4(a), the four modes were separated into two groups by TZ_1 , so that there are two modes in each passband. Modes E_1 and O_1 form the lower passband, and modes E_2 and O_2 form the upper one. The strength of stub-to-stub coupling can be freely tuned by the parameters g and L in Figure 4(b).

Through the aforementioned analysis, both the passband center frequencies and bandwidths of the designed dual-band BPF are independently controllable. Following the design theory, two dual-band BPFs working at 0.9/1.2 GHz and 1.5/1.8 GHz were designed. The width of the feedlines connected to port 2 and port 3 is W_f . L_{f1} and L_{f2} are the lengths of the two arms in the feedlines for the BPF working at 1.5/1.8 GHz, and L_{f3} and L_{f4} are the lengths of the two arms in the feedlines for the dual-band BPF working at 0.9/1.2 GHz. g_1 and g_3 indicates the gaps between the feedlines and the resonators. Thus, the external coupling for port 2 and port 3 can be easily tuned by changing g_3 and g_1 , respectively. The parameter W_f can also be used for fine adjustment of external couplings. The ratio L_{f1}/L_{f2} can be used

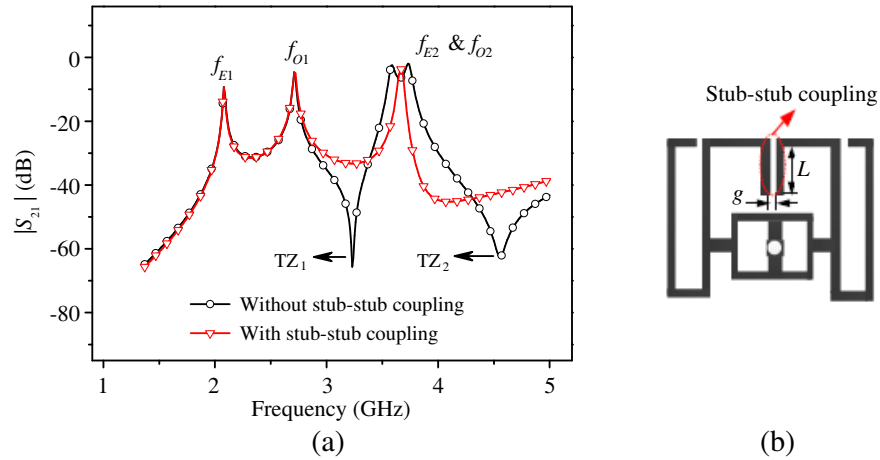


Figure 4. (a) Simulated $|S_{21}|$ under weak external coupling and (b) schematic of the stub-stub coupling.

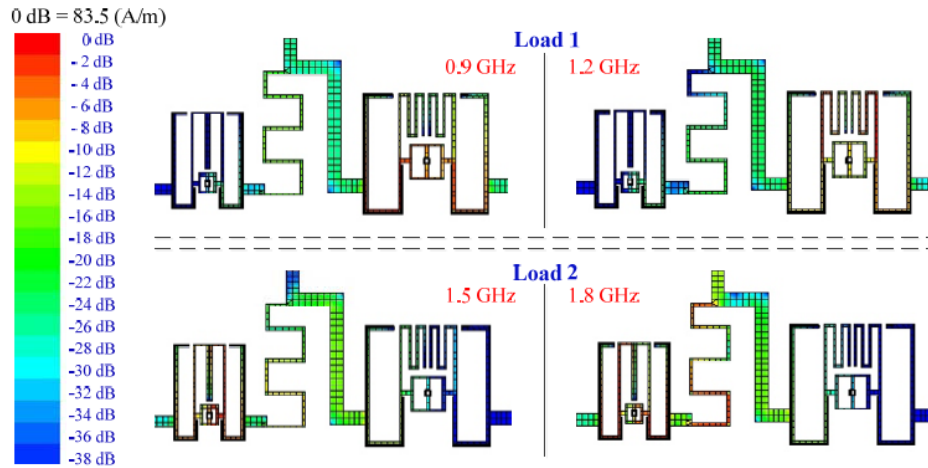


Figure 5. Current distribution of the proposed quad-channel diplexer.

to balance the external couplings for the two passbands of the dual-band BPF working at 1.5/1.8 GHz. Similarly, the ratio L_{f3}/L_{f4} can be used to balance the external couplings for the two passbands of the BPF working at 0.9/1.2 GHz. Then, a quad-channel diplexer was implemented by combing the two dual-band BPFs and the source-load coupling lines. In order to obtain a total reflection at the other Load and achieve high isolation level between channels, the lengths of the source-load coupling lines L' and L'' are determined following the principal that the length L'' for Load 1 (0.9/1.2 GHz) is approximately chosen as the quarter wavelength at the frequencies at Load 2 (1.5/1.8 GHz), and the length L' for Load 2 (1.5/1.8 GHz) is approximately chosen as the quarter wavelength at the frequencies at Load 1 (0.9/1.2 GHz). The widths of the source-load coupling lines W' and W'' are initially chosen to satisfy the external Q-quality of each channel [24], and they are further determined by the optimizer module in the commercial simulation software IE3d. Figure 5 demonstrates the current distribution of the proposed quad-channel diplexer at Load 1 (0.9/1.2 GHz) and Load 2 (1.5/1.8 GHz). It can be clearly observed that EM waves are transmitted in the diplexer from source to Load 1 and Load 2.

The layout of the diplexer is shown in Figure 6, and the optimized dimensions are determined as follows (all in mm): $L_1 = 30.6, L_2 = 1.0, L_3 = 2.9, L_4 = 1.1, L_5 = 2.4, L_6 = 11.5, L_7 = 43.6, L_8 = 2.2, L_9 = 6.5, L_{10} = 3.0, L_{11} = 1.2, L_{12} = 1.8, L_{13} = 8.0, L_{f1} = 18.6, L_{f2} = 7.4, L_{f3} = 25.3, L_{f4} = 10.9, W = 0.5, W_f = 0.3, W_P = 2.87, g_1 = 0.15, g_2 = 0.4, g_3 = 0.15, g_4 = 0.4, L' = 63.8, W' = 0.7, L'' = 31.7, W'' = 2.2$. The overall circuit size was $0.31\lambda_g \times 0.16\lambda_g$, where λ_g is the guided wavelength at 0.9 GHz (the 1st channel). Simulation and optimization were carried out by IE3d. Finally, the quad-channel diplexer was fabricated on the substrate with a relative dielectric of 2.45 and thickness of 1.0 mm.

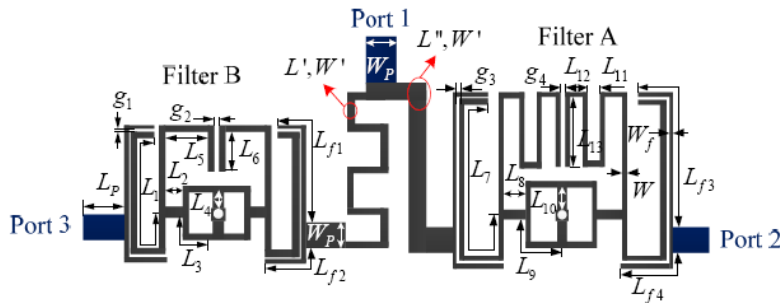


Figure 6. Layout of the proposed quad-channel diplexer.

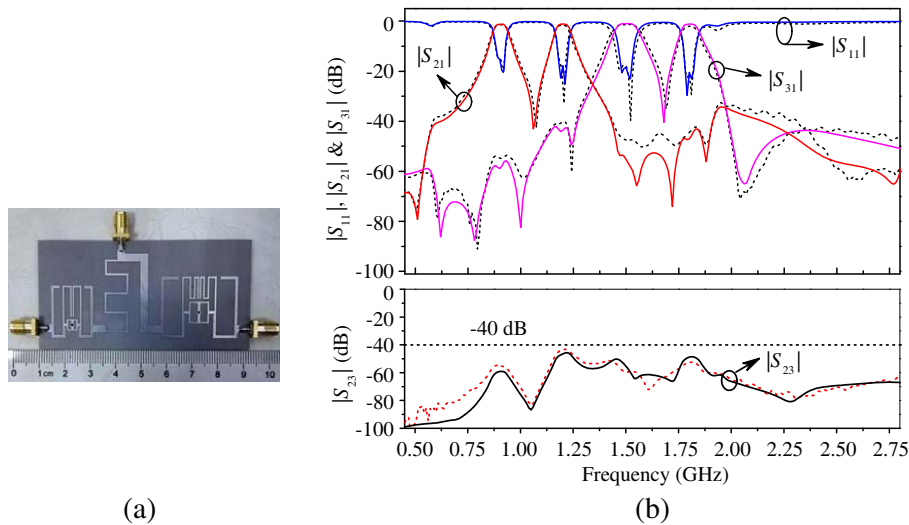


Figure 7. (a) Photograph of the fabricated quad-channel diplexer and (b) simulated (solid lines) and measured (dashed lines) S -parameters of the proposed quad-channel diplexer.

A photograph of the fabricated quad-channel diplexer is shown in Figure 7(a). The simulated and measured results are compared in Figure 7(b). The fabricated quad-channel diplexer has measured center frequencies at Load 1 (0.9/1.2 GHz) and Load 2 (1.5/1.8 GHz), the measured results have $|S_{11}|$ of 17.5/18.3 dB, $|S_{21}|$ of 1.36/1.5 dB, and 3-dB FBW of 7.2/5% at 0.9/1.2 GHz; and $|S_{11}|$ of 19.6/20.2 dB, $|S_{21}|$ of 1.3/1.6 dB, and 3-dB FBW of 7.3/4.1% at 1.5/1.8 GHz. When the widths of the passbands are specified, the maxima of $|S_{11}|$ in the first and second passbands can be tuned by changing g_3 , decrease of the parameter g_3 raises the coupling between port 2 and the resonator, and increase of the coupling above an optimal value raises the maxima of reflection in these two passbands [21]. The ratio L_{f3}/L_{f4} can be used for balancing the maxima in these two passbands. The maxima of $|S_{11}|$ in the third and fourth passbands can be controlled by changing g_1 , decrease of the parameter g_1 raises the coupling between port 3 and the resonator, and increase of the coupling above an optimal value raises the maxima of reflection in these two passbands. The ratio L_{f1}/L_{f2} are responsible for balancing the maxima in these two passbands. All the isolation levels are greater than 40 dB between channels. The measurement was performed on an Agilent 8917ES network analyzer.

4. CONCLUSIONS

In this paper, a novel quad-channel diplexer (0.9/1.2 GHz and 1.5/1.8 GHz) using quad-mode stub-loaded resonator is presented. The center frequency and bandwidth of each channel can be tuned freely by changing the corresponding physical dimensions. The source-load coupling lines are designed to achieve high isolation levels between channels. Due to its good performance and simple design procedure, the proposed diplexer will be widely used in multi-band wireless system.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China (NSFC) under Project No. 61271017.

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