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# Design of new quadruplexer with compact size, high isolation and wide stopband

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ABSTRACT

This study presents a quadruplexer (1.8/2.4/3.5/5.8 GHz) with compact size, high isolation, low insertion loss and wide stopband based on the multi-mode resonators. The quadruplexer is composed of four pairs of coupled multi-mode resonators (uniform impedance resonator, UIR and stepped impedance resonators, SIRs) and the source–load coupling lines. Each channel (passband) can be easily determined by tuning the impedance ratio ($K$) and length ratio ($\alpha$) of the SIRs so as to implement a 2-order bandpass filter individually. The source–load coupling lines are designed to correspond to the quarter-wavelength of the center frequency at each channel. The proposed quadruplexer shows a simple configuration, an effective design method and a small circuit size.



## 1. Introduction

To meet the requirements of modern wireless communication systems, the needs of diversification (multi-band and multi-service) and miniaturization (compact circuit size) are much demanded in future microwave devices [1]. The systems are also required to operate over a wide band or multi-frequency bands.

Planar multiplexers are the critical components of the transceiver in the advanced wireless communication systems. Recently, some literatures of multiplexers (especially for triplexer and quadruplexer) are proposed [2–6]. In [2], a diplexer with six-channels based on parallel-coupled microstrip bandpass filters was developed. In [3], the matching circuits for microstrip triplexers are proposed by the authors based on half-wavelength tapped-connected SIRs. However, the use of high-order coupled resonators and matching networks leads to an increased circuit size and insertion loss. Some multiplexers with the combination of multi-mode resonators and source–load coupling lines are proposed [4–6]. In [4], the quadruplexer consisting of a distributed coupling feeding line, output feeding lines and uniform resonator pairs is proposed. In [5], the quadruplexer composed of four folded tri-mode net-type resonator filters with one input and four output coupled line structures is proposed. In [6], a compact quad-channel diplexer using the coupled SIRs has been developed. These studies provide the good ideas and well implement on the multiplexer development. However, the cost of increasing circuit size, a little high insertion loss and higher order spurious responses by using the high-order coupled resonators, uniform impedance resonator (UIR) with/without shorted circuit or adding the complex matching networks should be further modified. Besides, a multiplexer with very wide stopband (around $10f_{01}$, where $f_{01}$ is the center frequency of lowest channel) is hard to design, because every resonant peak of the resonators should be carefully arranged under specific conditions.

In order to meet the requirements of advanced multiplexer developments, we proposed a quadruplexer with compact circuit size, high isolation, low insertion loss and very wide stopband ($>11f_{01}$) based on the multi-mode resonators for the first time. Only two resonators are used to form a passband at each channel. The quadruplexer has strong design feasibility due to appropriate arrangement of the coupling of the multi-mode resonators. The quad-channel at $f_{01}=1.8$, $f_{02}=2.4$, $f_{03}=3.5$ and $f_{04}=5.8$ GHz can be easily determined by properly tuning the impedance ratio ($K$) and length ratio ($\alpha$) of the multi-mode resonators. To improve the passband selectivity at each channel and isolation over the higher frequency band, the source–load coupling lines corresponded to quarter-wavelength at center frequency of each passband were used. By appropriate arranging the resonant peaks of each multi-mode resonator, the wide stopband ($>11f_{01}$, 2.1–20 GHz) can be achieved easily. The quadruplexer realized on a printed circuit board occupies an area of only $49\times33$ mm$^2$. The measured results are in good agreement with the full-wave electromagnetic (EM) simulation results [7].

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## 2. Quadruplexer design

Fig. 1 shows the coupling structure of the quadruplexer. Each channel is formed by only two resonators and no need to add the impedance matching networks at each output port (loading). The source–load coupling line to be a role of the common input port is designed to remove the complex input impedance matching junctions and achieving the compact circuit size. For comparison of previous works [2–6], the proposed quadruplexer shows simultaneously a small circuit size, high isolation and wide stopband. Fig. 2 shows the configuration of the quadruplexer. The quadruplexer composed of four pairs of the multi-mode resonators with impedance ratio ($K<1$) is used to generate the quad-channel at 1.8/2.4/3.5/5.8 GHz. Source–load coupling lines are used to provide the cross-coupling effects through the multipath propagation and to save the circuit size. For an example to the channel 1 (1.8 GHz), the source–load coupling line is designed under the conditions of no reflection at 1.8 GHz and total reflections at 2.4 GHz for channel 2, 3.5 GHz for channel 3 and 5.8 GHz for channel 4. It is noted that the source–load coupling lines correspond to the quarter-wavelength transmission lines (at each 1.8, 2.4, 3.5 and 5.8 GHz) to fulfill the above-mentioned conditions.

Fig. 3 shows the relations between the normalized $f_{S1}/f_0$ and $f_{S2}/f_0$ versus length ratio $\alpha$ with impedance ratio $K$=0.25, 0.3, 0.35, 0.4 and 0.45 of the stepped-impedance resonator. The basic structure of a half-wavelength ($\lambda/2$) microstrip SIRs is shown in Fig. 3. It consists of different characteristic impedances and is constructed by cascading a long-length ($2\theta_1$) high-impedance section ($Z_1$) in the center connected with the two short-length ($\theta_2$) low-impedance sections ($Z_2$) in the two sides, where the impedance ratio $K$ is defined as $K=Z_2/Z_1$. The impedance ratio and physical length of SIRs are adjusted to meet the fundamental resonances ($f_0$) and the first spurious frequencies ($f_{S1}$) over a wide frequency range. The resonance conditions are determined by $K\cot\theta_2=\tan\theta_1$ (odd mode) and $K\cot\theta_2=-\cot\theta_1$ (even mode) [8]. When $\theta_2$ is proportional to the physical length of SIR, the length ratio $\alpha$ of the SIR is defined as $\alpha=\theta_2/(\theta_1+\theta_2)=2\theta_2/\theta_t(\theta_t=2\theta_1+2\theta_2)$; therefore, the equations of $K\cot(\alpha\theta_t/2)=\tan[(\theta_t-\alpha\theta_t)/2]$ and $K\cot(\alpha\theta_t/2)=-\cot[(\theta_t-\alpha\theta_t)/2]$ are found to determine every resonant frequencies of the SIR. Fig. 3 shows the normalized $f_{S1}/f_0$ and $f_{S2}/f_0$ curves for a SIR with different $K$ and $\alpha$. The curves would be very useful for achieving the desired passbands of the quadruplexer without influencing each other. The marked points of A, B, C, D, E and F are chosen for the optimal design parameter in this work. The dimension of each resonator is summarized in Table 1.

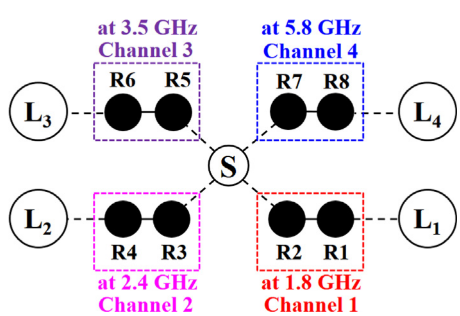


**Fig. 1.** Coupling structure of the quadruplexer. ($L_i$, $i$=1, 2, 3 and 4 shows the load port at each channel).

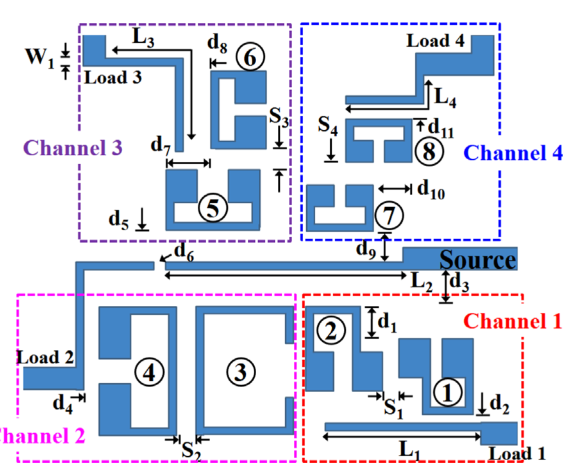


**Fig. 2.** Configuration of the quadruplexer.

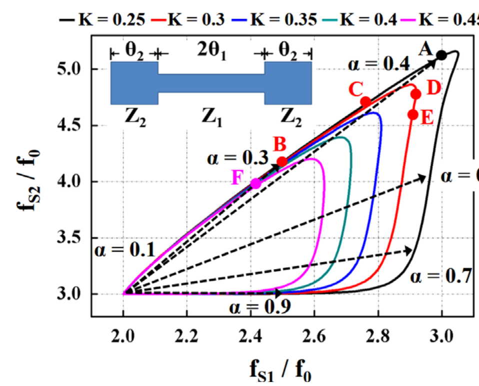


**Fig. 3.** Relations between the normalized $f_{S1}/f_0$ and $f_{S2}/f_0$ versus length ratio $\alpha$ with impedance ratio $K$=0.25, 0.3, 0.35, 0.4 and 0.45 of the SIRs. ($f_{S1}$ and $f_{S2}$ indicate the 1st and 2nd higher order spurious frequency).

**Table 1**
Parameters of the proposed quadruplexer (SIR: stepped impedance resonator and UIR: uniform impedance resonator).

| Resonator | $k$ | $\alpha$ | $\theta_1$ | $\theta_2$ | $Z_1$ | $Z_2$ |
|---|---|---|---|---|---|---|
| 1 (SIR) | 0.25 | 0.4 | 30 | 21 | 100 | 25 |
| 2 (SIR) | 0.3 | 0.4 | 30 | 21 | 100 | 30 |
| 3 (UIR) | 1 | n/a | n/a | n/a | n/a | n/a |
| 4 (SIR) | 0.3 | 0.3 | 35 | 15 | 100 | 30 |
| 5 (SIR) | 0.3 | 0.4 | 30 | 21 | 115 | 35 |
| 6 (SIR) | 0.3 | 0.45 | 26 | 21 | 115 | 35 |
| 7 and 8 (SIR) | 0.45 | 0.4 | 40 | 27 | 115 | 50 |

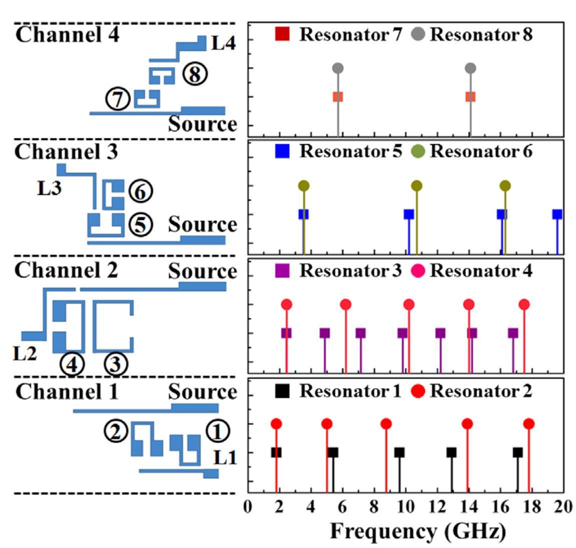


**Fig. 4.** The distribution of fundamental and higher order resonant frequencies of the multi-mode resonators for each channel.