Microstrip Quad-Channel Diplexer Using Quad-Mode Square Ring Resonators

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***Abstract*—A new compact microstrip quad-channel diplexer (2.15/3.60 GHz and 2.72/5.05 GHz) using quad-mode square ring resonators is proposed. The quad-channel diplexer is composed of two quad-mode square ring resonators (QMSRR) with one common input and two output coupled-line structures. By adjusting the impedance ratio and length of the QMSRR, the resonant modes can be easily controlled to implement a dual-band bandpass filter. The diplexer show a small circuit size since it's constructed by only two QMSRRs and common input coupled-line structure while keeping good isolations (> 28 db). Good agreements are achieved between measurement and simulation.**

***Index Terms*—quad-channel, diplexer, quad-mode square ring resonator (QMSRR), bandpass filter (BPF).**

I. Introduction

IN the multi-service and multi-band communication systems, multiplexers are widely used in the RF front ends of both the receiver and transmitter. Planar microstrip structures have became more and more attractive because of the compact size, low-cost integration and high practicality. Recently, microstrip diplexers [1]–[6], triplexers [7], [8] and quadruplexer [9] have been extensively researched.

For compact size, multi-mode stub loaded resonator is popularly adopted to implement multiplexers [4], [7]–[9]. Square ring resonator can also reduce the size of the multiplexer and have higher design freedom compared to stub loaded resonator [10], [11]. A conventional multiplexer consists of several bandpass filters with an input matching network which serves as a through pass at the center frequency of a bandpass filter and provide a short circuit at the center frequency of another bandpass filter [12]. Recently, source-load coupling lines [4], [13]and common resonator technology [1], [7], [8] are used to remove the matching network. However, reducing the whole size of multiplexer is still a challenge to designers.

In this letter, a microstrip quad-channel diplexer has been proposed. Fig.1(a) and Fig.1(b) show the difference between conventional and proposed coupling schemes of diplexer. As can be seen in Fig.2, thanks to the combination of common input coupled-line structure and quad-mode square ring resonator (QMSRR), a quad-channel diplexer which achieves a significant size reduction has been implemented. Each QMSRR excites four resonant modes and they can be controlled easily by tuning the size of the resonator. A common input coupled-line structure [6], [9] provides the coupling of signal energy for each channel instead of the 5-port matching network.

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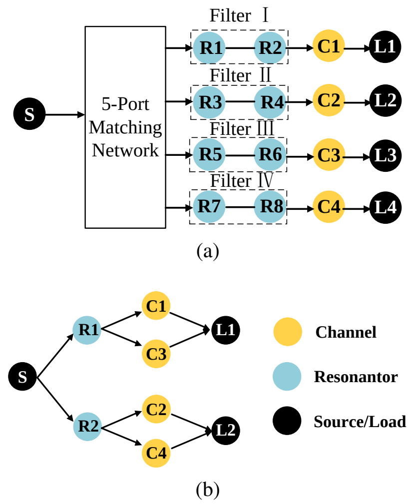


Fig. 1: coupling scheme of a quad-channel diplexer. (a)Conventional structure. (b) Proposed structure.

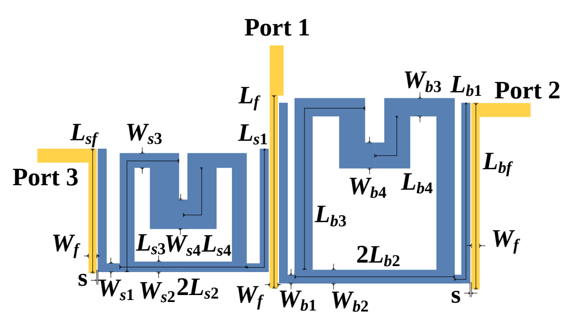


Fig. 2: Layout of the proposed quad-channel diplexer.

II. Quad-Mode Square Ring Resonators

As shown in Fig.3(a), the QMSRR consists of one square ring resonator and two open microstrip lines. Let Y_i and θ_i, i = 1, ..., 4, denote the electrical length and characteristic admittance of the i-th transmission line, respectively, which are corresponding to W_i and L_i, i = 1, ..., 4, denoting the physical width and length of the i-th microstrip in Fig.2, respectively. Due to the symmetrical structure of the proposed QMSRR, an even- and odd-mode based method can be utilized to evaluate further the performance of the QMSSR. AA' is the symmetry plane in Fig.3(a) and the even-mode and odd-mode equivalent circuits are shown in Fig.3(a) and Fig.3(b). The even-mode and odd-mode resonance conditions can be written as

$$\mathrm{Im}(Y_{in}^{e/o}) = 0 \quad (1)$$

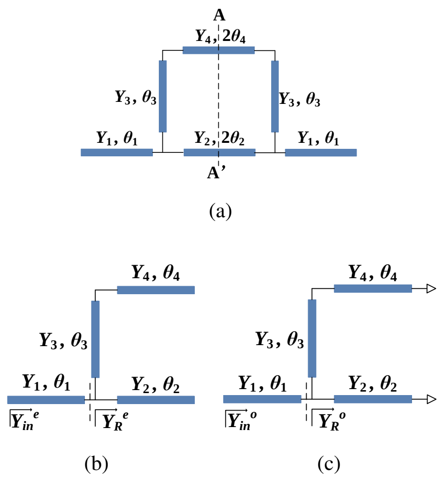


Fig. 3: Equivalent circuits of the (a) QMSRR in (b) Even-mode and (c) Odd-mode.

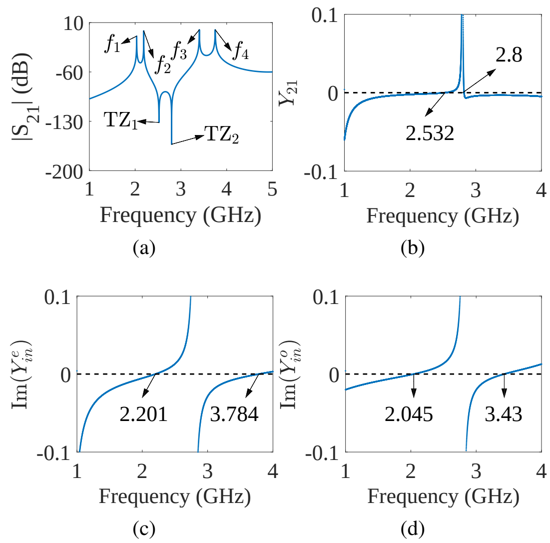


Fig. 4: QMSRR (a) Frequency response of the QMSRR with weak coupling (b) Transmission zeros (c) Even-mode resonant frequencies and (d) Odd-mode resonant frequencies.

where Im(·) means the imaginary part and

$$Y_{in}^{e/o} = Y_1 \frac{Y_R^{e/o} + jY_1 \tan(\theta_1)}{Y_1 + jY_R^{e/o} \tan(\theta_1)} \quad (2)$$

$$Y_R^e = jY_3 \frac{Y_4 \tan\theta_4 + Y_3 \tan\theta_3}{Y_3 - Y_4 \tan\theta_3 \tan\theta_4} + jY_2 \tan\theta_2 \quad (3)$$

$$Y_R^o = jY_3 \frac{-Y_4 \cot\theta_4 + Y_3 \tan\theta_3}{Y_3 + Y_4 \tan\theta_3 \cot\theta_4} - jY_2 \cot\theta_2. \quad (4)$$

The even-mode and odd-mode resonant frequencies can be found by solving the equation in (1) and are shown in Fig.4(b) and Fig.4(c). The transmission zeros (TZs) satisfy

$$Y_{21} = 0 \quad (5)$$

where Y_{21} denotes the transfer admittances of the QMSRR. Fig.4(b) plots the numerical results of the TZs. Fig.4(a) shows the corresponding 2 even-mode resonant frequencies f_2 = 2.188 GHz, f_4 = 3.75 GHz, 2 odd-modes resonant frequencies f_1 = 2.034 GHz, f_3 = 3.4 GHz and 2 transmission zeros (TZs) f_{z1} = 2.521 GHz, f_{z2} = 2.797 GHz found in the simulation by ADS, and numerical analysis and simulation results match well. Here, $\theta_1 = 30°$, $\theta_2 = 15°$, $\theta_3 = 40°$, $\theta_4 = 10°$, $Y_1 = 1/60$ s, $Y_2 = 1/50$ s, $Y_3 = 1/40$ s and $Y_4 = 1/30$ s are assumed at fundamental frequency $f_0 = 1$ GHz. Therefore, four frequencies can be easily controlled by changing the size of QMSRR with high degree of freedom according to the results from simulation and numerical analysis to get two proper dual-band bandpass filters (BPFs).

III. Design of the Quad-Channel Diplexer

Fig.2 shows the layout of the proposed quad-channel diplexer which consists of two QMSRR based dual-band BPFs, filter s (small one) and filter b (big one). For each QMSRR filter design, the passband center frequencies (CFs) and frational bandwidths (FBWs) can be determined by assigning the four resonant modes of QMSRR properly.

After the CFs and FBWs are set, parameters of BPFs can be determined according to Fig.4 and our previous works [11]: $\theta_{s1} = 30°$, $\theta_{s2} = 15°$, $\theta_{s3} = 40°$, $\theta_{s4} = 10°$, $Y_{s1} = 1/60$ s, $Y_{s2} = 1/50$ s, $Y_{s3} = 1/40$ s, $Y_{s4} = 1/30$ s for filter s and $\theta_{b1} = 30°$, $\theta_{b2} = 15°$, $\theta_{b3} = 40°$, $\theta_{b4} = 10°$, $Y_{b1} = 1/60$ s, $Y_{b2} = 1/50$ s, $Y_{b3} = 1/40$ s and $Y_{b4} = 1/30$ s for filter b. ADS LineCalc Tool can be utilized to calculate the corresponding physical dimensions, and then the filters were optimized in moment-method electromagnetic simulator Sonnet. In order to reduce the impact of impedance discontinuities, bends and open ends, the physical dimensions can be optimized by changing the lengths and widths of every section in QMSRR. For the sake of compact size, microstrips L_{s4} and L_{b4} are bent appropriately.

The next step is selecting the external quality factor Q_e to design the external coupling which satisfy the specifications of four channels. Generally, a smaller gap and a longer coupled-line can provide a stronger coupling. Two filters were placed on the different sides of the input common coupled-line firstly. Since both filters are designed to operate at four different frequencies, the loading effect between different channels can be ignored. Then the spacing s, length L_f, L_{sf}, L_{bf}, width W_f, W_{sf} and W_{bf} were optimized by Sonnet to obtain the Q_e aforementioned.

The design procedure is summarized as follows:

1) Given passbands' specifications, decide the dimensions of QMSRRs.

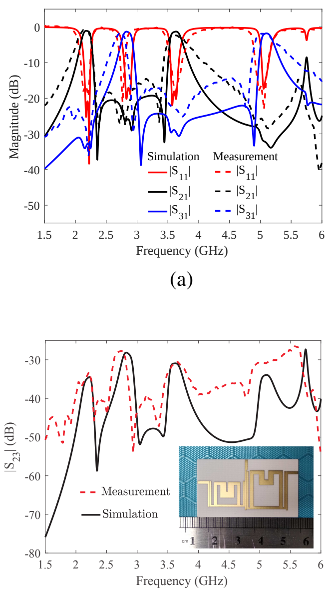
2) Determine the values of the length of the coupled-lines and spacings that result in the required Q_e, then, combine the filters with the input and output coupled-lines.

3) Carry out the optimization using Sonnet to get the final design.

For the demonstration, the proposed quad-channel diplexer was fabricated on a Rogers 4003c substrate with relative dielectric constant ϵ_r = 3.38, thickness h = 0.508 mm and loss tangent tanδ = 0.0027. The optimised physical dimensions are shown in Table I. And it was measured by using an

TABLE I: Dimensions of the Quad-Channel Diplexer (Unit: mm)

L_{s1}	L_{s2}	L_{s3}	L_{s4}	W_{s1}	W_{s2}	W_{s3}	W_{s4}
12.3	5.7	13.4	5.9	0.75	0.9	1.3	2.6
L_{b1}	L_{b2}	L_{b3}	L_{b4}	W_{b1}	W_{b2}	W_{b3}	W_{b4}
16.9	7.15	20.2	5.55	0.75	1.2	1.6	2.3
L_{sf}	L_{bf}	L_f	W_f	s			
11.2	16.8	17.4	0.7	0.1			



(a)

(b)

Fig. 5: Simulated and measured responses of the quad-channel diplexer (a) Transmission and reflection coefficient, (b) Isolation and photograph

Agilent E5071C network analyzer. The results of simulation and measurement are plotted in Fig.5 with the photograph of the diplexer. The CFs and FWBs and Q_es of four channels are 2.152 GHZ, 2.72 GHz, 3.595 GHz, 5.05 GHz, 8.17%, 5.88%, 3.06%, 4.36% and 12.23, 17, 32.68, 22.95 respectively. And the insertion loss and return loss are 0.81 dB, 1.426 dB, 2.315 dB, 1.901 dB and 16.34 dB, 21.2 dB, 19.65 dB, 16.37 dB, respectively. The overall size of the circuit is 31.95 mm by 16.7 mm, i.e., 533.565 mm^2 and only about 0.229 λ_0 by 0.1197 λ_0 (0.421 λ_g by 0.22 λ_g), where λ_0 and λ_g are the free-space wavelength and guided wavelength on the substrate at CF of channel 1. Due to the existence of two zeros of each QMSRR illustrated in Fig.4(a), good channel isolations better than 27dB are achieved. The measured results are in great agreements with the simulated ones.

Table II gives a performance comparison with some reported quad-channel multiplexer showing that the proposed diplexer possesses the merit of more compact size with the combination of QMSRR and common coupled-line structure instead of other topologies.

TABLE II: Performance Comparision with Some Reported Quad-Channel Multiplexers

Ref	Load /Channel	CF (dB)	IL (dB)	Isolation (dB)	Circuit size (mm^2/ λ_g^2/λ_0^2)
[3]	2/4	2.52, 4.025, 5.485, 7.145	N.A.	> 8	1170, 0.6439, 0.0413
[4]	2/4	1.5, 2.0, 2.4, 3.5	0.8, 1.0, 0.7, 1.5	> 30	1459, 0.078, 0.042
[13]	2/4	0.9, 1.2, 1.5, 1.8	1.36, 1.5, 1.3, 1.6	> 40	N.A., 0.0496, N.A.
[9]	4/4	0.9, 1.2, 1.5, 1.8	2.5, 2.4, 2.3, 2.1	> 40	2665.1, 0.0546, 0.0243
This work	2/4	2.15, 2.72, 3.60, 5.05	0.81, 1.43, 1.32, 0.90	> 28	533.565, 0.0926, 0.0274

IV. CONCLUSION

In this letter, the quad-mode square ring resonators are utilized to design the quad-channel diplexer with a simple and efficient method. The parameters of the diplexer are determined by the size of the QMSRRs and common input coupled-line structure instead of additional matching network. As a consequence, measured results shows that the quad-channel diplexer achieves a compact size, high isolation and good passband selectivity at each load. The proposed diplexer is quiet suitable for applications in the multi-band and multi-service communication system.

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