Wideband Filtering Crossover Based on Ring Resonator with Sharp Rejection

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Abstract **─** A wideband filtering crossover based on ring resonators with sharp rejection is proposed in this paper. Four transmission zeros near the crossover passband can be adjusted conveniently by the even/odd-mode characteristic impedance of the coupled lines. A high selectivity wideband filtering crossover located at 3.0 GHz is designed and fabricated for verification. Good filtering performance and high selectivity for the crossover are realized and experimentally verified.

Index Terms **─** Coupled lines, even/odd-mode, filtering crossover, transmission zero, wideband.

I. INTRODUCTION

Crossover is a very important component and can be integrated in Butler matrix, which exhibits two signal paths crossing over each other with perfect isolation and all ports matched. Air-bridge and bond-wire are always used to transport signals in different layers for conventional crossovers [1]-[2], resulting in complex structures and relatively high fabrication cost. Cascaded rings and branch-lines couplers are used to overcome these drawbacks [3]-[5]; however, multi-section rings and couplers enlarge the circuit size and the transmission insertion loss. The conductor-backed coupling lines can be used to realize wideband crossovers [6], which can avoid using cascaded structures. Moreover, microwave passive components including crossovers, filters, and couplers are always single elements, integrating two functions in one component is an effective method for size reduction, such as filtering balanced circuits [7] and filtering crossovers [8].

In this paper, a wideband filtering crossover with sharp rejection is proposed. Four transmission zeros for the crossover passband with good isolation performance over a very wide frequency range can be realized [9]-[10]. Using coupled lines and open stubs with different electrical wavelength, fifth-order passband can be easily achieved for the planar crossover. The desired crossover configuration can be obtained using even/odd-mode characteristic impedance of the coupled lines and characteristic impedance of the open stubs. A wideband filtering crossover located at 3.0 GHz with 3-dB bandwidth 26.3% (2.58-3.37 GHz) is designed and fabricated for verification. All the circuits and structures are simulated with Ansoft Designer v3.0 and Ansoft HFSS v13.0, and constructed on the dielectric substrate with ε_r = 2.65, h = 1.0 mm, and $tan\delta$ = 0.003.

II. DESIGN OF PROPOSED WIDEBAND CROSSOVER

Figure 1 shows an improved crossover based on dual-mode ring resonator [6], four quarter-wavelength side-coupled lines (electrical length θ, even/odd-mode characteristic impedance Z_{e1}, Z_{o1}) are attached to the four input/output ports. Four microstrip lines with characteristic impedance $Z_0 = 50\ \Omega$ are connected to Ports 1 to 4. Due to the symmetry of the single-band crossover, the even-odd-mode analysis is employed to simplify the analysis and to derive the impedance values [1]-[6], which are required to meet the following properties:

$$|S_{11}| = |S_{22}| = |S_{33}| = |S_{44}| = 0,$$
$$|S_{21}| = |S_{23}| = |S_{41}| = 0\ ,\ |S_{31}| = |S_{24}| = 1. \qquad (1)$$

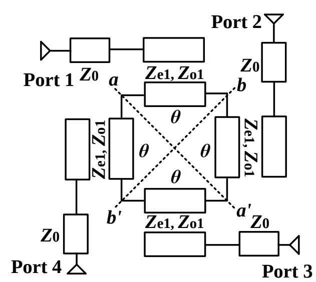

Fig. 1. Ideal circuit of the improved crossover based on ring resonator [6].

By placing electric wall (E-wall) and E-wall, magnetic wall (H-wall) and H-wall, E-wall and H-wall, H-wall, and E-wall along the symmetry lines a-a' and b-b', respectively, as shown in Figs. 2 (a)-(d); four even/odd eigen-admittances Y_{ee}, Y_{eo}, Y_{oe}, Y_{oo} can be required [6]:

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$$Y_{ee} = j\frac{2\tan\theta}{Z_{e1}+Z_{o1}},\ Y_{eo} = -j\frac{2(Z_{e1}+Z_{o1})\tan\theta}{(Z_{e1}-Z_{o1})^2\tan^2\theta - 4Z_{e1}Z_{o1}}, \quad (2)$$

$$Y_{oe} = j\frac{2(Z_{e1}+Z_{o1})\tan\theta}{Z_{e1}Z_{o1}},\ Y_{oo} = j\frac{2(Z_{e1}+Z_{o1})\tan\theta}{Z_{e1}Z_{o1}}. \quad (3)$$

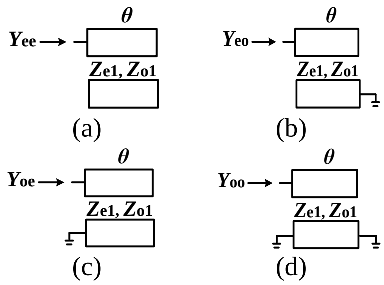


Fig. 2. Decomposed equivalent circuits of the crossover based on ring resonator: (a) even–even-mode circuit; (b) even–odd-mode circuit; (c) odd–even-mode circuit; (d) odd–odd-mode circuit.

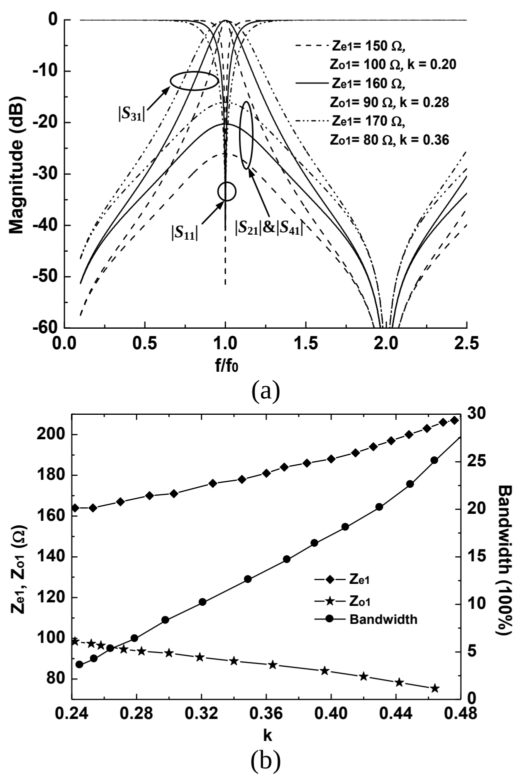


Fig. 3. (a) Simulated results of the crossover based on ring resonator, and (b) bandwidth versus coupling coefficient k.

After further calculation, we find that different combinations of design values that can be used to realize a broadband performance for the crossover. Figures 3 (a)-(b) show the simulated results of the crossover based on ring resonator versus Z_{e1}, Z_{o1}, and the bandwidth of the crossover increases with the coupling coefficient k increases ($k = (Z_{e1}-Z_{o1})/(Z_{e1}+Z_{o1})$), and the isolation between Ports 1 to 2, and 4 become worse as k increases. Due to the PCB fabrication precisions, the width for the transmission lines and coupled lines are always greater than 0.20 mm, so the maximum coupling coefficient k of the coupling lines in this work is nearly 0.45 ($\varepsilon_r = 2.65$, $h = 1.0$ mm), and the characteristic impedance of the transmission lines is always less than 130 Ω, so the bandwidth of the crossover cannot increase infinitely.

The ideal circuit of the proposed wideband filtering crossover is shown in Fig. 4, a two-stage coupling line is used to increase the bandwidth for Fig. 1, and four half-wavelength open stubs (electrical length 2θ, characteristic impedance Z_1) are attached in the input coupled lines, and four open/shorted coupled lines (Z_{e2}, Z_{o2}, θ) are shunted connected in the input/output Ports 1 to 4. As discussed in [7], [9], four transmission zeros realized by the half-wavelength open stubs and open/shorted coupled lines can be obtained as:

$$\theta_{tz1} = \pi/4, \qquad \theta_{tz2} = 3\pi/4, \quad (4)$$

$$\theta_{tz3} = \arccos\frac{Z_{e2}-Z_{o2}}{Z_{e2}+Z_{o2}}, \quad \theta_{tz4} = \pi - \theta_{tz3}. \quad (5)$$

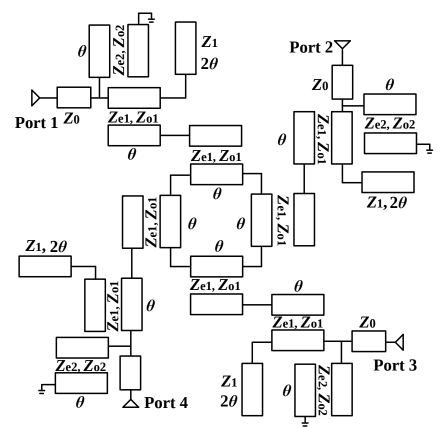
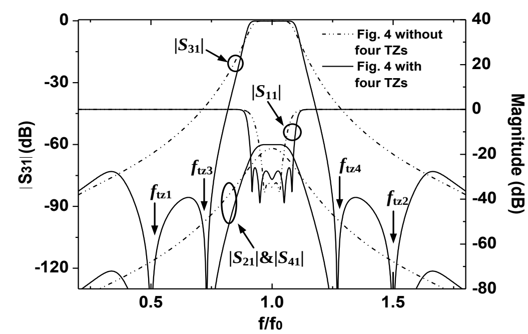


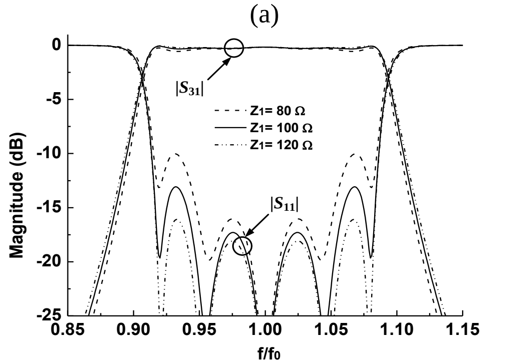
Fig. 4. Proposed wideband filtering crossover based on ring resonator.

The half-wavelength open stubs are all wide passband structures [11], they can be seen as an ideal open circuit in the center frequency of the crossover. In addition, we can find that two transmission zeros f_{tz3}, f_{tz4} don't change with Z_1, Z_{e1}, and Z_{o1}, so when the even/odd-mode characteristic impedance Z_{e1}, Z_{o1} are fixed, the bandwidth of the wideband crossover can be adjusted by the characteristic impedance of the open stubs Z_1, and the out-of-band performance of the crossover can be further improved by the two transmission zeros f_{tz3}, f_{tz4}. The simulated results of the wideband filtering crossover with/without four transmission zeros are shown in Figs.

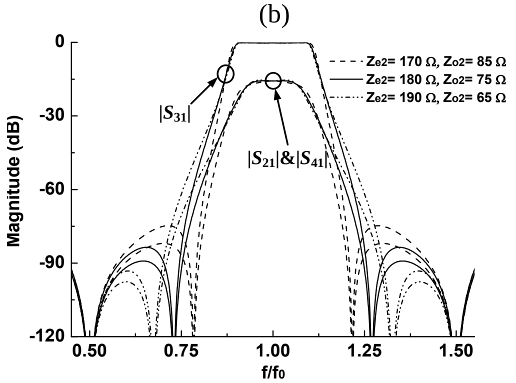
5 (a)-(c). The passband order can be increased from third to fifth, and four transmission zeros can be used to realize a wide passband for the crossover with sharp rejection, the two transmission zeros f_{tz3}, f_{tz4} nearly do not change the bandwidth of the wideband filtering crossover, and the in-band performance can be also adjusted by the characteristic impedance Z_1 of the four half-wavelength open stubs.



(a)



(b)



(c)

Fig. 5. Simulated results of the wideband filtering crossover. (a) With/without transmission zeros, (b) $|S_{31}|$, $|S_{11}|$ versus Z_1, and (c) $|S_{31}|$, $|S_{21}|$ versus Z_{e2}, Z_{o2}. ($Z_0 = 50\ \Omega$, $Z_1 = 120\ \Omega$, $Z_{e1} = 170\ \Omega$, $Z_{o1} = 108\ \Omega$, $Z_{e2} = 180\ \Omega$, $Z_{o2} = 75\ \Omega$).

Referring to the discussions and the simulated results, the 3-dB bandwidth of the filtering crossover is chosen as 26%, and the final parameters for Fig. 4 are $Z_0 = 50\ \Omega$, $Z_{e1} = 175\ \Omega$, $Z_{o1} = 112\ \Omega$, $Z_1 = 125\ \Omega$. The simulated results of Fig. 6 are illustrated in Fig. 7, and five transmission zeros are located at 1.5, 2.0, 2.2, 3.6 and 4.5 GHz, the passband $|S_{31}|$ is greater than -1.2 dB, the isolation $|S_{21}|$ and $|S_{41}|$ are less than -18 dB for 0~10.0 GHz.

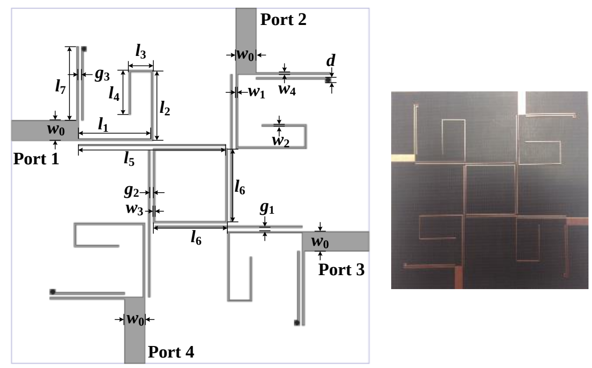
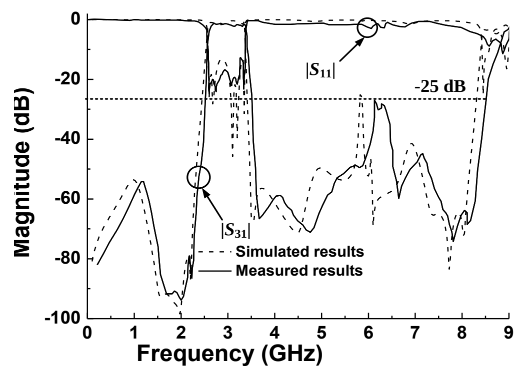
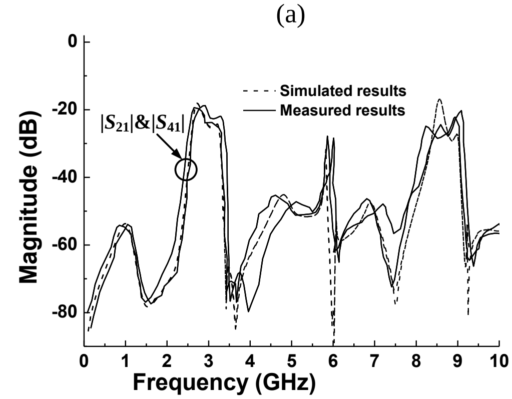


Fig. 6. Geometry of the wideband filtering crossover. ($l_1 = 18.0$, $l_2 = 15.5$, $l_3 = 8.45$, $l_4 = 13.0$, $l_5 = 36.3$, $l_6 = 18.25$, $l_7 = 18.25$, $w_0 = 2.7$, $w_1 = 0.24$, $w_2 = 0.27$, $w_3 = 0.23$, $w_4 = 0.3$, $g_1 = g_2 = 0.45$, $g_2 = 0.35$, $d = 0.6$, all in *mm*).



(a)



(b)

Fig. 7. Simulated and measured results of the crossover. (a) $|S_{31}|$, $|S_{11}|$, and (b) $|S_{21}|$, $|S_{41}|$.

III. EXPERIMENT AND RESULTS

The photograph, measured results of the wideband crossovers are also shown in Figs. 6-7. For the wideband crossover, five measured transmission zeros are located at 1.6, 2.0, 2.3, 3.5 and 4.7 GHz, the 3-dB bandwidth is 26.3% (2.58-3.37), the in-band $|S_{31}|$ is greater than -2.3 dB, the isolation $|S_{21}|$ and $|S_{41}|$ are less than -18.5 dB for 0~10.0 GHz ($3.3f_0$).

For the purpose of comparison, Table 1 illustrates the measured results for some crossovers with proposed wideband filtering crossover. It can be seen that, the proposed filtering crossover has wideband isolation for $|S_{21}|$ and $|S_{41}|$, and the upper stopband for $|S_{31}|$ can be extended up to $2.8f_0$ ($|S_{31}|$< -25 dB), and further circuit size reduction can be also realized by using folded lines in multi-layer circuits.

Table 1: Comparisons of measured results for some crossovers

Crossover Structures	TZs, $\|S_{31}\|$ 0-$2f_0$,	Isolation $\|S_{21}\|/\|S_{41}\|$, dB	Stopband $\|S_{31}\|$, dB	Filtering Response
Ref. [3]	0 (1.0 GHz)	25%, <-20	<-10, $1.50f_0$	No
Ref. [4]	0 (2.5 GHz)	14.0%, <-20	---	No
Ref. [6]	0 (2.5 GHz)	200%, <-12	---	No
Ref. [8]	4 (2.0 GHz)	100%, <-20	<-25, $2.50f_0$	Yes
This work	5 (3.0 GHz)	330%, <-19	<-25, 2.80f0	Yes

IV. CONCLUSIONS

In this paper, a wideband filtering crossover with sharp rejection based on ring resonator is proposed, four transmission zeros can be easily realized by the adding open stubs and open/shorted coupled lines. The proposed wideband filtering crossover has advantages of high selectivity, wide stopband and wideband. Good agreements between simulated and measured responses of the structures are demonstrated.

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