A new Class of MRR Structure based on Edge-Coupled Ring Resonators

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***Abstract*— A new class of multilayer ring resonators (MRR) structure is introduced based on edge-coupled ring resonators. Two similar MRR configurations, known as forward-coupling and reverse-coupling, are realized using this new prototype. It is shown that the same characteristics as multilayer rings can be achieved by edge-coupled rings. Second-order and third order bandpass filters are investigated. Both microstrip and stripline structure are studied. This study shows edge-coupled ring resonators behave similarly to MRRs.**

Keywords—multilayer ring resonators, MRR, edge-coupled, microstrip, stripline

I. Introduction

Topology and technology are the two main areas that can make significant impact on synthesis methods and manufacturing of microwave and high frequency devices. While new topologies change methodology, advanced materials improve technology. However, size, weight, and/or cost are of importance for microwave components when new ideas emerge [1].

It's been about a decade and half since MRR structures have been introduced [2]. Later, lumped element equivalent circuit models were proposed for MRRs in [3], balun and power dividers in [4], single band and dual band dipole antennas in [5], [6] and notched filters in [7]. So far, broadside-coupled ring resonators have been used in MRR structure. In this paper, it is shown that the edge-coupled ring resonators produce exactly similar responses like those of their broadside counterparts. Both microstrip and stripline structures are investigated here.

II. Second Order Microstrip Structure

Fig. 1 shows two edge-coupled circular ring resonators. The mean radius of the outer and inner rings are r_1 and r_2 and the width of the rings and gap sizes are denoted by W and S. Two loops are separated by a distance d and they are oriented such that the opening gaps are at opposite sides.

Resonant frequency of each ring occurs at half-wavelength corresponding to the ring length and can be found from

$$f_1 = \frac{c}{2L_1\sqrt{\varepsilon_{eff_1}}} \quad , \quad f_2 = \frac{c}{2L_2\sqrt{\varepsilon_{eff_2}}} \qquad (1)$$

$$L_1 = 2\pi r_1 - S_1 \quad , \quad L_2 = 2\pi r_2 - S_2$$

where c is the speed of light in free space, L_1 and L_2 are the average ring circumferences and ε_{eff} is the effective dielectric constant of each ring. Equations (1) are for loops with single resonance or single mode. Since two rings are coupled, both frequency of resonances will be shifted from the above calculations depending on the coupling coefficient values between the adjacent loops.

To realize bandpass filters, two ports are applied to the edges of gaps by transmission lines. Employing initial definitions used in MRR structures [2], two configurations are also possible here. When the ports are along the same line, it is called forward-coupling, Fig. 2(a), whereas when they are in the opposite sides of the gaps, it is called reverse-coupling, as depicted in Fig. 2(b).

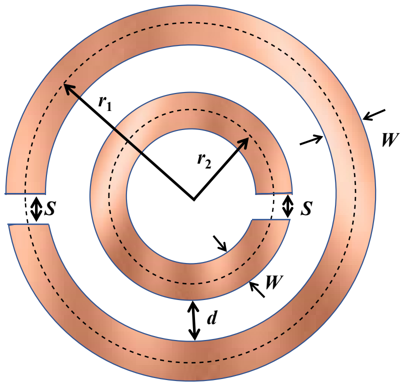
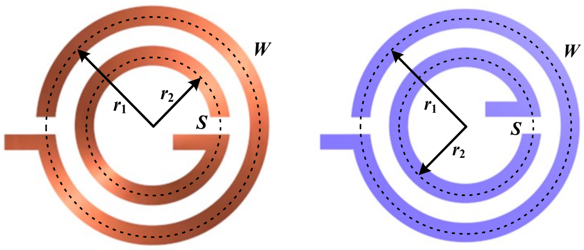


Fig. 1. Edge-coupled ring resonators.



(a) (b)

Fig. 2. Second order edge-coupled MRR structure (a) Forward-coupling (b) Reverse-coupling.

For the forward-coupling design, the dimensions of the rings are $r_1 = 13$ mm, $r_2 = 12.15$ mm, $W = 0.8$ mm, $d = 50$ µm. The gap S is an arc with 5 degrees angle which is approximately 1 mm. The substrate used in this design is Rogers RO3010 with $\varepsilon_r = 10.2$ and $h = 1.27$ mm. The ports are 50 Ω microstrip lines length 3 mm and width 1.3 mm. Substituting these parameter values into equations (1), the ring circumferences are computed: $L_1 = 80.5469$ mm and $L_2 = 75.2804$ mm. For this substrate and the ring width, the effective dielectric constant is equal to $\varepsilon_{eff} = 6.5$. If these values are inserted into the equations (1), two resonant frequencies will be obtained, $f_1 = 730.442$ MHz and $f_2 = 781.5426$ MHz. However, these resonant frequencies are for individual rings without considering coupling between them. The electromagnetic (EM) simulation responses, S_{11} and S_{21}, are shown in Fig. 3 which is exactly similar to the second order MRR filter with forward-coupling [2]. The passband is between 220 MHz to 1.46 GHz.

In reverse-coupling, Fig. 2(b), ring parameters are $r_1 = 13$ mm, $r_2 = 12.35$ mm, $W = 0.6$ mm, $d = 50$ µm, $S = 5°$. Substrate dielectric constant is $\varepsilon_r = 10.2$ and height $h = 2$ mm. Input/output terminals have the same sizes as forward coupling. Simulated S-parameters are presented in Fig. 4 that is the same as the second-order MRR filters with reverse-coupling [2] and two transmission zeros appeared next to the passband both in lower band and upper band. The 3-dB bandwidth extends from 402 MHz to 1.14 GHz.

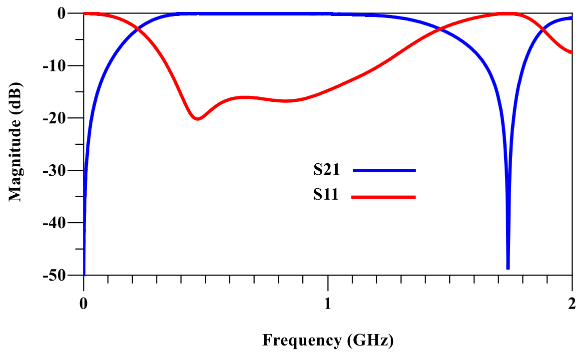


Fig. 3. Frequency response of second order edge-coupled ring resonators microstrip bandpass filter with forward-coupling.

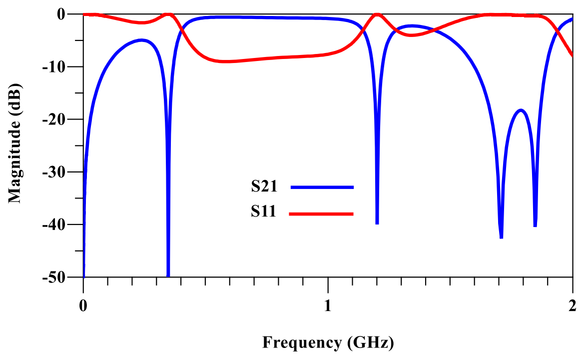


Fig. 4. Transmission and reflection coefficients of second-order edge-coupled ring resonators microstrip bandpass filter with reverse-coupling.

III. Third Order Microstrip Structure

Fig. 5 shows three edge-coupled ring resonators with forward- and reverse-coupling configurations. These two configurations and the arrangement of the rings are identical to the third-order MRR filters [2]. For the forward coupling type, Fig. 5(a), dimensions are r_1 = 13 mm, r_2 = 12.55 mm, r_3 = 12.1 mm, W = 0.4 mm, S = 5º, d = 50 µm, In/Out port widths 1.3 mm. The substrate has ε_r = 6.15 and thickness h = 1.3 mm. Average ring circumferences are L_1 = 80.5 mm, L_2 = 77.7 mm, L_3 = 75 mm and ε_{eff} = 4. Hence, resonant frequencies of uncoupled rings are computed: f_1 = 931.134 MHz, f_2 = 964.521 MHz and f_3 = 1000 MHz. EM simulation is exhibited in Fig. 6. This is a third-order BPF from 320 MHz to 1 GHz with asymmetrical response which verifies that this structure behaves similarly to the third-order MRR filter with forward-coupling [2].

In reverse-coupling, Fig. 5(b): r_1 = 13 mm, r_2 = 12.15 mm, r_3 = 11.3 mm, W = 0.8 mm, S = 5º, d = 50 µm. Here, ε_r = 6.15 and thickness is h = 4 mm. Responses are given in Fig. 7. The upper transmission zero in forward coupling moved to the lower band in reverse coupling. This filter characteristic exactly follows the third-order MRR filter which was introduced in [2]. The passband extends from 465 MHz to 1.22 GHz.

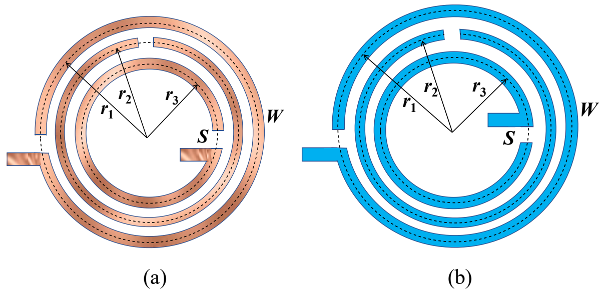


Fig. 5. Third-order edge-coupled MRR bandpass filters (a) Forward-coupling (b) Reverse-coupling.

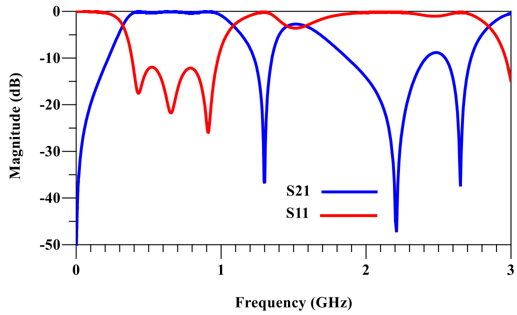


Fig. 6. Insertion and return losses of the three-pole edge-coupled MRR microstrip BPF with forward-coupling.

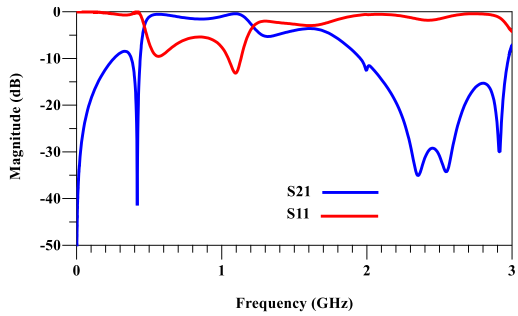


Fig. 7. Simulated performance of third order edge-coupled MRR microstrip bandpass filter with reverse-coupling.

IV. Second Order Stripline Structure

In the above studies microstrip is used. Here, edge-coupled ring resonators are investigated on stripline structure, Fig. 8. The dimensions in forward-coupling Fig.8(a) are r_1 = 13 mm, r_2 = 11.95 mm, W = 1 mm, d = 50 µm, S = 5º, I/O width 1.3 mm. Substrates are $\varepsilon_{r1} = \varepsilon_{r2}$ = 10.2 and height $h_1 = h_2$ = 1.27 mm. The simulated transmission and reflection coefficients are shown in Fig. 9. This response is clearly identical to the second order MRR BPF with forward coupling [2] between 330 MHz and 900 MHz. Resonant frequency of each ring is found from

$$f_{1,2} = \frac{c}{2L_{1,2}\sqrt{\varepsilon_r}} \quad , \qquad L_{1,2} = 2\pi r_{1,2} - S_{1,2} \qquad (2)$$

which gives f_1 = 583 MHz and f_2 = 634 MHz.

In reverse-coupling configuration Fig.8(b) the ring sizes are r_1 = 13 mm, r_2 = 11.15 mm, W = 1.8 mm, d = 50 µm, S = 5º, I/O terminal width 1.3 mm. Substrates dimensions are $\varepsilon_{r1} = \varepsilon_{r2}$ = 10.2 and heights $h_1 = h_2$ = 3 mm. Simulated S_{11} and S_{21} are illustrated in Fig. 10. This is a two–pole filter with 389 MHz–861 MHz bandwidth. This structure exactly behaves like the second-order MRR filters with reverse-coupling as described in [2].

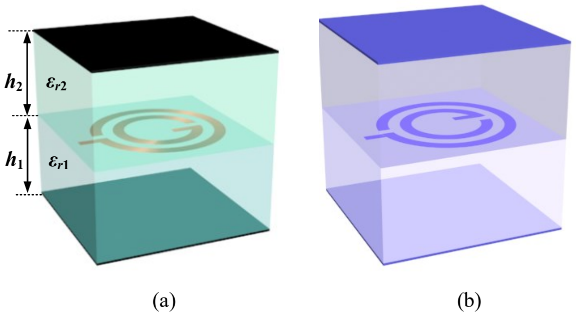


Fig. 8. Perspective view of the second-order edge-coupled ring resonators on stripline structure (a) Forward coupling (b) Reverse-coupling.

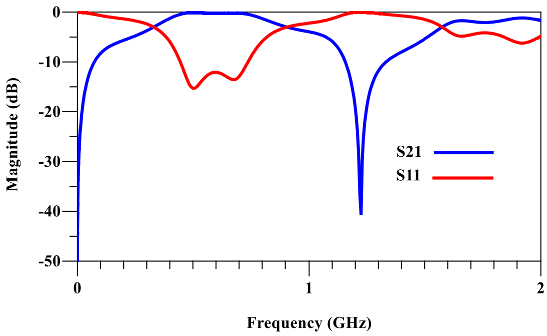


Fig. 9. Frequency response of second order edge-coupled ring resonators bandpass filter with forward-coupling on stripline structure.

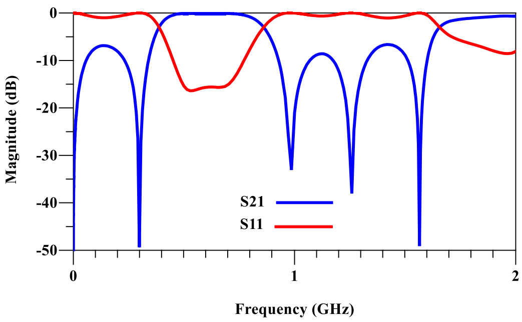


Fig. 10. Simulate S_{11} and S_{21} of second order edge-coupled ring resonators BPF with reverse-coupling on stripline structure.

V. Third Order Stripline Structure

The third-order filter geometry is similar to the previous case given in Section III and the structure here is stripline. In forward-coupling the circuit parameters are r_1 = 13 mm, r_2 = 12.55 mm, r_3 = 12.1 mm, W = 0.4 mm, d = 50 µm, S = 5°, I/O=1.3 mm. The dielectric mediums used are $\varepsilon_{r1} = \varepsilon_{r2}$ = 4.4 and thicknesses h_1 = h_2 = 1.7 mm. Simulated response is depicted in Fig. 11 which approves it behaves like third-order MRR with forward coupling. The filter covers passband from 298 MHz to 1 GHz.

In third-order reverse-coupling stripline structure: r_1 = 13 mm, r_2 = 12.45 mm, r_3 = 11.9 mm, W = 0.5 mm, d = 50 µm, S = 5°, I/O width 1.3 mm. Substrate dielectric constants are $\varepsilon_{r1} = \varepsilon_{r2}$ = 10.2 and heights are h_1 = h_2 = 1.2 mm. Simulation results are provided in Fig. 12. This is a BPF filter with operating range over 374 MHz –712 MHz. The performance of this filter and the presence of the transmission zeros are the same as the third-order MRR filters with reverse-coupling configuation [2].

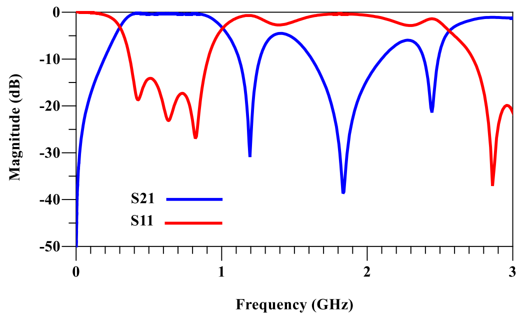


Fig. 11. Simulate responses of third order edge-coupled ring resonators bandpass filter with forward-coupling on stripline structure.

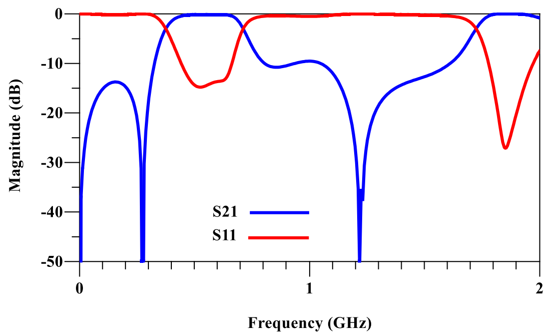


Fig. 12. Frequency responese of third order edge-coupled ring resonators BPF with reverse-coupling on stripline structure.

VI. Conclusion

A new class of MRR filters have been introduced base on edge-coupled ring resonators. Second order and third order filters were studied in both microstrip and stripline structures.

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