Realization of Quasi-elliptic Quadruplets with a Single Type of Coupling

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***Abstract* — A phase reversal scheme for changing the polarities of so-called electric and magnetic couplings between distributed resonators is explored. It demonstrates that the phase reversal can be achieved by shifting the excitation to the symmetric point of an open-ended half-wave resonator without altering the coupling geometry. Based on this technique, the polarities of conventional electric and magnetic couplings can be easily toggled. Two quasi-elliptic microstrip quadruplets are synthesized, fabricated and measured for demonstration.**

Index Terms — Coupling coefficient, cross couping, phase reversal, quadruplet, transmission zero.

I. Introduction

In design of bandpass filter with cross couplings, not only the magnitudes but also the polarities of coupling coefficients are required precise for realizing finite transmission zeros. The requirement of the polarities among all couplings are, however, in a relative sense [1]. It means that if the polarities of all coupling coefficients are reversed, the $|S_{21}|$ response will not be altered. This fact increases one degree of freedom for realizing the prescribed transmission zeros.

For coupled resonators, method for extracting their coupling coefficients by using an equivalent circuit is available in [2], where the phase response of S_{21} can be used to identify type of coupling, namely electric or magnetic. The S_{21} of these two types possess a phase difference of 180° around the design frequency. Later, we will see that this phase difference can be easily eliminated by moving one of the excitations to its symmetric position, since the voltage of a half-wave ($\lambda/2$) open-ended resonator is anti-symmetric about its center. This means both electric and magnetic couplings may have the same phase responses, and hence have coupling coefficients of identical polarities, if such movement is made.

In [3], a filtering balun is developed based on configuration of a filtering divider. The 180° phase difference between the two outputs is achieved by taking couplings from a $\lambda/2$-resonator at two positions symmetric about its center. In the filtering 180° hybrid [4], a $\lambda/2$-resonator is utilized to achieve the out-of-phase output for the delta port. In [5], layout of the filtering divider is symmetric about its center and the two outputs take out signals by tapping two open-ended resonators. The filtering balun function is accomplished by merely shifting one of the tapped points to its symmetric position of the same resonator to create the 180° phase change.

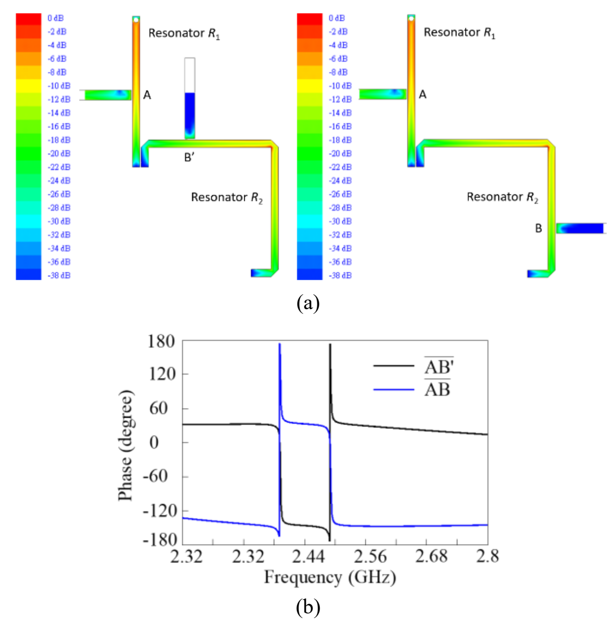


Fig. 1. First test of S_{21} phase reversal on a $\lambda/2$-resonator. (a) Circuit schematic and current densities for two excitations AB' and AB. (b) Phase responses.

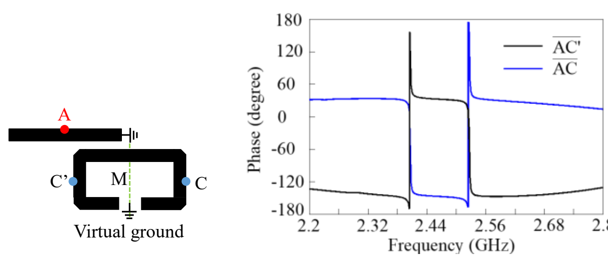
In this paper, we study the phase reversal scheme through a coupled open-ended $\lambda/2$-resonator. The scheme is then applied to design two quasi-elliptic quadruplet filters with all inter-resonator couplings of one type; one is of electric, and the other is of magnetic type. This demonstrates that the phase reversal scheme for inter-resonator couplings greatly increases flexibility in layout design of cross coupled filters. Herein, Sec.

II shows three tests of the phase reversal scheme, Sec. III demonstrates its application to design of quadruplets, Sec. IV compares the measured responses with the simulation results of two experimental circuits, and Sec. IV draws the conclusion.

II. Reversal of the S_{21} Phase Responses

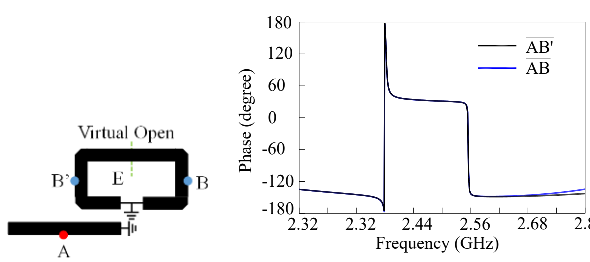
Fig. 1(a) shows the schematic of the first circuit for test of the phase reversal. The λ/4-resonator R_1 and the open-ended 180° resonator R_2 are coupled with their open ends. The excitation of R_1 is at point A, and those of R_2 are at B' and B for the two tests on the left- and right-hand sides, respectively, where points B' and B are symmetric about the center of the λ/2-resonator. Obviously, the couplings between R_1 and R_2 are of the electric type for both tests. Fig. 1(b) shows, however, that these two S_{21} phase responses are out of phases. This is because the voltage distribution of a λ/2 resonator is anti-symmetric about its center, and hence the voltages at points B' and B are out of phase [6]. It indicates that these two couplings have identical magnitudes but opposite signs. This reveals a fact that when a coupling of specific polarity is required, the I/O coupling position must be carefully chosen to ensure the relative polarity of the coupling.

Fig. 2(a) shows the second test with a λ/4- and a shorted λ/2-resonator, when the input port is at point A. Fig. 2(b) shows a similar phase reversal property when the output port is moved from C' to C.



(a) (b)

Fig. 2. Second test of S_{21} phase reversal. (a) Circuit schematic. (b) S_{21} phase responses.



(a) (b)

Fig. 3. Third test of S_{21} phase reversal. (a) Circuit schematic. (b) S_{21} phase responses.

Fig. 3(a) shows the third test. The coupling between the λ/4- and the shorted-λ/2 resonator utilizes their maximal current density segments so that coupling of magnetic type can be assured. As shown in Fig. 3(b), identical S_{21} phases are obtained for both output test port at points B and B'. This is because that the voltage on the λ/2-resonator is a half-sine wave from 0° to 180° and hence the voltages at B and B' have the same polarities.

III. Application to Cross-Coupled BPFs

Relative polarities of all couplings of a cross-coupled filter are critically important for realizing prescribed finite transmission zeros. Fig. 4 shows coupling scheme of a cross-coupled quadruplet. The solid circles represent resonators, the empty ones stand for the input and output ports, and M_{ij}'s denote couplings. To achieve a quasi-elliptic S_{21}, polarity of one of the above M_{ij}'s should be opposite to those of the other three [7, 8]. Based on the above phase reversal technique, it is possible to implement such a requirement with all couplings having the same polarities. There are two possibilities; one uses all electric and the other all magnetic couplings.

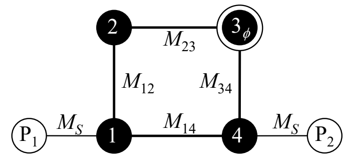


Fig. 4. Coupling scheme of a cross coupled quadruplet bandpass filter.

In the following, two quasi-elliptic quadruplets are designed at f_o = 2.4 GHz with an in-band ripple of 0.1 dB and fractional bandwidth Δ = 5%. The two zeros are designated at normalized lowpass frequencies Ω = ±1.7. The coupling coefficients are given as follows: $M_S = 0.9382$, $|M_{12}| = |M_{34}| = 0.7854$, $|M_{23}|$ = 0.7451 and $|M_{14}| = 0.1968$. Both circuits are designed on a RT/Duroid 5880 substrate ($\varepsilon_r = 2.2$, h = 0.508 mm, and tanδ = 0.0009), and the simulation data are obtained by a full-wave EM solver CST [9].

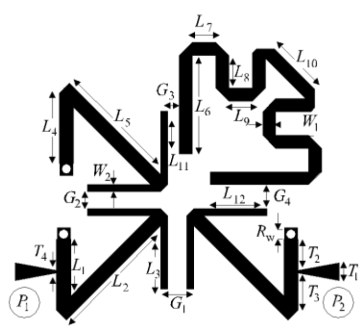


Fig. 5. Circuit layout of the quadruplet with all electric couplings. Geometric parameters in mm: $W_1 = 1.10$, $W_2 = 0.60$, $L_1 = 4.78$, $L_2 = 11.30$, $L_3 = 5.38$, $L_4 = 6.02$, $L_5 = 10.97$, $L_6 = 8.33$, $L_7 = 2.00$, $L_8 = 2.78$, $L_9 = 2.00$, $L_{10} = 3.41$, $L_{11} = 3.63$, $L_{12} = 4.76$, $G_1 = 1.61$, $G_2 = 0.44$, $G_3 = 0.28$, $G_4 = 0.31$, $T_1 = 1.50$, $T_2 = 2.63$, $T_3 = 3.15$, $T_4 = 0.20$, $R_w = 0.80$.

Fig. 5 shows the circuit layout of the quadruplet with all electric couplings. The arrow-shaped open ends of the λ/4-resonators are employed to implement the designated electric couplings. The hairpin λ/2-resonator is used to couple with the two neighboring resonators. Since these two electric couplings are out of phase, one of them can be referred to as negative electric coupling, meaning that of these two couplings, one polarity is positive and the other is negative, match with the rule given in [7].

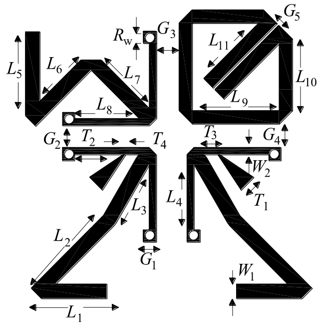


Fig. 6. Circuit layout of the second quadruplet with all magnetic couplings. Geometric parameters in mm: $W_1 = 1.10$, $W_2 = 0.60$, $L_1 = 5.46$, $L_2 = 8.53$, $L_3 = 5.53$, $L_4 = 5.38$, $L_5 = 6.97$, $L_6 = 4.85$, $L_7 = 5.64$, $L_8 = 5.38$, $L_9 = 7.24$, $L_{10} = 5.94$, $G_1 = 1.10$, $G_2 = 0.10$, $G_3 = 0.35$, $G_4 = 0.25$, $T_1 = 1.50$, $T_2 = 3.70$, $T_3 = 1.12$, $T_4 = 0.20$, $R_w = 0.80$.

Fig. 6 shows the circuit layout of the second experimental quadruplet. The arrow-shaped shorted ends of the three λ/4-resonators are of no doubt used to implement the magnetic couplings. The hairpin λ/2-resonator is designed to have magnetic couplings with the two neighboring resonators section close to its center, where the maximal current density occurs at resonance. It is known that the phases of the current densities are anti-symmetric, i.e., out-of-phase, about the center of the resonator. Thus, these two magnetic couplings are out of phases. Thus, the rule in [7] can be satisfied, and the quasi-elliptic response can be achieved.

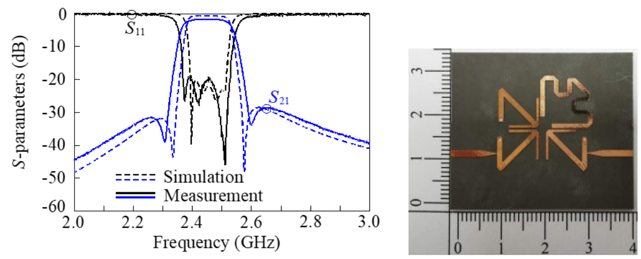
IV. Simulation and Measurement

The above two quadruplet bandpass filters are fabricated and measured. Fig. 7(a) compares the simulated and measured results of the quadruplet in Fig. 5. The measured data show an insertion loss of 2.7 dB and in-band return loss is better than 20 dB. Two transmission zeros can be observed at 2.37 and 2.58 GHz. Fig. 7(b) is photograph of the experimental circuit.

Fig. 8(a) compares the measured $|S_{21}|$ and $|S_{11}|$ with the simulated data for the quadruplet with all couplings of the magnetic type. In measurement, in-band insertion and return losses are 1.9 and 19 dB, respectively. The two transmission zeros at 2.35 and 2.59 GHz obviously enhance the frequency selectivity in the transition band. Fig. 8(b) is the photograph of the measured quadruplet.

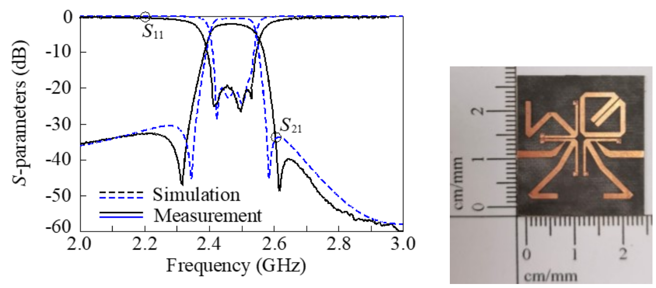
V. Conclusion

In conventional implementation of electric and magnetic couplings, their polarities can be changed by shifting the coupling position of a λ/2-resonator. This technique greatly increases design flexibility for practical implementation of cross-coupled bandpass filters where relative polarities of coupling coefficients are critical for creating finite transmission zeros. For demonstration, two quasi-elliptic quadruplets with one type of coupling are designed, fabricated, and measured. The measured responses for both circuits have good agreement with the simulated data.



(a) (b)

Fig. 7. Results of quadruplet filter in Fig. 5. (a) Measured and simulated S-parameters. (b) Photograph of the measured circuit.



(a) (b)

Fig. 8. Results of quadruplet filter in Fig. 6. (a) Simulated and measured S-parameters. (b) Photograph of the measured circuit.

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References

[1] J.-S. Hong and M. J. Lancaster, "Couplings of microstrip square open-loop resonator for cross-coupled planar microwave filters," *IEEE Trans. Microw. Theory Techn.*, vol.44, no.12, pp. 2099–2109, Dec. 1996.
[2] J.-S. Hong, *Microstrip Filters for RF/Microwave Application*, 2nd ed., New Jersey: Wiley, 2011.
[3] S.-C. Tang, P.-C. Chu, C.-H. Lin, L.-K. Wu and J.-T. Kuo, "Compact power divider and balun with quadruplet filtering responses," in *Proc. Eur. Microw. Conf. Cent. Eur.*, Prague, Czech, May 2019, pp.306–309.
[4] C.-K. Lin and S.-J. Chung, "A compact filtering 180° hybrid," *IEEE Trans. Microw. Theory Techn.*, vol. 59, no. 12, pp. 3030–3036, Dec. 2011.
[5] C.-H. Lin, C. L. Ng, P.-W. Wong and J.-T. Kuo, "Power divider and balun filters with a single cross-coupled quadruplet," in *Proc. Asia–Pacific Microw. Conf.*, Singapore, Dec. 2019, pp. 1703–1705.
[6] D. M. Pozar, *Microwave Engineering*. New York, NY, USA: Wiley, 2006.
[7] R. Levy, "Filters with single transmission zeros at real or imaginary frequencies," *IEEE Trans. Microw. Theory Techn*., vol. 24, pp. 172–181, Apr. 1976.
[8] J.-T. Kuo, C.-C. Wang, C. L. Ng, C.-H. Lin and P.-W. Wong, "New alternative realization of a cross-coupled quadruplet bandpass filter," in *Proc. Asia–Pacific Microw. Conf.*, Singapore, Dec. 2019, pp. 1143–1145.
[9] CST Studio Suite 2022, Dassault Systems Deutschland GmbH, Germany, 2022.