Microstrip Cascade Trisection Filter

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***Abstract*— A new configuration of odd-degree cascade trisection bandpass filter realized by combining microstrip hairpin resonator and λ/2-line open-circuited resonator is proposed. The general asymmetric Chebyshev function is used to synthesize the cascade trisection prototype. A five-pole microstrip cascade trisection bandpass filter with two asymmetrically prescribed transmission zeros located on opposite of the passband is designed and fabricated. The experimental result matches well with the theory.**

***Index Terms*—Cascade trisection network, cross-coupling, hairpin resonator.**

I. Introduction

HIGH-PERFORMANCE narrow-band cross-coupled planar microwave filters having finite transmission zeros had been proposed for reducing size, weight, and cost. In [1]–[3], the canonical and cascaded quadruplet (CQ) microstrip planar filters realized by microstrip square open-loop resonators and hairpin resonators have a symmetrical response. The folded diagonally coupled network and cross-coupled cascade trisection (CT) network generally provide asymmetric response [4], [5]. In [6] and [7], the asymmetric bandpass filter with diagonal cross-coupling is achieved by lumped element. For planar resonators, such as microstrip open-loop resonators and hairpin resonators, the diagonal cross-coupling is difficult to layout to obtain the desired coupling coefficients between resonators. The CT network shown in Fig. 1 can be easily achieved by using a microstrip resonator. Each trisection realizes one imaginary axis transmission zero and the prescribed transmission zeros can be arbitrarily placed in the complex s-plane. The trisection pseudointerdigital filter with one side attenuation pole has the advantage of the application for diplexer/multiplexer [8]. For compactness of filter, different planar resonators would be combined for CT network. One example, shown in Fig. 2, is the combination of a microstrip hairpin resonator and a $\lambda/2$-line open-circuited resonator. The cross-coupling between hairpin resonator is the magnetic coupling in Fig. 2(a) and electric coupling in Fig. 2(b). In Fig. 2(a), the coupling coefficient of the magnetic cross-coupling is negative and the attenuation pole is located below the passband. In Fig. 2(b), the coupling coefficient of the electric cross-coupling is positive and the attenuation pole is located above the passband.

II. Synthesis Procedure of the CT Network

For unity load and generator impedance, the transfer function $S_{12}(w)$ of a lossless reciprocal 2-port Nth degree Chebyshev network is

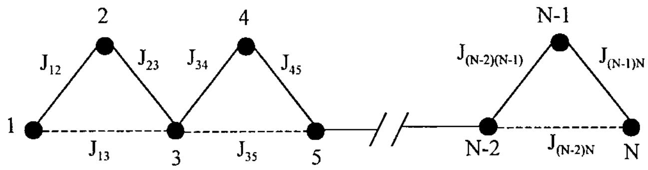

Fig. 1. Configuration of the CT prototype.

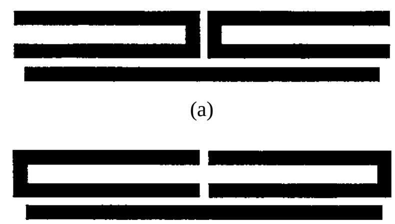

Fig. 2. A trisection realized by combining microstrip hairpin resonator and $\lambda/2$-line open-circuited resonator: (a) magnetic cross-coupling and (b) electric cross-coupling.

$$|S_{12}(w)|^2 = \frac{1}{1+\varepsilon^2 F_N^2(w)} \tag{1}$$

where ε is a constant controlled the ripple level. The function $F_N(w)$ described by Cameron [5] was

$$F_N(w) = \cosh\left[\sum_{n=1}^{N} \cosh^{-1}(x_n)\right] \tag{2}$$

and by Chambers and Rhodes [9] was

$$F_N(w) = \cos\left[\sum_{n=1}^{N} \cos^{-1}(x_n)\right] \tag{3}$$

where $x_n = (w-(1/w_n))/(1-(w/w_n))$ and $jw_n = s_n$ is the position of the nth transmission zero in the complex s-plane.

For a filter with same degree N and same transmission zero locations, the two return loss functions $S_{11}(w)$ derived from (2) and (3) have similar transmission zeros (symmetric with the imaginary axis) and reflection zeros. The synthesized network based on (2) and (3) should have the same response. In Fig. 1, each node i represents a shunt capacitor g_i and a shunt frequency invariant susceptance B_i. The main couplings, $J_{12}, J_{23}, \cdots, J_{(N-1)N}$, represented by a solid line, are normalized to unity and the dashed line represent the cross-couplings, $J_{13}, J_{35}, \cdots, J_{(N-2)N}$, between the non-adjacent resonators. This CT network can be synthesized by the transfer function (2), (3) with $N = 2m+1$ poles and m prescribed finite transmission zeros. The equivalent circuit of the CT network is shown in Fig. 3, in which the

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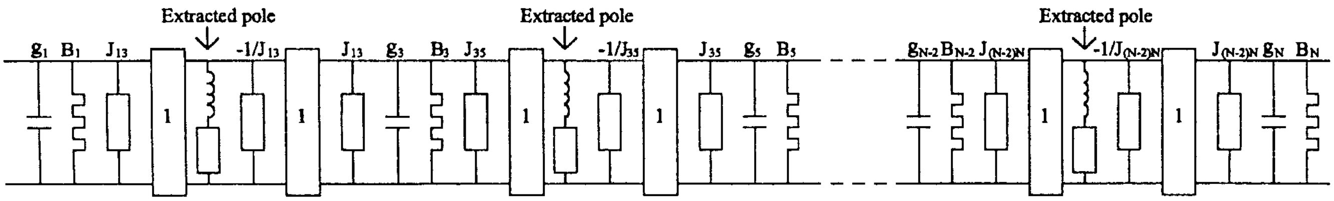

Fig. 3. Equivalent circuit of the CT prototype.

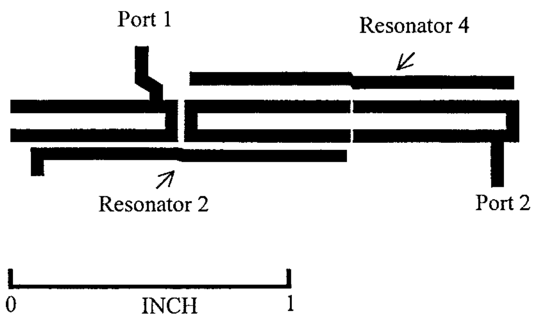

Fig. 4. Circuit configuration of a five-pole microstrip CT bandpass filter.

cross-couplings are $-J_{13}, -J_{35}, \cdots, -J_{(N-2)N}$. Following the synthesis method developed by Cameron [5], the low-pass prototype element values would be obtained. For narrow-band applications, an approximation result can be derived after a low-pass to bandpass transformation. The resonant frequency and the susceptance slope parameter of the ith resonator are [10]

$$f_{\mathrm{res,\,i}} = f_o\left[-\frac{\Delta B_i}{2g_i} + \sqrt{\left(\frac{\Delta B_i}{2g_i}\right)^2 + 1}\right]$$
$$b_i = \frac{g_i}{2\Delta}\left(\frac{f_o}{f_{\mathrm{res,\,i}}} + \frac{f_{\mathrm{res,\,i}}}{f_o}\right) \tag{4}$$

where f_o and Δ are the center frequency and bandwidth of the passband.

The external Q value of the resonator 1 and N coupled to the termination and the coupling coefficient between two resonators i, j are

$$(Q_e)_1 = b_1, \qquad (Q_e)_N = b_N, \qquad k_{ij} = \frac{J_{ij}}{\sqrt{b_i b_j}}. \tag{5}$$

As described in [5], the attenuation pole above the passband results in a positive cross-coupling in value and the attenuation pole below the passband results in a negative cross-coupling in value.

III. Example of Microstrip CT Bandpass Filter

A five-pole CT bandpass filter with 0.15-dB ripple and two asymmetric poles, $-j_2$ and $j_{1.8}$, placed on opposite sides of the passband is designed for 3-GHz center frequency and 3.33% fractional bandwidth. As mentioned previously, the combination of microstrip hairpin resonator and $\lambda/2$-line open-circuited resonator is appropriate for CT filter. The circuit configuration is shown in Fig. 4 and is fabricated on a Rogers RO4003 substrate with thickness 20 ml and

TABLE I
Prototype Element Values and Design Parameters of the Five-Pole CT Bandpass Filter

Resonator	g_i	B_i	J_{ij}	$f_{res,i}$	k_{ij}
1	0.9834	0.0028		2.999858	
2	1.586	0.6881		2.978385	
3	1.882	0.0194		2.999485	
4	1.6518	-0.7965		3.024207	
5	0.9834	0.0028		2.999858	
1-2			1		0.02669
1-3			-0.4026		-0.00986
2-3			1		0.019294
3-4			1		0.018905
3-5			0.4594		0.011256
4-5			1		0.026153

Note : Cross-coupling $-J_{13}$ = -0.4026 and $-J_{35}$ = 0.4594.

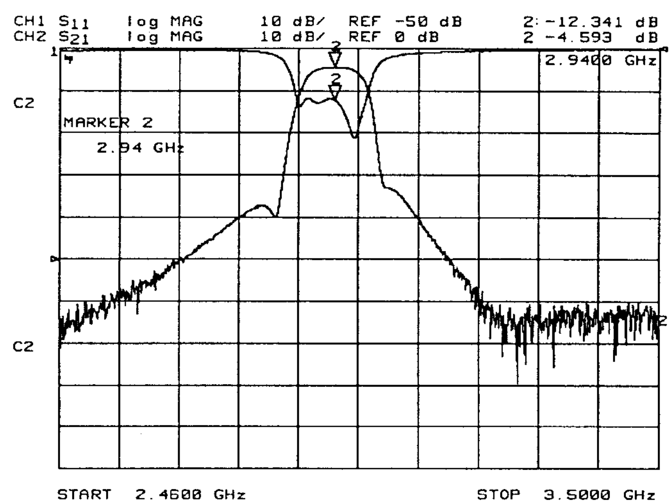

Fig. 5. Measured result of a five-pole microstrip CT bandpass filter.

relative dielectric constant of 3.38. The resonators 1, 3, 5 are realized by microstrip hairpin resonator and resonators 2, 4 by microstrip $\lambda/2$-line open-circuited resonator. The prototype element values and the design parameters are shown in Table I. In Table I, the resonant frequency of resonator 4 is higher than that of resonator 2 so that the line-length of the resonator 4 would be shorter than that of resonator 2. The calculation of the coupling coefficient is similar to [3] and an EM simulator—IE3D from Zeland Software Inc.—is used. The bend of left-hand side of the resonator 2 is to achieve the desired coupling coefficient between the resonators 1 and 2. The mixed (electric and magnetic) couplings between resonators 1 and 2 and between resonators 2 and 3 are out of phase. On the other hand, the mixed couplings between resonators 3 and 4 and between resonators 4 and 5 are in phase. The measured result is shown in Fig. 5. In Fig. 5, the measured center frequency is 2.94 GHz and 3.33% fractional bandwidth. The shift of the center frequency can be compensated by shortening the line length of the resonators. The insertion loss of the passband is 4.6 dB and the attenuation of the stopband at the transmission zero is about 35 dB. The lower attenuation pole, 2.84 GHz ($-j_{2.07}$), is due to the nonadjacent magnetic coupling between resonators 1 and 3, and the upper attenuation pole, 3.033 GHz ($j_{1.87}$), is due to the nonadjacent electrical coupling between 3 and 5. Both agree well with the prediction.

IV. Conclusion

The CT prototype synthesized from asymmetric Chebyshev polynomials allows for the placement of asymmetrically prescribed transmission zeros in the complex s-plane. The characteristics of the CT network is suitable for microwave filters realized by microstrip planar resonators. A novel microstrip CT bandpass filter realized by combining microstrip hairpin resonator and $\lambda/2$-line open-circuited resonator is presented. The attenuation poles above and below the passband are caused by the electric and magnetic couplings between nonadjacent resonators, respectively. A five-pole microstrip CT bandpass filter has been demonstrated. The measured result shows good agreement with the theory.

References

[1] J. S. Hong and M. J. Lancaster, "Canonical microstrip filter using square open-loop resonators," *Electron Lett.,* vol. 31, pp. 2020–2022, Sept. 1995.

[2] ——, "Couplings of microstrip square open-loop resonators for cross-coupled planar microwave filters," *IEEE Trans. Microwave Theory Tech.,* vol. 44, pp. 2099–2109, Nov. 1996.

[3] ——, "Cross-coupled microstrip hairpin-resonator filters," *IEEE Trans. Microwave Theory Tech.,* vol. 46, pp. 118–122, Jan. 1998.

[4] R. J. Cameron, "Fast generation of Chebyshev filter prototypes with asymmetrically-prescribed transmission zeros," *ESA J.,* vol. 6, no. 1, pp. 83–95, 1982.

[5] ——, "General prototype network-synthesis methods for microwave filters," *ESA J.,* vol. 6, no. 2, pp. 193–206, 1982.

[6] P. L. Field, I. C. Hunter, and J. G. Gardiner, "Asymmetric bandpass filter using a novel microstrip structure," *IEEE Microwave Guided Wave Lett.,* vol. 2, pp. 247–249, June 1992.

[7] ——, "Asymmetric bandpass filter using a ceramic structure," *IEEE Microwave Guided Wave Lett.,* vol. 2, pp. 361–363, Sept. 1992.

[8] R. R. Mansour, F. Rammo, and V. Dokas, "Design of hybrid-coupled multiplexers and diplexers using asymmetrical superconducting filters," in *IEEE MTT-S Int. Microwave Symp. Dig.,* 1993, pp. 1281–1284.

[9] G. Chambers and J. D. Rhodes, "Asymmetric synthesis," in *Proc. 11th European Microwave Conf.,* Sept. 1981, pp. 105–110.

[10] G. Macchiarella, "An effective technique for the synthesis of an equiripple low pass prototype filter with asymmetric frequency response and arbitrary transfer function zeros," in *Proc. 25th European Microwave Conf.,* 1995, pp. 722–724.