A Novel Coupling Structure Suitable for Cross-Coupled Filters With Folded Quarter-Wave Resonators

Chi-Yang Chang and Cheng-Chung Chen

***Abstract*—A new class of coupling structure for cross-coupled filters with folded quarter-wave resonators is presented. The cross coupling mechanism is realized by magnetic coupling from the short ends of the resonator. The proposed magnetic coupling solves the problem of response limitation of folded quarter-wave resonator cross-coupled filters that were introduced previously using electrical cross coupling. Several quadruplet and trisection filters are proposed and fabricated. The measured results matched well with the theoretical prediction.**

***Index Terms*—Cross-coupled filter, magnetic cross coupling, quarter-wave resonator.**

I. INTRODUCTION

RECENTLY, several compact microstrip cross-coupled filter configurations have been proposed [1]–[7]. While most of reported literatures use half-wave resonators [1]–[4], some use quarter-wave resonators [5]–[7] that have advantage on size reduce of the filter and stop-band rejection. In [6], [7], the planar cross-coupled filters realize the electrical cross coupling by bending the open end of quarter-wave or folded quarter-wave resonators. The various responses of the filters are achieved by alter one of the resonator in main coupling path to cause 180° phase difference. Among those quarter-wave resonator filters, the folded quarter-wave resonator filter [6] has the smallest size. However, for the folded quarter-wave resonator filter, the use of the open-end electrical coupling proposed in [6] have following shortcomings. Firstly, in order to obtain the flat group delay response, the quadruplet filter needs to reverse the second or the third resonator and leads to an asymmetric layout that makes filter design more complex. Moreover, in the case of trisection filters to be presented in this paper, if the electrical-cross-coupling is applied, the filter can have a transmission zero only at the lower stop-band. It is not possible to realize an upper stop-band transmission zero by reversing the second resonator in the trisection filter. To solve these problems, a novel magnetic coupling structure suitable for cross-coupled filter with folded quarter-wave resonators as shown in Fig. 1 and 2 is proposed in this paper. In Fig. 1(b) and Fig. 2(b), the cross coupling is achieved by magnetic coupling between the short-end of folded quarter-wave resonator. The quadruplet cross-coupled filter in Fig. 1(b) has a flat group delay response and is configured in symmetric manner similar to electrical cross-coupled filter shown in Fig. 1(a) that has a quasielliptical function response. The Trisection filter in Fig. 2(a) has a lower stop-band transmission zero response and Fig. 2(b) has an upper stop-band transmission zero response. By analyzing the coupling phase between main coupling path and cross coupling path, one can easily understand that different cross-coupled structures lead to different filter responses. The filter structures presented in this paper have been verified by simulated and experiment results.

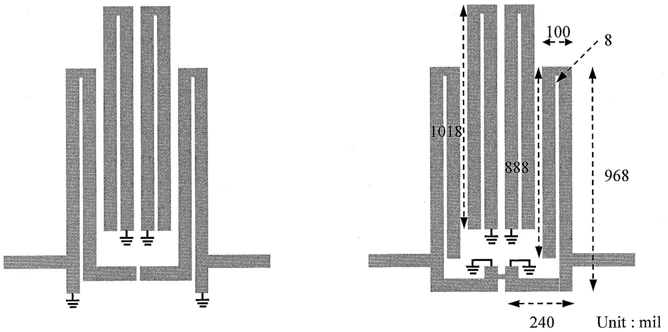

Fig. 1. Quadruplet filters using folded quarter-wave resonator. (a) Filter with quasielliptical function response and (b) filter with flat group delay response.

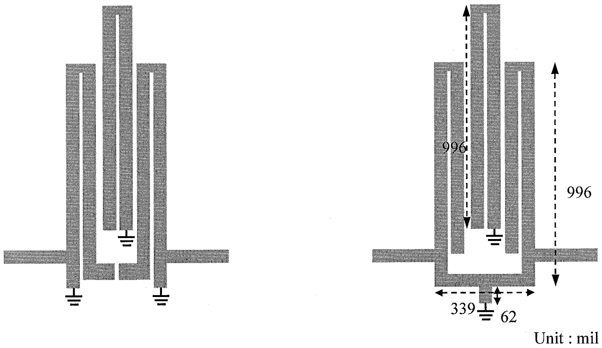

Fig. 2. Trisection filters using folded quarter-wave resonator. (a) Filter with lower stop band transmission zeros response and (b) filter with higher stop band transmission zeros response.

II. CIRCUIT DESIGN

Shown in Fig. 1(a) is the circuit layout of quadruplet cross-coupled filter using folded quarter-wave resonators introduced in [6]. The filter is composed of folded quarter-wave resonators

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The authors are with the Institute of Electrical Communication Engineering, National Chiao Tung University, Hsinchu 300, Taiwan, R.O.C.

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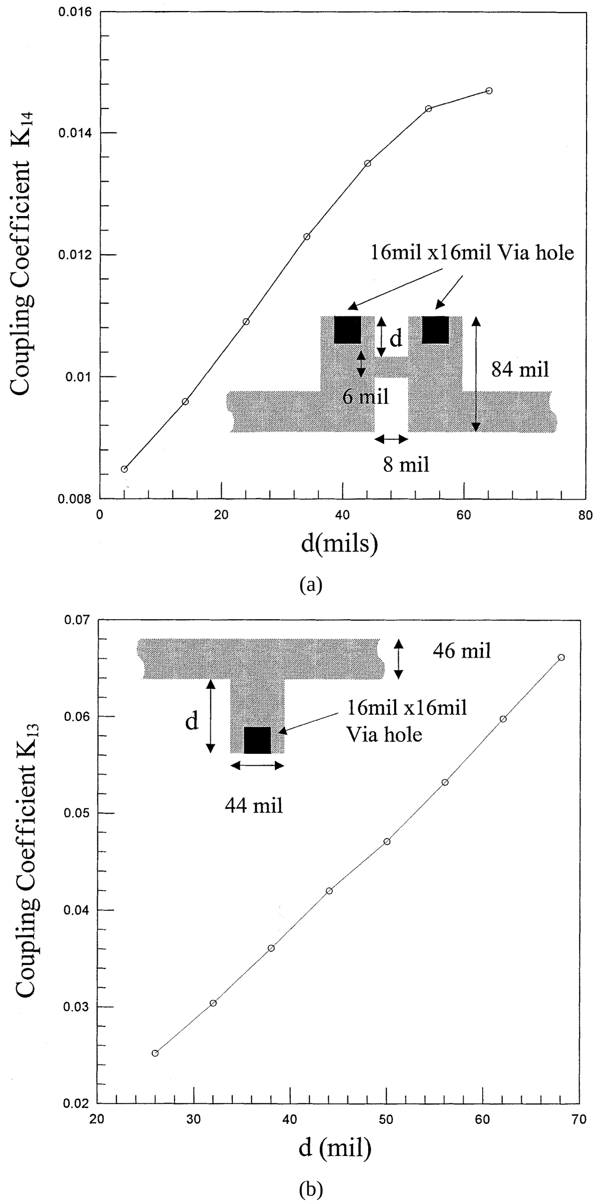
TABLE I
DESIGN PARAMETERS FOR QUADRUPLET AND TRISECTION CROSS-COUPLED FILTER

Filter type	Transmission zero	Fractional bandwidth(%)	Passband ripple (dB)	Coupling coefficients
Quadruplet filter with flat group delay response	$\pm 1.3+j0$	5	0.05	$K_{12}=K_{34}=0.0463$, $K_{23}=0.0294$, $K_{14}=0.0124$, Qe=18.42
Trisection filter with higher stop band transmission zero	$0+j1.5$	5	0.01	$K_{12}=K_{23}=0.0415$, $K_{13}=0.0614$, Qe=12.36

in comb-type coupling and the cross coupling is realized by the electrical coupling from the open end of first and fourth resonators. According to the analysis in [6], the filter has quasielliptical function response. In Fig. 1(b), a new structure of quadruplet filter similar to Fig. 1(a) is proposed except that the cross coupling between first and fourth resonator is achieved by magnetic coupling between short ends of resonators. As shown in Fig. 1(b), a short high impedance line connects two resonators at proper position near two short ends. The specified strength of cross coupling can be realized by appropriately adjust the distance between this high impedance line and two short ends. If this high impedance line is omitted, the magnetic cross coupling could be too weak to realize enough coupling strength. The magnetic cross coupling in Fig. 1(b) shows 180° phase difference to the electrical cross coupling in Fig. 1(a) at both frequency range $f > f_0$ and $f < f_0$. As a result, the filter response changes from quasielliptical function to flat group delay.

The trisection filters using folded quarter-wave resonator is shown in Fig. 2. The first and second resonators of the filters are coupled by comb-type coupling and the second and third by interdigital-type. The filter in Fig. 2(a) has a transmission zero at lower stop-band as a result of electrical cross coupling through the open ends of first and third folded quarter-wave resonators. On the contrary, the filter in Fig. 2(b) has an upper stop band transmission zero as a result of magnetic cross coupling. Note the layout of magnetic cross coupling in Fig. 2(b) is different from that in Fig. 1(b). It is because the desired strength of cross coupling for trisection filter is larger than quadruplet filter on condition that both filters have same position of transmission zero. To achieve this, layout with larger magnetic coupling is proposed as shown in Fig. 2(b). In Fig. 2(b), the first and third resonators are shorted to grounding via a common transmission line. The transmission line served as a mutually coupled inductors and the length of the line determine the strength of the magnetic cross coupling. The method proposed in [6], [7] to analyze the phase difference between main coupling and cross coupling path can be used to analyze the stop-band behavior of the proposed cross-coupled filters. Let us concentrate our attention to newly proposed structure Figs. (1b) and (2b). After the coupling phases along main coupled and cross coupled path are studied and added up, the simulated results demonstrate that the filter in Fig. 1(b) has 0° phase difference between main coupling and cross coupling at both frequency range $f < f0$ and $f > f0$. Consequently, the filter with flat-group delay response is realized. With the same procedure, we conclude the phase difference between the main coupling path and the cross coupling path of the trisection filter in Fig. 2(b) is 0° for $f < f_0$ and 180° for $f > f_0$. Thus, the filter has the response with a transmission zero at the upper stop-band.



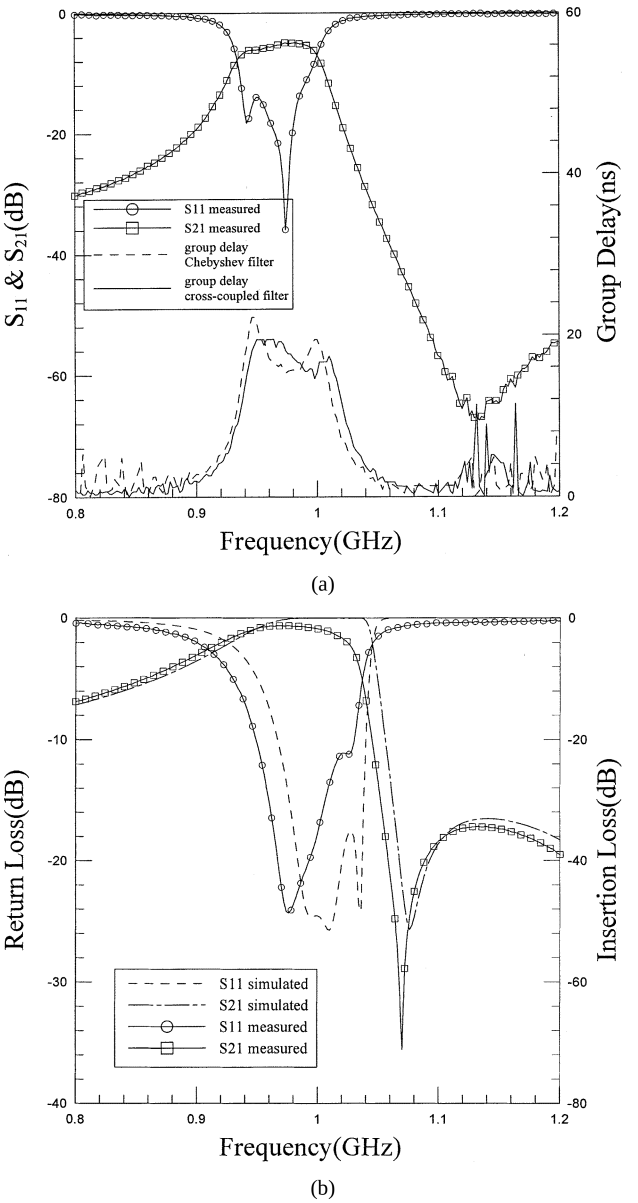
(a)

(b)

Fig. 3. Coupling structures and design curve for magnetic cross coupling. (a) Fig. 1(b) and (b) Fig. 2(b).

III. DESIGN EXAMPLES

To verify the proposed filter configurations, the quadruplet filter in Fig. 1(b) and trisection filter in Fig. 2(b) are designed. The physical parameters are obtained by determining the coupling coefficients between resonators and external quality factor using a full-wave EM simulator from Sonnet [8]. The coupling coefficients are synthesized following the method described in [9], [10] and listed in Table I. The coupling coefficient of electrical cross coupling of the filter in Fig. 2(a) is achieved by determining the gap between two open ends of resonators. On



(a)

(b)

Fig. 4. (a) Measured results of quadruplet filter with flat group delay response in Fig. 1(a) and Chebyshev filter. (b) Measured and simulated results of trisection filter in Fig. 2(b).

the other hand, the coupling coefficient of magnetic cross coupling of the filter in Fig. 1(b) is achieved by determining the distance between the high impedance connecting line and two short ends. In Fig. 2(b), the length of common transmission line connected to grounding determines the coupling coefficient of magnetic cross coupling of the filter. Fig. 3(a) and Fig. 3(b) present the design curves and physical parameters for the determination of magnetic coupling coefficients of the filters in Fig. 1 and Fig. 2(b) respectively. As for the external quality factor, the singly loaded method introduced in [11] is used to determine the tap-in position of input and output resonators.

The trial filters are fabricated on a Rogers RO4003 substrate. The substrate has a relative dielectric constant of 3.38, a thickness of 20 mils, and a copper cladding of half an ounce. Fig. 4(a) shows the measured S_{11}, S_{21} and group delay of the cross-coupled filter in Fig. 1. Comparing with the Chebyshev filter using folded quarter-wave resonator, this CQ filter shows flat pass-band group delay characteristics. The measure results of trisection filter in Fig. 2(b) are shown in Fig. 4(b). The filter has a higher stop band transmission zero as the results of magnetic cross coupling.

IV. CONCLUSIONS

We have presented a novel coupling structure to realize the trisection and quadruplet cross-coupled filter formed by folded quarter-wave resonators. The newly proposed magnetic coupling structure solves the problem of limitation of response of a trisection filter and layout symmetry of a quadruplet filter. Either open end or short end of the folded quarter-wave resonators can be bent to achieve cross coupling. With this newly proposed cross coupling structure, a designer has larger degree of freedom to design a CT or CQ cross-coupled filter.

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