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Folded quarter-wave resonator filters with Chebyshev, flat group delay, or quasi-elliptical function response

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Abstract: This paper presents the design and realization of a new class of miniaturized microstrip filters using folded quarter-wave resonators. Various kinds of filter response are realized by proper arrangement of the resonator. The design rules for cross-coupled filter with quasi-elliptical function and flat group delay response are provided. The measured results are matched well with the theoretical prediction.

I. INTRODUCTION

The Combline and Intedigital filters are two of the smallest size in those of microwave filters [1]. Using the quarter-wave resonators make the filters very compact and have good stopband rejection. Recently, several compact filter configurations using halft wave resonators have been proposed [2-5]. The hairpin filter [2] is most popular because its physical length is only about a quarter-wavelength long. Moreover, by introducing the cross coupling between nonadjacent hairpin resonators, the quasi-elliptical function response or flat group delay response can be realized [4]. In [5], the folded half-wavelength resonators are proposed to design multi-level bandpass filters.

In this paper, we present new kinds of microstrip Combline and Intedigital filters using the folded quarter-wave resonators as shoen in Fig. 1. The physical length of folded quarter-wave resonator is about 1/8 wavelength of microstrip line at resonance frequency. This makes the filter structures more compact comparing with conventional interdigital filter and combline filter using quarter-wavelength resonators.

In addition to the conventional chebyshev response, the cross-coupled filters using same resonators are also proposed as shown in Fig. 2. The cross coupling is introduced by bending the resonators. By analyzing the coupling phase between main path and cross path, both quasi-elliptical function and flat group delay response can be realized with proper designed gap spacing.

II. CIRCUIT DESIGN

Shown in the Fig.1 are the schematics of proposed combline (Fig. 1(a)) and interdigital (Fig. 1(b)) filters using folded quarter-wave resonator. The couplings between first and second resonators as well as between third and fourth resonators are from open ends of the resonator. The coupling between second and third resonator are from short end of the resonator. Folding of the quarter-wave resonator avoids the 90-degree comb-type coupling between two resonators. As a result, the lumped capacitor, which is used in combline filter to avoid 90-degree comb type coupling, is no more required.

Shown in Fig. 2(a) is the proposed cross-coupled filter with quasi-elliptical function response. It is basically a comb-line filter similar to fig. 1(a) except that two open end of first and fourth resonators are bend to achieve electric cross coupling. Shown in fig. 2(b) is another cross-coupled filter with flat group delay response. The only difference of circuit configuration between these two cross-couple filters is the reversed arrangement of third resonator (or second resonator). The reverse of the resonator causes 180-degree phase change in the main coupling path of filter and as a result, changes the response of filter from quasi-elliptical function to flat group delay response.

It is known that a cross couple filter has quasi-elliptical function response if the main coupling and cross coupling is out of phase and flat group delay response if the main coupling and cross coupling is in phase [6]. To understand the responses of the proposed cross-coupled filters, we have analyzed the coupling phase relation between each resonator and added up the phase difference along the main coupling path and the cross coupling path. Fig. 3(a) shows the schematics circuit used to simulate the phase relation between the first resonator and second resonator of the cross coupled filter shown in Fig. 2(a). In Fig. 3(a), the folded quarter-wave resonator is presented by coupled line model and a voltage source is coupled to one of two resonators via a coupling capacitor. A circuit simulator such as Microwave Office™ can be used here to analyze the phase difference between main coupling path and cross coupling path. Shown in Fig. 3(b) is the simulated magnitude and phase response of V1 and V2. The amplitude responses (dash line) show two resonant peaks at f_1 and f_2 corresponding to the coupling between two resonators. The phase response show that V1 and V2 are in phase at $f > f_0$ and out of phase at $f < f_0$. It implies that there is 180-degree phase shift at $f<f_0$ and 0-degree phase shift at $f>f_0$ between the first and the second resonator. Using same method, the phase shift between each resonator can be obtained and added up to get the total phase difference through main coupling path as well as cross coupling path. It can be summarized that the phase difference between main coupling path and cross coupling path of the cross-coupled filter in Fig. 2(a) is 180-degree at both frequency range $f< f_0$ and $f>f_0$. In contrast, the filter in Fig. 2(b) has zero-degree phase difference at $f< f_0$ and $f>f_0$. As a result, the filter in Fig. 2(a) has quasi-elliptical function response while the filter in Fig. 2(b) has flat group delay response.

III. DESIGN EXAMPLES

To verify the proposed filter configurations, the chebyshev filters shown in fig.1 and cross couple filter in fig. 2 were designed and fabricated on a Rogers RO4003 substrate. The substrate is with a relative dielectric constant of 3.38, a substrate thickness of 20mils, and a copper cladding of half ounce. The filters were designed at center frequency at 1 GHz and the fractional bandwidth is 5 %. The physical parameters are obtained by determining the coupling coefficient between resonators and external quality factor using a full-wave EM simulator from Sonnet[7]. The design parameters were obtained using the method described in [6,8]. The quasi-elliptical function filter is designed with a real frequency zero at 0+j 1.7 and the flat group delay filter is designed with real axis zero at 1.3+j0.

Fig. 4 shows the measured results of the comb-line filter (Fig. 1(a). Fig. 4 shows the measured results of interdigtal filter (Fig. 1(b)). The midband insertion losses of both filter configurations are about the same. It is observed that combline filter has better stop band rejection comparing to that of the interdigital filter.

Shown in Fig. 5 is the measured response the cross-coupled filter in the Fig. 2(a). Two finite frequency transmission zeros are located at two side of stop-band. Fig. 6 shows the measured S_{11}, S_{21} and group delay of the cross-coupled filter in Fig. 2(b). As predicated, the filter shows flat pass-band group delay characteristics. The measured responses of the proposed cross-coupled filters are matched with the theoretical results.

IV. CONCLUSIONS

We have presented new kinds compact microstrip filter using folded quarter-wave resonators. Both com-line and interdigital configurations have been introduced. In addition to the conventional Chebyshev filter, we have further proposed the cross-coupled filter with quasi-elliptical and flat group delay responses. To demonstrate our design, four filter configurations has been designed and fabricated. The measured results show good agreement with theoretical prediction.

ACKNOWLEDGEMENT

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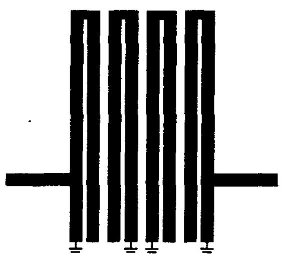
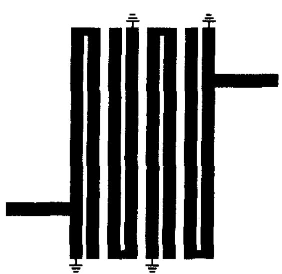
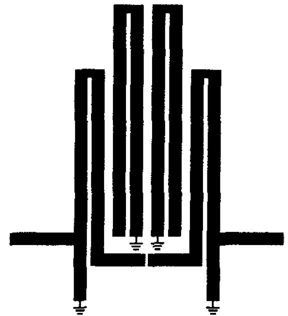


(a)

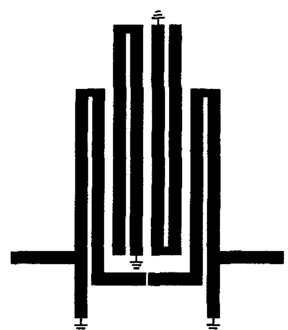


(b)

Fig. 1 Proposed microsrip filter using folded quarter-wave resonator (a) combline filter; (b) interdigital filter.



(a)



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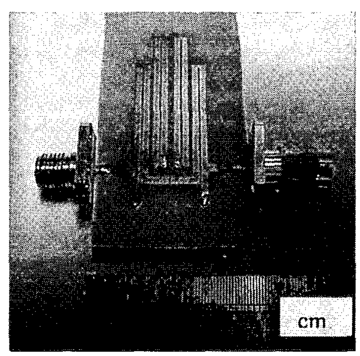
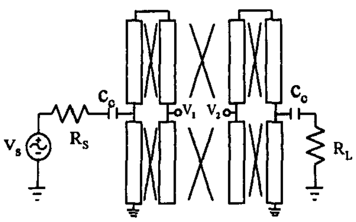
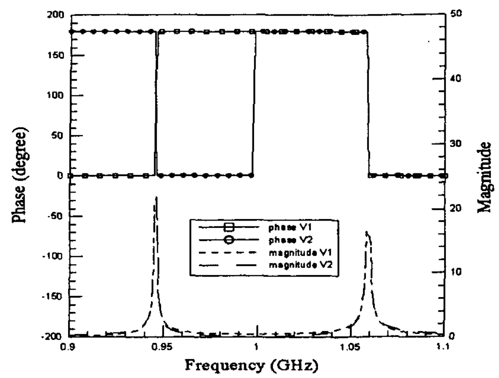


(c)

Fig. 2 Proposed microsrip cross-coupled filter (a) quasi-elliptical response; (b) flat group delay response; (c) the photograph of filter in (a).



(a)



(b)

Fig. 3 Simulation of the magnitude and phase response of first and second resonators in Fig. 1(a), (a) Schematic circuits; (b) simulated results.

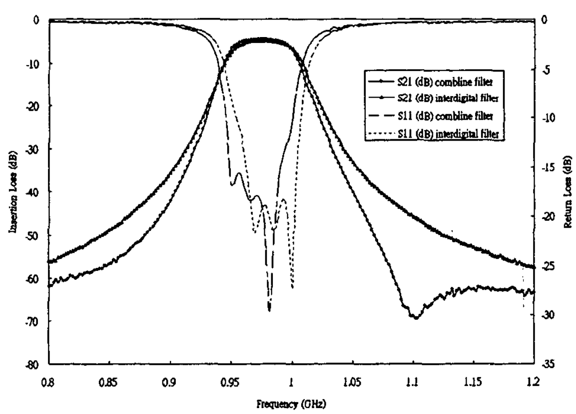


Fig. 4 Measured results of combline and interdigital filter.

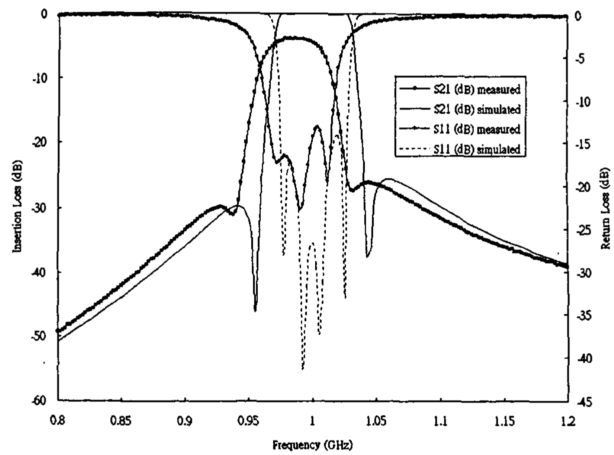


Fig. 5 Measured and simulated results of cross-coupled filter with quasi-elliptical function response.

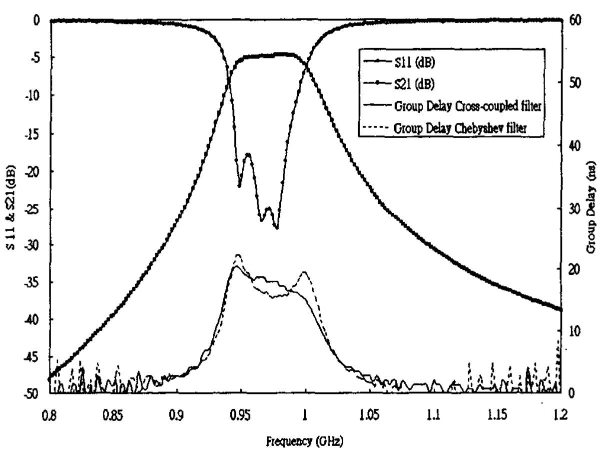


Fig. 6 Measured results of cross-coupled filter with flat group delay response.