A Modified Parallel-Coupled Filter Structure That Improves the Upper Stopband Rejection and Response Symmetry

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***Abstract*—A modified parallel-coupled microstrip line filter structure is presented. Using this new structure, the filter upper stopband rejection is improved by at least 15 dB, and the filter response symmetry is also improved. Compared with the traditional parallel-coupled filter, the modified filter uses less space and is easy to lay out owing to its in-line structure. Several examples show the performance improvement of the filters fabricated in both low-dielectric-constant (2.55) and high-dielectric-constant (10.2) substrates.**

I. Introduction

The microstrip parallel-coupled filter, first proposed by Cohn in 1958 [1], has been one of the most commonly used filters in the past 30 years. This type of filter has many advantages, such as easy design procedures, a wide bandwidth range (from a few percent to more than 40%), and a planar structure. The filter can be fabricated easily and it exhibits reasonably good performance compared with other planar circuit filters. Unfortunately, there are several disadvantages of the traditional parallel-coupled filter.

One of the disadvantages is that the first spurious passband of this type of filter appears at twice the basic passband frequency; therefore, the rejection of the upper stopband is worse than that of the lower stopband. The reason that the spurious passband appears at twice the basic passband frequency is the inequality of the even- and odd-mode velocities of the coupled microstrip line. Sometimes the upper stopband rejection may be as low as 20 dB. This phenomenon greatly limits the applications of the parallel-coupled filter.

Another disadvantage of the parallel-coupled filter is that the filter response shows steeper roll-off on the lower frequency side than on the higher frequency side. This is the so-called frequency response asymmetry. The asymmetry is apparent when looking at the response of the passband group delay. The frequency response symmetry is also important in such applications as those involving pulsed signals. In the past, both design and the realization of a symmetrically responsed filter have posed difficulties [2], [3].

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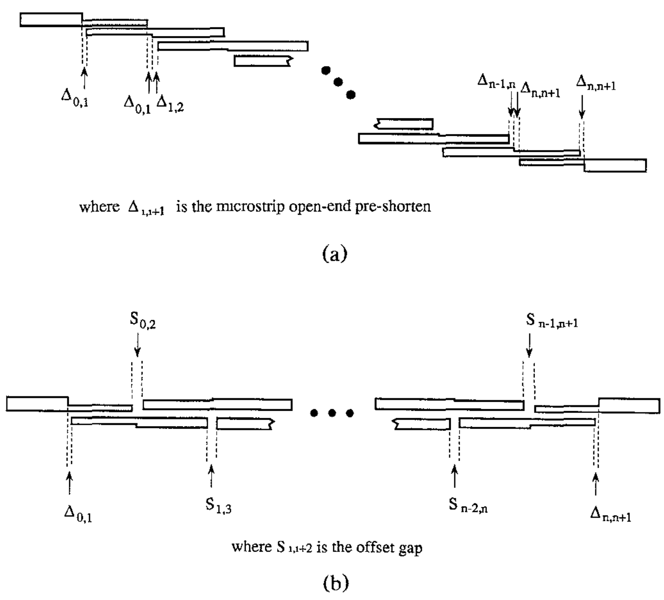

Fig. 1. The traditional and modified parallel-coupled filter. (a) The traditional filter. (b) The modified filter.

In this paper, we introduce a modified parallel-coupled filter. Compared with the traditional parallel-coupled filter, the modified filter shows improvements of the upper stopband rejection by at least 15 dB (the improvement value depending on the substrate and the filter parameters) and of the response symmetry. The new filter will fit in quite a narrow channel. It will take up less room than the equivalent shorted stub filter. Also, the input and output lines can be collinear.

II. Circuit Description

Fig. 1 shows the traditional parallel-coupled filter and the modified parallel-coupled filter. Instead of the microstrip open ends in the traditional parallel-coupled filter, there are microstrip gaps in the modified version. Fig. 2(a) shows a detailed view of the gaps. These gaps are of the offset type. Since the gaps are critical to the filter performance, closed-form equations for the gap equivalent circuit are required for the filter performance analysis. Unfortunately, even now

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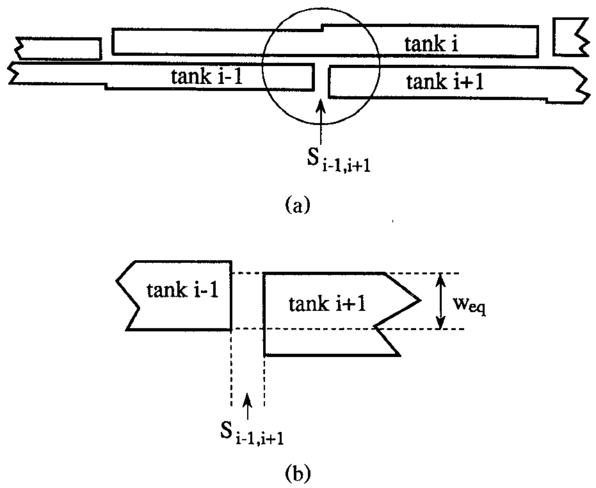

Fig. 2. The offset gap in modified filter. (a) Detailed view. (b) Approximation model.

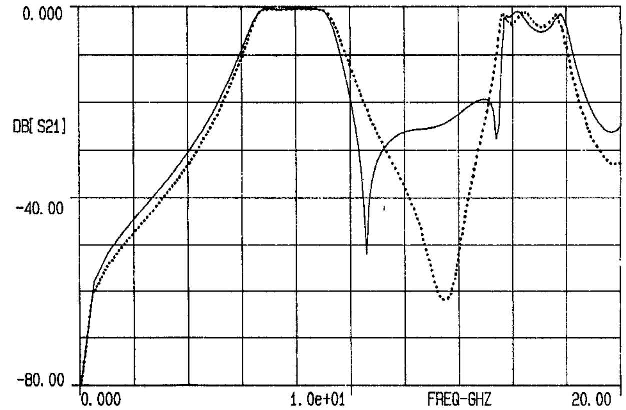

Fig. 3. The influence of the gap spacing on filter performance. The filter parameter is shown in the filter 1 column of Table I. ——— $S_{02} = 2$ mil, $S_{13} = 3$ mil; $\cdots$ $S_{02} = 5$ mil, $S_{13} = 8$ mil.

TABLE I
FILTER DESIGN PARAMETERS

Specifications \ Filter number	1	2	3	4	5
Type of design	Chebyshev	Chebyshev	Chebyshev	Chebyshev	Chebyshev
Center freq.	8 GHz	8 GHz	10 GHz	10 GHz	10 GHz
% bandwidth	25%	25%	40%	40%	40%
Passband ripple	0.1 dB	0.1 dB	0.1 dB	0.1 dB	0.1 dB
Substrate ϵ_r	10.2	2.55	10.2	2.55	2.55
Substrate thickness	25 mil	29.5 mil	25 mil	29.5 mil	29.5 mil
Number of poles	3	3	3	3	4
S_{02}†	7 mil	12 mil	5 mil	15 mil	25 mil
S_{13}†	10 mil	17 mil	5 mil	15 mil	30 mil
Δ_{01}†	6.2 mil	9.7 mil	5.3 mil	10.3 mil	10.5 mil
Δ_{12}†	7.1 mil	11 mil	6.2 mil	11.4 mil	11.7 mil
Δ_{23}†	—	—	—	—	12.1 mil
System impedance*	50 Ω	82 Ω	50 Ω	60 Ω	60 Ω

†Defined in Fig. 1.
*The non-50-Ω system impedance is tapered to 50 Ω at input and output.

closed-form design equations for the gap are only available for the aligned microstrip gaps (the line with the same width on both sides of the gap) [4]. Using the approximation method shown in Fig. 2(b), the calculated filter response is in reasonably good agreement with the measured result. In Fig. 2(b), the offset gap is equivalent to an aligned gap with a line width of w_{eff} and a gap width of $s_{i-1,i+1}$. By carefully choosing the gap width, one can optimize the stopband rejection and the response symmetry. An interesting phenomenon is that when the offset gap spacing is reduced, a very sharp high side skirt can be achieved, as shown in Fig. 3. There are two microstrip open ends in the modified parallel-coupled filter, and $2 \cdot (n+1)$ open ends in the traditional parallel-coupled filter, where n is the number of poles of the filter. To treat these open ends, a preshortening method is used. The preshortened length $\Delta_{i,i+1}$, where $i = 1,2,3,\cdots,n$, in Fig. 1(a) and $\Delta_{0,1}, \Delta_{n,n+1}$ in Fig. 1(b) are obtained from [5]. By including the equivalent circuit of the gaps and the open ends to the filter, the performances of both the traditional and the modified parallel-coupled filter may be calculated.

III. FILTER EXAMPLES

To verify the performance improvement five filters were built in both traditional and modified forms. The filter parameters are shown in Table I. The filters were fabricated on two kinds of substrates: one is a woven type PTFE substrate with a thickness of 29.5 mil and a dielectric constant of 2.55; the other is Duroid 6010 with a thickness of 25 mil and a dielectric constant of 10.2. These two dielectric constant values cover those most commonly used in microwave substrates. Filters 1 through 4 are three-pole designs with bandwidths of 25% and 40% and were fabricated on both low- and high-dielectric-constant substrates described above. Filter 5 is a four-pole design with a bandwidth of 40% and was fabricated on a low-dielectric-constant substrate.

IV. THE CALCULATED AND TESTED RESULTS

The filters were measured using an HP-8510 network analyzer. The filter under test was shielded by a foam-type wave absorber to eliminate the unwanted radiation, which can influence the performance curve in the rejection band.

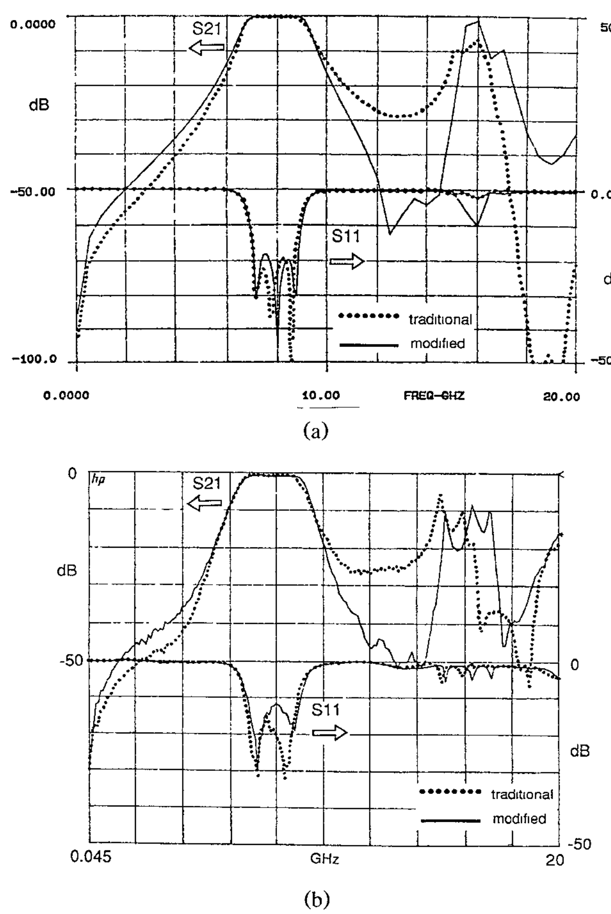

Fig. 4. The performances of filter 1: (a) calculated and (b) measured.

Fig. 4 shows the computed performance of filter 1, and Fig. 4(b) shows the measured performance of filter 1. The curves in Fig. 4(a) and (b) are well matched. This shows that the approximation method in the previous section for the computer-aided design of this modified filter is possible. The upper stopband rejection improves from 25 dB to about 50 dB.

Fig. 5(a) shows S_{11} and S_{21} for filter 2. In Fig. 5(a), the upper stopband rejection is improved from 30 dB to about 60 dB. Fig. 5(b) show the calculated and measured group delay curves of the traditional parallel-coupled filter (filter 2). The two curves in Fig. 5(b) are well matched. In Fig. 5(b), the group delay shows apparent asymmetry. This is a natural characteristic of the traditional parallel-coupled filter. Fig. 5(c) shows the calculated and measured group delay curves of a modified parallel-coupled filter 2. Although the calculated and measured curves are not matched as well as in Fig. 5(b), they are acceptable. The worst calculation accuracy is from the approximation of the offset gap model. It is believed that by using a more accurate model for offset gaps [6], [7], a better calculation result may be achieved. Comparing Fig. 5(c) to Fig. 5(b), the group delay symmetry is seen to be improved.

Figs. 6–8 show the measured performance of filters 3, 4, and 5. In Fig. 6, the upper stopband rejection is improved from 33 dB to about 60 dB. In Fig. 7, the upper stopband rejection is improved from 38 dB to about 60 dB. In Fig. 8 the upper stopband rejection is improved from 45 dB to

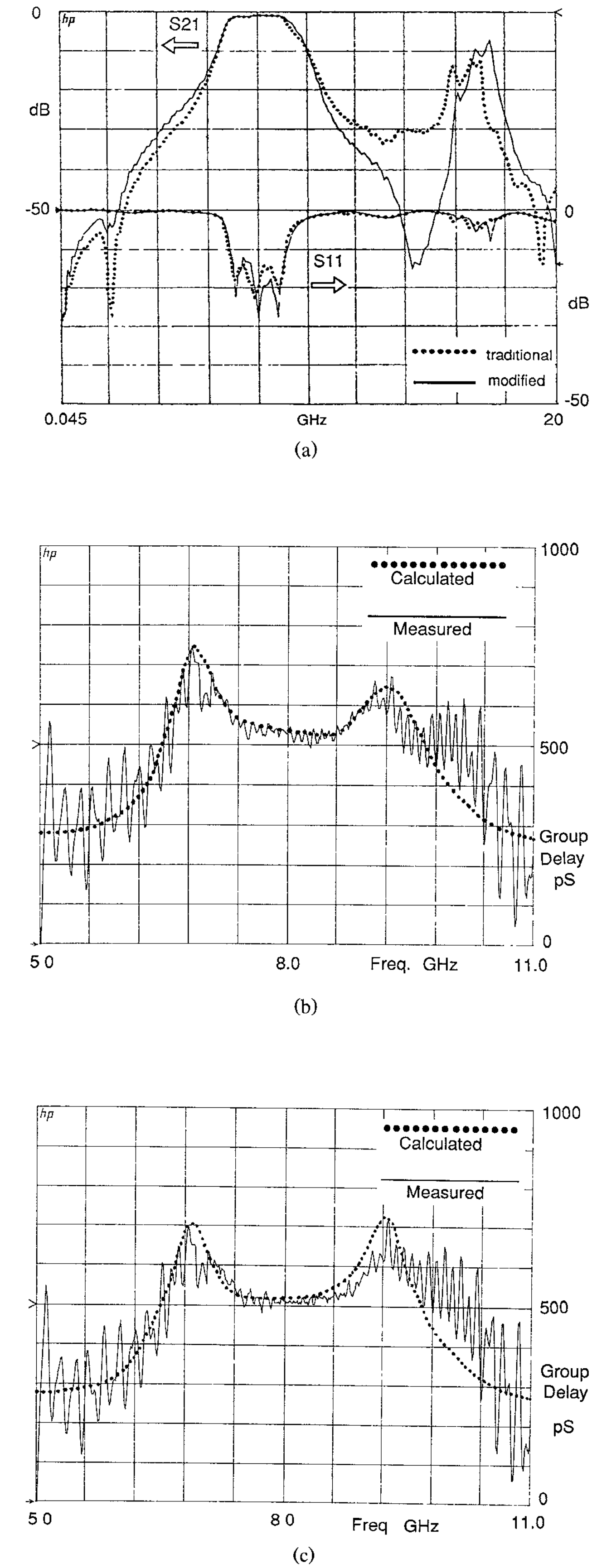

Fig. 5. The performances of filter 2. (a) Measured S_{11} and S_{21} of filter 2. (b) Group delay of traditional parallel-coupled filter 2. (c) Group delay of modified parallel-coupled filter 2.

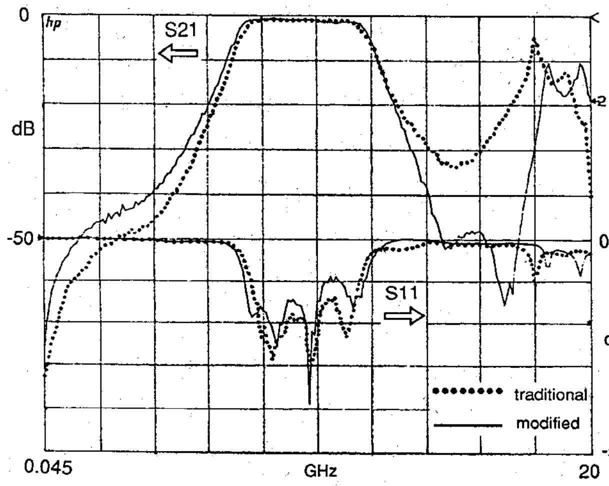

Fig. 6. The measured performances of filter 3.

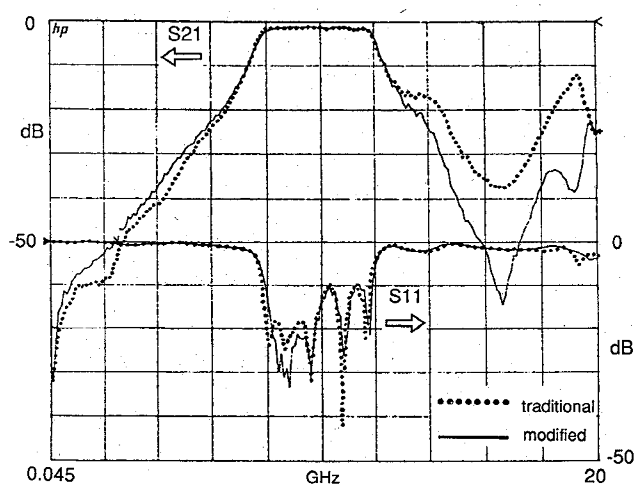

Fig. 7. The measured performances of filter 4.

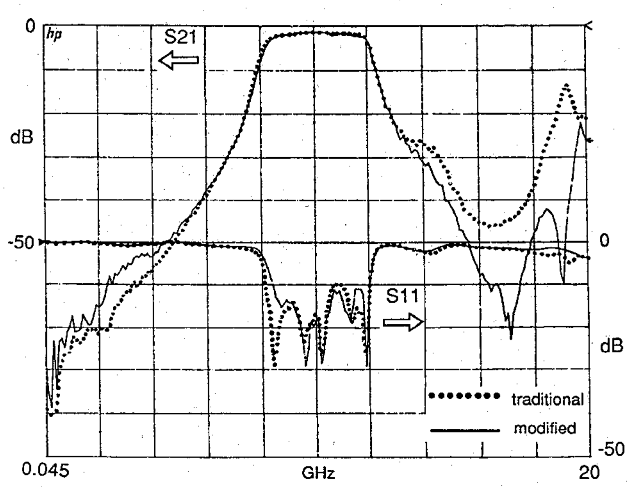

Fig. 8. The measured performances of filter 5.

about 70 dB. The stopband rejection values stated above are peak rejection values.

Summarizing the above five examples and many different calculated filter cases, we may conservatively conclude that the modified parallel-coupled filter improves the upper stopband rejection by at least 15 dB, and the filter group delay symmetry. It can also be seen that the improvement of the filters built in high-dielectric-constant substrate is greater than those in low-dielectric-constant substrate. This is due to the smaller even-mode and odd-mode wave velocity difference in the low-dielectric-constant substrate case than in the high-dielectric-constant substrate.

V. Conclusions

A modified parallel-coupled filter structure has been designed and fabricated. The modified filter shows improvement of the upper stopband rejection by at least 15 dB and of the group delay symmetry. An approximation method to treat the offset gaps has been introduced. Using this approximation gap model, the calculated result has been found to be in acceptably good agreement with the measured result. The modified filter uses less area than traditional parallel-coupled filter, and such fabrication limitations as smallest gaps and line widths are the same as in the traditional filter. The in-line structure of the modified filter solved the layout problem in many extreme cases.

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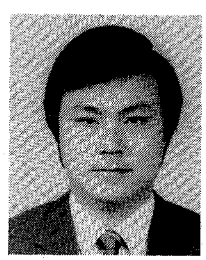

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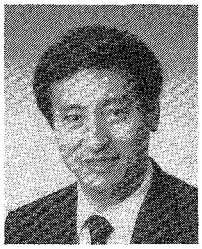

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