Modified Parallel-Coupled Filter With Two Independently Controllable Upper Stopband Transmission Zeros

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***Abstract*—A microstrip cross-coupled filter with two independently controllable transmission zeros on upper stopband is presented. The initial filter structure is a conventional Chebyshev-response parallel-coupled filter that can be easily realized by the analytical method. The newly proposed coupling/shielding lines can effectively control the cross and main couplings without changing the original filter layout. This approach allows a designer to eliminate the tedious segmentation method, which is usually used to establish the relation between the coupling coefficient and physical distance between resonators. A three-order filter is designed and fabricated for demonstration.**

***Index Terms*—Cross-coupled, microstrip filters, transmission zeros.**

I. INTRODUCTION

THE cross-coupled microstrip filters have been extensively studied in recent years. Research efforts are focused mainly on two aspects. One is in finding a new shape for a resonator. Another is developing novel synthesis methods, which enable a designer to arrange resonators in different ways to achieve an advanced response, such as a generalized Chebyshev response. Resonators with different shape, such as loop [1], hairpin [2], and patch [3] have been arranged in specific topologies for improving the selectivity or in-band group delay of filters. Some widely applied topologies are cascade quadruplet (CQ) and cascade trisection (CT) [4]. Besides CQ and CT, novel synthesis methods have lead to novel topologies containing couplings of source/load to multiresonator [5], [6]. In short, novel physical structures accompanied with advanced synthesis methods have enriched the possibilities of a microstrip filter.

However, the designs of cross-coupled filters are not as straightforward as conventional ones such as parallel-coupled filter, end-coupled filter, etc. In the design of a cross-coupled filter, there are no explicit expressions to relate synthesized electrical parameters to physical dimensions of a filter. Therefore, when designing a cross-coupled filter, the first step is to synthesize a coupling matrix. Then, use the segmentation method to relate coupling strength to the physical distance between resonators [1]. The drawback of the design procedures is that once the size of the resonator changes, designers must redo the segmentation method to find physical dimensions of filters. Moreover, since the segmentation method can only provide approximated dimensions of the filter, fine tunings are always needed.

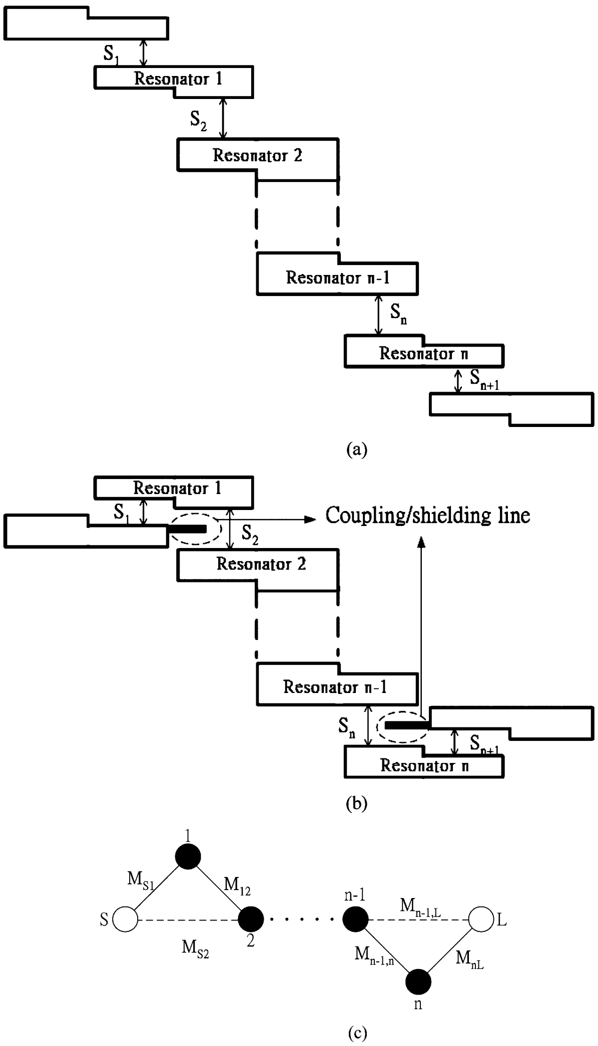

Fig. 1. (a) Conventional parallel-coupled filter. (b) The modified filter. (c) The coupling route of the modified filter.

To skip the tedious designing routine of the segmentation method, we propose an easy designing procedure to realize a filter with two upper stopband transmission zeros. The basic

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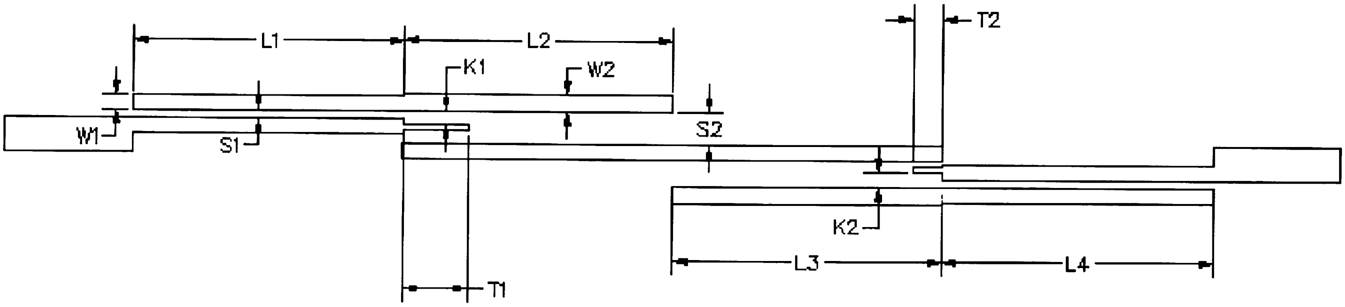

Fig. 2. Layout of the fabricated filter (in mil). L1 = 354, L2 = 354, L3 = 354, L4 = 354, S1 = 11, S2 = 35, W1 = 19, W2 = 21, K1 = 19, K2 = 20, T1 = 87, T2 = 39. The line with of coupling/shielding lines is 8 mil.

structure of the proposed filter utilizes the conventional microstrip parallel-coupled filter [7], as shown in Fig. 1(a), to serve as the initial design. Then, vertically flip feeding lines of the source and the load, as shown in Fig. 1(b). As described by Chang and Itoh [8], the physical dimensions keep the same during flipping. Next, adding the proposed coupling/shielding lines at the ends of input and output feed lines, as depicted in Fig. 1(b). Fig. 1(c) shows the coupling diagram of Fig. 1(b) and the coupling elements can be optimized and fine-tuned by the method proposed in [9]. The proposed layout of the filter is somewhat similar to those of [8]. Nevertheless, the strengths of couplings M_{S2} and $M_{\mathrm{L,n-1}}$ in the filters described in [8] are extremely weak and not taken into account during filter design procedures. In this letter, we introduce these coupling/shielding lines to control the strength of M_{S2} and $M_{\mathrm{L,n-1}}$, which makes it possible to independently control two transmission zeros in the upper stopband.

II. CIRCUIT DESCRIPTION AND DESIGN FEASIBILITY

The design procedures start with the conventional microstrip parallel-coupled filter. Following easy design procedures, dimensions of a Chebyshev-response parallel-coupled filter as shown in Fig. 1(a) can be obtained. Then, vertically flip feeding lines of the source and the load with respect to resonator "1" and resonator "n," respectively. Note that the gap spacing S_{i} in Fig. 1(a) is identical to that in Fig. 1(b). During practical layout, designers may shorten resonators in advance to prevent the feed lines from directly connecting to resonator "2" or resonator "$n-1$" if needed.

To introduce two independently controllable transmission zeros on the upper stopband, the design procedures can be started with the Chebyshev-response coupling matrix and perturb it by introducing cross couplings $M_{\mathrm{S,2}}$ and $M_{\mathrm{L,n-1}}$ to form two trisection blocks as shown in Fig. 1(c). During this procedure, it is found that in order to keep equal ripple in-band response, the strength of $M_{1,2}$ and $M_{\mathrm{n-1,n}}$ must be decreased and the frequencies of the resonators need to be adjusted. Therefore, a suitable manner to simultaneously introduce couplings $M_{\mathrm{S,2}}$ and $M_{\mathrm{L,n-1}}$, and decrease the strength of $M_{1,2}$ and $M_{\mathrm{n-1,n}}$ is needed. The coupling/shielding lines shown in Fig. 1(b) seem to be a perfect candidate. The coupling/shielding lines can introduce couplings M_{S2} and $M_{\mathrm{L,n-1}}$, and decrease the strength of M_{12} and $M_{\mathrm{n-1,n}}$ by shielding part of their coupling gaps. Practically speaking, the length, width, and vertical position of the coupling/shielding line can be adjusted. Here, we fix the line width and adjust the line length and vertical position. The vertical position of the coupling/shielding line has little effect on shielding but has a strong influence on cross-coupling. In Chebyshev-response parallel-coupled filters, the relations $S_1 < S_2$ and $S_{\mathrm{n+1}} < S_{\mathrm{n}}$ always hold, which makes it possible to add a coupling/shielding line at the end of the feed lines. Another merit of the parallel-coupled filter structure is that when adjusting the length of the resonator to align the resonant frequencies, the coupling between resonators is nearly unchanged. The feasibility of nearly independently tuning the coupling and frequencies makes it easy to implement the asynchronous tuned filter as that in Fig. 1(c).

III. DESIGN EXAMPLE AND EXPERIMENT

To show the feasibility of the proposed structure, an example is given below. The center frequency, in-band return loss, and fractional bandwidth of the filter are chosen to be 5 GHz, 20 dB, and 5%, respectively. The filter is built on a Rogers RO4003 substrate with $\varepsilon_r = 3.58$, thickness= 20 mil, and $\tan\delta = 0.0021$. The initial dimensions of the parallel-coupled filter are obtained by the analytical method described in [7]. The coupling/shielding lines with length T_1 and T_2 are added at the ends of feed lines as shown in Fig. 2, to introduce two transmission zeros separately. Two prescribed transmission zeros are located at 5.35 and 5.7 GHz, respectively. The initial value of T_1 and T_2 can be arbitrarily set at $T_1 = 50$ mil and $T_2 = 30$ mil. The S-parameter of the filter is then obtained with the help of the commercial EM simulator Sonnet [10]. Next, the method described in [9] can be used to extract the coupling matrix from the simulated S-parameters. The physical dimensions of the filter are then adjusted according to the extracted coupling matrix to match the prescribed response [11]. After a total of five EM-simulation, matrix extraction, and physical parameter adjusting loops, one can get the simulated results as shown in Fig. 3. The measured results are also shown in Fig. 3 for comparison. The corresponding physical sizes are shown in Fig. 2. The corresponding coupling matrix M is extracted as follows:

$$\begin{bmatrix} 0 & 1.0103 & 0.4275 & 0 & 0 \\ 1.0103 & -0.7811 & 0.8549 & 0 & 0 \\ 0.4275 & 0.8549 & 0.4562 & 1.0258 & 0.2334 \\ 0 & 0 & 1.0258 & -0.3857 & 1.1058 \\ 0 & 0 & 0.2334 & 1.1058 & 0 \end{bmatrix}.$$

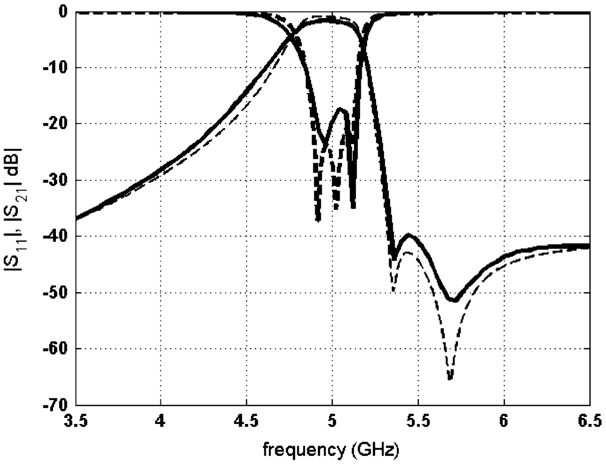

Fig. 3. Simulated and measured responses. Solid line: measured results. Dashed lines: EM simulated results.

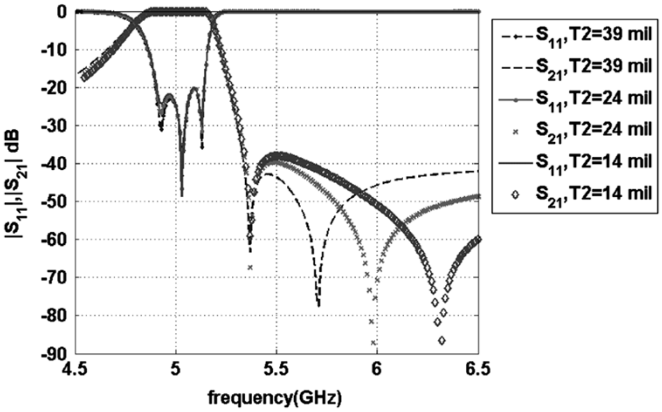

Fig. 4. EM simulated results of three different cases. The dimensions of the simulated filter are the same as these shown in Fig. 2 except $T2$ is set to different values.

It should be emphasized that the filter shown in Fig. 2 has exactly the same layout as the initial design except for two coupling/shielding lines. Therefore, designers can easily realize this filter through trial and error without the use of the matrix extracting procedure.

It is mentioned in Section II, that the introduction of the coupling/shielding lines in this manner can effectively adjust the transmission zeros with slight perturbation of the passband return loss. To demonstrate the merits of easy tuning of the proposed structure, three EM simulations are taken in which the length of the coupling/shielding line $T2$ are set to 14, 24, and 39 mil, respectively, while the other dimensions are the same as those given in Fig. 2. From the EM simulated results shown in Fig. 4, it is obvious that the transmission zero can be tuned over a wide range with negligible change in the passband return loss.

IV. CONCLUSION

We have proposed a modified parallel-coupled-line filter with two independently controllable transmission zeros in the upper stopband. The initial dimensions of the modified filter are similar to conventional ones, thus, the tedious segmentation method is not needed. Trimming the positions and lengths of proposed coupling/shielding lines, two independent transmission zeros can be easily implemented. The systematic method and suitable physical structure makes it possible to efficiently design a filter with proper response.

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