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A New Compact Microstrip Stacked-SIR Bandpass Filter with Transmission Zeros

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***Abstract* – This paper presents a new class of bandpass filters based on a stacked-SIR (stepped impedance resonators) configuration. By stacking multi-coupled SIR's, the longitudinal dimension of the resulting filter is not increased despite the increase of the filter order, so that the area of the whole filter is very compact. The use of SIR's assures that the filters have a wide upper stopband. In addition, with proper tapped input and output couplings, this new bandpass filter structure is capable of generating at least two transmission zeros. Of filters of orders 2 and 4, simulated responses show three transmission zeros in the stopband. Two third-order filters with transmission zeros purposely located at twice the center passband frequency ($2f_0$) are fabricated and measured to demonstrate the design.**

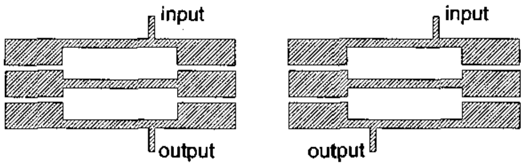
I. INTRODUCTION

In a modern microwave communication system, bandpass filters with the compact size and high selectivity are essential to the RF front end. To enhance the selectivity and stopband rejection of a microwave filter, an intuitive way is to increase the order of the filter, with a tradeoff of increasing the size of the whole circuit. In the classical design with parallel coupled-line filter [1], this problem becomes particularly serious, since the whole circuit consists of a cascade of N+1 quarter-wavelength coupled sections.

Tapped combline filters [2-3], on the other hand, features compact in size and broad stopband performance. Nevertheless, lump or MIM capacitors and via holes or special arrangement for grounding are usually required for designing this type of filters. The tapped couplings to the input and output ports have extra advantages [4-5] in generating two extra independent transmission zeros. In [5], this skill has been fully utilized to design a stepped impedance resonator (SIR) filter with upper stopband being extended to eight times the passband frequency (f_0).

In this paper, we propose a new compact filter structure, which is a stack of multi-coupled SIR's, configured with tapped-line input/output couplings. The whole circuit is implemented in a fully planar microstrip structure, and demonstrates very good reliability and repetition in circuit fabrication. It is found that the transmission zeros of the filter can be accurately predicted using multi-port network analysis, based on the quasi-TEM modal parameters of multiple coupled microstrip lines (MCML's).

The presentation is organized as follows. Section II introduces the structure and design procedure of the filter. Section III describes the analysis of filter based on $2N$-port formulation of MCML's. The analysis provides an efficient way to predict all the transmission zeros of the filter. Section IV shows several simulation responses with different orders and feeding positions for comparison. Section V presents some simulation and measured results.



(a) (b)

Fig.1 Geometries of the proposed third-order bandpass filters using the stacked-SIR configuration with two possible feeding structures. (a) Symmetric feed. (b) Skew-symmetric feed.

II. THE STACKED-SIR FILTER

Fig.1 shows the planar view of a third-order stacked-SIR bandpass filter with two possible feed configurations: one is symmetric feed and the other is skew-symmetric feed [6]. For filter of order two, the central SIR is removed, and for a filter of order more than three, more SIR's are inserted and stacked in vertical direction. Conceptually, the whole structure is close to that of a combline filter, since the midpoints of each SIR have zero voltage at the fundamental

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resonance, and the lower impedance sections of the SIR's play the roles of the capacitors required in a combline filter. However, there are at least three important differences between these two structures and the combline filter. First, perpendicularly stacking the SIR's makes their ends collinear. This arrangement contributes major couplings between adjacent resonators. Second, each SIR has identical capacitance of the open-ended low-impedance section. Third, skew-symmetric feed [6] shown in Fig. 1(b) cannot be implemented in a combline filter. This feed structure can yield three transmission zeros in a folded coupled-line filter.

The design of the filter is based on the procedure given in [2]. First choose a proper impedance ratio of the high-impedance and low-impedance sections. Then adjust the dimension of the SIR to have a correct resonant frequency and a satisfactory rejection level in the stopband. Finally, determine the spacing between each pair of adjacent resonators via their coupling coefficient, which is specified by the g_n values of the low-pass prototype. The coupling coefficient is obtained using the method described in [7].

III. PREDICTION OF THE TRANSMISSION ZEROS

It is known that the tapped-line input and output coupling can create transmission zeros [5]. The zeros are the frequencies at which either of the tapped points at the input and output resonators sees a quarter-wave uncoupled open stub. Here, the two open ends of the input and output SIR's are coupled with adjacent resonators, so that the positions of the zeros cannot be simply determined as above. Furthermore, the design procedure given in the last section is not valid for predicting the zeros in the stopband. Thus, the prediction for the transmission zeros in the stopband needs a further analysis.

The whole filter can be treated as a cascade of several sections of MCMLs, as shown in Fig.2. The $2N$-port impedance matrix for each MCML section can be expressed as:

$$[Z]=-j\begin{bmatrix} Z_A & Z_B \\ Z_B & Z_A \end{bmatrix} \tag{1}$$

where

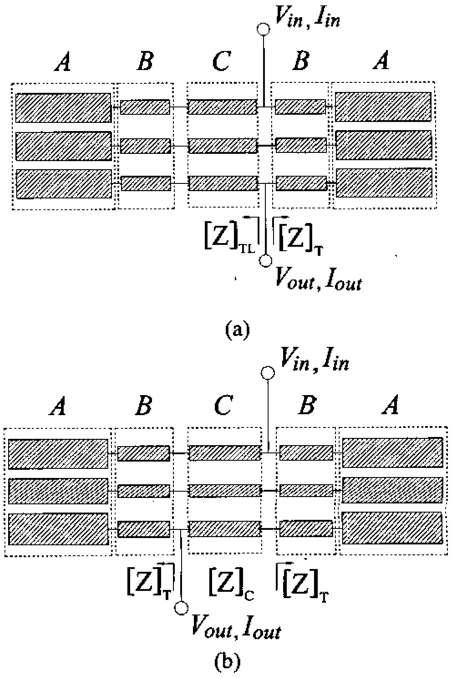
$$Z_A = M_V diag(Z_{0i}\cot\beta_i\ell)M_I^{-1} \tag{2}$$

$$Z_B = M_V diag(Z_{0i}\csc\beta_i\ell)M_I^{-1} \tag{3}$$

In (2) and (3), M_v is the eigen-voltage matrix, M_I the eigen-current matrix, Z_{0i} the characteristic impedance, and β_i the phase constant of mode i of the MCML section.

The cascade of MCML networks is analyzed as follows. Let the input impedance matrix for the cascade of MCML section B followed with the open-circuited section A be $[Z_T]$, which is an $N\times N$ matrix with N the order of the filter. In Fig.2(a), the $[Z_{TL}]$ is the input impedance matrix of MCML section C with load impedance matrix $[Z_T]$. The final two-port impedance matrix can be obtained by imposing proper KVL and KCL conditions at the tapped points. For the case of Fig.2(b), the two-port impedance matrix can be found in a similar fashion.

A Fortran program is developed to perform the above analysis, for efficiently predicting the filter behavior in the stopband. It is important in establishing the relationship between the transmission zeros and the tapped positions at the input and output resonators.



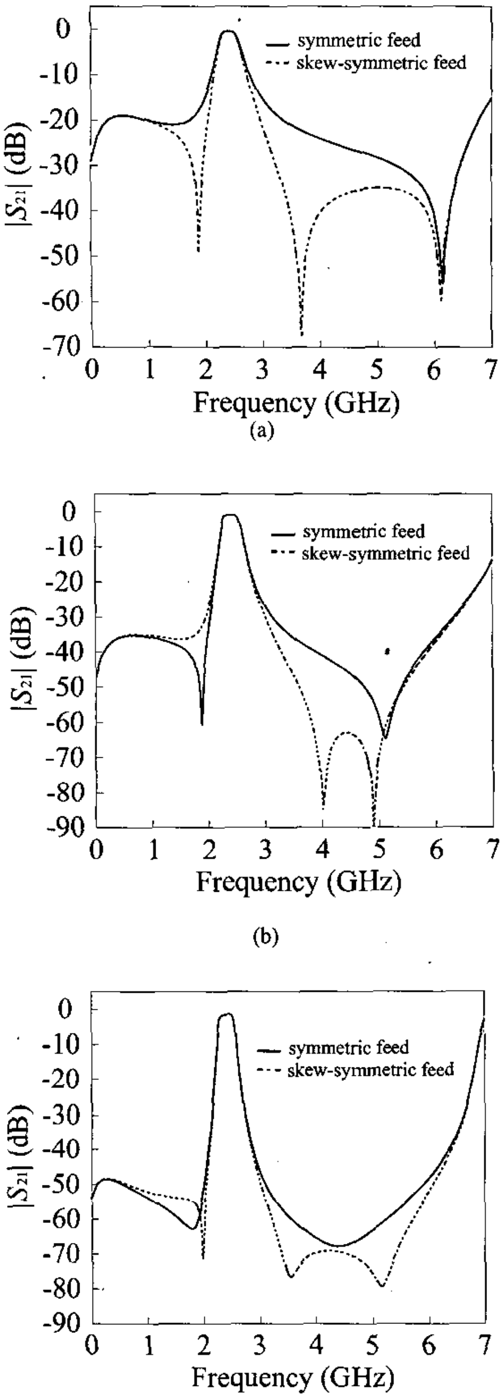
(a)

(b)

Fig.2 Analysis of the filters by network parameters.

IV. THE EXTRA TRANSMISSION ZEROS

Fig.3 plots the simulation responses for three stacked-SIR filters with the two feed structures shown in Fig.1. The responses in Fig. 3(a), for a second-order bandpass filter, have three and one zeros in the stopband for the skew-symmetric and symmetric feeds, respectively. For the responses of a third-order filter shown in Fig. 3(b), both feed structures have two zeros. Both zeros for the skew-symmetric feed are in the upper stopband, while those for the symmetric feed are on both sides of the passband. Fig. 3(c) shows the results for a fourth-order filter. The results for the structure with skew-symmetric feed are similar to that for the second-order filter in Fig. 3(a). It is to be noted that the passband of the filter is unaltered by the feed scheme.



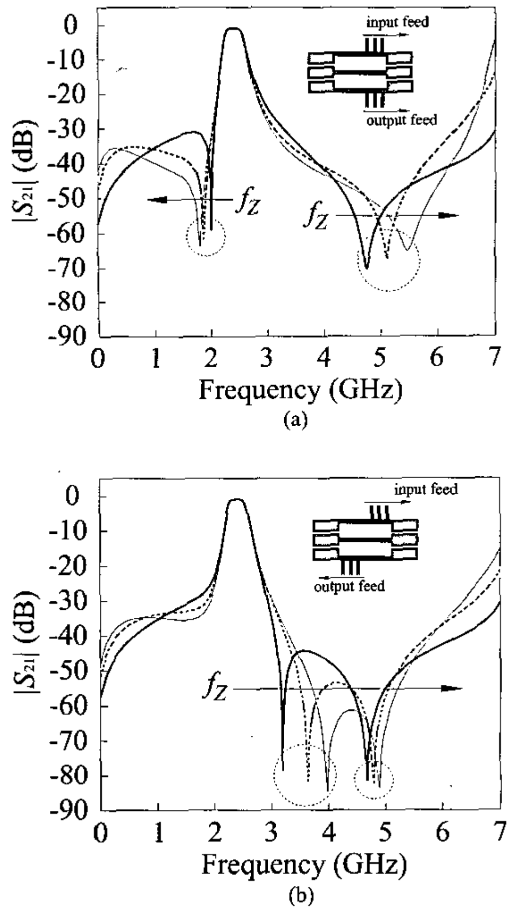
(a)

(b)

(c)

Fig.3 Simulation for three stacked-SIR filters with the two feed structures shown in Fig.1. (a) Second-order filters. (b) Third-order filters. (c) Fourth-order filters.

Fig.4 plots the tuning of the zeros by sliding the tapped positions at the input and output resonators. It indicates that the zeros are tunable as described in [5].



(a)

(b)

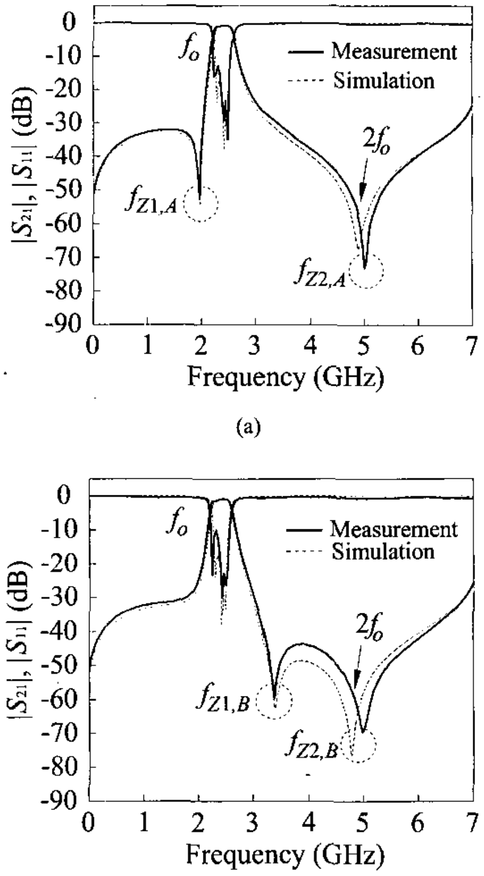
Fig.4 Comparisons of the $|S_{21}|$ simulation responses for the filters of order three with various tapped positions. (a) Symmetric feed. (b) Skew-symmetric feed.

V. SIMULATION AND MEASUREMENT RESULTS

Fig.5 shows the simulation and measurement results for the filters with symmetric feed (filter A) and skew-symmetric feed (filter B). The filters are designed at 2.45GHz to have an order of three, fractional bandwidth of 10%, and ripple level of 0.1dB. The substrate dielectric constant is 2.2 and the thickness is 20mil (0.508mm). Here, the simulated results are obtained by the full-wave simulator IE3D [7]. Fig.5 also marks the positions for the predicted and measured zeros. It can be seen that the simulation and measurement results are in well agreement.

In Fig.5, the zeros are purposely selected to be at near $2f_0$ to enhance the suppression of the spurious harmonic at twice the design frequency. Table I lists the specifications of the designed filters.

The photographs of the proposed filters are shown in Fig. 6. The size of each filter is about 3×0.5 cm^2.



(a)

(b)

Fig.5 The $|S_{21}|$ and $|S_{11}|$ simulation and measurement responses for (a) filter *A* (b) filter *B*.

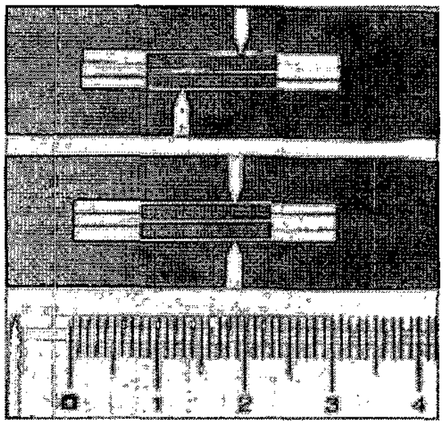


Fig. 6 The photographs of the filters in Fig.5.

TABLE I

THE SPECIFICATIONS AND FREQUENCIES OF THE ZEROS OF THE TWO FABRICATED FILTERS

Filter	f_o GHz	N	Δ	Ripple	Calculation (f_{z1}, f_{z2}) GHz	Measured (f_{z1}, f_{z2}) GHz
A	2.45	3	10%	0.1 dB	(2.00,4.83)	(1.95,5.00)
B	2.45	3	10%	0.1 dB	(3.57,4.88)	(3.35,5.00)

V. CONCLUSION

A new compact microstrip stacked-SIR bandpass filter structure is proposed. This new design provides a miniature circuit design of planar bandpass filter. The tapped-line input and output structures are proved to create transmission zeros in the stopband. The zeros can be accurately predicted by a multi-port network analysis. Two filters with the transmission zeros at $2f_0$ are designed and fabricated to demonstrate the idea of this work. Simulated and measured responses show a very good agreement.

ACKNOWLEDGEMENT

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