A Universal Building Block for Advanced Modular Design of Microwave Filters

Smain Amari, *Member, IEEE*, and Uwe Rosenberg, *Senior Member, IEEE*

***Abstract*—A universal building block for modular design of microwave filters is introduced. The second order block contains two resonators which are not coupled to each other. By adjusting the strengths and signs of its coupling coefficients, the block can be used to design bandpass, bandstop and linear-phase filters. For bandpass filters, Chebychev as well as symmetric and asymmetric pseudo-elliptic responses with one or two finite transmission zeros can be designed. For linear-phase filters, two finite transmission zeros can placed practically anywhere in the complex plane as long as the realizability condition is met. Bandstop filters with no finite reflection zeros as well as symmetric and asymmetric pseudo-elliptic responses with one or two finite reflection zeros can be achieved by the same building block. The block is so flexible it can even generate bandstop responses with complex finite reflection zeros for group delay control. Higher order filters are designed modularly by cascading the appropriate number of building blocks. Coupling matrices of a number of cases are presented to demonstrate the flexibility and the universality of the building block.**

***Index Terms*—Band-pass filters, bandstop filters, Chebychev filters, design, elliptic filters, linear-phase filters, resonator filters, synthesis.**

I. Introduction

MICROWAVE filters are commonly divided into few classes such as bandpass, bandstop or linear-phase filters. Each type contains different responses depending on the location of the transmission and reflection zeros or the shape of the passbands and stopbands. A consequence of this division is the development of different design techniques for the different types of microwave filters.

Bandpass microwave filters of the Chebychev or the Butterworth type are ordinarily designed by directly coupling an appropriate number of resonators [1]. Elliptic filters, which require transmission zeros at finite frequencies, are designed by introducing additional couplings between resonators which are not directly coupled. Self-equalized and linear-phase filters are also designed using the same principle. However, because of the fact that group-delay flattening transmission zeros must occur with definite symmetry in the complex plane, only filters of order four and higher have been reported in the literature.

Bandstop filters are designed using techniques similar to those used to design Chebychev bandpass filters. In this case, bandstop elements are placed an odd multiple of the quarter wavelength apart. Only limited work has been reported on the design of elliptic bandstop filters [2] and [3].

Another issue in microwave filters is the effect of manufacturing errors. Tuning is generally used to compensate for these errors. Another approach is to design the filter modularly so as to minimize the effect of these errors. This can be achieved by focusing on modular designs in which separate building blocks are responsible for generating and controlling specific parts of the response of the filter. Tuning might still be necessary but it is not as lengthy and elaborate for modularly designed filters. A paradigm of this approach is the cascaded doublets (CD), cascaded triplets (CT) and cascaded quadruplets (CQ).

The work reported here was aimed at identifying basic building blocks for modular design of microwave filters with the following features:

- The block yields bandpass, bandstop and linear-phase filters with only minor or no modifications to its topology.
- The block yields Chebychev, pseudo-elliptic and elliptic filters with only minor or no modifications to its topology.
- The block yields both symmetric and asymmetric bandpass and bandstop filters with no modifications to its topology.
- The block should lend itself to easy cascading for the design of less sensitive higher-order filter without severely compromising its characteristics.

Obviously, the building block must be able to generate up to two transmission zeros to be used as a separate group-delay flattening element. A building block, called the modified doublet, is introduced in this paper to address the issues listed above.

II. The Modified Doublet

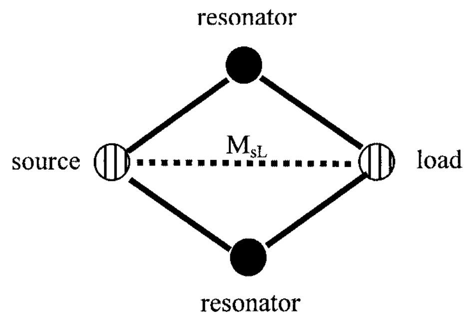

Fig. 1. Coupling and routing scheme of a Modified Doublet (MD).

A Modified Doublet (MD) is a second order structure whose coupling and routing scheme is shown in Fig. 1.

Note that, as in the case of the doublet, the two resonators are not coupled to each other [4]. However, the source and the load

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S. Amari is with the Royal Military College, Kingston, ON, Canada K7K 7B4 (e-mail: smain.amari@rmc.ca).

U. Rosenberg is with the Marconi GmbH, Backnang, Germany (e-mail: Uwe.Rosenberg@ieee.org).

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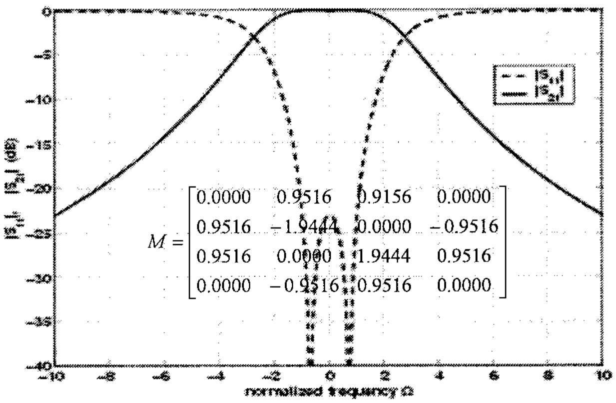

Fig. 2. Response of coupling matrix in the inset. The Chebychev response is evident despite the bypassing of one resonator.

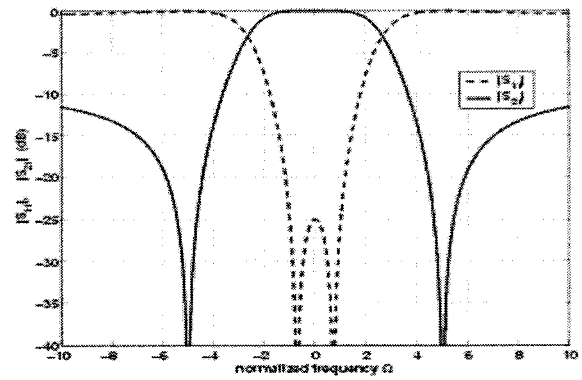

Fig. 3. Response of coupling matrix (1). The two attenuations poles are evident.

are directly coupled in order to be able to generate up to two transmission zeros. This is necessary for group-delay flattening transmission zeros which can appear only with quadrangle symmetry for a lossless network.

For some filtering functions, such as Chebychev bandspass filters, the source-load coupling coefficient ($\mathrm{M_{sL}}$) is eliminated, i.e., the source is decoupled from the load. For all other cases, this coupling coefficient is present.

It may be surprising that this structure, even with the source-load coupling coefficient removed ($\mathrm{M_{sL}} = 0$) can generate a Chebychev bandpass response since one resonator is always bypassed between the source and load. In developing the rigorous algorithm giving the number of finite transmission zeros of a given topology of coupled resonators, it was purposely emphasized that the algorithm gives the ***maximum*** number and that fewer zeros may be generated if the coupling coefficients are of mixed signs [5]. It will be shown that the Modified Doublet (MD) is such a structure. The three different types of filters, bandpass, bandstop and linear-phase are examined and synthesized separately using the general synthesis technique in [6].

To design higher order filters, the building block can be cascaded with special nodes placed between the different blocks [7].

III. Bandpass Filters

We first carry out the synthesis of bandpass Chebychev and pseudo-elliptic filters with attenuation poles at finite frequencies.

A. Second Order Bandpass Chebychev Filter

It can be rigorously shown that if the source is directly coupled to the load in Fig. 1, i.e., if $\mathrm{M_{sL}} \neq 0$, two transmission zeros are generated. We therefore seek a Chebychev bandpass filter with an in-band return loss of 25 dB in which the source is not directly coupled to the load ($\mathrm{M_{sL}} = 0$). The application of the synthesis technique in [6] yields the following coupling matrix given in the inset of Fig. 2.

The response of this coupling matrix is shown in Fig. 2. It is evident that the Chebychev response is achieved. The response obtained from a second order Chebychev polynomials is also plotted simultaneously to confirm the absence of transmission zeros at finite frequencies. The two curves agree within plotting accuracy and are not distinguishable.

B. Second Order Bandpass Filter With One Transmission Zero

To generate one transmission zero (at a finite frequency) in the previous coupling scheme, we still need to decouple the source and the load, i.e., $\mathrm{M_{sL}} = 0$. In this case, the Modified Doublet (MD) reduces to the doublet introduced in [4]. Since this case has been investigated in [4], including measured results, it is not examined here any further to save space.

C. Bandpass Filter With Two Transmission Zeros

To generate two transmission zeros at finite frequencies using the coupling scheme in Fig. 1, we need to couple the source to the load. As a specific example, we extract a coupling matrix to yield an in-band return loss of 25 dB and attenuation poles at normalized frequencies $\Omega = -5$ and $\Omega = 5$. The result is

$$M = \begin{bmatrix} 0.0000 & 0.9107 & 0.9107 & -0.1756 \\ 0.9107 & -2.1550 & 0.0000 & -0.9107 \\ 0.9107 & 0.0000 & 2.1550 & 0.9107 \\ -0.1756 & -0.9107 & 0.9107 & 0.0000 \end{bmatrix}. \quad (1)$$

The response of this coupling matrix is shown in Fig. 3 where it is clear that all the specifications are met.

IV. Bandstop Filters

We now examine the synthesis of second order bandstop (band-reject) filters using the coupling scheme in Fig. 1

A. Second Order Bandstop Filter With no Finite Reflection Zeos

To design a second order bandstop filter we need to generate two attenuation poles in the stopband which is taken to extend from $\Omega = -1$ to $\Omega = 1$. We assume that the minimum attenuation in the stopband is 25 dB. The two reflection zeros of this second order block must be moved to infinity. It can be readily verified that the coupling matrix given in the inset in Fig. 4 yields the desired response. The response of this coupling matrix is shown in Fig. 4. It is interesting to note that the insertion

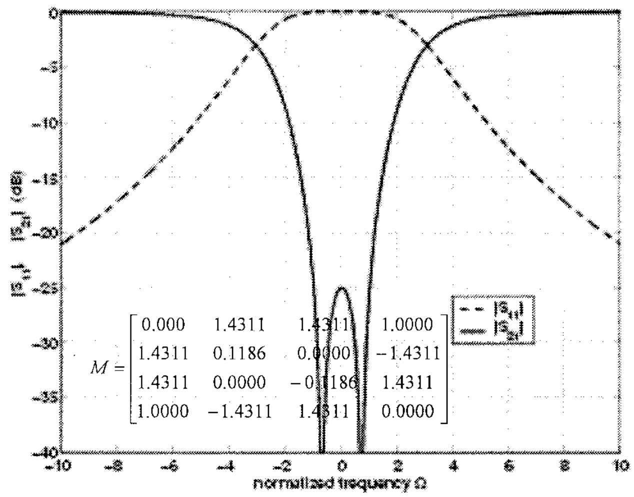

Fig. 4. Response of coupling matrix in inset. The return loss of this bandstop filter is identical to the insertion loss of the bandpass filter in Fig. 2 and vice versa.

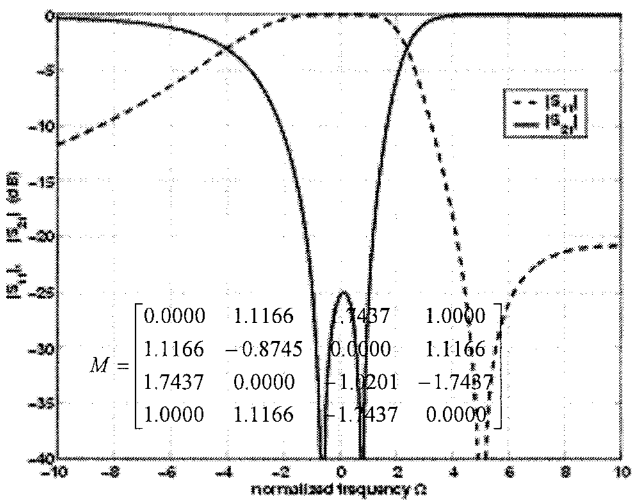

Fig. 5. Response of bandstop filter with one finite reflection zero. The coupling matrix is given in the inset.

loss in Fig. 4 is identical to the return loss of the bandpass filter in Fig. 2.

B. Bandstop Filter With One Reflection Zero

The next example is a second order bandstop filter with a reflection zero at normalized frequency $\Omega = 5$ and an in-band attenuation of 25 dB. The coupling matrix given in the inset in Fig. 5 satisfies all these requirements.

C. Bandstop Filter With Two Reflection Zeros

This example is a bandstop filter with two reflection zeros at $\Omega = \pm 5$ and a minimum of attenuation of 25 dB in the stopband. The response in Fig. 6, which satisfies all these requirements, is obtained from the coupling matrix given in the inset of the same figure.

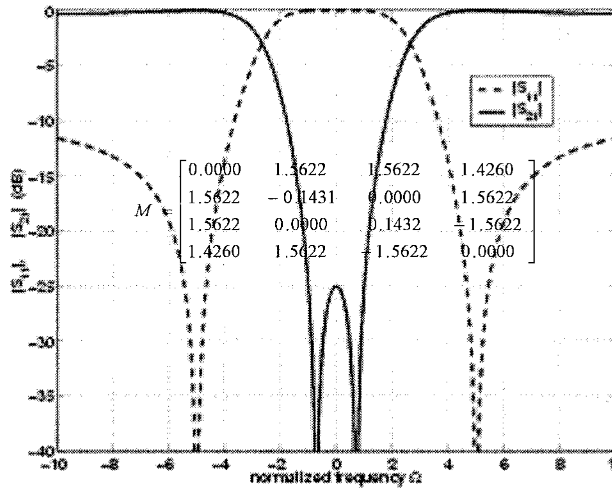

Fig. 6. Response of an elliptic bandstop filter. The coupling matrix is given in the inset.

V. Filter With Real Transmission Zero

We finally give a coupling matrix to reproduce a second order response with two transmission zeros located at $\Omega = -2.2j$ and $\Omega = 2.2j$ and an in-band return loss of 20 dB. The response of this matrix is not given for lack of space.

$$M = \begin{bmatrix} 0.0000 & 1.1337 & 1.1337 & 0.5654 \\ 1.1337 & 1.7015 & 0.0000 & 1.1337 \\ 1.1337 & 0.0000 & -1.7015 & 1.1337 \\ 0.5654 & 1.1337 & 1.1337 & 0.0000 \end{bmatrix}. \quad (2)$$

VI. Conclusions

A new versatile building block for modular design or microwave filters was introduced. The second order block generates bandpass, bandstop, and linear phase filters with no, one, or two transmission (reflection) zeros at finite frequencies.

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