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Novel Broadside Trisection Filters Employing Nonresonating Nodes

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Abstract— **This work presents novel filter topologies implemented in microstrip technology. The topologies combine printed line resonators with non resonating nodes (NRN) to implement transmission zeros in a very flexible way. Depending on the number of resonators and NRN, the filtering response exhibits a single transmission zero either below or above the passband, or two transmission zeros, one at each side of the passband. Several examples are designed and validated, using the new proposed structures.**

I. INTRODUCTION

The development of novel structures to implement bandpass microwave filters with enhanced characteristics, represents an important issue to modern communication systems.

Useful topologies to implement microwave filters can be derived from the combination of the so-called basic *trisection* building block [1]. This building block consists of three coupled resonators, and it is able to implement a single transmission zero. An important characteristic of this topology is that several trisections can be cascaded in order to implement higher order filtering structures [2],[3]. The synthesis procedure of this kind of structures has been deeply studied. It can be carried out by a method based on the extraction of circuit elements [1], or alternatively by a method based on similarity transformations applied to the generalized coupling matrix [4]. On the other hand, several waveguide structures implementing the trisection, or more complex topologies formed by cascading several trisections, have been introduced in different contributions [5].

Typically, a trisection is formed by coupling together three resonators. However, internal non resonating nodes (NRN) can also be included in the filter topology. The use of NRN increases the flexibility, and allows to better control the position of the transmission zeros implemented by a specific filtering structure. An example can be found in [6],[7], where out-of-tune resonators inside the passband are used to implement transmission zeros.

This contribution is focused on the development of new bandpass microwave filters combining different topologies using the trisection block (see Fig. 1). One novel aspect of the work is the combination of the trisection topology with NRNs, as shown in Fig. 1. Also, by changing the position of resonators and NRNs, different useful characteristics can be obtained (see parts (b) and (c) of Fig. 1). Finally, by combining a single trisection with an internal NRN (Fig. 1(e)), an interesting filter topology with two transmission zeros is obtained. The filters are designed in compact microstrip technology. In order to implement the required coupling routings of these topologies, side couplings are combined with broadside couplings for maximum flexibility.

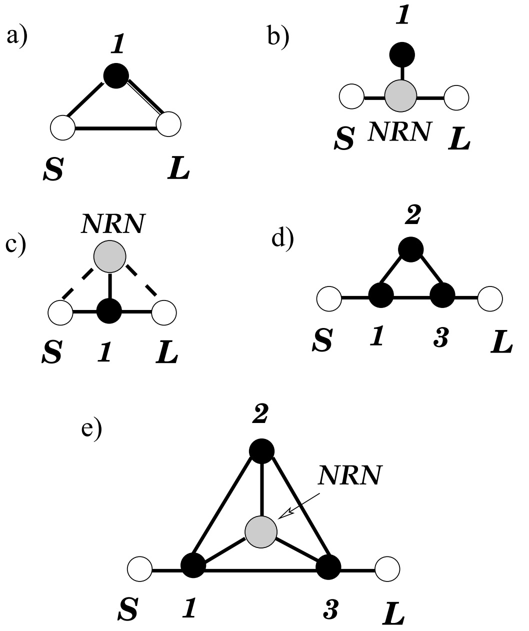

Fig. 1. Coupling schemes. a) Singlet (see [6]). b,c) First order blocks using a NRN. d) Third degree trisection. e) Trisection with an internal NRN.

Furthermore, the different possibilities to implement transmission zeros in these topologies are discussed. This will include the implementation of one transmission zero placed below or above the passband, and of two transmission zeros on both sides of the passband.

II. THEORY AND RESULTS

The basic structure under study is sketched in Fig. 2. This structure, shielded by a metallic enclosure, is composed of several metallic lines printed on two dielectric layers (interfaces C_1 and C_2).

The most simple configuration using a trisection block is the topology known as singlet. The singlet was first explored in [6]. The topology of this block, which is a first order

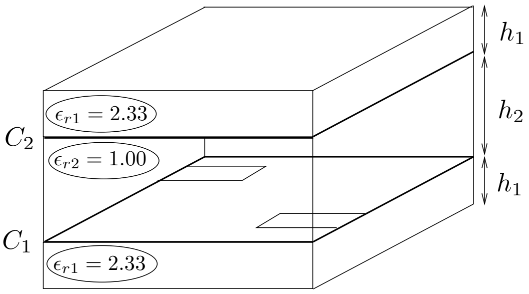

Fig. 2. Structure used to design the filters with the coupling schemes shown in Fig. 1. C_1 and C_2 are the interfaces where microstrip lines are printed. The width of the input/output ports, as well as the width of the printed microstrip lines in the interfaces C_1 and C_2, will be fixed to 1.49 mm. Also $h_1 = 0.51$ mm throughout the paper.

fully canonical transversal filter, is shown in Fig. 1(a). Its coupling matrix can directly be obtained with the synthesis technique presented in [8]. This configuration presents a single transmission zero, which can be placed below or above the passband depending on the coupling signs between the nodes of the structure.

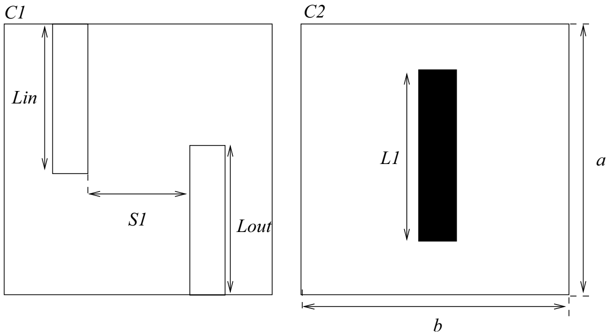

Fig. 3. Proposed configuration of layers $C1$ and $C2$ to implement the scheme (a) of Fig. 1. Dimensions: $a = 32$ mm, $b = 16$ mm, $S_1 = 0.06$ mm, $L_{in} = L_{out} = 17$ mm, and $L_1 = 23.994$ mm, $h_2 = 2.2$ mm in Fig. 2.

As it was stated in [6], a coupling matrix with all the couplings terms positive will produce a filtering response with a transmission zero placed above the passband. This is the situation of the broadside coupled structure with the printed lines configuration shown in Fig. 3. In this structure both the direct coupling between the ports and the broadside couplings to the resonator are positive. Consequently, only a transmission zero above the passband can be implemented using this structure. By way of illustration, a first order filter with a bandwidth of 10 MHz centered at 4.4 GHz has been designed. The minimum in-band return loss is 10 dB, and the transmission zero is located above the passband, at 4.57 GHz. The synthesis procedure of [8] leads to the following coupling matrix:

$$M = \begin{pmatrix} 0 & 1.2197 & 0.0491 \\ 1.2197 & -0.1793 & 1.2197 \\ 0.0491 & 1.2197 & 0 \end{pmatrix} \quad (1)$$

Fig. 4 shows the frequency response of the broadside structure, designed according to the previous coupling matrix. The whole filter has been analyzed using a full wave spectral domain integral equation technique, presented in [9]. The dimensions and the designed structure are collected in the caption of Fig. 3. For comparison, in Fig. 4 the results obtained with the above coupling matrix are also presented, showing good agreement with respect to the response of the broadside coupled structure.

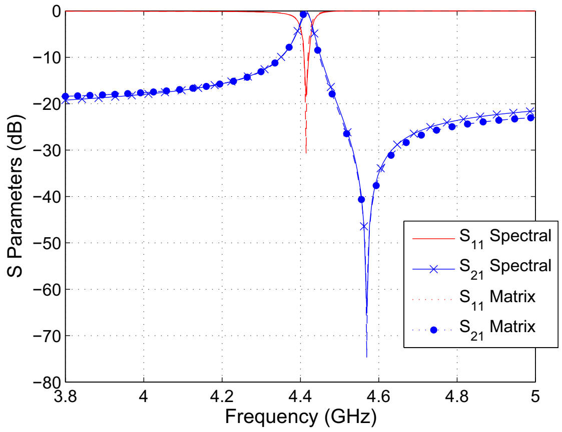

Fig. 4. S-parameters of the filter with the configuration shown in Fig. 3.

Apparently, it is not possible to place a transmission zero below the passband using the simple microstrip topology of Fig. 2. This is because the synthesis of the transversal coupling matrix indicates that a negative coupling would be required, whereas the coupling coefficients in the proposed microstrip structure are all positive. Nevertheless, a spurious response below the passband can be used for this purpose, as it was pointed out in [10]. This spurious response can also be viewed as a NRN, since it can be implemented by a resonator which is resonating at a frequency far from the passband.

The simplest topology with one NRN and only one resonator is the topology sketched in Fig. 1(b). To implement this topology with the proposed two-layer structure, a microstrip line with a resonant frequency smaller than the working frequency can be added to the interface C_1 of Fig. 2. In this new structure the resonator is still placed at the interface C_2. We have verified that this structure indeed produces a transmission zero below the passband. However, the coupling to the NRN is always larger than the coupling to the resonator. Consequently, in practice only narrow bandpass filters can be designed with this topology. For this reason, a more convenient topology is the one shown in Fig. 1(c), where the resonator and the NRN are swapped together. This topology can be easily designed with the configuration sketched in Fig. 5, where the black printed line represents the resonator and the longer grey line acts as NRN. Note that the coupling between the input/output ports and the NRN has been maintained (dashed lines in Fig. 1(c)). This is to point out that this coupling is nonzero despite that it is going to be small as compared to the coupling between the input/output ports and the resonator.

Using this broadside coupled structure, together with the idea of spurious resonances introduced in [10], it is possible to

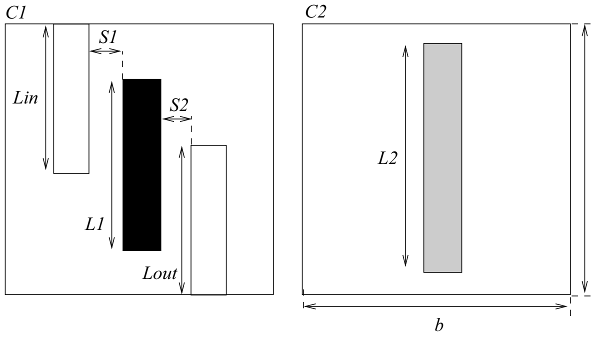

Fig. 5. Proposed configuration of layers $C1$ and $C2$ to implement the scheme (c) of Fig. 1. Dimensions: $a = 32$ mm, $b = 16$ mm, $S_1 = S_2 = 0.505$ mm, $L_{in} = L_{out} = 15$ mm, $L_1 = 23.994$ mm, and $L_2 = 27$ mm, $h_2 = 3.06$ mm in Fig. 2.

implement a transmission zero below the passband. By way of illustration, a practical example with a bandwidth of 40 MHz centered at 4.41 GHz has been designed. The transmission zero will be placed at 4 GHz. By an optimization technique prepared to handle NRNs (see [11]), the following coupling matrix can be obtained:

$$M = \begin{pmatrix} 0 & 0.9000 & 0.0046 & 0 \\ 0.9000 & 1.3000 & 0.0350 & 0.9000 \\ 0.0046 & 0.0350 & 0.0009 & 0.0046 \\ 0 & 0.9000 & 0.0046 & 0 \end{pmatrix} \qquad (2)$$

In this case, node 2 (third column in the previous coupling matrix) is the NRN. We can confirm in this matrix that the coupling from the ports to the NRN is of only 0.0046, smaller than the coupling from the ports to the resonator (which is 0.9). Fig. 6 shows the frequency response of the broadside coupled structure with the printed microstrip lines configuration of Fig. 5. In the same graphic we also present the response of the optimized coupling matrix for comparison purposes.

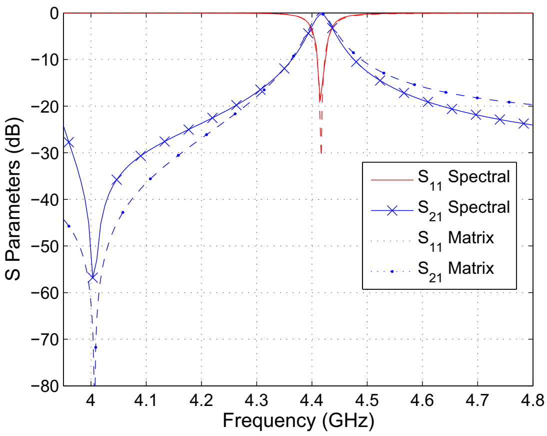

Fig. 6. S-parameters of the filter with the configuration shown in Fig. 5.

The next example to be designed consists in a typical trisection (topology shown in Fig. 1(d)). It is well known that a single trisection block implements only one transmission zero, in a third order filter. For the practical design, the bandwidth is 65 MHz centered at 4.4 GHz. The minimum in-band return loss is 13 dB, and the transmission zero is located above the passband, at 4.5 GHz. The synthesis procedure of [4] leads to the following coupling matrix:

$$M = \begin{pmatrix} 0 & 0.8895 & 0 & 0 & 0 \\ 0.8895 & 0.0472 & 0.8050 & 0.2254 & 0 \\ 0 & 0.8050 & -0.2583 & 0.8050 & 0 \\ 0 & 0.2254 & 0.8050 & 0.0472 & 0.8895 \\ 0 & 0 & 0 & 0.8895 & 0 \end{pmatrix} \qquad (3)$$

The proposed layout to implement this coupling matrix with our broadside coupled structure is shown in Fig. 7. To easily implement the coupling routing, the second resonator is placed at the interface C_2, and it is broadside coupled to the other resonators. Note that it is possible to implement the frequency response of this matrix with the proposed configuration, because all the coupling coefficients are positive. On the other hand, with the configuration shown in Fig. 7 it is not possible to implement a transmission zero below the passband. This is because a negative coupling coefficient is necessary, and it cannot be implemented employing this layout.

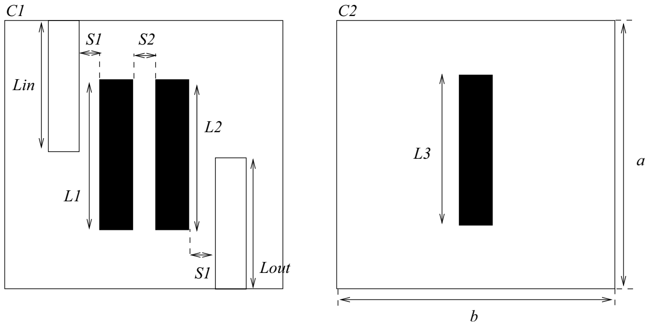

Fig. 7. Proposed configuration of layers $C1$ and $C2$ to implement the scheme (d) of Fig. 1. Dimensions: $a = 32$ mm, $b = 16$ mm, $S_1 = 0.25$ mm, $S_2 = 4.7$ mm, $L_{in} = L_{out} = 15$ mm, $L_1 = L_2 = 23.99$ mm, and $L_3 = 23.96$ mm, $h_2 = 3.06$ mm in Fig. 2.

The response of the designed filter employing the microstrip configuration shown in Fig. 7 agrees with the predicted behavior of the coupling matrix (Fig. 8). The results obtained with the ADS© software tool are also included for validation.

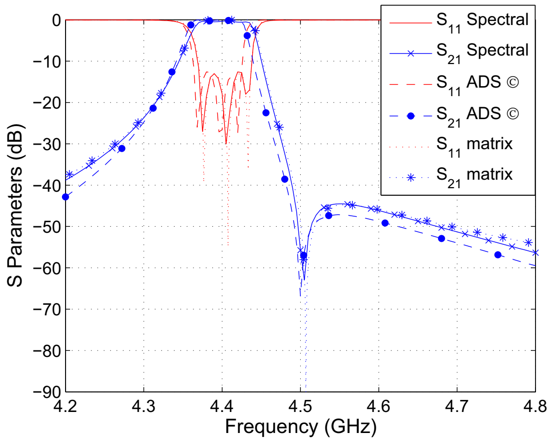

Fig. 8. S-parameters of the filter with the configuration shown in Fig. 7.

Note that by combining the above ideas, it is possible to implement a more advanced filter structure. The strategy is to combine the trisection block with positive couplings, with a NRN to produce a transmission zero based on the spurious resonance concept [7]. First, a first order design with one transmission zero placed below the passband was implemented by using one NRN (Fig. 1(c)). Second, a trisection block was designed to produce one transmission zero placed above the passband (Fig. 1 (d)). Now, an innovative topology is introduced, where both previous ideas are combined in order to implement a third order filter with two transmission zeros, one at each side of the passband. This topology is sketched in Fig. 1(e). Furthermore, we can easily implement this topology using our broadside coupled structure, since all the couplings of the trisection are positive. The basic layout is shown in Fig. 9. Again, the grey printed line represents the NRN.

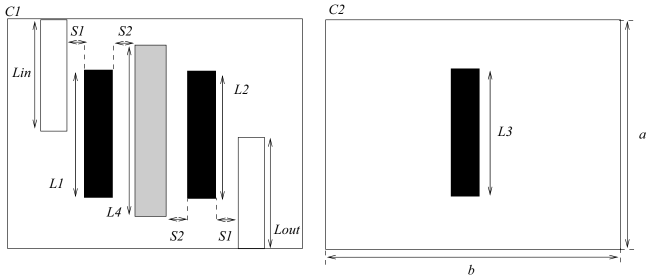

Fig. 9. Proposed configuration of layers $C1$ and $C2$ to implement the scheme (e) of Fig. 1. Dimensions: $a = 32$ mm, $b = 16$ mm, $S_1 = 0.25$ mm, $S_2 = 1.005$ mm, $L_{in} = L_{out} = 15$ mm, $L_1 = L_2 = 23.99$ mm, $L_3 = 23.994$ mm and $L_4 = 27.4$ mm. $h_2 = 3.06$ mm in Fig. 2

We can observe that the structure is similar than the trisection. The difference is that we have now included an NRN between the two resonators in the C_1 interface. The NRN is tuned for a resonant frequency below the passband. This will cause the appearance of a transmission zero below the passband following the spurious resonance concept. Note that it would be impossible to implement two transmission zeros, one at each side of the passband, with the single trisection topology previously presented. However, this is possible thanks to the combination of the NRN with the trisection.

The response of this last filter is shown in Fig. 10. Again, results obtained with the ADS© software tool are included to further validate the proposed filter configuration.

III. CONCLUSIONS

Novel broadside coupled filter structures employing both resonating and NRNs have been introduced. Depending on the number of nodes and the nodes arrangement, filters with a single transmission zero either below or above the passband can be designed. A new filter topology has been introduced by combining for the first time a trisection block with a NRN to implement two transmission zeros on both sides of the passband. The usefulness of the new proposals has been confirmed by means of several practical design examples, obtaining good results.

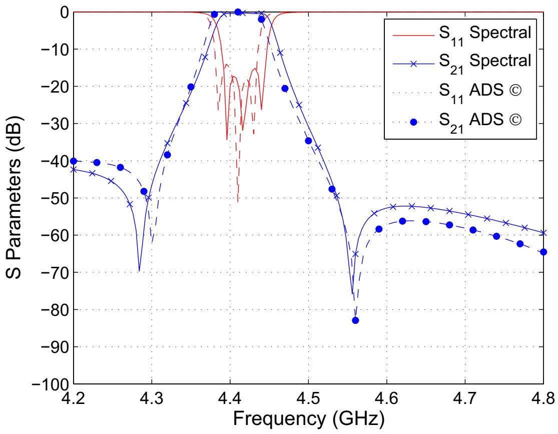

Fig. 10. S-parameters of the filter with the configuration shown in Fig. 9.

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