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Novel Implementations for Microstrip Resonator Filters in Transversal Topology

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Abstract— **This paper presents novel implementations of bandpass filters in multilayered microstrip technology. The structures presented implement transversal filter topologies of order three. In order to allow for easy implementation of the required couplings, multilayered broadside configurations are proposed. We demonstrate that with the proposed configurations, both dualband and quasi-elliptic responses can be easily synthesized, by only changing the sign of certain entries in the coupling matrix. To easily adjust the signs of the couplings, novel resonators are proposed, including simple half-wavelength transmission line resonators, meander line resonators and short-circuited resonators. Experimental validation for one prototype is presented, demonstrating the validity and usefulness of the proposed configurations.**

I. INTRODUCTION

The interest in the development of new filter configurations with enhanced performances is motivated by the deployment of new communication systems with increased bandwidth allocations. One of the important issues that must be taken into consideration for new applications, is the selectivity of the filter, and the ability to reject unwanted spurious signals that may interfere in the crowded electromagnetic spectrum. Also, the increasing difficulties in the selection of communication channels, has fostered research in new multiband filters [1].

One important research line for filter design in the last years has been the development of transversal coupling topologies. This has been motivated by the availability of an exact synthesis technique of the generalized coupling matrix, after the work presented in [2]. In this topology, the input/output ports are coupled to all of the resonators of the filter, while all inter-resonator couplings are zero. One of the advantages of this topology is that it provides high flexibility to place a maximum number of transmission zeros in the insertion loss response of the filter. A wide class of frequency responses can be synthesized, ranging from multiband to quasi-elliptic responses. Normally, all these frequency responses can be easily implemented by adjusting the signs of certain elements of the coupling matrix.

On the contrary, a big disadvantage of the pure transversal topology, is that it is difficult to implement in practice many coupling paths from the input/output ports to all the resonators of the structure, still maintaining all other inter-resonator couplings to zero. Due to these difficulties, practical transversal implementations have been limited up to now to simple structures of order two [3].

In this contribution we propose novel microtrip filters implementing the pure transversal coupling topology. For the first time, third order transversal filters are implemented using printed resonators. To increase the number of coupling paths from the input/output ports to the resonators, broadside couplings are used in multilayer arrangements. To easily adjust the signs of the couplings, three different compact printed resonators are combined in the transversal filters, namely basic half wavelength printed line resonators, meander line resonators and central short-circuited stubs. We show that by combining appropriately all these types of resonators, several useful transfer functions can be effectively implemented. In this work we will show as an example the design of a multiband transversal filter and of a quasi-elliptic filter. Measured results of one prototype are presented to show the validity of the new structures.

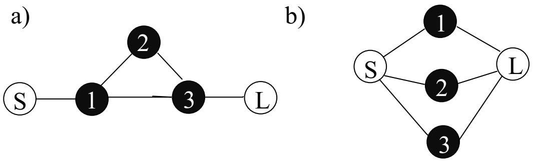

Fig. 1. Coupling schemes. (a) Single trisection. (b) Transversal third order topology.

II. NOVEL MICROSTRIP TOPOLOGIES

The coupling and routing scheme of the third-order transversal filter, that will be designed in this paper, is shown in Fig. 1(b). The dark circles represent resonators, the source and the load are shown as empty circles, and the solid lines represent coupling between nodes. For comparison, in Fig. 1(a) we present a typical topology of a third order filter containing one trisection [4]. As it can be seen, in the transversal topology all resonators are directly coupled to the input/output ports, while all other inter-resonator couplings are zero. The purpose of this section is to introduce new microstrip structures to implement this transversal coupling scheme.

The first step in the design process of a filter is the calculation of the coupling matrix that synthesizes the desired frequency response. It should be noted that for the topologies presented in Fig. 1(b), a maximum of two transmission zeros at finite frequencies can be implemented. This can be inferred by the application of the minimum path rule [2]. For the pure transversal topology shown in Fig. 1(b), the coupling matrix can be easily calculated using the procedure presented in [2]. For multiband frequency responses, the procedure described in [5] can instead be used.

Once the coupling matrix has been computed, the next step is to synthesize the required couplings with a suitable topology [6]. In the next subsections we present several examples using novel microstrip structures. These structures contain different kind of printed line resonators, and side-couplings are combined with broad-side couplings, when necessary, to provide for the required coupling paths. Two strategies are used to adjust the sign of the couplings. The first is to use oversized resonators (meander line resonators) working at higher order resonances. The second is to use short-circuited or open-ended terminations, as appropriate, to adjust the corresponding signs.

A. Transversal filter with dual-band operation and two transmission zeros

The first example corresponds to a pure transversal topology as shown in Fig. 1(b), implementing a dual bandpass response. This topology can implement up to two transmission zeros at finite frequencies. By adjusting the signs of the couplings, different responses can be obtained, ranging from quasi-elliptic responses to dual-band responses. In the case of a dual band response, a transmission zero can be placed in-between the two passbands to increase rejection. The other transmission zero can be used to increase rejection at the other side of one of the passbands.

For the synthesis of the coupling matrix, the technique presented in [5], for dual-band transfer functions, has been used. The filter contains two bands, with a total bandwidth of 30 MHz (lower passband) and 100 MHz (upper passband), and return loss of 15 dB. The coupling matrix obtained using the procedure described in [2], [5] is the following:

$$M_A = \begin{pmatrix} 0 & -0.357 & 0.421 & -0.563 & 0 \\ -0.357 & 1.596 & 0 & 0 & 0.357 \\ 0.421 & 0 & -1.099 & 0 & 0.421 \\ -0.563 & 0 & 0 & 0.098 & 0.563 \\ 0 & 0.357 & 0.421 & 0.563 & 0 \end{pmatrix} \tag{1}$$

For the practical implementation of this filter we select a microstrip structure with two dielectric substrates broadside coupled, as shown in Fig. 2. In the first substrate we print two resonators, together with the input/output lines. In the substrate on top we print the remaining resonator. In this way we can obtain a pure transversal topology of order three, with a very compact microstrip structure. We can observe in the (M_A) coupling matrix (1), that the couplings of two resonators change in sign from the input to the output port. This can be obtained by using simple ($\lambda/2$) printed line resonators. On the contrary, the signs of the couplings for the third resonator must be the same. To avoid the sign change, a printed line resonator can be operated at the (λ) resonance. This can be done easily by introducing a meander line resonator, as shown in Fig. 3.

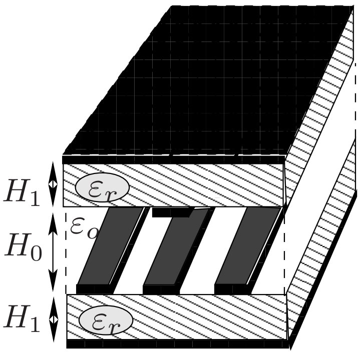

Fig. 2. 3D-view of the proposed filter containing two broadside coupled dielectric substrates.

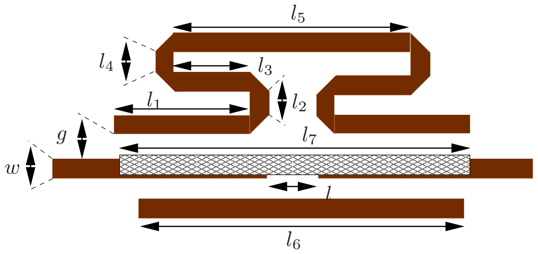

Fig. 3. Layout of a third order transversal microstrip filter, implementing the coupling scheme of Fig. 1(b).

In Fig. 3 we show the basic topology used for the implementation of the filter in microstrip technology. The dotted resonator is broadside coupled to the input/output ports. To do this, the resonator is printed in the dielectric placed on top.

The planar structure shown in Fig. 2 and Fig. 3 can be analyzed with the commercial software Agilent-ADS©. In Fig. 4 we present the results obtained from the analysis of the (M_A) coupling matrix, together with the results obtained from the analysis of the multilayered structure, after the design process. The dimensions obtained for this topology are shown in Table I. We can observe very good agreement between the two responses.

TABLE I
DIMENSIONS OF THE DESIGNED DUAL-BANDPASS FILTER SHOWN IN FIG. 3.

Dimension	**Value (in mm.)**	**Dimension**	**Value (in mm.)**
w	1.85	l_1	20.8
g	0.3	l_2	1.5
H_0	5.0	l_3	13.2
H_1	1.27	l_4	1.5
ε_r	6.15	l_5	26.0
$L_{in} = L_{out}$	30.0	l_6	51
l	5.0	l_7	54

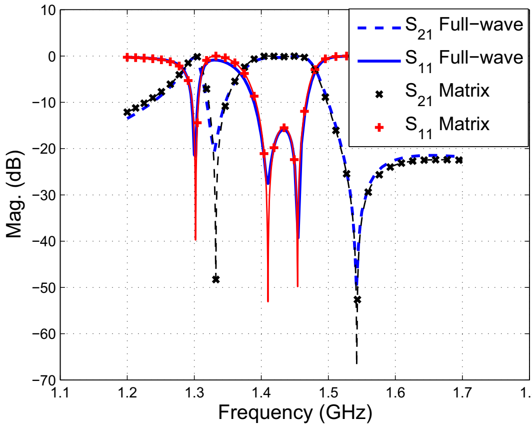

Fig. 4. Fullwave simulations and coupling matrix response for the dual bandpass filter shown in Fig. 3.

B. *Transversal filter with pseudo-elliptic frequency response*

It is interesting to observe that the same configuration as introduced in the previous subsection can also be used to synthesize a single-band transfer function with quasi-elliptic response. Two transmission zeros can be placed on both sides of the passband for maximum selectivity, by changing the sign of one of the couplings.

To illustrate the concept, we now design a single-bandpass filter with quasi-elliptic response and a bandwidth of 110 MHz. The two transmission zeros are located at 1348 MHz and 1504 MHz, and the ripple level is 15 dB. Since the topology corresponds to a transversal filter of order three, the synthesis procedure reported in [2] can be directly used to obtain the coupling matrix:

$$M_B = \begin{pmatrix} 0 & 0.352 & 0.421 & -0.756 & 0 \\ 0.352 & 1.190 & 0 & 0 & 0.352 \\ 0.421 & 0 & -1.099 & 0 & 0.421 \\ -0.756 & 0 & 0 & 0.130 & 0.760 \\ 0 & 0.352 & 0.421 & 0.756 & 0 \end{pmatrix} \tag{2}$$

We can see that the coupling matrix is very similar to the (M_A) matrix previously computed. Only one of the resonators changes the sign of the coupling to the input port (compare second column of matrices M_B and M_A). Also, the third resonator has to be adjusted (in coupling and length) to recover the desired response (see fourth column of the matrix).

Note that the additional sign change can be implemented in one of the $(\lambda/2)$ resonators, by placing a short-circuit in the central point of the line. This short-circuit will force an even symmetry of the electric field in the resonator, so the sign will not change anymore from input to the output port. In this way we can easily implement the same sign for the coupling elements $M_{S1} = M_{L1} = 0.352$. In Fig. 5 it is shown the new layout for the proposed microstrip configuration.

Again, the dotted resonator is printed on the layer on top. The only modification of this structure with respect to the layout presented in Fig. 3, is the via-hole introduced at the central point of this resonator, used to implement the required short-circuit. Also, the other $(\lambda/2)$ resonator has been adjusted by slightly shortening its length. It is important to point out that the meander resonator has not been changed, as indicated by the third column of matrix (M_B), which is identical to the matrix (M_A). The final dimensions for this filter are given in Table II.

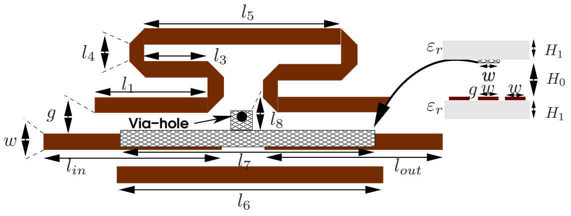

Fig. 5. Layout of the third order transversal filter with quasi-elliptic response. The sign of one coupling is changed by introducing a short-circuit in the central point of one resonator.

TABLE II

DIMENSIONS OF THE DESIGNED PSEUDOELLIPTIC FILTER SHOWN IN FIG. 5.

Dimension	Value (in mm.)	Dimension	Value (in mm.)
w	1.85	l_2	1.5
g	0.3	l_3	13.2
H_0	2.0	l_4	1.5
ε_r	6.15	l_5	26.0
$L_{in} = L_{out}$	30.0	l_6	49.6
l	5.0	l_7	45.4
l_1	20.8	l_8	1.5

In Fig. 6 we present the results obtained from the analysis of the (M_B) coupling matrix (2), together with full wave simulations of the structure shown in Fig. 5.

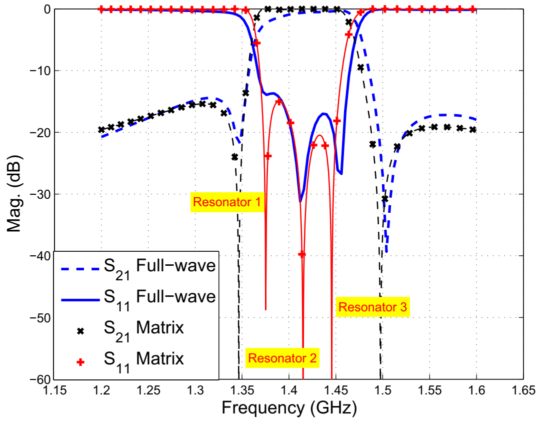

Fig. 6. Fullwave simulation and coupling matrix response of the pseudo-elliptic transversal filter shown in Fig. 5.

We can observe good agreement between both responses. Only at the beginning of the passband, the full-wave simulation shows a slight deviation. It is believed that this is due to a spurious radiation of the via-hole at these frequencies.

III. Results and experimental implementation

For a practical validation of the filter designs presented in this paper, several prototypes have been manufactured and tested in microstrip technology. In this contribution we will report the results obtained for the dual-bandpass filter. The basic layout of the fabricated filter is shown in Fig. 3. The substrate selected for manufacturing is an RT-Duroid/6006, with a relative permittivity $\varepsilon_r = 6.15$, and thickness $H_1 = 1.27$ mm.

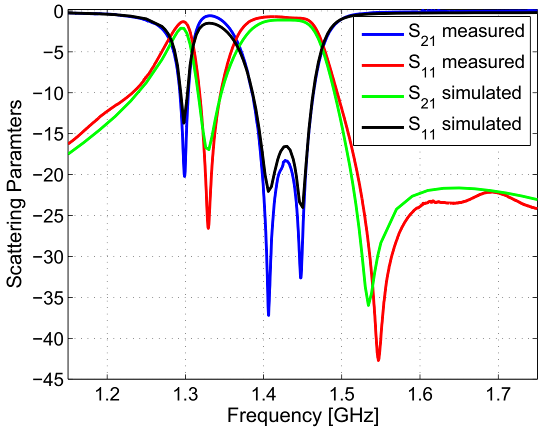

Fig. 7. Comparison between simulated results and measured results for the filter shown in Fig. 3.

In Fig. 7 we present the results obtained for the filter shown in Fig. 3, when losses are included in the simulations. Both, dielectric losses ($tan(\delta) = 0.002$) and losses in the printed metalizations ($\sigma = 4 \cdot 10^7 \Omega^{-1}$/m), are considered. Measured results are also included in Fig. 7 for comparison. We can observe good agreement between measured and predicted responses, for both passbands of the filter. The first passband shows an insertion loss of 1.3 dB and a return loss of 15 dB, while the upper passband has a maximum insertion loss of 1 dB and return loss of 17 dB.

The manufactured prototype is shown in Fig. 8. The basic structure consists of two different dielectric substrates separated by a layer of air, providing the required broadside coupling to the input/output ports. The substrates are properly aligned to allow for a precise adjustment of this broadside coupling (H_0 separation in Fig. 5). The lower dielectric substrate of the filter (coupling matrix M_A, (1)) contains the input/output ports and two of the resonators (one of type half wavelength and one of type meander line), and it can be seen at the top of the photo. The meander line resonator implements the third column of the coupling matrix M_A, while the half wavelength resonator implements the fourth column. The bottom of the photo shows the upper dielectric substrate, containing the third resonator. This substrate contains the basic printed line resonator, also of type half wavelength, needed to implement the second column of the coupling matrix M_A (1).

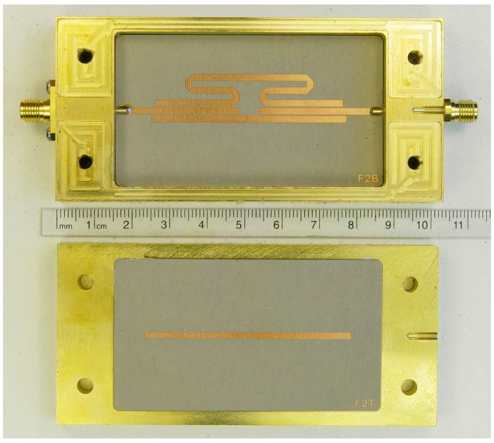

Fig. 8. Photo of the manufactured prototype.

IV. Conclusions

Two third-order novel microstrip bandpass filters have been designed. The coupling schemes chosen correspond to transversal third-order filters, exhibiting two transmission zeros, and have been implemented for the first time in microstrip technology. It is shown that several frequency responses can be implemented, such as dual-band or pseudo-elliptic. Several strategies to adjust the signs of the couplings have been proposed. This includes the use of printed resonators of different lengths, and the introduction of short-circuits when appropriate. Measured results are presented for one prototype. The obtained measurements show good agreement with respect to theoretical predictions, showing the validity of the proposed structures.

V. Acknowledgments

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