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AN IMPROVED OPTIMIZATION METHOD IN THE DESIGN OF MICROWAVE BAND-PASS FILTERS

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This paper presents the design, simulation/optimization and measured results of a 4th order microstrip bandpass filter using open loop square resonators, with a central frequency 5.5GHz and 275MHz bandwidth. The design of microwave filters with cross-couplings is improved by applying a new multiple-steps optimization procedure. After a thorough optimization of the filter's layout by this method, the filter was fabricated and measured. The results of measurements are in good agreement with the specifications of the filter, showing the efficiency of the applied optimization method.

Keywords: microwave band-pass filters, cross-coupling, open-loop square resonator, optimization method

1. Introduction

The various modern wireless microwave and RF communication systems require high performance, narrowband bandpass filters having low insertion loss and high selectivity.

The microstrip open-loop square resonator is widely used to fulfill these requirements, as it is well known for its compact size, low cost and easy fabrication.

According to the early work on filter synthesis [1], it is known that a good frequency selectivity can be obtained with filters exhibiting ripple in the pass-band and poles of attenuation in the stopbands. Such a filter response can be realized using filters with cross-couplings between nonadjacent resonators [1].

The synthesis of filters with different characteristics is based on the use of the generalized normalized coupling matrix **M**. For a filter of order N, this matrix has $N + 2$ rows and columns and contains, in a normalized form, all the coupling coefficients between resonators, all couplings between resonators and the access lines represented by the corresponding loaded Q's of the resonators, and all frequency offsets of the individual resonators with respect to the central frequency of the filter.

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The normalized matrix **M** corresponding to some given frequency response of the filter scan be obtained through a basic synthesis procedure. For certain usual structures, the synthesis of **M** is presented in [1], [2].

The design of microwave band-pass filters starts from a synthesized **M** matrix and ends by generating a planar layout corresponding, as well as possible, to the values in **M**. [3].

2. Design specifications

In this work we have used a microstrip substrate Rogers 3003, with a dielectric constant of 3.0 and with a thickness of 20 mils (0.508 mm). The coupling scheme of the proposed filter is shown in Fig.1 [4]. The design of the band-pass filter starts with the next requirements:

- Center frequency of 5.5GHz and bandwidth of 275MHz (5% fractional bandwidth);
- 50 ohms terminal impedances;
- Two attenuation poles, symmetrically located at normalized frequencies ±2 (5.3625 GHz and 5.6375 GHz);
- 1 dB ripple in the pass-band (corresponding to a return loss of 6.8 dB);
- Number of open loop square resonators, n = 4.

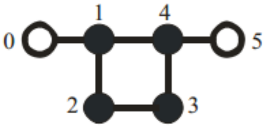

Fig.1 Couplings in the chosen filter configuration

3. Design of the fourth-order filter, with two attenuation poles

The design work starts by generating [2] a normalized matrix **M:**

$$\mathbf{M}=\begin{bmatrix} 0 & -0.68751 & 0 & 0 & 0 & 0 \\ -0.68751 & 0 & 0 & -0.65822 & -0.07463 & 0 \\ 0 & 0 & 0 & -0.62228 & 0.65822 & 0 \\ 0 & -0.65822 & -0.62228 & 0 & 0 & 0 \\ 0 & -0.07463 & 0.65822 & 0 & 0 & 0.68751 \\ 0 & 0 & 0 & 0 & 0.68751 & 0 \end{bmatrix}$$

This synthesized matrix **M** can be tested by considering a model of the filter composed of ideal lumped resonators and ideal admittance inverters, having a central frequency of 5.5 GHz and terminations of 50 Ω. Choosing tuning capacitors of 100 pF, the characteristic admittances of the inverters corresponding to these couplings, ignoring their signs, are:

Table 1

The values of the characteristic normalized admittances of the inverters

$J_{in-1} = J_{4-out}$	$J_{1-2} = J_{3-4}$	J_{2-3}	J_{1-4}
0.0404157	0.1137322	0.10752	0.012895

A lumped elements model of bandpass filter corresponding to the matrix (**M**) is plotted in Fig.2 and its response [5] is shown in Fig.3.

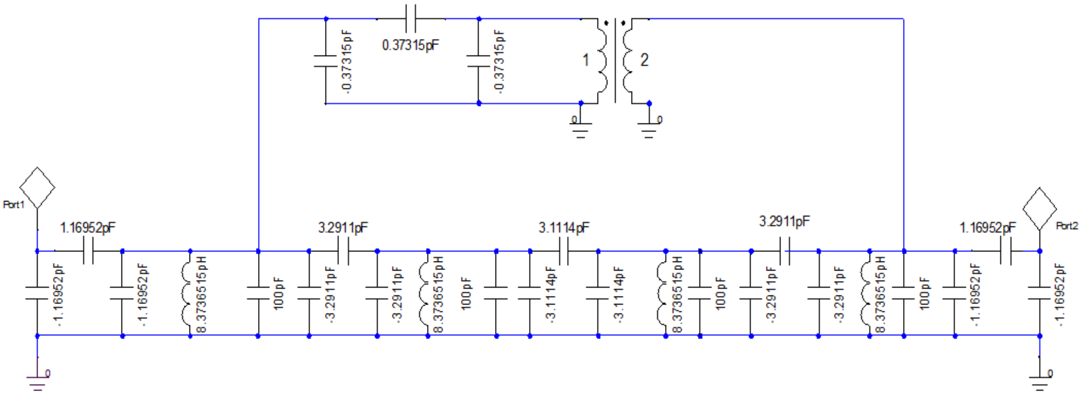

Fig.2 Lumped elements model of the BPF

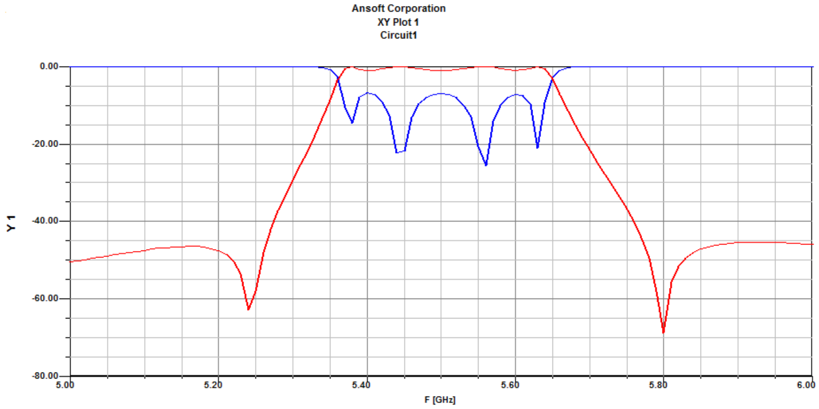

Fig.3 Lumped filter simulated response

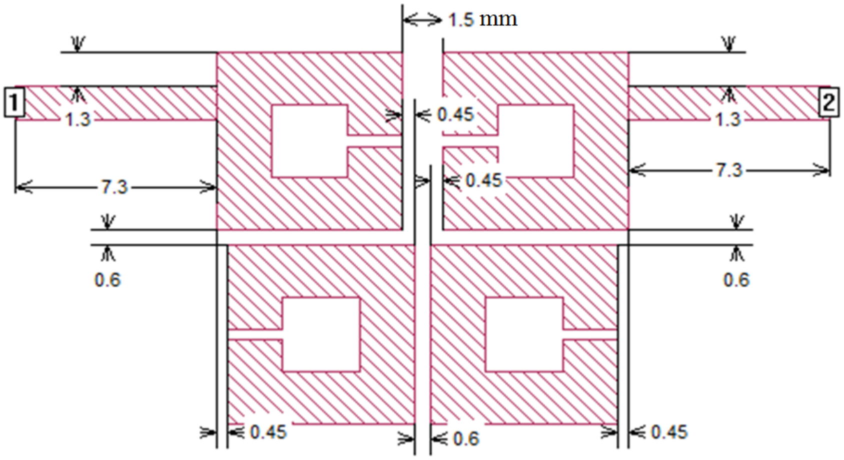

Fig.4 Band-pass filter basic structure (dimensions in millimeters)

The first proposed layout of the designed filter can be seen in Fig.4. It was obtained by usual CAD design methods for band-pass filters [6].

4. Optimization process

The simulated response of the basic filter's structure shows that it needs to be improved. Improvements can be obtained by small changes in the resonant frequencies of the component resonators and/or couplings, to bring the filter closer to design specification. The ways of adjusting the filter's layout are defined by a specific [7, 8] optimization procedure.

4.1 Optimization process steps:

Step 1: Additional ports are placed on each resonator of the filter, allowing the interconnection of the filter layout with external lumped elements, as shown in Fig.5.

Step 2: External capacitors are connected from such an additional port to ground to allow fine tuning of the resonant frequency of each resonator. External capacitors are connected between two such additional ports, to allow fine changes in the coupling coefficient between these resonators.

Step 3: The filter's response is optimized with respect to the additional external capacitor values, by fast circuit simulation software. The result of the optimization is shown in Fig.6.

Step 4: All of these external capacitors have to be gradually removed, by compensating their effects through fine changes in the layouts, by CAD procedures [6].

The final (optimized) layout and its simulated responses are shown in Fig.7 and Fig.8 respectively.

In this paper a modified optimization procedure was applied. The novelty stays in the fact that after removing each capacitor, the optimization procedure is repeated, with respect to the remaining external reactances. This procedure intends to reduce as much as possible the error(s) appeared during the CAD elimination of additional capacitors.

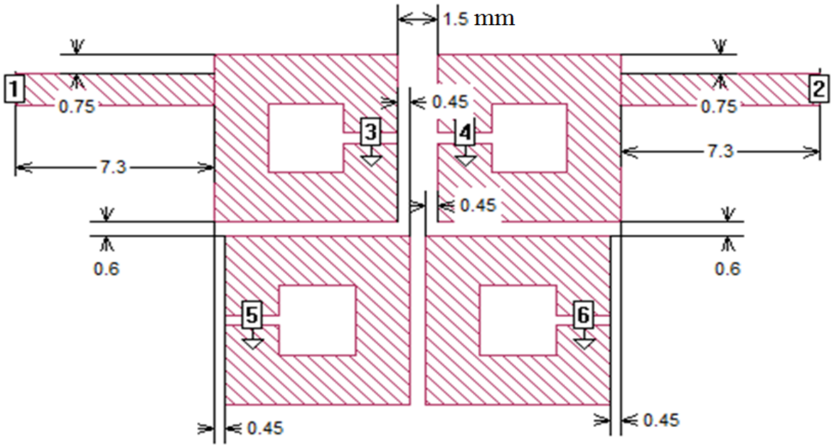

Fig.5 Filter layout with extra ports (dimensions in millimeters)

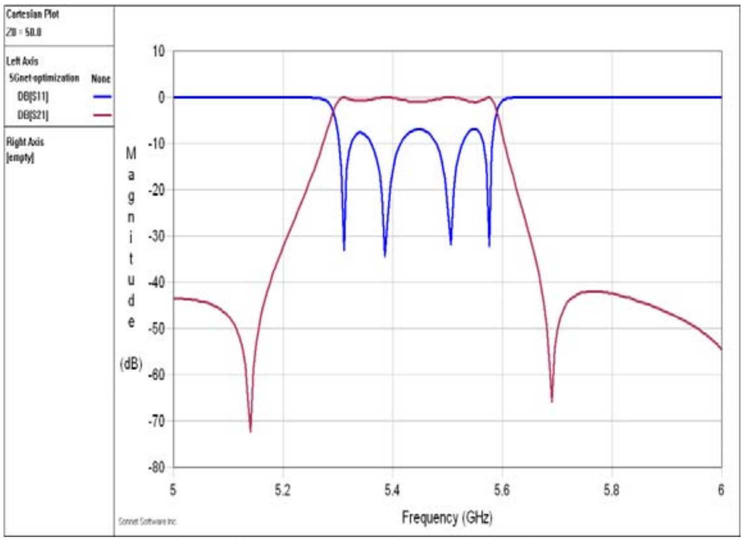

Fig.6 Filter response (after optimization).

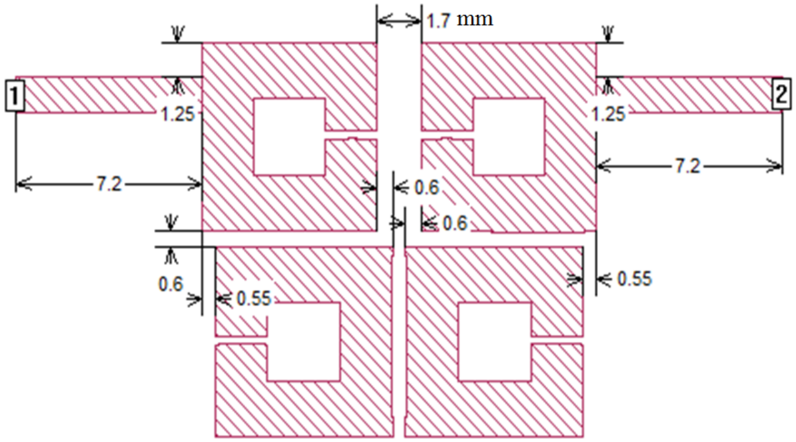

Fig.7 Final layout of planar band-pass filter (dimensions in millimeters)

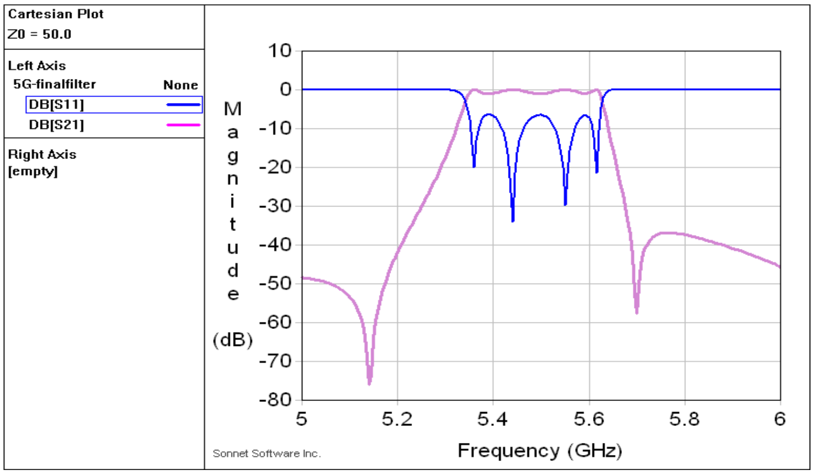

Fig.8 Final characteristics of the optimized lossless filter

In the final stage of the design, the expected losses should be included: substrate loss tangent is 0.0013, while the metallization is copper with thickness of 0.017 mm and with a conductivity of 5×10^{7} S/m. Finally, including in the simulation all these losses were obtained the results in Fig.9.

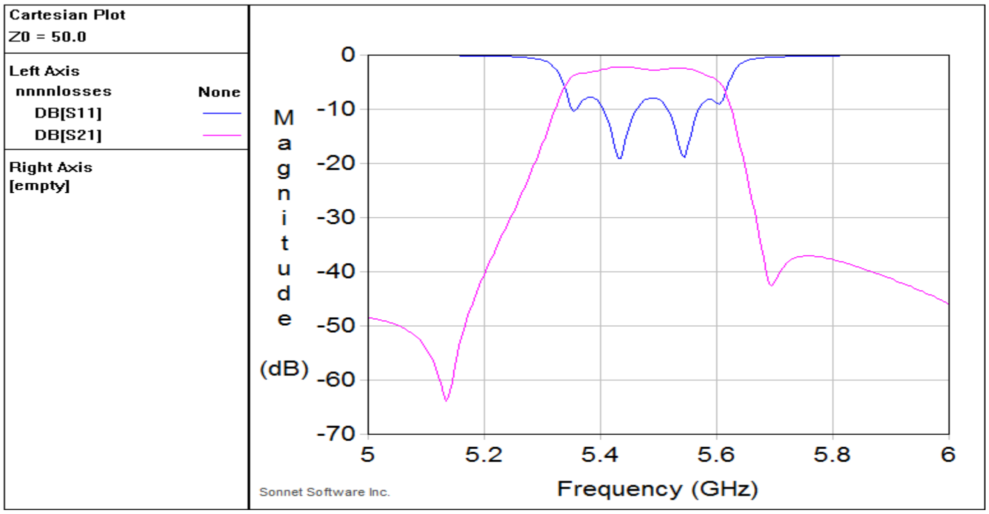

Fig.9 Simulated response of the lossy filter

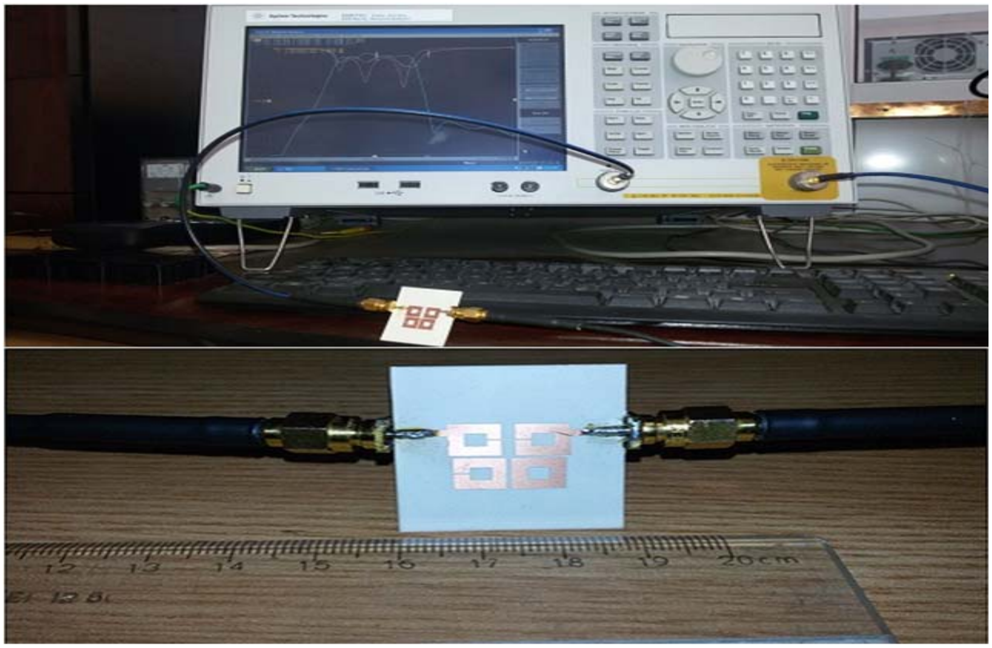

Fig.10 Experimental model of the designed filter

5. Experimental Results

The filter circuit is fabricated on Rogers-3003 dielectric substrate as shown in fig.10. The experimental model was tested with an Agilent Technologies E5071C VNA. Its measured characteristics are shown in fig.11. Both S_{21} simulated response of the lossless and lossy designed bandpass filter are compared with measured S_{21} response, in Fig. 12. It can be noticed that measured responses are very close to the filter requirements. However, some differences are present, such as the slight shift of the center frequency in the fabricated filter response.

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Tr1 S11 Log Mag 5.000dB/ Ref -25.00dB [F2 Smo]
Tr2 S21 Log Mag 5.000dB/ Ref -25.00dB [F2 Smo]
Tr3 S22 Log Mag 5.000dB/ Ref -25.00dB [F2 Smo]
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Fig.11 the measured characteristics of the filter

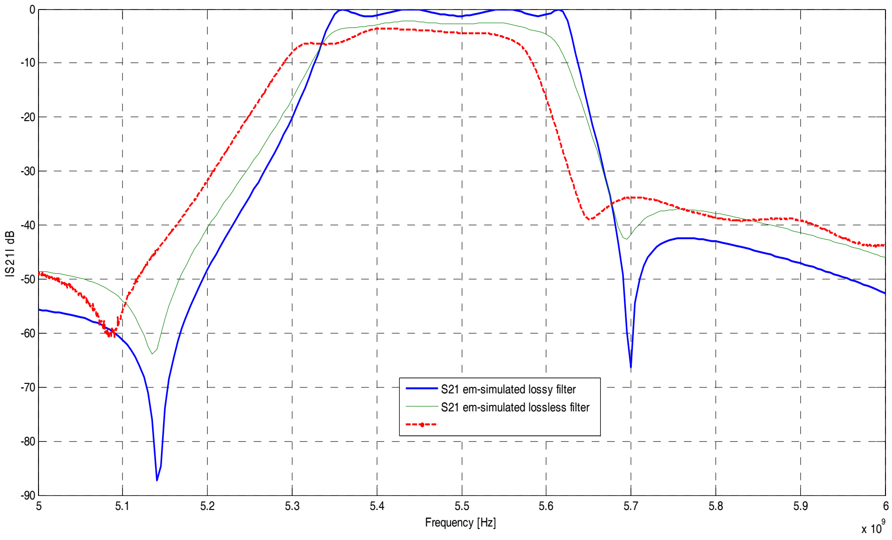

Fig.12 Comparison of measurements and simulated results

6. Conclusions

In this paper the design, simulation/optimization and fabrication of a 4-resonator planar microwave BPF with a pair of attenuation poles are presented. The EM-simulated, optimized and measured performances of this filter show a good agreement to the specifications, certifying the design method.

The design is based on electromagnetic field simulations, combined with a new multiple-step optimization procedure.

The multiple-steps optimization method proposed in this paper leads to more accurate results than the results obtained from the single-step optimization procedure.

Acknowledgement

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R E F E R E N C E S

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