Integration of Optimized Low-Pass Filters in Band-Pass Filters for Out-of-Band Improvement.

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Abstract — **We propose an original structure for the design of high performance filters with simultaneously controlled band-pass and band-reject responses. The band-reject response is controlled thanks to the integration of low-pass structure. So, The spurious resonances of the band-pass filter are reject up to the low-pass filter ones. In this way, we have to optimize the response of the low-pass structure in order to control the out-of-band response of the band-pass filters.**

I. INTRODUCTION

The synthesis of microwave integrated filters is basically based upon equivalencies between the ideal electrical scheme depending on the selected mathematical transfer function and corresponding design topologies. In this way, approximations are commonly used, so as to fit both ideal and synthesized responses around a resonant frequency (for band-pass filters), using for example the slope parameter method.

Consequently, in-band specifications are usually respected when implementing microstrip or coplanar band-pass filters, but parasitic responses appear, mainly at 1^{st}, 2^{nd} and 3^{rd} harmonic frequencies; indeed, the basic resonant structure produces uncontrolled additional poles and zeros outside the operating bandwidth. Different methods to attenuate these spurious resonances have already been proposed [1] [2] [3].

In many applications, a low-pass filter is cascaded with the band-pass filter in order to reject such spurious responses, thus increasing both the size of the complete filter and transmission losses. In addition, such a technique is only efficient in suppressing the first higher order parasitic resonances, the same synthesis limitations being encountered for the low-pass filter (in terms of spurious harmonics).

In this paper, we improve the out-of-band response in introducing directly a low-pass filter in the band-pass filter while keeping constant the performance of the filter in the in-band. Then, we have to improve the out-of-band response of the low-pass filter in order to suppress spurious resonances of the band-pass filter beyond the first one.

In this way, two methods can be used. The first one consists in improving the electrical response of the low-pass lumped filter in the attenuated band by extending the available characteristic impedance range through an appropriate technological approach [4]. The integration of such low-pass filter in a band-pass filter has already been presented [5]. The second way concerns the achievement of a new low-pass filter synthesis [6]. Once the low-pass filter responses have been improved, they have been integrated within a band-pass filter in order to improve its out-of-band response.

II. IMPROVEMENT OF THE LOW-PASS FILTERS OUT-OF BAND RESPONSE

The two previous mentioned methods are presented and discussed in this part. The implementation of the classical microstrip semi-lumped design (see Fig. 1b) usually leads to the electrical response presented on Fig. 2. Parasitic resonances appears at about 3 or 4 f_0 in relation with the restricted available characteristic impedance range (25 Ohms < Zc < 95 Ohms).

We have proposed in a previous work the use of multilayer configurations (see Fig. 1a), then achieving either higher or lower characteristic impedances (125 Ohms and 5 Ohms respectively) with a better factor form. This results in a significant improvement of the out-of-band rejection, as illustrated in Fig. 2. Nevertheless, such technology induces drastic conditions on the implementation.

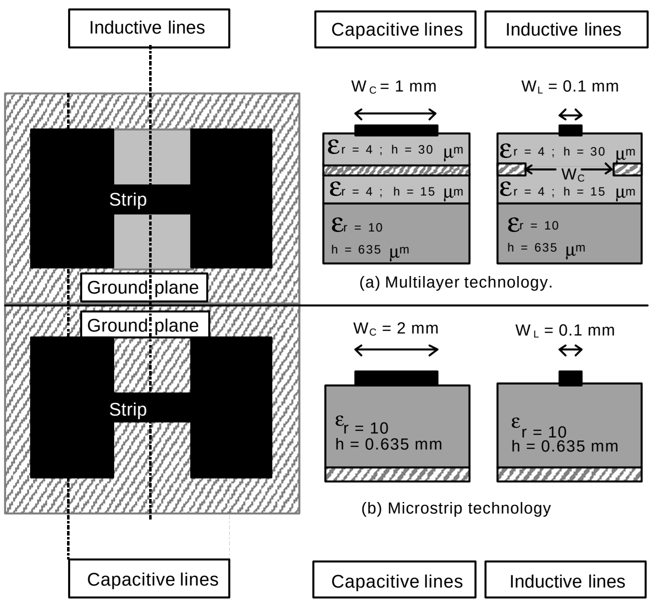

Fig. 1. Layout of the semi-lumped design (microstrip (b) and multilayer technology(a)).

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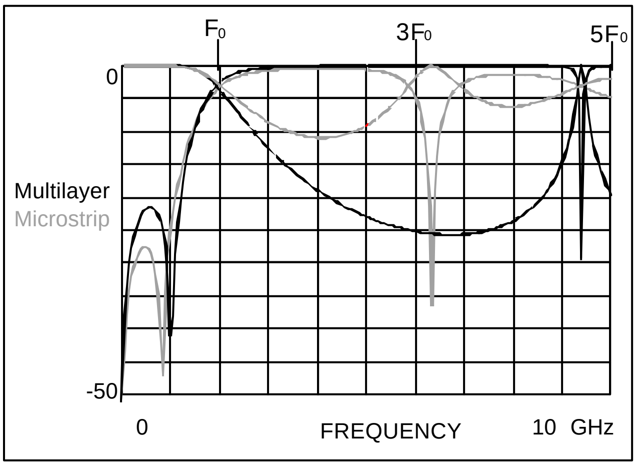

Fig. 2. Comparison between microstrip and multilayer technologies. (classical semi-lumped synthesis)

So, we have developed a new efficient low-pass structure which allows the use of classical open stub topologies (see figure 3). Such architecture is basically attractive for ensuring a good rejection near the band-pass, in accordance with the resonators' selectivity.

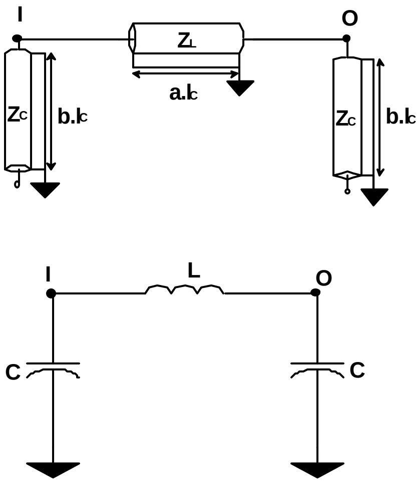

Fig. 3. The new topology and its equivalent circuit.

Then, we established new synthesis formulas in order to optimize the electrical response of such structures, by introducing additional tuning coefficients **a** and **b**.

The equivalencies between ideal and microstrip scheme shown in figure 3 are based upon semi-lumped synthesis. **a** and **b** can be modified in relation with equations (1) and (2) so as to take into account technological possibilities along the complete operating bandwidth.

$$Z_C = \tan\left(\frac{b2\pi\ f_C l_C}{c}\right)\Big/ C2\pi\ f_C \qquad \textbf{(1)}$$

$$Z_L = L2\pi\ f_C \Big/ \sin\left(\frac{a2\pi\ f_C l_C}{c}\right) \qquad \textbf{(2)}$$

fc and c are respectively the cut-off frequency and the speed of light.

Indeed, **a** and **b** compensate for the achievable characteristic by artificially modifying the electrical length of the stubs and the inverters.

A comparison between classical and modified synthesis is shown on figure 4.

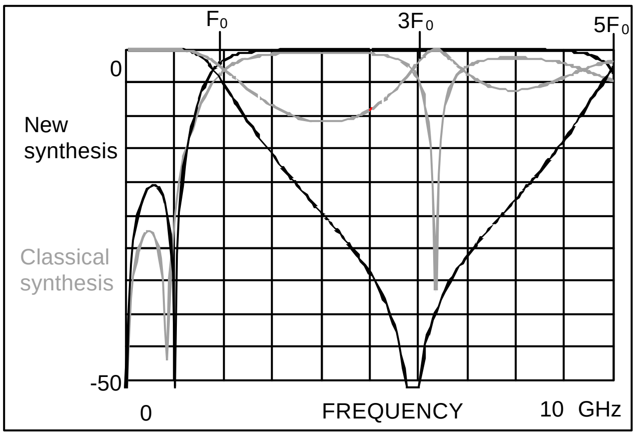

Fig. 4 Comparison between classical and modified topology. (microstrip technology)

We can notice that the spurious resonance are rejected up to 5 f_0, and the rejection near the effective band is also improved.

III. INCLUDING THE NEW LOW-PASS FILTERS INTO BAND-PASS STRUCTURES

Here, low-pass structures are directly integrated in the different elements of a band-pass filter and can be synthesized in order to ensure a high rejection level of higher resonant frequencies.

This solution is applied to the well-known band-pass filter based upon quarter-wavelength shunt stubs and series impedance inverters depicted on figure 5-a [7]. The associated electrical response is also presented on this figure, and the numerous spurious resonances around harmonic resonant frequencies can be observed.

So, we have modified the geometry of the different impedance inverters of a 2nd order filter, so as to insert an equivalent low-pass structure inside each basic inverter. The electrical response of the complete filter is modified in the out-of-band region (see figure 5-b) while it remains quite similar in the desired operating bandwidth.

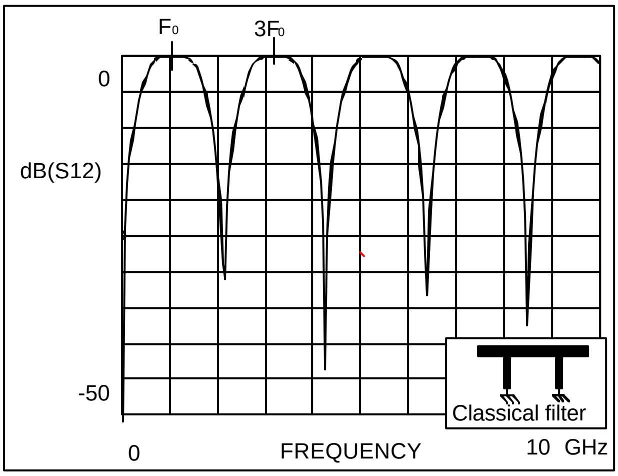

Fig. 5-a. Theoretical response of classical filter.

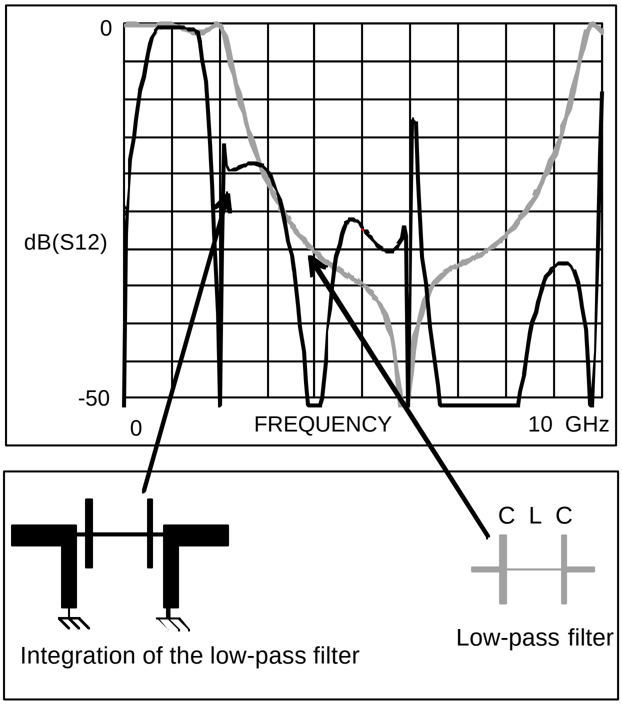

Fig. 5-b. Basic idea and theoretical response.

IV. EXPERIMENTAL RESULTS

A third-order band-pass filter (f_0 = 1 GHz, BW = 40 %) has been designed on a classical substrate (AR1000, ε_R = 10, h = 635 μm) and tested (fig.6).

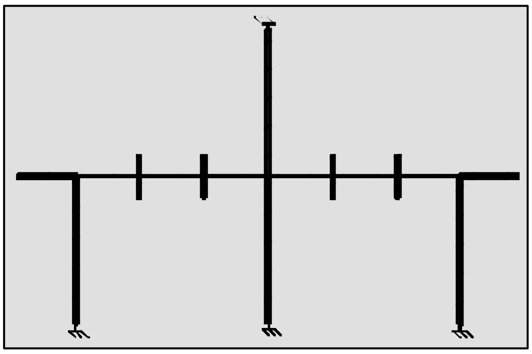

Fig. 6. Layout of the third-order band-pass filter.

As depicted on the figure 7, good performances are achieved inside the operating bandwidth (Return losses < -24.5 dB, Insertion losses > -1.1 dB) while the first spurious resonance appears at about 6 GHz (I.L.= -10 dB). This corresponds approximately to the 6^{th} harmonic frequency. This is quite a significant improvement with respect to classical results (Harmonic behavior from $3F_0$). Moreover, measurements fit very well with theoretical simulations.

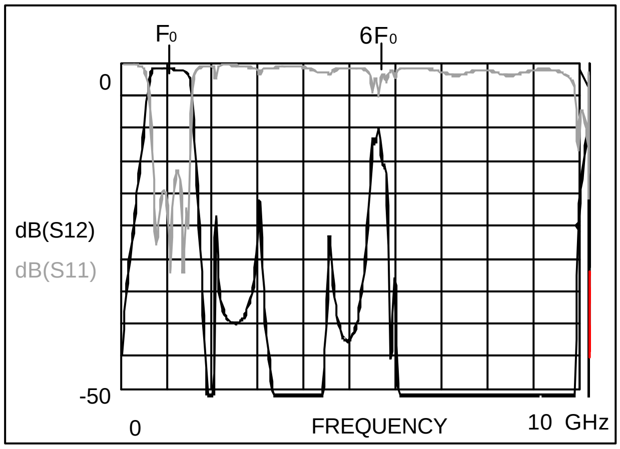

Fig.7 Electrical response of the third-order band-pass filter.

V. CONCLUSION

Original approaches concerning the improvement of band-pass filters performances have been proposed. The insertion of low-pass filters into conventional resonant structures appears as quite a convenient solution for suppressing spurious responses in a desired rejected bandwidth, without any degradation concerning size area, insertion losses and transmission losses. Moreover, despite classical topologies are considered, we succeed in optimizing the electrical response by inserting additional tuning parameters (**a**, **b**) which compensate for the characteristic impedance limitations.

Furthermore, improvements can be proposed by choosing lower characteristic impedances which have a direct incidence on the spurious resonances location. Unfortunately, this also results in additional distorsions due to junction discontinuities influences. Controlling the resonator lengths through the tuning coefficients **a** and **b** rather than modifying extensively the characteristic impedances appears, in our point of view, as a better procedure.

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