A Novel Design Method for Improvement of Narrow Band-pass Planar Filter Response

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***Abstract* — This paper discusses a method used to design a planar band-pass filter in Ku band frequency range for a given satellite application. In order to fit a hardened specification, a filter topology, based on dual behavior resonators (DBRs), is used. In association with this topology, we propose an automated design procedure that combines both circuit and full-wave simulations. It is based on a statistical sensitivity study performed by DOE analysis. After development of the base filter, the out-of-band rejection is improved using topological modifications in order to favor transmission zeros occurrence.**

I. INTRODUCTION

Recent evolutions in telecommunications systems, notably in the mobile, terrestrial and satellite communication domains have led up to hardened constraints in terms of selectivity, electrical performances and bulk reduction of planar filters. Within this context, development of highly selective filters with low insertion losses and reduced cost is presently a fast expanding activity domain. The major problem in the design of such selective filters is about insertion losses, which are directly close to the selectivity level. For instance, for a Rx filter, high rejection levels are often required to suppress the Tx signal located in a very close frequency band. This must be achieved while keeping correct insertion losses level in the pass-band.

This paper deals with the design of selective filters with important reject level in Ku frequency band. Our investigations were first focused on the topology that best fit the desired specifications; they led us to propose a planar solution based on dual behavior resonators (DBRs). But, efficiency of the discontinuity circuit models in Ku band with the chosen shape factor was too low. Moreover, inter-resonators coupling had been neglected. Thus, the circuit simulation strongly differed from the global electromagnetic analysis, and then needed a correction method reported, here, in the third part. It is based on a statistical sensitivity analysis performed on a commercial circuit simulator (Agilent-ADS-2002©) and simulated via Momentum electromagnetic software. In the fourth part, the filter out-of-band rejection is improved by insertion of transmission zeros around the pass-band.

II. SPECIFICATION AND FILTER TOPOLOGY

The filter to be designed corresponds to a Ku band RF one for telecommunication satellite transceiver. Figure 1 details the specifications to be fitted in: the 3-dB pass-band is 12.75 -13.25 GHz, the rejection level in 10.7 - 12 GHz frequency band is 35 dB, no specification for upper band beyond 13.25 GHz is required. Moreover, its size must not exceed 20 mm × 10 mm. Implementation is on alumina substrate ($\varepsilon r = 9.9$, $\tan\delta = 2.10\text{-}4$, $h = 254\ \mu m$, $t = 5\ \mu m$ (Au metal thickness)).

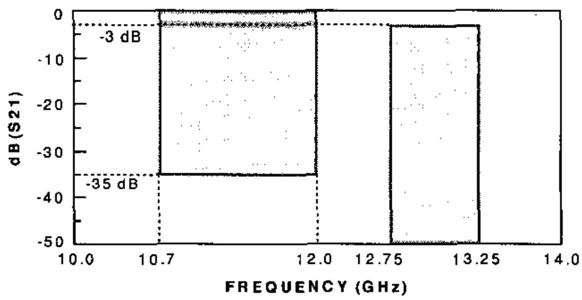

Fig. 1. Filter specifications.

Basically, coupled-lines topologies are well suited for narrow band-pass filters. Nevertheless, in view of the desired insertion losses and rejection levels, such topologies become unsuitable with the above filter specifications. A filter topology based on dual behavior resonators [1], which means both stop-band and pass-band, was therefore chosen. Such a resonator results from two different open-ended stubs set in parallel. Each stub brings a transmission zero on either side of the pass-band. A global synthesis has been developed which allows the designer to independently control the bandwidth, the upper and lower frequency bands of an n-order filter, *i.e.* composed of n DBRs [2].

III. BASE FILTER DESIGN

As a first approach, a 4th-order filter was designed from the nominal values given by the synthesis (Fig. 4), and then simulated using a circuit modeling approach. In our concern to simplify the filter topology, the upper-

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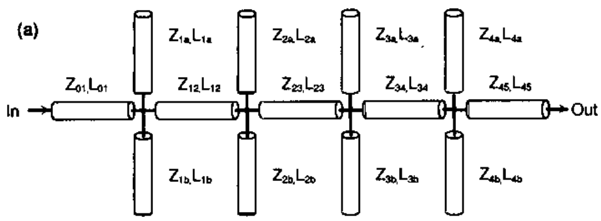
frequency stub lengths, *i.e.* L_{1a}, L_{2a}, L_{3a}, L_{4a} (Fig. 2), are chosen to be equal. Hence, the lower transmission zeros are joined. It is the same for the lower frequency stub lengths (L_{1b}, L_{2b}, L_{3b}, L_{4b}) and the associated transmission zeros.

(a)



(b)

$Z_{01}=Z_{45}$ (Ω)	$Z_{12}=Z_{34}$ (Ω)	Z_{23} (Ω)
42.214	46.249	62.965

$L_{01}=L_{12}=L_{23}=L_{34}=L_{45}$ (mm)
5.656

$Z_{1a}=Z_{2a}=Z_{3a}=Z_{4a}$ (Ω)	$Z_{1b}=Z_{2b}=Z_{3b}=Z_{4b}$ (Ω)
34.768	39.704
$L_{1a}=L_{2a}=L_{3a}=L_{4a}$ (mm)	$L_{1b}=L_{2b}=L_{3b}=L_{4b}$ (mm)
4.525	6.625

(c)

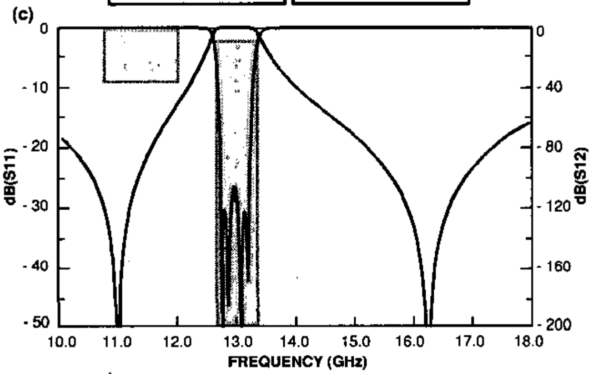


Fig. 2. 4th-order ideal DBRs filters topology (a), electrical characteristics (b) and frequency response (c).

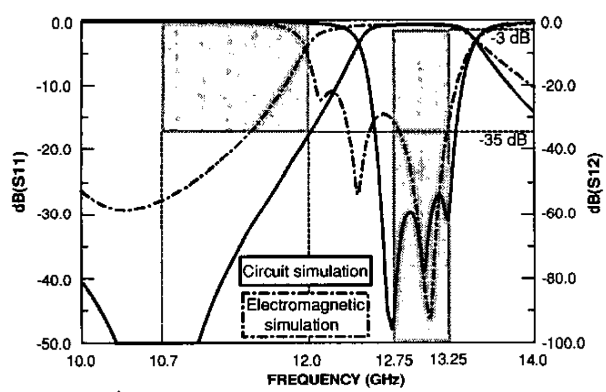


Fig. 3. 4th-order DBRs filter circuit and electromagnetic simulation results with nominal values.

A post simulation with electromagnetic software (Momentum©) was carried out with these nominal values. The simulation results felt short of our requirement. The main problems concerned the bandwidth broadening and the rejection level as depicted in Fig. 3. An optimization procedure using an electromagnetic simulator is unsuitable because of the long simulation time required. As a consequence, a novel correction method using circuit simulator is proposed here.

IV. Correction Process

A correction process is carried out using a sensitivity study based on an experimental statistical analysis (DOE: Design Of Experiment [3]) available in ADS-2002© simulation framework. By varying the dimensions, such an analysis allows one to enhance the dominating parameter, which controls the filter electrical characteristics, and to evidence the main effects of size variations [4]. The DOE simulation yields the central frequency, bandwidth and lower rejection frequency with ±1% evolution of the filter dimensions. One should note that the filter response variations versus dimension evolutions remain unchanged whatever the type of simulation (circuit or full-wave) is. Furthermore, the linear behavior of such electrical-characteristic variations stemming from a quantitative study allows one to make accurate dimension corrections.

The correction process consists of different steps. First, the central frequency, bandwidth and rejection levels are corrected. Nevertheless, these alterations are made without taking the filter matching levels into account. Secondly, matching levels are corrected further to a new DOE analysis. But, as matching levels correction slightly affected electrical characteristics, additional corrections were needed. This was done by re-using the first step procedure. During the correction process, each change in filter dimensions affected its electrical characteristics in a predictable way thanks to quantitative studies. Hence, the whole correction process can be automated.

The resulting filter layout obtained at the conclusion of the sole correction process is depicted in Fig. 4. Figure 5 illustrates the good agreement between the electromagnetic simulation results and desired specification. Moreover, the use of such a design method substantially shortens computation time because only two electromagnetic simulations are needed to reach the required specification. Despite a slight frequency shift (< 1%) due to standard tolerance on dielectric constant ($\varepsilon r = 9.9 \pm 0.15$), the electromagnetic simulated results fit well the experimental ones (Fig. 5).

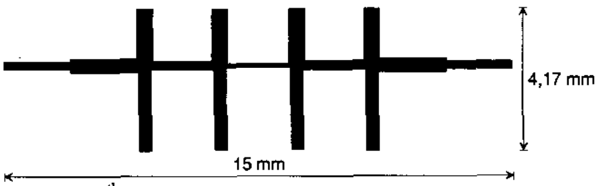


Fig. 4. 4th-order DBRs filters layout.

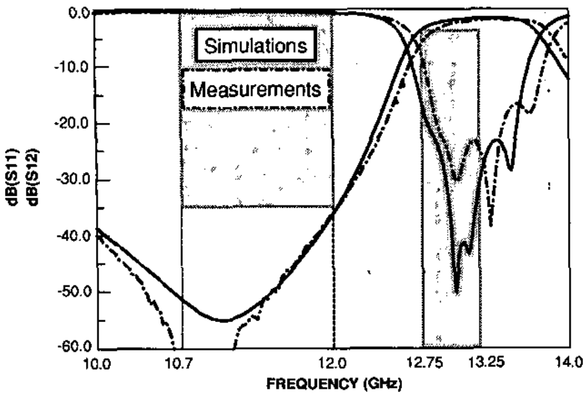


Fig. 5. Simulation (Momentum) and experimental results of the 4th- order ideal DBRs filters.

V. Transmission Zeros Addition

Such a method is particularly interesting when the filter electrical response constraints and complexity are both hardened. For the moment, we have only dealt with the in-band filter optimization. Let us now consider the case of transmission zeros insertion so as to improve the out-of-band rejection level. Indeed, transmission zeros are usually introduced by mutual coupling effects between non-adjacent resonators [5]. In order to favor this coupling effect, the filter topology needs modification simply made by folding the structure as described in Fig. 6.

In view of the filter topology, many topological modifications are conceivable. Indeed, resonators as well as inverters can be folded. The modified topologies depicted in Fig. 6 represent some of the changes achievable to generate a single coupling effect.

Nevertheless, the filter symmetry must be kept. Moreover, a preliminary experiment had shown us that some among modified topologies were more efficient than the others: only couplings of stubs non-adjacent, but of different nature, *i.e.* high- and low-frequency, significantly improved the filter response. These conditions significantly limit the number of folded structures (Fig. 8).

As described in Fig. 7, four folded filter topologies are available with a 4th-order filter; with respect to the favored coupling effects, they can be grouped two by two as follows: either K17 and K46 (Figs. 7.a and. 7.c) or K28 and K35 (Figs. 7.b and 7.d). Preliminary simulation results were in favor of K17 and K46 coupling effects because of their efficiency in transmission zeros addition. Hence, the studied filter topology is the one depicted in Fig. 7.(a).

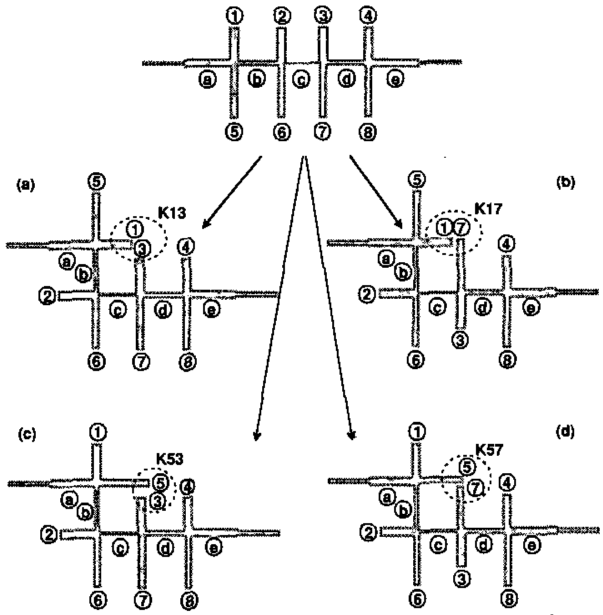


Fig. 6. Some modified topologies that favor non-adjacent stubs coupling (single coupling).

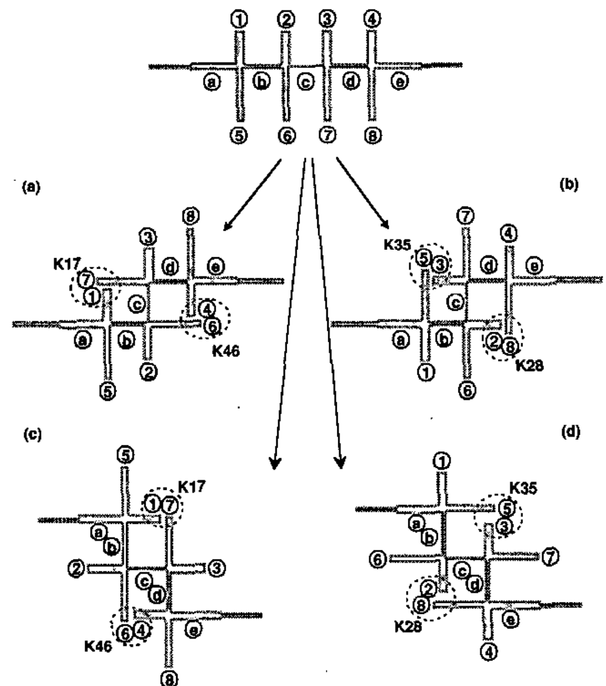


Fig. 7. Conceivable modified 4th-order DBRs filter topologies that maintain the filter global symmetry.

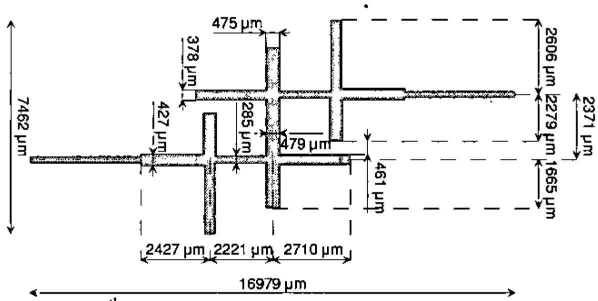


Fig. 8. 4[th]-order DBRs folded filter layout and dimensions.

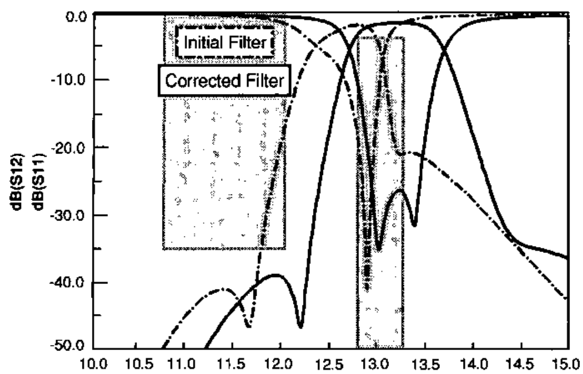


Fig. 9. Comparison between initial and corrected filters electromagnetic simulation results.

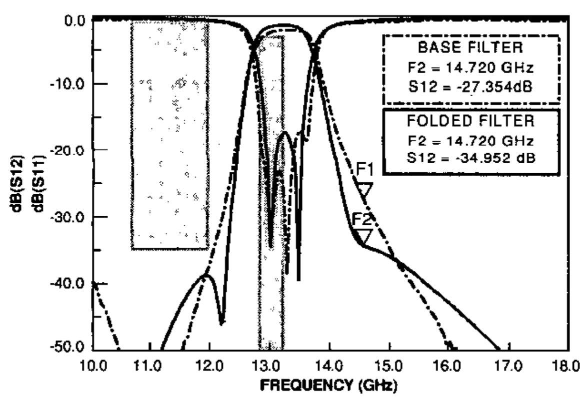


Fig. 10. Comparison between base and folded DBRs filters experimental results.

Such a folded topology, detailed in Fig. 8, allows addition of a transmission zero above the pass-band. Considering the filter symmetry, the coupling coefficients K17 and K46 are the same. The two resulting transmission zeros frequencies are, therefore, joined.

Because of topological modifications, cross-junctions are not symmetrical, which significantly debases the filter electrical response (Fig. 9). Thus, a correction process is necessary and can be made by using the design method described above. At the close of the correction process, the resulting filter layout, presented in Fig. 8, was simulated through a full-wave analysis. The electromagnetic results are in good agreement with the desired specification (Fig. 9). Below the pass-band, one should, however, note an additional transmission zero. It is due to the changes in lower-frequency stub lengths inherent to cross-junction modification. Moreover, Figure 10 highlights the contribution of the modified topology to filter electrical-response improvement: at the transmission zero frequency, the rejection level is, indeed, increased by 7 dB.

VI. Conclusion

This paper reports on a design method applied to a narrow band-pass filter based on dual behavior resonators (DBRs). Our goal was to fit hardened specifications in terms of rejection and insertion losses. In order to reach these specifications, the design procedure combines circuit modeling approach and electromagnetic analysis. It is based on the use of statistical sensitivity study performed by a DOE analysis available on ADS-2002©. Such a method saves a great deal of computation time by dismissing any optimization steps with electromagnetic simulator. Once efficiency of the design method for the base filter has been proven, investigations are focused on the development of more complex function in terms of electrical response and topology. The use of folded filter topologies allows addition of transmission zeros. In view of the base filter topology, DBRs filter offers multiple solutions to improve the out-of-band rejection level. One among them is of very high interest because of its significant contribution to the variation in transmission zeros frequency. Such a folded filter topology was designed following the method previously developed. The experimental results obtained verified the validity of the proposed concept.

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