Automated Electromagnetic Optimization Method for Microwave Devices

S. Bila, D. Baillargeat, S. Verdeyme, and P. Guillon

***Abstract*— We present a relevant automated electromagnetic (EM) optimization method which combines a fast analytical model deducted from a rigorous and accurate EM analysis and the global analysis of the device performed with a finite-element method (FEM). We apply the automated method to the optimization of a volumic dielectric resonator filter. First, we present the definition of the analytical coarse model, then we use this model as a starting point for the EM optimization of structure dimensions. The accuracy of this automated method is then demonstrated, considering the good agreement between theoretical optimization results and experimental ones.**

***Index Terms*—Finite-element method, microwave devices, optimization methods.**

I. INTRODUCTION

NEW available tools and growing computer capabilities now allow microwave circuits designers to develop automated electromagnetic (EM) optimization methods [1], [2].

Nowadays, studies of complex microwave devices are performed applying analytic or EM methods. In the first case, complex devices are generally divided into several segments which are modeled independently from each other. Then, these models are put together to describe the device behavior. The indirect couplings between them cannot then be taken into account.

To overcome these difficulties, the complex device can be analyzed applying a rigorous EM method. This analysis may be a global one, considering the whole device. It then gives accurate results, but it requires significant memory space and time, and it cannot perform optimization.

The other solution is the segmented EM analysis. The device is divided in several segments and each segment may be characterized by a generalized $[S]$ matrix. This segmented method allows memory saving, but its accuracy depends on the structure complexity and on the number of modes preserved between segments.

The hybrid optimization approach presented in this letter relies on a combination of these two EM analyzes, applying a finite-element method (FEM) software developed in our laboratory. This three-dimensional (3-D) EM analysis software is defined in the frequency domain and permits rigorous analyzes of whole complex devices. It has been already presented in several papers [3], so we do not describe it in this letter.

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The authors are with I.R.C.O.M., Faculté des Sciences, 87060 Limoges Cédex, France.

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Applying our optimization method, we first split the studied device, and each segment behavior is analyzed using the FEM. For each segment, the generalized $[S]$ matrix is then approximated applying neural networks to define its analytical coarse model. Then, the coarse models of each segment are chained to define the coarse model of the whole device. This model may lack the necessary accuracy we need and has a limited validity range, but it permits to explore different optimization starting points in less time. The coarse model response gives the basic dimensions of the device, then they are optimized in few iterations applying a global EM analysis of the structure.

We can note that the originality of this optimization method is to perform, using EM methods, all segmented and global analyses.

In the first part of this letter, we describe the optimization method and apply it to design a dielectric resonator (DR) filter. Finally, comparisons between theoretical and experimental results show good agreement.

II. DESCRIPTION AND APPLICATION OF THE OPTIMIZATION METHOD

Our optimization approach may be applied to a wide range of microwave devices such as volumic or monolithic microwave integrated circuit (MMIC) structures which can be passive and/or active. In order to demonstrate its feasibility, the method is applied to a volumic filter, composed of a cylindrical dielectric resonator, embedded in a teflon support, and adjusted in a cylindrical metallic cavity. The structure is excited with two input/output rectangular irises connected to standard rectangular waveguides. The device is presented on Fig. 1.

Step 1): The first step of our method is to define a coarse model of the device in physical and geometrical domains of optimization. According the complexity of the device, the structure is divided in several segments S_i which are characterized by their generalized matrices $[S_i]$ using the FEM. Applying this analysis, we consider at each segment port, the useful coupling modes between segments S_i and S_{i+1}. Then each matrix $[S_i]$ is approximated with a software based on neural networks [4] developed in our laboratory and is implanted on a commercial circuit software (JOmega from HPEESOF) to define a coarse model for each segment S_i. These elements are chained together to define an analytical coarse model of the whole device. We can then obtain the analytical coarse response named $R_A[\Phi_{Aj}^{(1)}, \Phi_{Aj}^{(2)} \cdots]$, where $\Phi_{Aj}^{(1)}, \Phi_{Aj}^{(2)} \cdots$ are the coarse parameters.

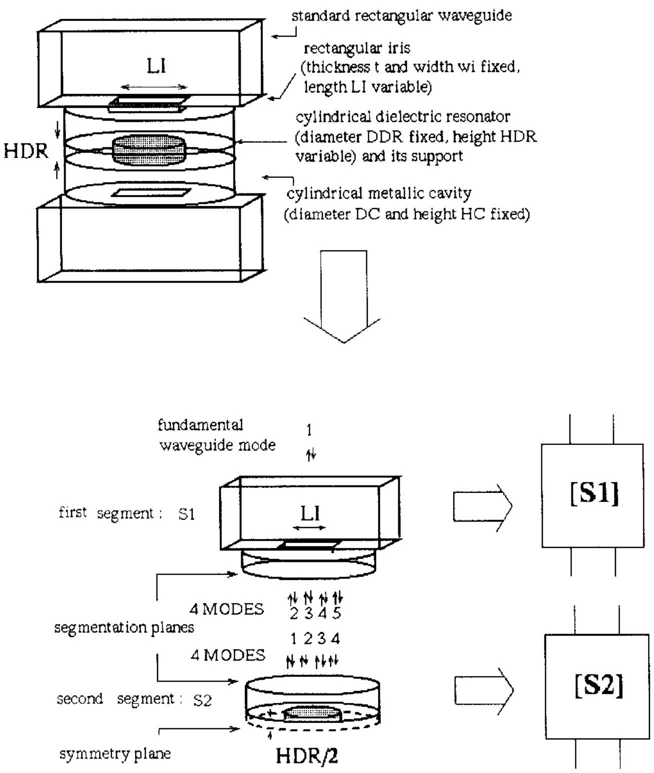

Fig. 1. Description of the DR filter.

In our case, the device is divided in two independent segments. We choose to define the response of the first segment S_1 as a function of the iris length (L_I), which determine the input/output coupling and of the frequency (f). The second segment S_2 response is established as a function of the dielectric resonator height (H_{DR}) which determines the central frequency of the filter and of the frequency (f). In this case, four modes are required at the segmentation plane between S_1 an S_2 to obtain similar responses between global EM analysis and segmented one. The combination of the coarse model elements, defines the considered device response $R_A(L_{IAj}, H_{DRAj})$ with its coarse parameters L_{IAj} and H_{DRAj}.

Step 2): In the second step, the structure dimensions are approximately determined considering the coarse model, from the filtering pattern fixed by the designer. In this way, we perform an optimization with the analytical model, and its response $R_A[\Phi_{A0}^{(1)}, \Phi_{A0}^{(2)} \cdots]$ which agrees the filtering pattern, becomes the objective response named R_{OBJ}. We then have to satisfy R_{OBJ} with the global EM analysis.

Step 3): In the third step, the whole device is now considered applying the global FEM. The first EM global response $R_G[\Phi_{G0}^{(1)} = \Phi_{A0}^{(1)}\, \Phi_{G0}^{(2)} = \Phi_{A0}^{(2)} \cdots]$ is computed, where $\Phi_{G0}^{(1)}, \Phi_{G0}^{(2)} \cdots$ are the global analysis parameters. We compare $R_G[\Phi_{G0}^{(1)}, \Phi_{G0}^{(2)} \cdots]$ with R_{OBJ}, and if R_G disagrees, we establish a mathematical link T between the different parameters as well as

$$R_A[\Phi_{Aj+1}^{(1)}, \Phi_{Aj+1}^{(2)} \cdots] = R_G[\Phi_{Gj}^{(1)}, \Phi_{Gj}^{(2)} \cdots]$$

with

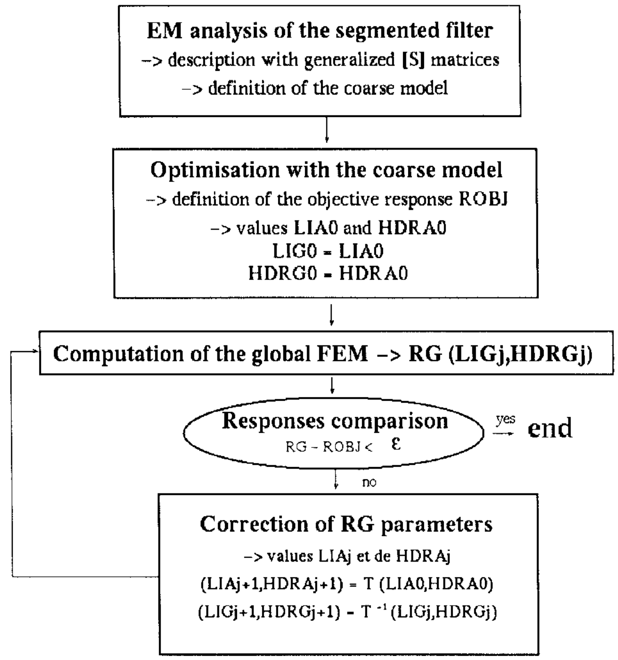

Fig. 2. Optimization chart.

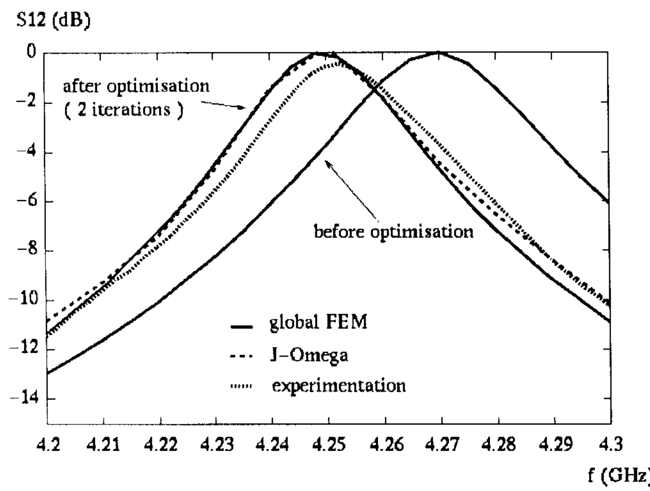

Fig. 3. Complete optimization and experimentation.

$$[\Phi_{Aj+1}^{(1)}, \Phi_{Aj+1}^{(2)} \cdots] = T[\Phi_{A0}^{(1)}, \Phi_{A0}^{(2)} \cdots].$$

Then, the global parameters are computed for another optimization applying the opposite link T^{-1}:

$$[\Phi_{Gj+1}^{(1)}, \Phi_{G+1}^{(2)} \cdots] = T^{-1}[\Phi_{Gj}^{(1)}, \Phi_{Gj}^{(2)} \cdots].$$

In our example, we compute

$$L_{IGj+1} = L_{IGj} - (L_{IAj+1} - L_{IA0})$$

and

$$H_{DRGj+1} = H_{DRGj} - (H_{DRAj+1} - H_{DRA0}).$$

We proceed with the loop presented on the optimization chart on Fig. 2, as long as the objective response R_{OBJ} is not satisfied by R_G.

In our example, for the different cases we have studied, only two or three iterations applying the global analysis were required to optimize the filter dimensions. The computing time is around 20 min for each iteration on a HP735 workstation.

So, when R_G is agree with R_{OBJ}, the dimensions of the whole structure are defined rigorously applying the FEM

III. Experimental Test

In our case, the filter dimensions are optimized in order to obtain a transmission response characterized by a central frequency equal to 4.25 GHz and a 30-MHz bandwidth at −3 dB.

The optimization of the coarse model gives the basic dimensions

$$L_{IA0} = 22.47 \text{ mm}$$

and

$$H_{DRA0} = 5.8 \text{ mm}.$$

After an EM optimization of the whole device applying only two iterations, we obtain the final optimized dimensions:

$$L_{IG2} = 22.00 \text{ mm}$$

and

$$H_{DRG2} = 6.0 \text{ mm}.$$

The filter is then built and tested. The difference between theoretical and experimental frequencies is equal to 0.2%, and for the bandwidth at −3 dB, the error is equal to 2%. We can see the complete optimization example and the good agreement between theory and experimentation on Fig. 3.

IV. Conclusion

During this study, we have developed a hybrid EM optimization method based on the combination between a coarse model established from a segmented FEM analysis and a rigorous and accurate global FEM analysis of the device.

We have demonstrated the efficiency of this method applied to define a DR filter dimensions with few iterations. Moreover, the good agreement between theoretical and experimental results proves the method accuracy.

We have now to apply this method to more complex planar or volumic microwave devices, then to establish progressively new library elements for circuit analysis and optimization.

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