A GENERALIZED ELECTROMAGNETIC OPTIMIZATION PROCEDURE FOR THE DESIGN OF COMPLEX INTERACTING STRUCTURES IN HYBRID AND MONOLITHIC MICROWAVE INTEGRATED CIRCUITS

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ABSTRACT

An adaptive electromagnetic optimization procedure to facilitate field-theoretic design of hybrid and monolithic integrated circuits is presented. This approach provides full-wave characterization of complex MIC and MMIC geometries by including various effects such as coupling, spurious radiation, surface wave modes, and interactions with package modes. Application of this procedure utilizing commercially available electromagnetic simulators will be presented to demonstrate its versatility.

I. INTRODUCTION

With recent advances in commercially available electromagnetic simulators [1]-[7], there is considerable emphasis on achieving first-pass success of MICs and MMICs. The design methodology now consists of keeping in mind not only the performance of a circuit, but to ensure its manufacturability. This necessitates a close relationship between the "designed" and "fabricated" circuits. Accurate active and passive structure models are, therefore, required to enhance circuit simulation accuracy. The models of active devices are well established and the composite device models based on several wafers or lots are available. The equivalent circuit parameter values are available in terms of mean and standard deviation.

The passive structures are essential building blocks of any MIC or MMIC. In general, the limitation of currently used tools is their accuracy beyond approximately 18 GHz. These tools use passive element models which are either obtained using quasi-static approximations; or field-theoretic approaches under simplifying assumptions; or closed form expressions using quasi-static results. Due to some differences in structural dimensions and process parameters, the accuracy of these models are difficult to assess. With the help of full-wave electromagnetic simulators, the accuracy of an existing model can be improved since they take into account various effects such as coupling, spurious radiation, excitation of surface waves, and package mode interaction. They can also provide accurate descriptions of passive structures for which the models are not available at all.

While the advent of electromagnetic simulators have indeed enhanced the accuracy of simulations, the MIC and MMIC design process is still essentially tedious since a designer must first obtain the response of various constituent structures using an electromagnetic simulator and then evaluate the overall performance in a circuit simulator. The approach presented in [8] and [9] first requires identifying the subcircuits, obtaining their performance with an electromagnetic simulator, and then performing optimization using a circuit simulator. This approach requires deembedding of structures. The use of different grid sizes, enclosure size, as well as absence of neighboring structures degrades the accuracy of simulations.

In order to alleviate this problem and to provide designers a tool to obtain prescribed functional form of a filtering or matching structure, we have developed a generalized computer-aided optimization procedure utilizing electromagnetic simulators. In our approach, the objective function for a given structure is calculated directly from the output of an electromagnetic simulator. Thus, complex interacting structures can be optimized without identifying and analyzing sub-circuits. It retains the flexibility in discretizing the circuit with a coarse or fine grid. Furthermore, the availability of an optimization shell outside of a circuit simulator is useful since only the final optimized data needs to be transferred to the circuit simulator. This approach is quite different than the one presented earlier in [8], [9], where

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deembedded subcircuits are simulated using an EM simulator, and a circuit simulator is used to perform the optimization.

In this paper, we shall address problems involving geometrical discretization, and implementation of various optimization techniques for different types of EM simulators. The procedure is implemented and verified using a commercially available EM simulator.

II. IMPLEMENTATION OF THE AUTOMATION ALGORITHM

In order to perform an optimization, it is necessary to automate the procedure for iteratively analyzing circuits. We have developed a general algorithm, capable of interfacing to different EM simulators [1]-[7], different objective functions, and different optimization routines [10], [11]. The algorithm is outlined below in Figure 1.

The optimization instructions define the variables and objectives of the optimization. In general, these variables are not input parameters for an EM simulator, but they are related to them. For example, optimizing a single length dimension is a univariate optimization. However, several input parameters can depend on the value of this length. Thus, it is necessary to map each optimization variable to all of its dependent input parameters (e.g. geometrical coordinates). This mapping allows the computer to represent an arbitrary circuit geometry as a single vector. Using a synthesis routine, the computer generates all necessary input files for a given EM simulator. After performing an analysis, another routine is used to collect the relevant data from the output files. This data is used to calculate the objective function, which represents the error between the actual and desired responses. The optimization routine is used to iteratively search for a vector which minimizes this error. Once that vector is found, it is translated into the optimized circuit geometry.

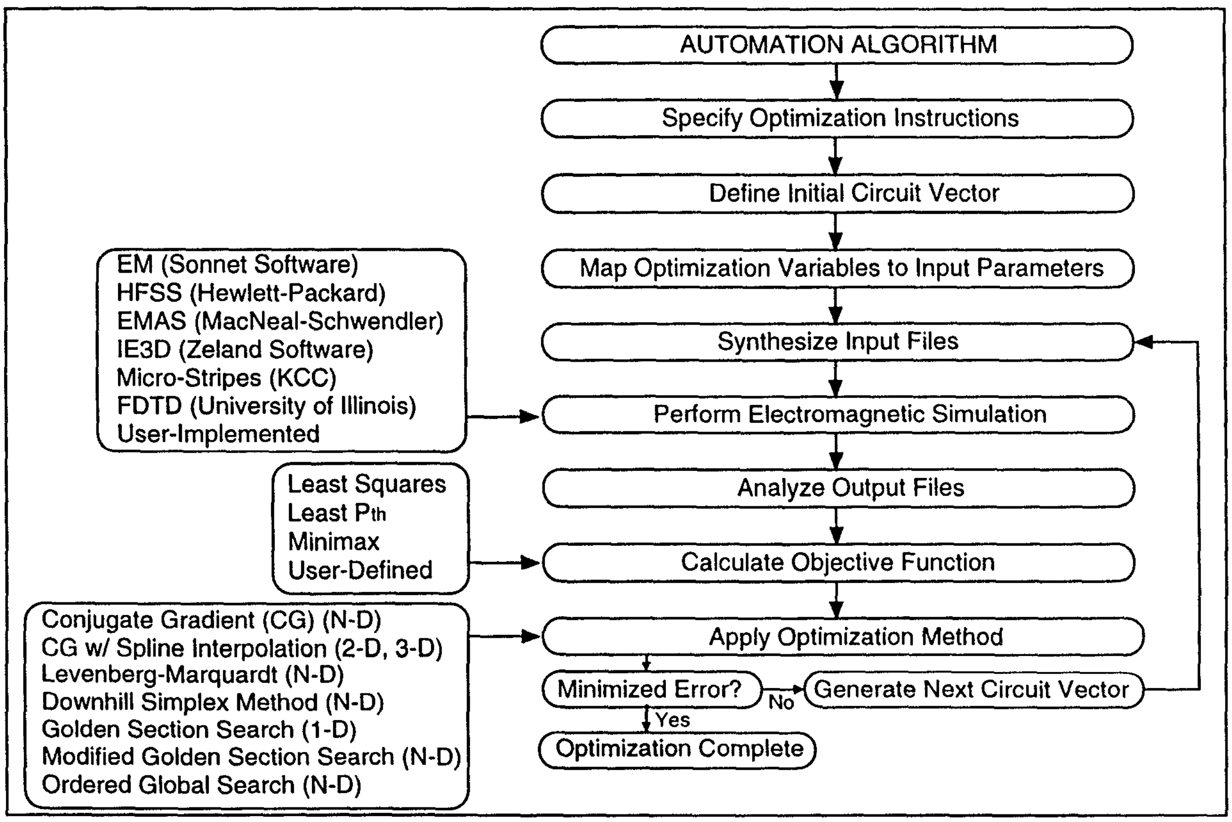

Figure 1. Flowgraph of the Automation Algorithm

Using the above mentioned procedure, we developed a program which interfaces to Sonnet Software's **em** [1]. This is a 2.5-D method of moments (MOM) program capable of computing S-parameters of predominantly planar circuits. Input file synthesis and output file analysis are handled by specialized I/O routines. The **em** analysis is performed under a command shell; and the objective function is calculated from the output and optimization data sets. The program allows for optimizing conductor shapes on a fixed rectangular grid. The objective function is implemented using a general least p^{th} method. The optimization routine can be selected among several by setting various options in the source code makefile. The routines currently incorporated into the code include a global search method, single and multi-dimensional searches with and without derivatives [10], and an IMSL conjugate gradient method [11]. Some of these routines are fairly specialized, while others are more general and flexible. Depending on the type of geometry, optimization, and degree of computational intensity, an appropriate algorithm can be selected.

III. MULTI-STAGE IMPEDANCE TRANSFORMER EXAMPLE

The verification of this program is demonstrated in this paper using an example where we used it to minimize the return loss of a three-stage quarter-wavelength impedance transformer. The initial circuit geometry and some dimensions are given below in Figure 2.

This circuit transforms an impedance of 50 Ohms at port 1 to 150 Ohms at port 2. It is desired to minimize the return loss at port 1 over the frequency band from 5 to 15 GHz. This can be achieved by varying the widths of the three sections of line. The program was run using a non-differentiating optimization routine with a least-squares objective function. The optimization produced the results shown in Fig. 3. It indicates a significant decrease in return loss between the initial and final circuits. The optimization time was considerably short compared to manually iterating through the analyses, and it didn't require the attention and effort of an engineer. In addition, the final circuit is very accurate, allowing for first-pass manufacturing. Results of several other test cases are available and will be included in the final version of this paper.

IV. CONCLUSIONS

An adaptive electromagnetic optimization procedure has been presented to facilitate field-theoretic design of hybrid and monolithic integrated circuits. We have outlined the general algorithm and its implementation. This program has been verified with several test cases published in the literature. It is now being utilized in the design of V- and W-band MMICs where the accuracy of models is not well established, and compact commercial MMICs where proximity effects are quite significant. Further developments include implementation of this procedure to other commercially available EM simulators, and implementation of discrete and combinatorial optimization techniques.

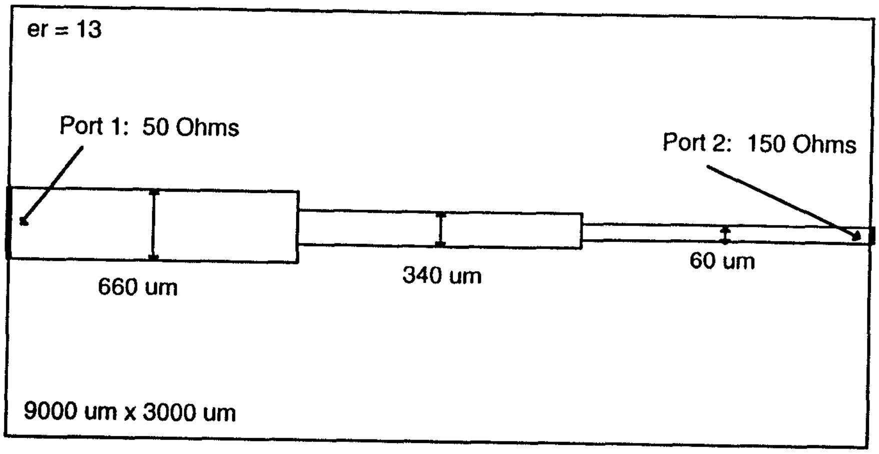

Figure 2. Initial Circuit Geometry

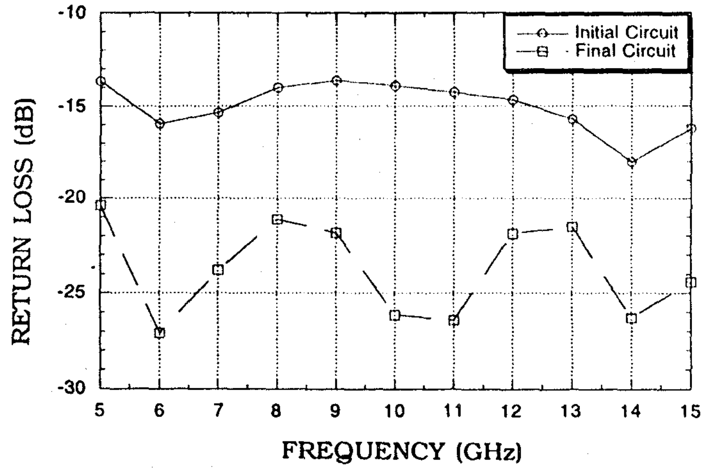

Figure 3. Return Loss of Impedance Transformer

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