MICROWAVE CIRCUIT ANALIZE USING SPACE MAPPING RLC MICROWAVE OSCILLATORS

Alexandru STEFAN

Bloomfield College, NJ, USA

Abstract: *During the past three decades, several robust optimization techniques have been developed. These techniques supplied designers with strong and reliable tools necessary for the complex and demanding needs of modern circuit design. They utilize the circuit responses and possibly derivative information in the optimization loop. Recently, commercial software packages have been developed that solve Maxwell's equations for circuits of arbitrary geometrical shapes. Such simulators are denoted as Electromagnetic (EM) simulators. They utilize different methods of the analysis of microwave circuits such as the Finite Element Method (FEM), the Method of Moments (MoM),etc. These simulators are accurate but they require intensive CPU time. The optimization algorithms employ the coarse model in the search for the fine model minimizer. This is done through a parameter mapping, the so called space mapping, which in effect makes the coarse model behave as the fine model. We call this combination of the space mapping and the coarse model, the mapped coarse model. Hence, in the space mapping technique, applied on microwave oscillators circuits, mapped coarse model is to take the place of the fine model in search for a minimizer model. Beginning with space mapping conditions we can present some software for optimization algorithms applied on microwave RLC oscillator circuits.*

Keywords: *algorithms, approximating functions, Fourier analysis, trigonometric regression, multiple regression.*

1. INTRODUCTION

Utilizing EM simulators for optimizing microwave circuits can be formidable. The initial use of these simulators was limited to validating designs obtained through traditional optimization of empirical/analytical models. Over the years, empirical and circuit theoretic models of many microwave circuits have been developed and accumulated. The empirical and circuit-theoretic models are denoted as "coarse" models. Advances in the technology of workstations and PCs enabled traditional EM optimization of simple structures. However, the increasing complexity of microwave circuits still makes traditional EM optimization a formidable task. A mathematical link (mapping) is established between the spaces of the parameters of the empirical and EM models. This approach directs the bulk of the required CPU time to the fast model while preserving the accuracy and confidence supplied by few EM analyses. The target of circuit optimization is to determine a set of values for the circuit parameters such that certain design specifications are satisfied. These specifications represent constraints on the circuit responses.

Usually, a model of the physical circuit is utilized in simulating and thus optimizing the circuit. Traditional optimization techniques utilize the simulated circuit responses directly and possibly available derivatives. Engineering models used in simulating the circuit responses vary in accuracy and speed. Usually, accurate models are computationally expensive and less accurate models are fast. In some engineering problems, applying traditional optimization using the accurate models directly may be prohibitively impractical. On the other hand, applying optimization using the less accurate models may indicate feasibility of the design but could lead to unreliable results. These results must be validated using the accurate models or even using measurements. It follows that alternative optimization approaches must be utilized.

The problems to be solved by the optimization algorithms in this presentation have two models available: first model denoted the fine model, being the model of primary interest, and the second denoted the coarse model. It is expected that the coarse model somehow resembles the behavior of the fine model. Further, it is expected that the coarse model is cheaper to evaluate than the fine model, and therefore it is most likely less accurate than the fine model. The optimization algorithms employ the coarse model in the search for the fine model minimizer. We call this combination of the space mapping and the coarse model, the mapped coarse model.

2. SPACE MAPPING OPTIMIZATION TEST PROBLEMS

The test problems used for this material are based on *Parallel Resonator Problems*, the RLC problem concerns design of parallel RLC lumped resonators. The coarse model is a parallel RLC lumped resonator with three designable parameters. The objective is to minimize the maximum deviation between the input reflection coefficient and some design specifications over all simulated frequencies. The specifications consists in a pass band at the center frequencies and a stop band at all other frequencies.The problem has four fine models that also model a parallel RLC lumped resonator, but the fine models also have some parasitic elements. The fine models are related to the same design problem (i.e. the same specifications) as the coarse model.

Here are the characteristics of the differences between the models:

RLCA: The fine model has an exact linear mapping to the coarse model.

RLCB: The fine model has an exact nonlinear mapping to the coarse model.

RLCC: The fine model has an inexact non-linear mapping (different topology) to the coarse model.

RLCD: The fine model has an inexact non-linear mapping to the coarse model.

Using SM theory we developed algorithms for this analyze based on the following definitions:

regularization with regard to the distance to z*,

$$p_{\lambda}(x) \in \arg\min \begin{Bmatrix} (1-\lambda)\|c(z)-f(x)\| + \\ +\lambda\|z-z^{*}\| \end{Bmatrix} \quad (1)$$

regularization with regard to the distance to x,

$$p_{\lambda}(x) \in \arg\min \begin{Bmatrix} (1-\lambda)\|c(z)-f(x)\| + \\ +\lambda\|z-x\| \end{Bmatrix} \quad (2)$$

regularization using gradient information,

$$p_{\lambda}(x) \in \arg\min \begin{Bmatrix} (1-\lambda)\|c(z)-f(x)\| + \\ +\lambda\|z'(z)-f'(x)\| \end{Bmatrix} \quad (3)$$

With this theoretical introduction we are now in a position to introduce the algorithms.

3. THE OPTIMIZATION ALGORITHMS

ALG1: Original Space Mapping Algorithm.

The function ALG1 implements the original space mapping technique solving the problem using a trust region secant method. The secant method involves a linear Taylor model of the space mapping with a secant approximation to the Jacobian matrix.

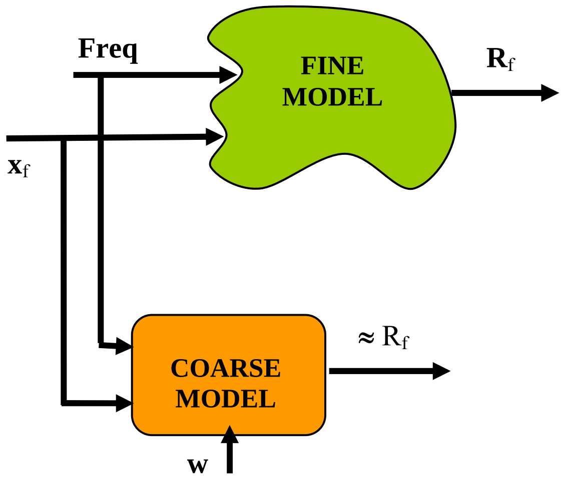

Fig. 1 ALG1

ALG2: Hybrid Space Mapping Algorithm.

The function ALG2 implements the hybrid space mapping algorithm, with a gradual switching between the mapped coarse model and the linear Taylor model of the fine model.

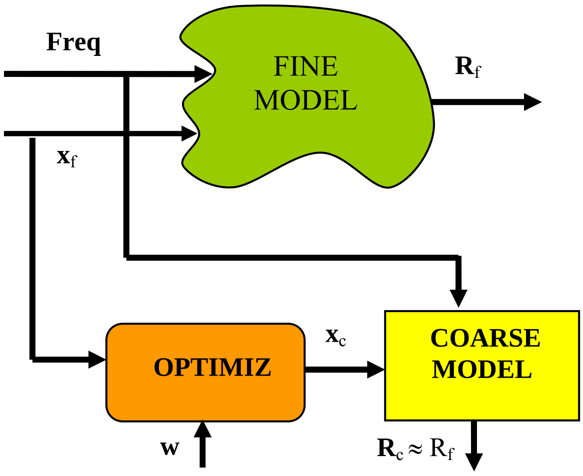

Fig. 2 ALG2

ALG3: Hybrid Space Mapping with Orthogonal Updates.

The function ALG3 implements a hybrid space mapping algorithm with orthogonal updating steps of the space mapping approximation. If the space mapping fails within the first n iterations the algorithm evaluates the fine model at a step in a direction orthogonal to previous steps, this is in order to improve the quality of the space mapping secant approximation. Which of the orthogonal directions that is chosen and the length of the step in that direction can be controlled by the options ortho met, ortho scale type and ortho scale. If a single orthogonal step is not sufficient, further steps are taken, until the fine model has been evaluated at most n times. Thereafter the algorithm switches to a linear Taylor model of the fine model.

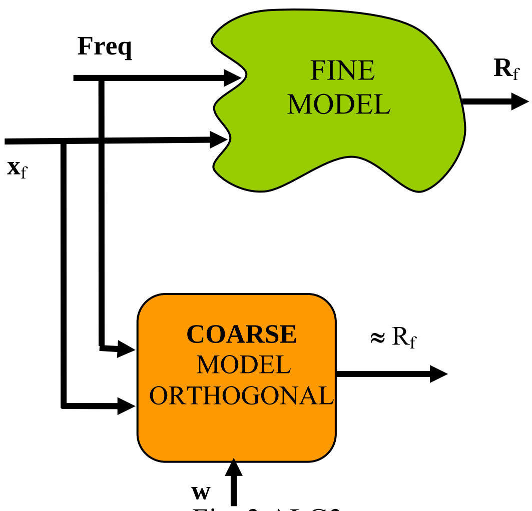

Fig. 3 ALG3

ALG4: Hybrid Space Mapping with Response Correction.

The function ALG4 implements a hybrid space mapping algorithm with response correction of the mapped coarse model.

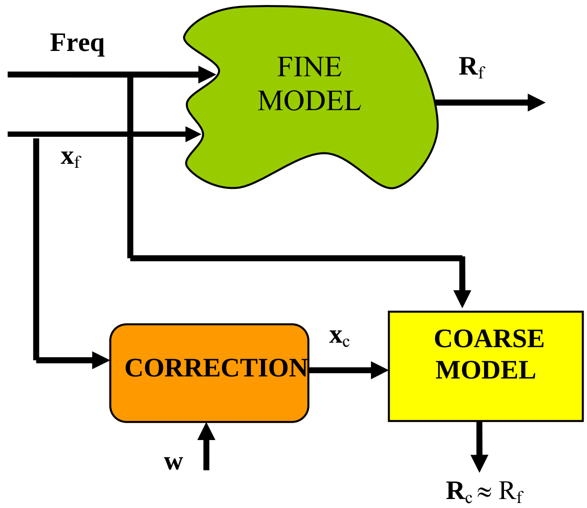

Fig. 4 ALG4

After software implementation for all four algorithms we run convergence tests on all microware RLC microwave circuits problems and the results for all problems are presented in [13] and the Exact non-linear mapping (RLCB) example Table 1.

Table 1 Exact non-linear mapping (RLCB)

	ALG.1	ALG.2	ALG.3	ALG.4
10^{0}	1	1	1	1
10^{-1}	65	2	2	2
10^{-2}	-	13	24	23
10^{-3}	-	-	59	67
10^{-4}	-	-	83	-
10^{-5}	-	-	93	-
10^{-6}	-	-	123	-
10^{-8}	-	-	139	-
10^{-10}	-	-	148	-
10^{-12}	-	-	152	-
10^{-14}	-	-	154	-
STOP	VE	VE	VE	VK

VK: The algorithm stop because the fine model evaluation reached the condition (3);
VE: The algorithm stop because the lengh of the last tentative step was to small.

4. CONCLUSION

The original space mapping algorithms are in general not preferable over any other algorithms we have studied and presented in this paper, exept special cases presented in [13]. It is most likely a better choice to initialize a direct, classical method with Jacobian approximation obtained from the course model, than to use the original space mapping algorithms.

The Hybrid Space Mapping algorithms showed good results for initial convergence and for microwave RLC circuits the Hybrid Space Mapping with Response Correction are recommended because of the good final convergence better to that of the direct, classical method started in the course model minimizer.

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