Expanded Space Mapping Design Framework Exploiting Preassigned Parameters

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Abstract — **We present a novel design framework for microwave circuits. We expand the original space mapping technique by allowing preassigned parameters (which are not used in optimization) to change in some components of the coarse model. We refer to those components as "relevant" components and we present a method based on sensitivity analysis to identify them. As a result, the coarse model can be calibrated to align with the fine model. Our algorithm establishes a mapping from some of the optimizable parameters to the preassigned parameters of the relevant components. This mapping is updated iteratively until we reach the optimal solution. We illustrate our approach through a microstrip design example.**

I. INTRODUCTION

The concept of calibrating coarse models (circuit based models) to align with fine models (typically an EM simulator) in microwave circuit design has been exploited by several authors [1]-[2]. In [1], this calibration is performed by means of optimizable parameter space transformation known as space mapping. In [2], this is done by adding circuit components to nonadjacent individual coarse model elements. Here, we expand the original space mapping technique [1]. We calibrate the coarse model by allowing some of the preassigned parameters (we call them the key preassigned parameters (KPP)) to change in some of the coarse model components. Examples of KPP are dielectric constant and substrate height in microstrip structures. We assume that the coarse model consists of several components such as transmission lines, junctions, etc. We decompose the coarse model into two sets of components. We allow the KPP to change in the first set and keep them intact in the

second set. We present a method based on sensitivity analysis to perform this decomposition.

At each iteration, our algorithm extracts the KPP such that the coarse model matches the fine model. Then it establishes a mapping from some of the optimizable parameters to the KPP. The mapped coarse model (the coarse model with the mapped KPP) is then optimized and compared with the fine model. If the fine model response satisfies the specifications the algorithm stops. Otherwise the algorithm extracts the KPP at the current solution and updates the mapping.

II. BASIC CONCEPTS AND DEFINITIONS

Consider a microwave circuit with two kinds of models: a fine model and a coarse model. We decompose the coarse model into two sets of components: Set A and Set B. In Set A, we allow the KPP of each component to change throughout the design process such that the coarse model matches the fine model. In Set B, we keep the KPP intact. The coarse model components in Set A are referred to as the relevant components. The vector x_0 contains the original values of the KPP and has a dimension of n_0. Assume that the total number of coarse model components is N, the number of components in the Set A is $m \leq N$ and the set I is defined by

$$I = \{1, 2, \cdots, N\} \quad (1)$$

The vector of the KPP of the components in Set A (the relevant components) is given by

$$x = [x_{j_1}^T \ x_{j_2}^T \ldots x_{j_m}^T]^T \quad (2)$$

where x_{j_i} is a vector containing the KPP of the ith relevant component and $j_1, j_2, \ldots, j_m \in I$. The dimension of the vector x is (mn_0). The vector x_f represents the optimization variables: it has a dimension of n. The responses of the fine and coarse models at the frequency points of interest are denoted by $R_f(x_f)$ and $R_c(x_f, x)$, respectively.

We assume that we can establish a mapping from some of the optimization variables to the vector x. This

mapping is established such that the coarse model aligns with the fine model. The mapping is given by

$$x = P(x_r) \tag{3}$$

$$x_f = [x_r^T \quad x_s^T]^T \tag{4}$$

where the dimension of the vector x_r is n_r. In this work, we assume that the mapping given by (3) is linear

$$x = c + B_r \, x_r \tag{5}$$

where B_r is a matrix of dimension $(mn_0) \times n_r$ and c is a vector of dimension (mn_0). Fig. 1 illustrates these concepts. The matrix B_r is sparse as we will see in the examples.

III. COARSE MODEL DECOMPOSITION

In this section, we present a method based on sensitivity analysis to decompose the coarse model components into two sets of components. The first set (Set A) contains those components that the coarse model response is very sensitive to any small change in their KPP. The second set (Set B) contains those components for which the coarse model response is insensitive to any change in their KPP. The method is summarized in the following steps.

Step 1 for all $i \in I$ in (1) evaluate

$$S_i = \left\| \left(\frac{\partial R_c^T}{\partial x_i} D \right)^T \right\|_F \tag{6}$$

where the matrix D is for scaling.
Step 2 Evaluate

$$\hat{S}_i = \frac{S_i}{\max_{j \in I} \{ S_j \}}, i \in I \tag{7}$$

Step 3 Put the ith component in Set A if $\hat{S}_i \geq \delta$ otherwise put it in Set B.

The matrix D is a diagonal matrix whose elements are the values of the original KPP (that is the elements of the vector x_0). The scalar δ is a small positive number less than 1. In this work we set $\delta = 0.2$.

IV. THE ALGORITHM

A. General Description

The algorithm starts by decomposing the coarse model into two sets of components as shown in Section III. The initial values for the mapping parameters B_r and c are 0 and X_0, where
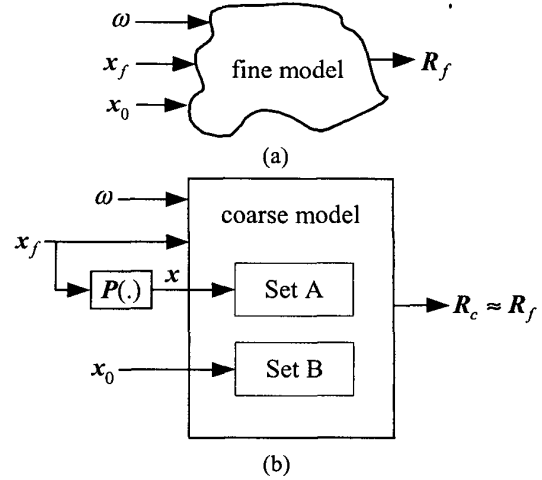

Fig. 1. Changing the KPP in some of the coarse model components (the components in Set A) results in aligning the coarse model (b) with the fine model (a).

$$X_0 = [x_0^T \cdots x_0^T]^T \tag{8}$$

At the ith iteration the algorithm obtains the optimal solution of the mapped (enhanced) coarse model by solving

$$x_f^{(i)} = \arg \min_{x_f} U(R_c(x_f, B_r \, x_r + c)) \tag{9}$$

where U is an appropriate objective function. The fine model is simulated at the mapped coarse model solution $x_f^{(i)}$. The algorithm stops if the fine model satisfies the specifications or the solutions obtained in two successive iterations are very close $\left\| x_f^{(i)} - x_f^{(i-1)} \right\| \leq \varepsilon$. If the stopping criteria are not satisfied the algorithm extracts the vector of the KPP $x^{(i)}$ corresponding to $x_f^{(i)}$

$$x^{(i)} = \arg \min_x \left\| R_f(x_f^{(i)}) - R_c(x_f^{(i)}, x) \right\| \tag{10}$$

The mapping parameters B_r and c are updated at every iteration by solving a system of linear equations. In the first few iterations we have an underdetermined system of linear equations which has an infinite number of solutions. We choose the minimum norm solution which makes the KPP as close as possible to their original value. That is, we choose B_r as close as possible to 0 and c as close as possible to X_0 in (8). The flow chart of the algorithm is shown in Fig. 2.
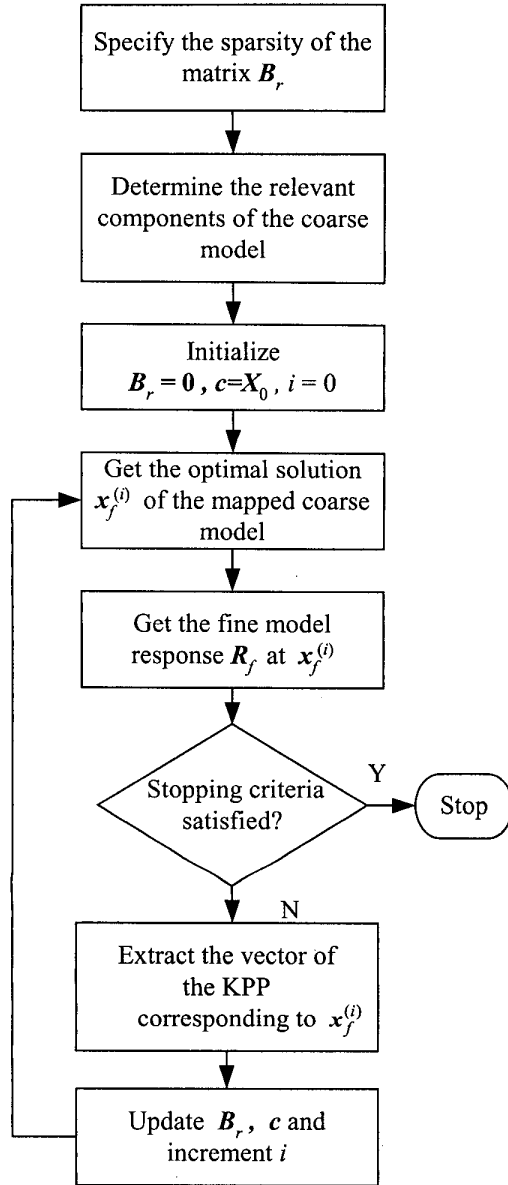
Fig. 2.   The flow chart of the algorithm.

B. Software Implementation

The algorithm is currently implemented in Matlab™ [3]. The user should write a text input file which includes the coarse and fine model names and directories, the frequency range and the design specifications. The current implementation can drive OSA90/hope [4] as a circuit simulator and Sonnet's *em* [5] through OSA90/hope [4].

It also uses the optimizers in OSA90/hope. Driving other EM/circuit simulators in an automatic way is not trivial from inside a programming environment such as Matlab™. In our lab, we have developed a tool to drive such simulators. This tool is a Windows based program which calls the commercial EM simulator, opens the proper windows and fills in the necessary information required to simulate a microwave structure. We created such a tool for driving Momentum [6].

IV. THREE-SECTION MICROSTRIP TRANSFORMER

In this example we consider a 3:1 impedance microstrip transformer (Fig. 3(a)). The source and load impedances are 50 and 150 Ω, respectively. The design specifications are

$$|S_{11}| \leq -20\text{dB, for 5GHz} \leq \omega \leq 15\text{GHz}$$

The fine model is analyzed by Sonnet's *em* [5]. The coarse model in Fig. 3(b) is analyzed by OSA90/hope [4]. The optimization variables are the widths and the lengths of the microstrip transmission lines in Fig. 3(a). That is,

$$x_f = [W_1\ W_2\ W_3\ L_1\ L_2\ L_3\ ]^T$$

The KPP are the dielectric constant $\varepsilon_r = 9.7$ and the substrate height $H = 25\text{mil}$. Therefore, the vector $x_0 = [25\text{mil } 9.7]^T$.

The coarse model consists of five components as shown in Fig. 3(b). The algorithm applies the coarse model decomposition technique in Section III. The sensitivity of the coarse model response to any change in the KPP of the ith component is shown in Table I. Therefore, the algorithm chooses the components 1, 3 and 5 as the relevant components. The vector of the KPP of those components is given by

$$x = [x_1^T\ x_3^T\ x_5^T\ ]^T$$

where $x_i = [\varepsilon_{ri}\ H_i]^T$, i=1,3,5. The vector x_r in (5) is given by

$$x_r = [W_1\ W_2\ W_3\ ]^T$$

The matrix B_r is sparse

$$B_r = \begin{bmatrix} x\ x\ 0\ 0\ 0\ 0 \\ 0\ 0\ x\ x\ 0\ 0 \\ 0\ 0\ 0\ 0\ x\ x \end{bmatrix}^T$$

where x denotes a nonzero entry. The algorithm takes three iterations (four fine model simulations) to reach the

(a)

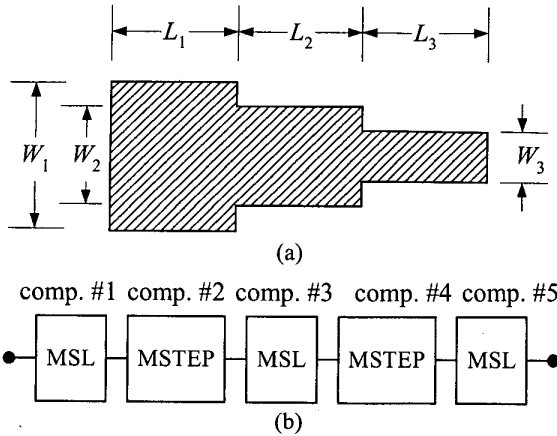comp. #1 comp. #2 comp. #3 comp. #4 comp. #5

(b)

Fig. 3.   The 3:1 microstrip transformer (a); the coarse model (b).

TABLE I
COARSE MODEL SENSITIVITIES TO ANY CHANGE IN THE KPP
OF THE COARSE MODEL COMPONENTS

Component #	$\hat{S}_i$
1	1
2	0.0454
3	0.3886
4	0.0365
5	0.7651

optimal solution

$x_f = [0.3348\ 0.1355\ 0.0383\ 2.9903\ 3.0794\ 3.1389]^T$

where all parameters are in mm. The result at the final iteration is shown in Fig. 4.
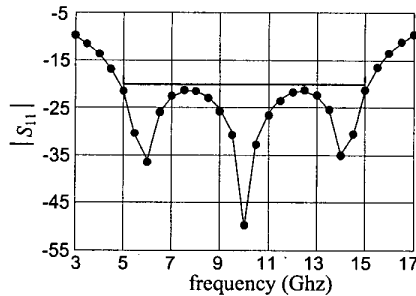

Fig. 4.   The fine (•) and mapped coarse model (—) response of the microstrip transformer at the final iteration.

V. CONCLUSION

We expand the original space mapping technique for circuit design. We deliberately change the KPP in some of the coarse model components to align the coarse model with the fine model. A mapping is established from the optimization variables to the KPP. This mapping is sparse and needs only few fine model simulations to be fully established. The mapping is updated iteratively until we reach the optimal solution. We have successfully applied our approach to several design problems.

ACKNOWLEDGEMENT

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