# Implicit Space Mapping EM-Based Modeling and Design Exploiting Preassigned Parameters

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*Abstract* — **We present a simple new approach to EM-based microwave modeling and design. It is a special case of a novel concept we call Implicit Space Mapping. We propose to calibrate a suitable coarse model against a fine model (full wave EM simulation) by relaxing certain coarse model preassigned parameters. Our algorithm updates these preassigned parameters through parameter extraction, reoptimizes the coarse model to suggest a new EM design and terminates when relevant stopping criteria are satisfied. We illustrate our approach through an HTS filter example.**

## I. Introduction

The Space Mapping (SM) concept of using coarse models (computationally fast circuit-based models) to align with fine models (typically CPU intensive full-wave EM simulations) has been exploited by several authors [1]-[8]. Several notable implementations of SM have been reported. Pavio presented a companion approach [6]. Snel [7] derived models for RF components. Swanson and Wenzel [8] used SM to optimize mechanical adjustments by iterating between a finite element simulator and circuit simulator.

In [1]-[3], a calibration is performed through a mapping between optimizable parameters of the fine model and corresponding parameters of the coarse model such that their responses match. This mapping is iteratively updated. In [4], the coarse model is calibrated against the fine model by adding circuit components to nonadjacent individual coarse model elements. The component values are updated iteratively. The ESMDF algorithm [5] calibrates the coarse model by extracting certain preassigned parameters such that corresponding responses match. It establishes an explicit mapping from optimizable to preassigned parameters.

Our new approach does not establish an explicit mapping. In each iteration we extract selected preassigned parameters to match the coarse model with the fine model. With these fixed, we reoptimize the calibrated coarse model. Then we assign its optimized parameters to the fine model. We repeat this process until the fine model response is sufficiently close to the target response. The preassigned parameters, which are updated, accommodate the “mapping”. It is a special case of a new concept we call Implicit Space Mapping (ISM).

Examples of preassigned parameters are dielectric constant and substrate height in microstrip structures. Typically, they are not formally optimized. As in [5] we allow the preassigned parameters (of the coarse model) to change in some components and keep them intact in others.

We implement our technique in Agilent ADS [9].

## II. Implicit Space Mapping (ISM)

We denote the fine model responses at a point $\boldsymbol{x}_f$ by $\boldsymbol{R}_f(\boldsymbol{x}_f)$. The original design problem is

$$\boldsymbol{x}_f^* = \arg\min_{\boldsymbol{x}_f} U(\boldsymbol{R}_f(\boldsymbol{x}_f)) \tag{1}$$

where $U$ is the objective function and $\boldsymbol{x}_f^*$ is the optimal fine model design. Solving (1) using direct optimization methods may be prohibitive.

We denote by $\boldsymbol{x}_c$ a coarse model point and by $\boldsymbol{x}$ a set of other (auxiliary) parameters, for example, preassigned parameters. The corresponding coarse model response vector is $\boldsymbol{R}_c(\boldsymbol{x}_c, \boldsymbol{x})$.

As indicated in Fig. 1, ISM aims at establishing an implicit mapping $\boldsymbol{Q}$ between the spaces $\boldsymbol{x}_f$, $\boldsymbol{x}_c$ and $\boldsymbol{x}$

$$\boldsymbol{Q}(\boldsymbol{x}_f, \boldsymbol{x}_c, \boldsymbol{x}) = \boldsymbol{0} \tag{2}$$

such that

$$\boldsymbol{R}_f(\boldsymbol{x}_f) \approx \boldsymbol{R}_c(\boldsymbol{x}_c, \boldsymbol{x}) \tag{3}$$

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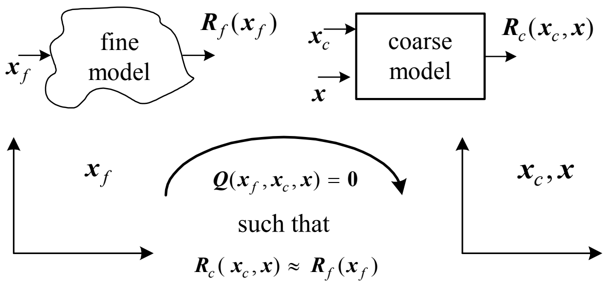



Fig. 1. Illustration of Implicit Space Mapping (ISM).

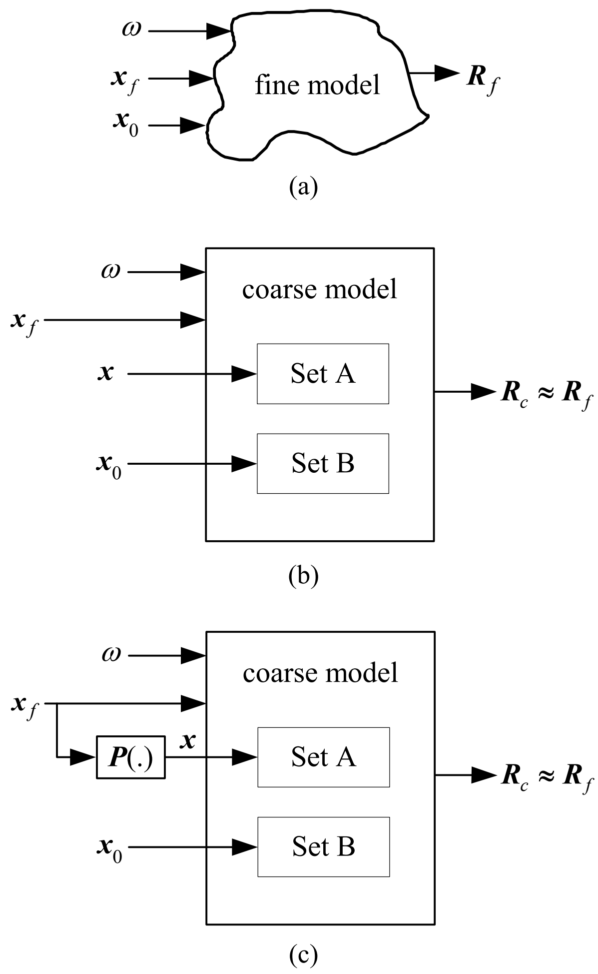



Fig. 2. Calibrating (optimizing) the preassigned parameters $\boldsymbol{x}$ in Set A results in aligning the coarse model (b) or (c) with the fine model (a). In (c) we illustrate the ESMDF approach [5], where $\boldsymbol{P}(\cdot)$ is a mapping from optimizable design parameters to preassigned parameters.

over a region in the parameter space. In general, ISM optimization obtains a space-mapped design $\bar{\boldsymbol{x}}_f$ whose response approximates an optimized $\boldsymbol{R}_c$ target. $\bar{\boldsymbol{x}}_f$ is a solution of the nonlinear system

$$\boldsymbol{Q}(\boldsymbol{x}_f, \boldsymbol{x}_c^*, \boldsymbol{x}) = \boldsymbol{0} \tag{4}$$

which is enforced through a Parameter Extraction (PE) procedure w.r.t. $\boldsymbol{x}_c$ and $\boldsymbol{x}$, and subsequent prediction (optimization) of the next fine model iterate. The first step in all SM-based algorithms obtains an optimal coarse model design $\boldsymbol{x}_c^*$ for given $\boldsymbol{x}$. The corresponding response is denoted by $\boldsymbol{R}_c^*$. In ISM $\boldsymbol{x}_c^*$ depends on the current value of $\boldsymbol{x}$. It will change iteratively.

We have developed a new theory for ISM. It can be shown that existing SM formulations are special cases of the theory.

## III. An Algorithm

In Fig. 2 we represent a microwave circuit whose coarse model is decomposed. We categorize the preassigned parameters into two sets as in [5]: Set A of "designated" components and Set B. In Set A, we vary certain preassigned parameters $\boldsymbol{x}$. In Set B, we keep preassigned parameters $\boldsymbol{x}_0 \in \Re^{n_0}$ fixed. We can follow the sensitivity approach of [5] to formally select components for Set A and Set B.

As implied in Fig. 2(b), in each iteration of PE

$$\boldsymbol{x}_c = \boldsymbol{x}_f^{(i)} \tag{5}$$

Notice from Fig. 2(b) that we do not explicitly establish a mapping between the optimizable parameters and the preassigned parameters. This contrasts with [5], where the mapping is explicit (see Fig. 2(c)). Therefore, our proposed approach is easier to implement in commercial microwave simulators.

After PE w.r.t $\boldsymbol{x}$, we obtain the coarse model parameters $\boldsymbol{x}_c$ by optimization. Then we set (prediction)

$$\boldsymbol{x}_f = \boldsymbol{x}_c^{*(i)} \tag{6}$$

where

$$\boldsymbol{x}_c^{*(i)} = \arg\min_{\boldsymbol{x}_c} U(\boldsymbol{R}_c(\boldsymbol{x}_c, \boldsymbol{x}^{(i)})) \tag{7}$$

*Summary of the Algorithm*

*Step* 1 Select candidate preassigned parameters $\boldsymbol{x}$ as in [5] or through experience.

*Step* 2 Set $i = 0$ and initialize $\boldsymbol{x}^{(0)}$.

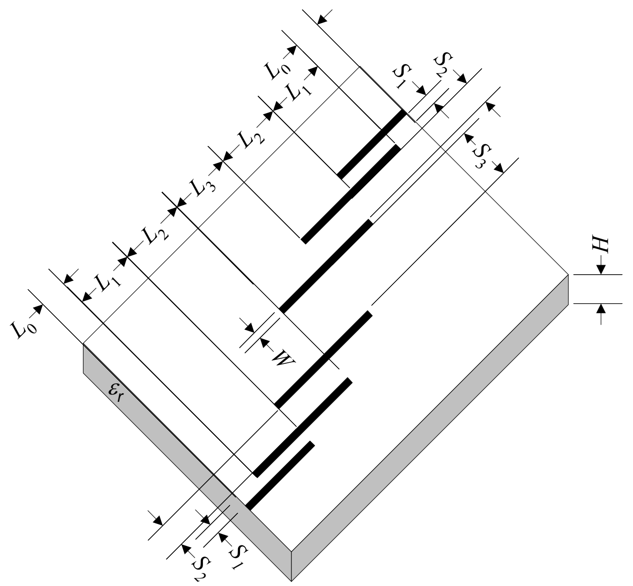
*Step* 3  Obtain the optimal *coarse model* parameters by solving (7) and predict $x_f^{(i)}$ from (6).

*Step* 4  Simulate the fine model at $x_f^{(i)}$. Terminate if a stopping criterion (e.g., response meets specifications) is satisfied.

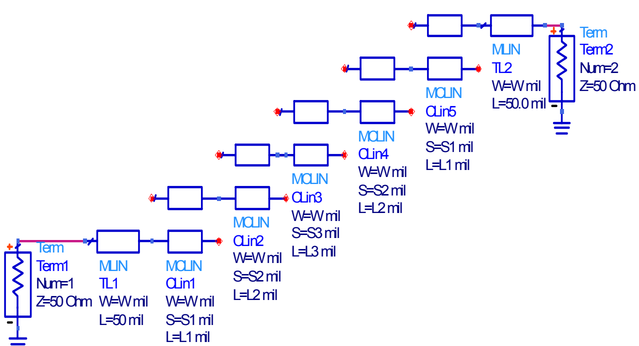
*Step* 5  Calibrate the coarse model by extracting the preassigned parameters $\boldsymbol{x}$ (noting (5))

$$\boldsymbol{x}^{(i+1)} = \arg \min_{\boldsymbol{x}} \left\| \boldsymbol{R}_f(\boldsymbol{x}_f^{(i)}) - \boldsymbol{R}_c(\boldsymbol{x}_f^{(i)}, \boldsymbol{x}) \right\|$$

*Step* 6  Increment $i$ and go to Step 3.




(a)




(b)

Fig. 3. The HTS filter [10]: (a) the physical structure and (b) the coarse model as implemented in Agilent ADS [9].

## IV. HTS Filter Example

We consider the HTS bandpass filter in [10]. The physical structure is shown in Fig. 3(a). Design variables are the lengths of the coupled lines and the separation between them, namely,

$$\boldsymbol{x}_f = [S_1 \; S_2 \; S_3 \; L_1 \; L_2 \; L_3]^T$$

The substrate used is lanthanum aluminate with $\varepsilon_r$= 23.425, $H$= 20 mil and substrate dielectric loss tangent of 0.00003. The length of the input and output lines is $L_0$=50 mil and the lines are of width $W$= 7 mil. We choose $\varepsilon_r$ and $H$ as the preassigned parameters of interest, thus $\boldsymbol{x}_0$=[20 mil 23.425]$^T$. The design specifications are

$$|S_{21}| \le 0.05 \quad \text{for } \omega \ge 4.099 \text{ GHz and for } \omega \le 3.967 \text{ GHz}$$

$$|S_{21}| \ge 0.95 \quad \text{for } 4.008 \text{ GHz} \le \omega \le 4.058 \text{ GHz}$$

This corresponds to 1.25% bandwidth.

Our Agilent ADS [9] coarse model consists of empirical models for single and coupled microstrip transmission lines, with ideal open stubs. See Fig. 3(b). Set A consists of the three coupled microstrip lines. Notice the symmetry in the HTS structure, i.e., coupled lines 5 "CLin5" is identical to "CLin1" and "CLin4" is identical to "CLin2". Here, Set B is empty. The preassigned parameter vector is

$$\boldsymbol{x} = [\varepsilon_{r1} \; H_1 \; \varepsilon_{r2} \; H_2 \; \varepsilon_{r3} \; H_3]^T$$

The fine model is simulated by Agilent Momentum [11]. The relevant responses at the initial solution are shown in Fig. 4(a), where we notice severe misalignment. The algorithm requires only 3 iterations (3 fine model simulations). The total time taken is 26 min (one fine model simulation takes approximately 9 min on an Athlon 1100 MHz). Table I shows initial and final designs. Table II shows the variation in the preassigned (coarse model) parameters. Responses at the final iteration are shown in Fig. 4(b).

The PE uses real and imaginary $S$ parameters and the ADS quasi-Newton optimizer, while coarse model optima are obtained by the ADS minimax optimizer.

## V. Conclusions

We present an effective technique for microwave circuit modeling and design w.r.t. full-wave EM simulations. We vary preassigned parameters in a coarse model to align it with the EM (fine) model. Since explicit mapping is not involved this "Space Mapping" technique is more easily implemented than [5]. The HTS filter design is entirely done by Agilent ADS and Momentum, with no matrices to keep track of.

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TABLE I
OPTIMIZABLE PARAMETER VALUES OF THE HTS FILTER

| Parameter | Initial solution | Solution reached by the algorithm |
|---|---|---|
| $L_1$ | 189.65 | 187.10 |
| $L_2$ | 196.03 | 191.30 |
| $L_3$ | 189.50 | 186.97 |
| $S_1$ | 23.02 | 22.79 |
| $S_2$ | 95.53 | 93.56 |
| $S_3$ | 104.95 | 104.86 |
| all values are in mils | | |

TABLE II
THE INITIAL AND FINAL PREASSIGNED PARAMETERS OF THE CALIBRATED COARSE MODEL OF THE HTS FILTER

| Preassigned parameters | Original values | Final iteration |
|---|---|---|
| $H_1$ | 20 mil | 19.80 mil |
| $H_2$ | 20 mil | 19.05 mil |
| $H_3$ | 20 mil | 19.00 mil |
| $\varepsilon_{r1}$ | 23.425 | 24.404 |
| $\varepsilon_{r2}$ | 23.425 | 24.245 |
| $\varepsilon_{r3}$ | 23.425 | 24.334 |

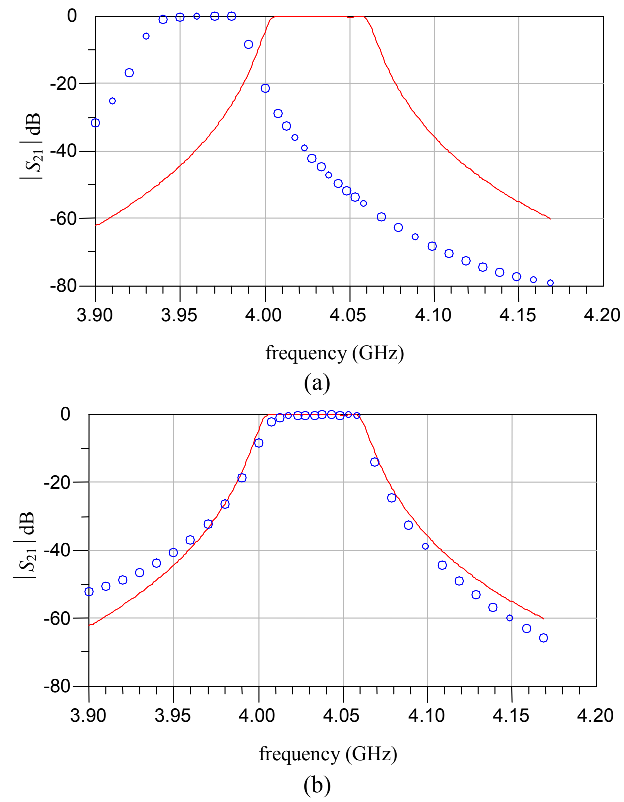


Fig. 4. The fine (○) and optimal coarse model (—) responses at the initial solution (a) and at the final iteration (b).

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