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A GENERALIZED SPACE MAPPING TABLEAU APPROACH TO DEVICE MODELING

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Abstract
A novel, comprehensive framework to engineering device modeling called Generalized Space Mapping (GSM) is introduced. The accuracy of available empirical models of microwave devices can be significantly enhanced by exploiting GSM. The new concept is verified on several device modeling problems, typically utilizing very few full-wave EM simulations, yielding remarkable improvement in accuracy.

Introduction

We generalize Space Mapping (SM) [1], Frequency Space Mapping (FSM) [2] and Multiple Space Mapping (MSM) [3] to build a new engineering device modeling framework called Generalized Space Mapping (GSM). This framework is flexible enough to permit a number of implementable special cases. An exciting observation is that GSM closely follows sound engineering design practice. Our contribution is a straightforward mathematical formulation suitable for device modeling with a clear practical interpretation. It is expected to be useful in assisting designers to evaluate the accuracy of empirical models and/or to discriminate between them. Intuitively meaningful quantitative measures of model accuracy can be developed through careful interpretations of GSM.

Two fundamental special cases are presented. One is a basic Space Mapping Super Model (SMSM) which maps designable device parameters and the other is a basic Frequency-Space Mapping Super Model (FSMSM) which maps the frequency variable as well as the designable device parameters.

Brief Summary of The GSM Concept

Two spaces are defined in GSM. The first space is called the EM space or the "fine" model space. It contains the physical parameters of the microwave device to be analyzed. The second space is called the "coarse" model space or the empirical model space, representing the transformed physical parameters.

Consider a device with physical parameters represented by an n-dimensional vector $\boldsymbol{x}_f$. The response $\boldsymbol{R}_c(\boldsymbol{x}_f)$ produced by the empirical model deviates from the response $\boldsymbol{R}_f(\boldsymbol{x}_f)$ produced by an EM simulator. Therefore, the aim is to find a new set of parameters represented by an n-dimensional vector $\boldsymbol{x}_c$ such that $\boldsymbol{R}_c(\boldsymbol{x}_c) \approx \boldsymbol{R}_f(\boldsymbol{x}_f)$ in a specified frequency range and over a certain region of parameters. We assume a linear mapping $\boldsymbol{P}$ from the fine model space to the coarse model space [1] over a specified region of parameters in the fine model space: $\boldsymbol{x}_c = \boldsymbol{P}(\boldsymbol{x}_f) = \boldsymbol{c} + \boldsymbol{B}\,\boldsymbol{x}_f$, where $\boldsymbol{c}$ is a constant vector of dimension n and $\boldsymbol{B}$ is an n x n matrix. We call this the Space Mapping Super Model (SMSM) concept (Fig. 1(a)).

In SMSM, the frequency variable used in the two models is the same. However, a better match between the model responses can be achieved by using a transformed frequency in the coarse model [2]. We call this the Frequency-Space Mapping Super Model (FSMSM), in which we map both the fine model parameters and frequency. There are many variations of FSMSM, including the general case (Fig. 1(b)) in which the coarse model parameters and transformed frequency depend on the fine model parameters and frequency. The mapping is $(\boldsymbol{x}_c, \omega_c) = \boldsymbol{P}(\boldsymbol{x}_f, \omega)$, where ω_c and ω are the coarse and fine model frequencies, respectively.

Multiple Space Mapping (MSM) was introduced in [3]. There are different ways to apply MSM to device modeling. One way is to divide the device response vector $\boldsymbol{R}$ (in both models) into N subset of responses (or

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vectors) $\boldsymbol{R_k}$, $k = 1, 2, ...N$. An individual mapping is established for each sub-response as illustrated in Fig. 2. The *k*th mapping targeting the sub-response $\boldsymbol{R}_k$ is given by

$$(\boldsymbol{x}_{ck}, \omega_{ck}) = \boldsymbol{P}_k(\boldsymbol{x}_f, \omega) \tag{1}$$

Or, in matrix form, assuming a linear mapping,

$$\begin{bmatrix} \boldsymbol{x}_{ck} \\ \omega_{ck} \end{bmatrix} = \begin{bmatrix} \boldsymbol{c}_k \\ \delta_k \end{bmatrix} + \begin{bmatrix} \boldsymbol{B}_k & \boldsymbol{s}_k \\ \boldsymbol{t}_k^T & \sigma_k \end{bmatrix} \begin{bmatrix} \boldsymbol{x}_f \\ \omega \end{bmatrix} \tag{2}$$

where $\{\boldsymbol{c}_k, \boldsymbol{B}_k, \boldsymbol{s}_k, \delta_k, \boldsymbol{t}_k, \sigma_k\}$ are the parameters characterizing the mapping $\boldsymbol{P}_k$. These mapping parameters can be evaluated, directly or indirectly, by solving the optimization problem

$$\min_{\boldsymbol{c}_k, \boldsymbol{B}_k, \boldsymbol{s}_k, \delta_k, \boldsymbol{t}_k, \sigma_k} \left\| \begin{bmatrix} \boldsymbol{e}_{k1}^T & \boldsymbol{e}_{k2}^T & \cdots & \boldsymbol{e}_{km}^T \end{bmatrix}^T \right\| \tag{3}$$

where *m* is the number of base points selected in the fine model space and $\boldsymbol{e}_{kj}$ is an error vector given by

$$\boldsymbol{e}_{kj} = \boldsymbol{R}_f(\boldsymbol{x}_f^{(j)}, \omega) - \boldsymbol{R}_c(\boldsymbol{x}_{ck}^{(j)}, \omega_{ck}), \quad j = 1,2,...,m \tag{4}$$

subject to suitable constraints on the mapping parameters, as discussed in the full paper.

An important variation of the mapping in (2), to be described, is to use the inverse of the frequency variable (which is proportional to the wavelength) instead of the frequency itself.

Typical Examples

For the microstrip right angle bend (Fig. 3), the fine model is analyzed by Sonnet's ***em*** [4]. The "coarse" model is taken from [5]. The FSMSM was applied (with inverse frequency variable) in the region 20 mil $\le W \le$ 30 mil, 8 mil $\le H \le$ 16 mil and $8 \le \varepsilon_r \le 10$ over the range 1 GHz to 41 GHz. The modulus of complex S_{21} error before and after applying FSMSM at 50 points is shown in Figs. 4(a) and (b), respectively.

For the microstrip step junction (Fig. 5), the fine model is analyzed by Sonnet's ***em*** [4]. The "coarse" model is an element of OSA90/hope [6]. Parameters are junction widths W_1 and W_2, substrate height *H* and relative dielectric constant ε_r. The region of interest is 20 mil $\le W_1 \le$ 40 mil, 10 mil $\le W_2 \le$ 20, 10 mil $\le H \le$ 20 mil and $8 \le \varepsilon_r \le 10$. The frequency range considered is 2 GHz to 40 GHz. There are six responses to be matched: the real and imaginary parts of S_{11}, S_{21} and S_{22}. It is difficult to establish one mapping to match all responses simultaneously, therefore we use MSM as in Fig. 2, with the response sets {Im[S_{11}], Im[S_{21}], Im[S_{22}], Re[S_{21}])} and {Re[S_{11}], Re[S_{22}]}. (Space, here, does not permit a description of the algorithm for creating these responses sets.) A separate FSMSM (with inverse frequency variable) targeting each set was established. The MSM-FSMSM empirical model of the step junction was tested at 50 uniformly distributed random points. The modulus of complex S_{21} error after applying MSM-FSMSM is shown in Fig. 6.

Conclusions

The powerful new GSM approach to device modeling is introduced. Our paper will provide full details of the SMSM concept, the FSMSM concept and the MSM concept. Our approach typically uses only a few EM simulations to dramatically enhance the accuracy of existing empirical device models. It is easy to implement and preserves the compactness and simplicity of the original empirical models. The GSM approach is an effective CAD tool in terms of CPU time, memory requirement, ease of use and accuracy.

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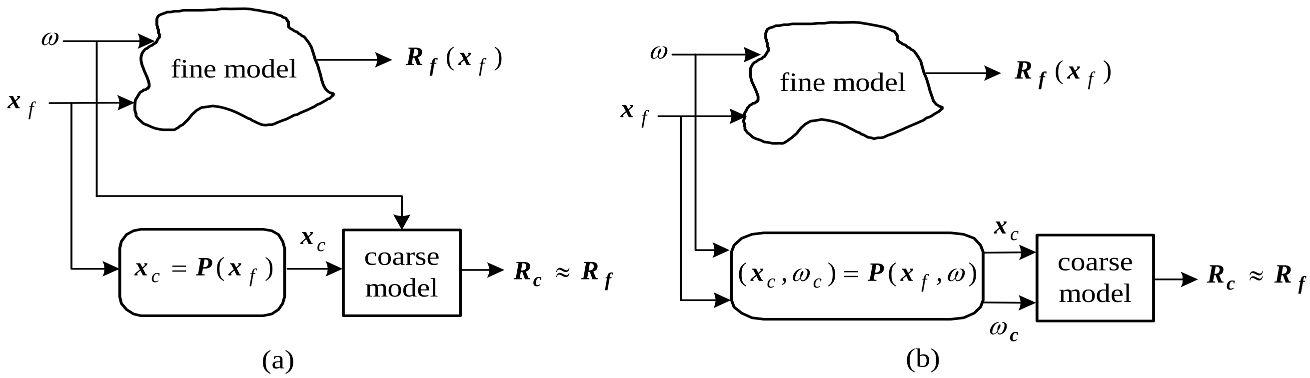

Fig. 1. The Space Mapping Super Model (SMSM) concept (a) and the Frequency-Space Mapping Super Model (FSMSM) concept (b).

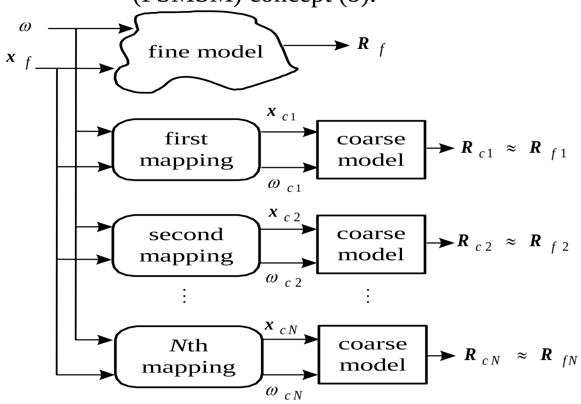

Fig. 2. The Multiple Space Mapping (MSM) concept for different device responses.

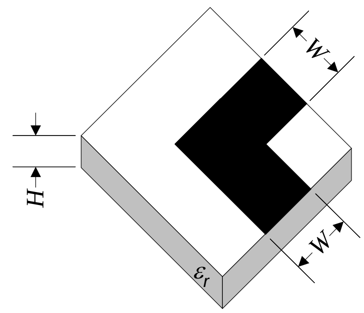

Fig. 3. Microstrip right angle end.

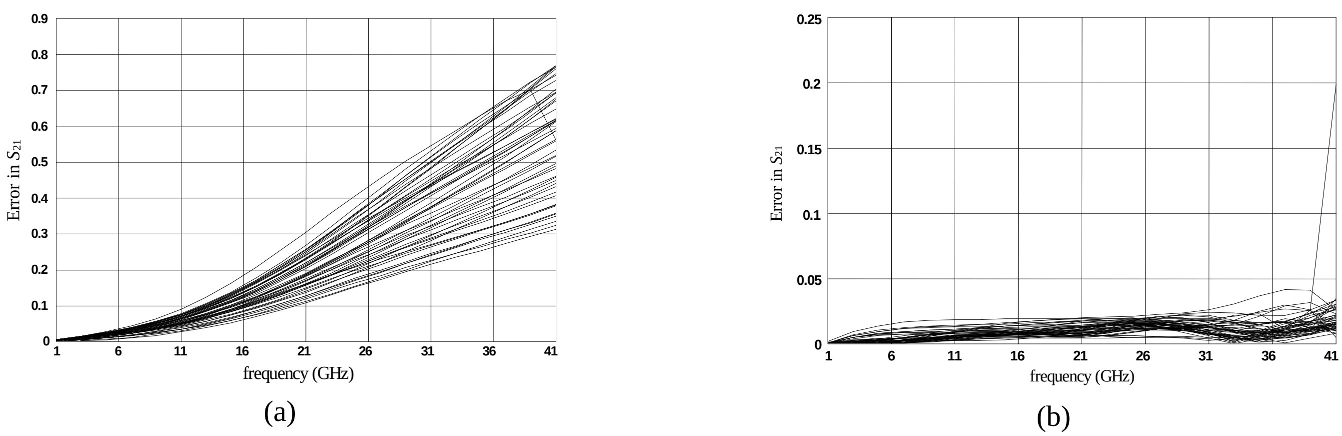

Fig. 4. Jansen empirical model [5] of the right angle bend: (a) modulus of the complex S_{21} error before applying FSMSM; (b) modulus of the complex S_{21} error after applying FSMSM.

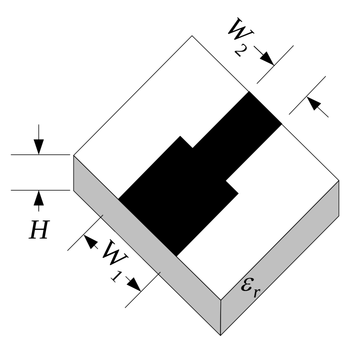

Fig. 5. Microstrip step junction.

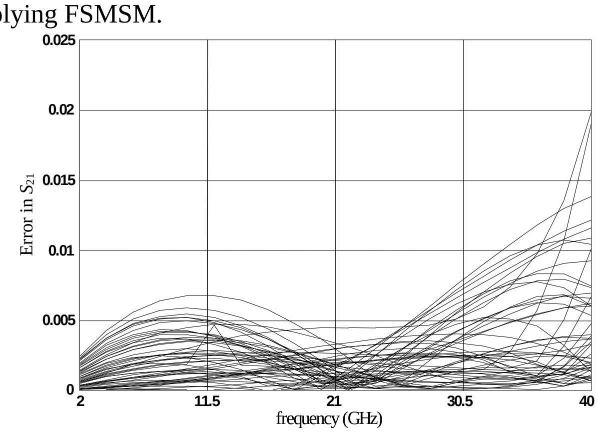

Fig. 6. Modulus of the complex S_{21} error for the MSM-FSMSM microstrip step junction.