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MICROWAVE DEVICE MODELLING EXPLOITING GENERALIZED SPACE MAPPING

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Abstract We present a comprehensive framework to engineering device modeling which we call Generalized Space Mapping (GSM). GSM significantly enhances the accuracy of available empirical models of microwave devices by utilizing a few relevant full-wave EM simulations. Our approach has been verified on several modeling problems. We present a microstrip shaped T-junction example.

I. INTRODUCTION

We generalize the Space Mapping (SM) [1], the Frequency Space Mapping (FSM) [2] and the Multiple Space Mapping (MSM) [3] concepts to build a new engineering device modeling framework. We refer to the concept generically as the Generalized Space Mapping (GSM) concept. GSM is expected to be useful in assisting designers to evaluate the accuracy of empirical models and/or to discriminate between them.

Three fundamental cases are presented: Space Mapping Super Model (SMSM) which maps designable device parameters, a basic Frequency-Space Mapping Super Model (FSMSM) which maps the frequency variable as well as the designable device parameters and Multiple Space Mapping (MSM). We present two variations of MSM: MSM for Device Responses (MSMDR) and MSM for Frequency Intervals (MSMFI). Two model types are defined in the SM process: a "coarse" model, typically an empirical model, and a "fine" model, typically a full-wave EM simulator.

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II. THE GSM CONCEPT

Consider a microwave device with physical parameters represented by an n-dimensional vector $\boldsymbol{x}_f$. In general, the response $\boldsymbol{R}_c(\boldsymbol{x}_f, \omega)$ produced by the coarse model deviates from the response $\boldsymbol{R}_f(\boldsymbol{x}_f, \omega)$ produced by an EM simulator, where ω is the frequency variable. Therefore, the aim is to find a mapping from the fine model parameters and the frequency variable to a new set of parameters and a new frequency variable so that the responses of the two models match. The mapped coarse model parameters are represented by an n-dimensional vector $\boldsymbol{x}_c$ and the mapped frequency variable is represented by ω_c. We call this scheme Frequency-Space Mapping Super Model (FSMSM) as illustrated in Fig. 1. A special case of FSMSM is to map only the fine model parameters and leave the frequency variable unchanged. We call this the Space Mapping Super Model (SMSM). Once FSMSM or SMSM are established the enhanced coarse model can be utilized for analysis or design purposes.

The mapping relating the fine model parameters and frequency to the coarse model parameters and frequency is given by

$$[\boldsymbol{x}_c \quad \omega_c]^T = \boldsymbol{P}(\boldsymbol{x}_f, \omega) \tag{1}$$

Or, in matrix form, assuming a linear mapping,

$$\begin{bmatrix} \boldsymbol{x}_c \\ \omega_c^{-1} \end{bmatrix} = \begin{bmatrix} \boldsymbol{c} \\ \delta \end{bmatrix} + \begin{bmatrix} \boldsymbol{B} & \boldsymbol{s} \\ \boldsymbol{t}^T & \sigma \end{bmatrix} \begin{bmatrix} \boldsymbol{x}_f \\ \omega^{-1} \end{bmatrix} \tag{2}$$

where $\{\boldsymbol{c}, \boldsymbol{B}, \boldsymbol{s}, \delta, \boldsymbol{t}, \sigma\}$ are the parameters characterizing the mapping $\boldsymbol{P}$. The constant vectors $\boldsymbol{c}$, $\boldsymbol{s}$, $\boldsymbol{t}$ are n-dimensional, $\boldsymbol{B}$ is an n x n matrix and δ, σ are scalar. The mapping parameters in (2) are evaluated by matching the coarse model with the fine model at some base points in the region of interest [4].

The numerical values of the mapping parameters in (2) can give the designer physically-based intuitive information on the entire modeling process. The deviation of the optimal values of these parameters from those corresponding to a unit mapping indicates the degree of proximity between the coarse and fine model. This important feature can be used to compare between two coarse models.

III. MULTIPLE SPACE MAPPING (MSM)

Multiple Space Mapping (MSM) was introduced in [3]. We present two variations of MSM for device modeling. We refer to them as MSM for Device Responses (MSMDR) and MSM for Frequency Intervals (MSMFI). In MSMFI we divide the frequency range of interest into M intervals and evaluate a separate mapping for each interval as illustrated in Fig. 2. In MSMDR we divide the device response vector $\boldsymbol{R}$ (in both models) into L subsets of responses (or vectors) $\boldsymbol{R}_i, i = 1, 2, ..., L$. An individual mapping is established for each subset of responses. For more details about the development of MSMDR and MSMFI the reader is referred to [4].

IV. CASE STUDY

Microstrip Shaped T-Junction

In this example we consider a shaped T-junction (Fig. 3(a)). The T-junction is symmetric in the sense that all input lines have the same width *w*. The fine model is analyzed by Sonnet's ***em*** [5] and the coarse models is composed of empirical models of simple microstrip elements (see Fig. 3(b)) of OSA90/hope [6]. The fine and coarse model parameters are given by $\boldsymbol{x}_f = [\, w \;\; h \;\; w_1 \; w_2 \; x \; y \;\; \varepsilon_r \,]^T$, $\boldsymbol{x}_c = [\, w_c \;\; h_c \; w_{1\mathrm{c}} \; w_{2\mathrm{c}} \; x_c \; y_c \;\; \varepsilon_{cr} \,]^T$. The region of interest is given by:15mil $\le h \le$ 25mil, 5mil $\le x \le$ 15mil, 5mil $\le y \le$ 15mil, $8 \le \varepsilon_r \le 10$ and the frequency range is 2 GHz to 20 GHz with a step of 2 GHz. The width *w* of the input lines is determined so that the characteristic impedance of the input lines is 50 ohm. The width w_1 is taken as 1/3 of the width *w*. The width w_2 is obtained so that the characteristic impedance of the microstrip line after the step connected to port 2 is twice the characteristic impedance of the microstrip line after the step connected to port 1 (see Fig. 3(b)). The number of base points in the region of interest is 9.

MSMFI is applied to enhance the accuracy of the T-Junction coarse model. It divided the total frequency range into two intervals: 2 GHz to 16 GHz and 16 GHz to 20 GHz. Figs. 4(a) and (b) show $|S_{11}|$ and $|S_{22}|$ by Sonnet's ***em*** [5], the T-junction coarse model and the T-junction enhanced coarse model at two test points in the region of interest. The enhanced coarse model for the shaped T–Junction can be utilized in optimization [4].

V. CONCLUSIONS

The powerful GSM approach to device modeling is introduced. Three derivative concepts are illustrated: the SMSM concept, the FSMSM concept and the MSM concept. Our approach uses only a few EM simulations to dramatically enhance the accuracy of existing empirical device models. It involves only simple matrix operations which makes it an effective CAD tool in terms of CPU time, memory requirement, ease of use and accuracy.

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[6] OSA90/hope™ Version 4.0, formerly Optimization Systems Associates Inc., P.O. Box 8083, Dundas, Ontario, Canada L9H 5E7, now Agilent Technologies, 1400 Fountaingrove Parkway, Santa Rosa, CA 95403-1799.

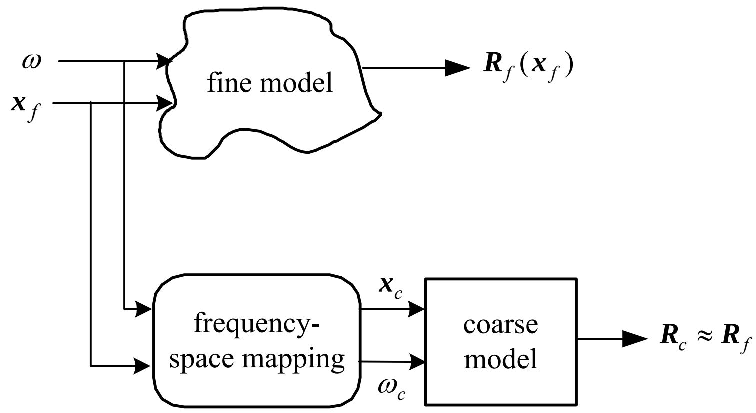

Fig. 1. The Frequency-Space Mapping Super Model (FSMSM) concept.

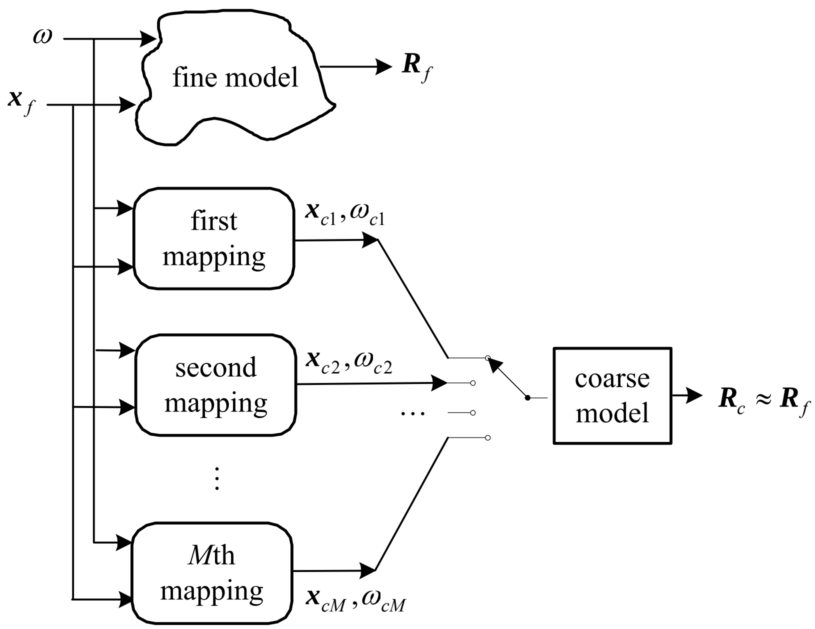

Fig. 2. The Multiple Space Mapping for Frequency Intervals (MSMFI).

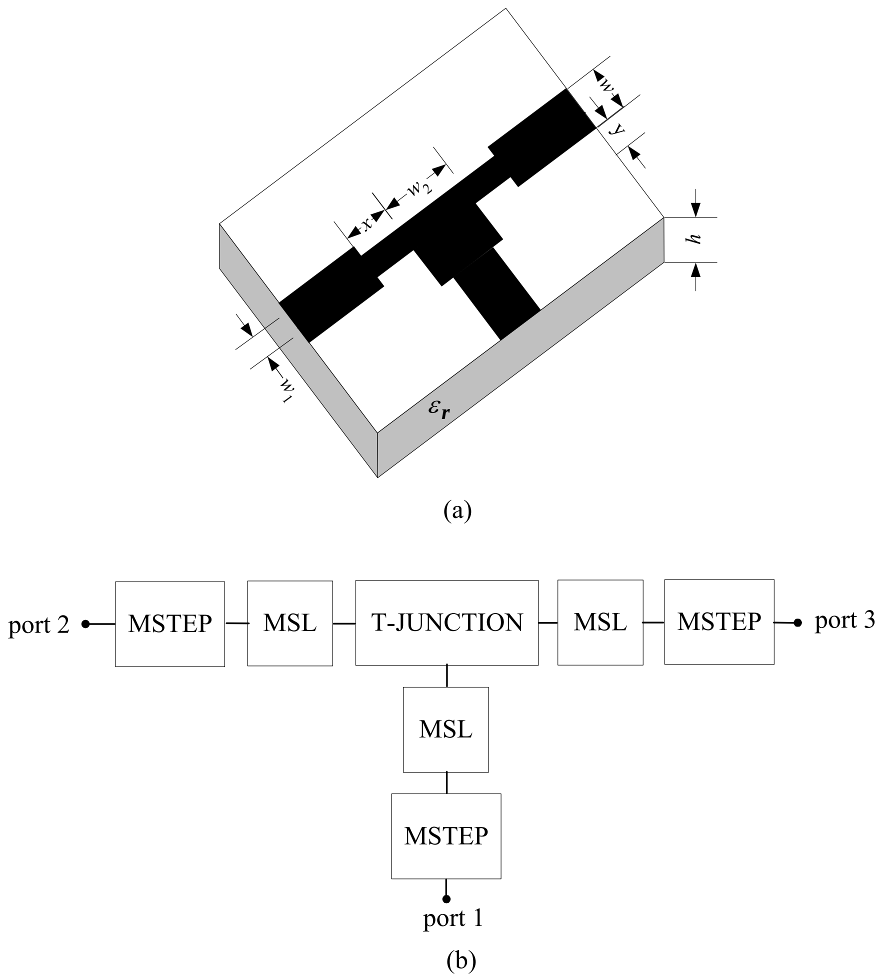

Fig. 3. Microstrip shaped T-junction: (a) the physical structure (fine model); (b) the coarse model.

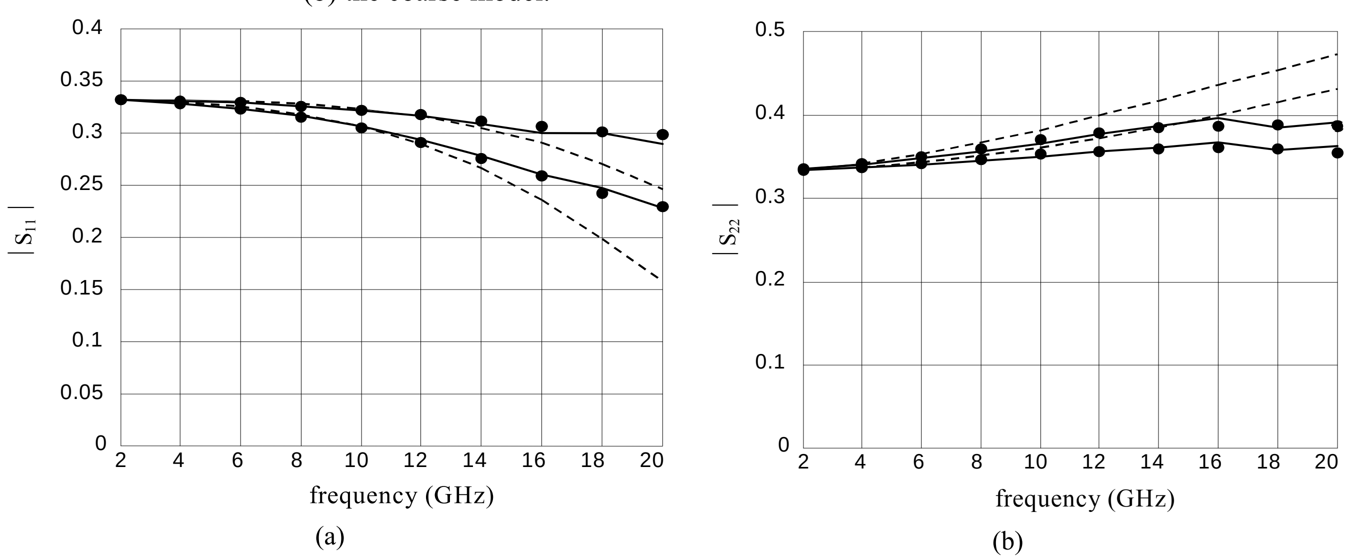

Fig. 4. Responses of the shaped T-Junction at two test points in the region of interest by Sonnet's ***em*** (●), by the coarse model (---) and by the enhanced coarse model (—).