Parameterized Surrogate models of Broadband Passive Electronic Components

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Abstract

A self-organizing sampling and modeling algorithm is presented for building compact multivariate surrogate models of general passive electronic components. The algorithm builds compact analytical circuit models and represents the scattering parameters of the passive components as a function of its geometrical parameters and as a function of the frequency. The model generation algorithm combines iterative sampling and modeling techniques. It groups a number of full-wave electromagnetic (EM) simulations in one multivariate analytic model. The analytical surrogate circuit models can easily be implemented and used in commercial circuit simulators. The compact models combine EM-accuracy and generality, with circuit simulation speed and flexibility.
Keywords: *Surrogate models, passive systems, design automation, CAD.*

1 Introduction

Accurate models for arbitrary passive microwave and RF components are important for the design of high-speed electronic circuits. Numerous efforts have been spent to build models for general structures based on full-wave EM simulations [1]-[4]. Previously used techniques include lookup tables, curve fitting techniques and neural networks. A common drawback of these efforts is the lack of knowledge about the accuracy of the resulting models, and there are capacity issues with higher dimensional models.

We developed an adaptive multivariate modeling technique, called MAPS

(Multidimensional Adaptive Parameter Sampling) [5]-[8], for building parameterized analytical models of general passive components.

The MAPS technique builds a global analytical model of the scattering parameters, handling frequency and geometrical dependencies separately. Multinomial fitting techniques are used to model the geometrical dependencies, while rational fitting techniques are used to handle frequency dependencies.

The modeling process does not require any prior knowledge of the circuit under study. Different adaptive algorithms are combined to efficiently generate a parameterized fitting model that meets the predefined accuracy. The number of computational expensive EM simulations is minimized for efficiency reasons. The adaptive sample selection process avoids oversampling and undersampling.

The model complexity is also automatically adapted to avoid overmodeling (overshoot or ringing) and undermodeling, and the surrogate model covers the whole parameter and frequency space.

2 Adaptive Modeling Algorithm

The scattering parameters S are represented by a weighted sum of multivariate orthonormal polynomials (multinomials) P_m. The multinomials only depend on the multivariate coordinates $\bar{x}$ in the parameter space R, while the weights C_m only depend on the frequency f:

$$S(f,\bar{x}) \approx M(f,\bar{x}) = \sum_{m=1}^{M} C_m(f) P_m(\bar{x}) \quad (1)$$

The weights C_m are calculated by fitting equation (1) on a set of D data points $\{\bar{x}_d,\ S(f,\bar{x}_d)\}$(with $d = 1, \ldots, D$). The number of multinomials in the sum is adaptively increased until the error function:

$$E(f,\bar{x}) = |M(f,\bar{x}) - S(f,\bar{x})| \quad (2)$$

is lower than a given threshold (which is function of the desired accuracy of the model) in all the data points. For numerical stability and efficiency reasons orthonormal multinomials are used, i.e. the multinomials $P_m(\bar{x})$ satisfy the condition :

$$\sum_{d=1}^{D} P_k(\bar{x}_d) P_l(\bar{x}_d) = \begin{cases} 1\ for\ k = l \\ 0\ for\ k \neq l \end{cases} \quad (3)$$

A multilevel accuracy algorithm is used, i.e. the accuracy level is increased in consecutive steps, and all intermediate surrogate models are stored.

3 Adaptive Sampling Algorithm

The modeling process starts with an initial set of data points. New data points are selected adaptively in such a way that a predefined accuracy Δ for the models is guaranteed. The process of selecting data points and building models in an adaptive way is often called *reflective exploration.* Reflective exploration is useful when the process that provides the data is very costly, which is the case for full-wave electro-magnetic (EM) simulators. Reflective exploration requires *reflective functions* that are used to select a new data point. The main reflective function used in the MAPS algorithm is the difference between two different models (different order M in equation (1)). A new data point is selected near the maximum of the reflective function. When the magnitude of the reflective function becomes smaller than the desired accuracy Δ over the whole parameter space, no new data point is selected.

If one of the scattering parameters has a local minimum or maximum in the parameter space of interest, it is important to have at least one data point in the close vicinity of this extremum in order to get an accurate approximation. Therefore, if there is no data point close to a local maximum or minimum of $M(f,\bar{x})$, the local extremum is selected as a new data point. For resonant structures, the power loss has local maxima at the resonance frequencies. Again, to get an accurate approximation, a good knowledge of these local maxima is very important.

The scattering parameters of a linear time invariant (LTI) passive circuit satisfy certain physical conditions. If the model fails these physical conditions, it cannot accurately model the scattering parameters. The physical conditions act as additional reflective functions: if they are not satisfied, a new data point is chosen where the criteria are violated the most.

The complete flowchart of the algorithm is shown in figure 1.

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5 Conclusion

An efficient adaptive multivariate sampling and modeling algorithm is presented for building compact surrogate models of general passive electronic

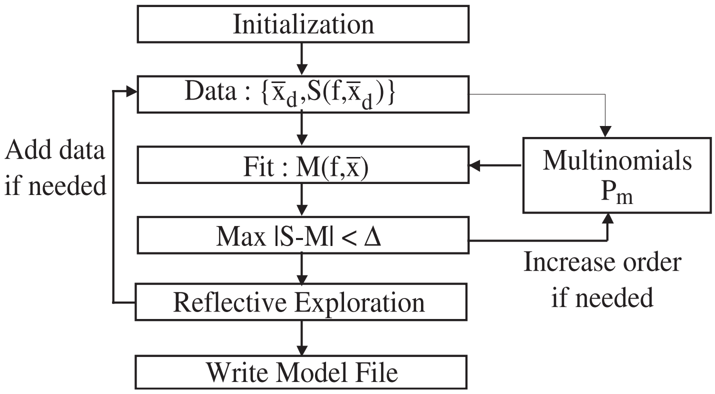

Figure 1: Flowchart of adaptive sampling and modeling algorithm

components. This algorithm can be applied to all kinds of linear time-invariant (LTI) systems. The adaptive sample selection process minimizes the number of computational expensive data samples, and avoids oversampling and undersampling. The adaptive model selection process determines the required model complexity, and avoids overmodeling and undermodeling.

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