Automated Circuit Modeling Tool for Arbitrary Passive Microwave and RF Components

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An automated circuit-modeling tool is developed for arbitrary passive components. The tool builds compact, parameterized, analytical models based on full-wave EM simulations. The scattering parameters (or the transmission line parameters) of the components are stored as a multidimensional function of frequency and geometrical parameters. The modeling algorithm combines adaptive data selecting and modeling techniques. The circuit models guarantee EM-accuracy and generality, and circuit simulation speed and flexibility.

I. INTRODUCTION

Accurate parameterized circuit models for arbitrary microwave and RF components are required for the design and optimization of high-speed electronic circuits. Several numerical EM techniques (such as the method of moments) can be used to accurately model passive components. However, most numerical EM techniques require a significant amount of expertise and computer resources, so that they are often only used for verification purposes. On the other hand circuit simulators are very fast, and offer a lot of different analysis possibilities. However, the number of available analytical models is limited, and the accuracy is not always guaranteed up to RF or microwave frequencies.

Numerous efforts (e.g. lookup tables [1], curve fitting techniques [2] and neural networks [3]) have been made to build models for general interconnection structures based on EM simulations. A common drawback of the previous efforts is the lack of knowledge about the accuracy of the resulting models.

We developed an automated tool for building parameterized circuit models of general passive microwave and RF components with user-defined accuracy [4]-[5]. The analytical models represent the scattering parameters (or transmission line parameters) as a multidimensional function of frequency and geometrical parameters.

The models are based on full-wave EM simulations, and can easily be incorporated in circuit simulators. This brings EM-accuracy and generality in the circuit simulator, without sacrificing speed. The model generation process is fully automated. Data points are selected efficiently and model complexity is automatically adapted. The algorithm consists of an adaptive modeling loop (section II) and an adaptive sample selection loop (section III). An example is given to illustrate the technique (section IV).

II. ADAPTIVE MODEL BUILDING ALGORITHM

The scattering parameters S (or transmission line parameters R, L, G and C) are approximated by a weighted sum of multidimensional orthonormal polynomials (*multinomials*) P_m. The multinomials only depend on the coordinate $\bar{x}$ in the multidimensional parameter space R, while the weights C_m only depend on the frequency f:

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

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, …, D). The number of multinomials M is adaptively increased until the error function $E(f,\bar{x}) = | S(f,\bar{x}) - A(f,\bar{x})|$ is lower than a user-defined accuracy level in all the data points. For numerical stability and efficiency reasons orthonormal multinomials are used.

III. ADAPTIVE DATA SELECTING ALGORITHM

The modeling process starts with an initial set of data points. New data points are added adaptively until the user-defined accuracy level is guaranteed.

The process of selecting data points and building models in an adaptive way is called *reflective exploration* [6]. Reflective exploration is useful when the process that provides the data is very costly, which is the case for full-wave EM simulators. Reflective exploration requires *reflective functions* that are used to select a new data point. The difference between 2 consecutive approximate models (with different order M in (1)) is used as a reflective function. A new data point is selected near the maximum of the reflective function. No new data points are added if the magnitude of the reflective function is smaller than the user-defined accuracy level Δ (over the whole parameter space).

Physical rules are also checked. If the approximate modeling function $A(f,\bar{x})$ violates certain physical rules, a new data point is chosen where the criteria are violated the most.

Furthermore, at least one data point is chosen in the close vicinity of local minima and maxima of the modeling function $A(f,\bar{x})$ over the parameter space of interest.

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

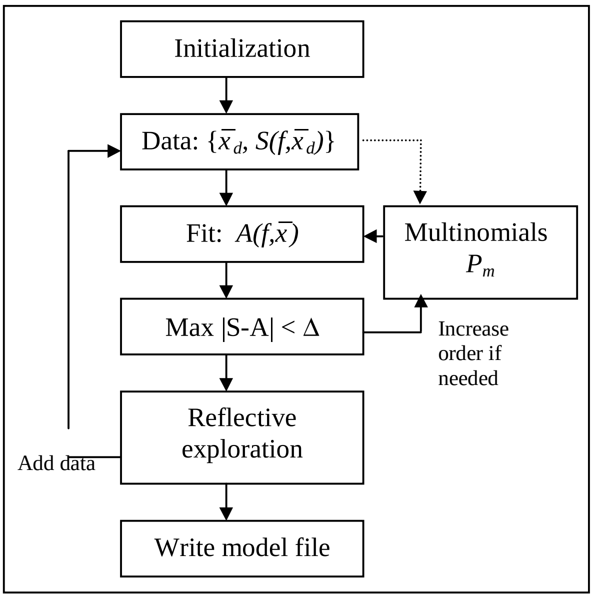

Figure 1: Adaptive multidimensional modeling algorithm

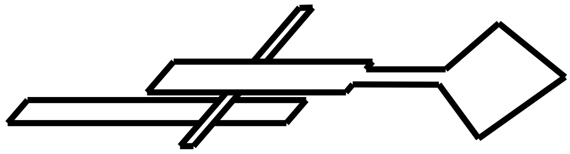

Figure 2: Slot-coupled microstrip-fed patch antenna structure

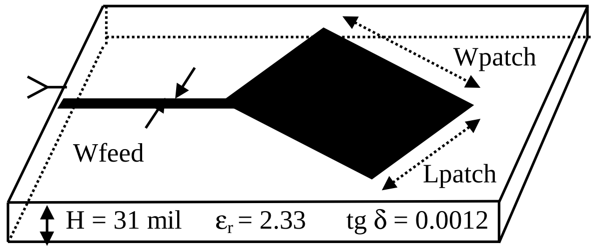

Figure 3: Layout of corner-fed patch

IV. EXAMPLE: SLOT-COUPLED MICROSTRIP-FED PATCH ANTENNA

The automated modeling tool was used to generate analytical circuit models for *all* sub-parts (*transmission line*, *open end*, *slot coupler*, *step in width*, *corner-fed patch*) of a *slot-coupled microstrip-fed patch antenna* structure (figure 2). This modeling step is a one-time, up-front time investment.

A double sided duroid substrate was used (thickness = 31 mil & 15 mil, ε_r = 2.33, tg δ = 0.0012).

First, parameterized circuit models were built for *all* substructures of the circuit. For example, the *corner-fed patch* (figure 3) circuit model was built over the following parameter range (table 1):

Table 1
Parameter ranges of corner-fed patch

variable	min	max
Lpatch	320 mil	400 mil
Wfeed	5 mil	30 mil
f	5 GHz	15 GHz

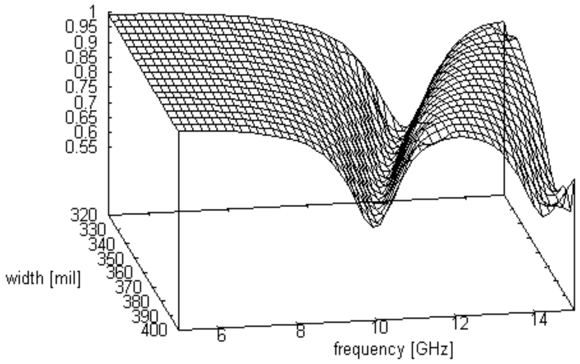

Figure 4: S_{11} of corner-fed patch (Wfeed = 8 mil)

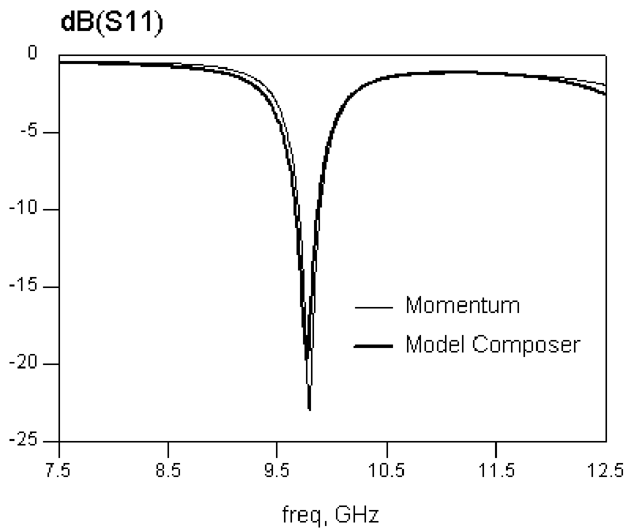

Figure 5: S_{11} of Slot-coupled microstrip-fed patch antenna

The automated modeling tool selected 25 data points (= discrete layouts) in an adaptive way, and grouped all S-parameter data all in one global, compact, analytical model. ADS Momentum was used as planar EM simulator [7]. The desired accuracy level was set to -55 dB. In figure 4, the reflection coefficient S_{11} of the *corner-fed patch* is shown as a function of frequency and width.

Then, the parameterized circuit models were used to simulate the overall antenna structure (figure 2). Figure 5 shows S_{11} simulated with Momentum, and with the new analytical circuit models for all sub-components (divide and conquer approach). Both results correspond very well. However, the simulations based on the circuit models easily allow optimization and tuning, and took only a fraction of the time of the full-wave simulation (2 seconds compared to 96 minutes on a 450 MHz Pentium II).

V. CONCLUSION

A new adaptive technique was presented for building parameterized models for general passive planar interconnection structures. The models are based on full-wave EM simulations, and have a user-defined accuracy. Once generated, the analytical models can be grouped in a library, and incorporated in a circuit simulator where they can be used for simulation, design and optimization purposes. A patch antenna example was given to illustrate the technique. The results based on the parameterized models correspond very well with the global full-wave simulations. However, the time required for a simulation using the compact analytical circuit models was only a fraction of the time required for a global full-wave simulation.

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