# Agilent EEsof EDA

## How to Build EM-Accurate Parameterized Passive Models?

Agilent Technologies

# How to build EM-accurate, parameterized passive models

*Getting the product out the door right the first time is paramount to the bottom line. Modern EM parametric modeling tools can help make it happen.*

## By Mounir Adada

**T**o meet time-to-market goals, the designers of high-frequency wireless and wireline devices rely on electronic design automation (EDA) software. Computer simulation of circuits and systems is an essential part of the development process, and accurate component and circuit models are required
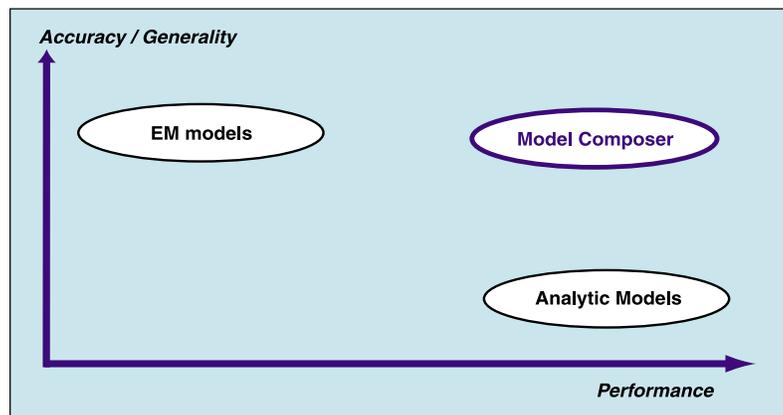


**Figure 1. A model composer's EM-based modeling accuracy against performance.**

to ensure that the simulations reliably predict real-world performance. As frequencies of operation and circuit complexity increase, the accuracy of these models must keep pace. Recent developments in modeling technology now empower designers to define the accuracy of their high-frequency passive models. Designers no longer have to settle for pre-defined generalized models that only work for limited frequency ranges and process properties.

Using new technology, engineers can automatically generate key passive models using the frequency range, material properties, number of parameters and desired accuracy. Linear simulators enable generation of electromagnetic (EM) accurate parameterized passive models with the simulation speed of analytical models. With this technology, designers are no longer restricted by the limitations of older modeling methods.

## Accurate models enable fast simulations

The fastest simulations are obtained with linear circuit analysis EDA tools. These tools rely on accurate analytical (mathematical) models to provide trustworthy results. With wireless and wireline designs constantly increasing in complexity and operating at higher frequencies, design engineers may exceed the limits of their EDA tool's passive analytical models. When these passive models are used outside their intended operational range, the EDA tool may return inaccurate simulation results.

The inconsistencies of legacy modeling techniques from the 1970s and 1980s hinder the accuracy of these models when they are applied to different processes and frequencies. Exceeding a model's frequency limit causes errors due to failure to account for higher-order propagation modes.

Limitations of the equivalent circuit model, such as frequency-independent inductive or capacitive elements, also lead to simulation errors. Because most EDA tools do not proactively report such errors, they may not be discovered during simulation — becoming apparent only when a prototype fails to perform as expected.

Many error-prone passive models tend to be of a discontinuous nature (i.e. microstrip or stripline cross, step, bend, open, gap, etc.) where multimode propagation is common. These structures can be fully characterized using full-wave EM simulation. These results can be applied to produce an accurate S-parameter model of the discontinuity, which can be used by the circuit simulator.

## The challenges of modeling

Developing such new models is a complex task. To model a single parameter over a range of values, several sample points are required. Because the model can be a function of parameters such as line width, length, metal thickness, dielectric constant, substrate thickness and loss tangent, an exponential growth exists in the number of samples as the number of parameters increases.

Also, developing a new model usually requires a highly skilled person working for several weeks — or even months — to define, develop and test the desired analytical model. If the requirement is for a complete library of models, the total effort is multiplied by the number of models needed. The model development task needs to be weighed against
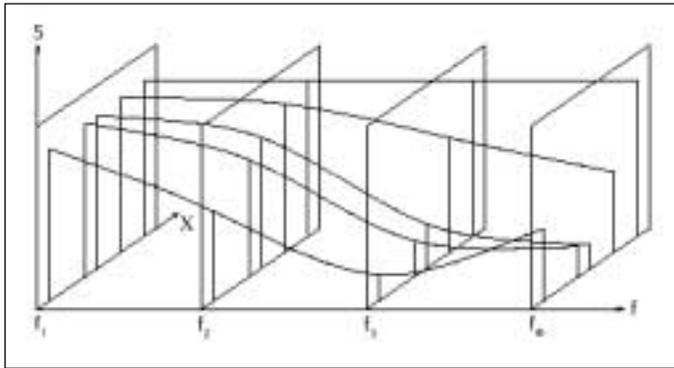
Figure 2. AFS rational models over the desired frequency range, derived from full-wave EM simulation.
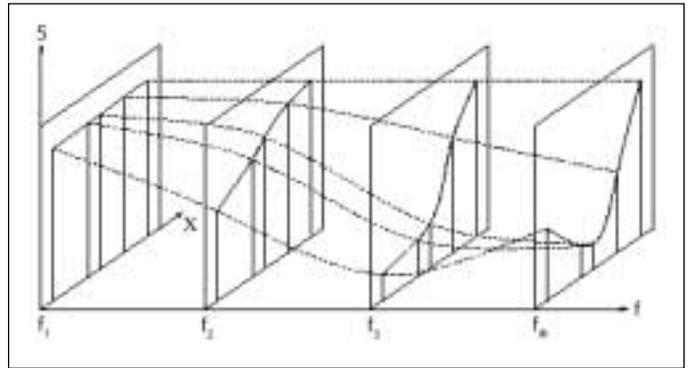

Figure 3. Multinomial models are created at discrete frequencies.

measurement-based or EM-based modeling on a case-by-case basis.

Some of the methods traditionally used for developing analytical models have limitations. Methods that use pre-calculations of equivalent circuits, including look-up tables, fitted equations and interpolation, can have a limited number of samples and insufficient interpolation methods.

An example that presents problems for these techniques is high-Q resonant circuits, such as those used in narrow band filters. Applying discrete data grids and interpolation techniques to such circuits can cause the generated model to suffer from either "undersampling" or "oversampling." With under-sampling, too few data samples are collected and the model is not completely defined — especially close to resonance, where the behavior changes rapidly with changing frequency. In an effort to be sure that enough data are collected in this one critical area, the model may suffer from oversampling, with too many data samples and inefficient model generation.

## A model composer

As an alternative to building classic analytical models, engineers can use a full-wave EM modeling tool to fully characterize a given passive component. This method permits accurate characterization of the actual passive structure to be used, accounting for higher-order mode propagation, dispersion and other parasitic effects. However, the calculation time required for full-wave EM simulation of a given component makes real-time circuit tuning impossible.

This model accuracy dilemma has been addressed by a new model generation technology that combines the speed of analytical models and the

accuracy of full-wave EM simulation by creating a compact parameterized passive model (see Figure 1).

This article is based on a model composer that is a next-generation, highly computationally intensive simulator. It combines the accuracy of EM simulation with the speed of analytical models by creating a single compact model built on specific process information, the desired frequency range and a set of pre-selected model parameters. The finished models are a design kit library, which is accessible to all designers who are using the same process.

Modern modeling software takes advantage of computer advances by being wizard-driven. Wizards help make it mistake-proof. Users can select the model type, frequency range, process properties and the required associated parameters. Once this set of information is supplied through the wizard, the rest is done automatically.

The final compact models have the accuracy of EM simulation while maintaining the ultra-fast simulation speeds typical of standard analytical models. This combination brings increased accuracy to performance-enhancing and time-saving design automation techniques, such as real-time tuning and optimization.

High-performance modeling systems allow designers to bypass the traditional limits of generalized passive models that only work for limited frequency ranges and substrate properties. Additionally, there is no longer a need to make the big investment of time and resources to develop their own models. Models can be generated to build complete passive component libraries tailored to the frequencies of interest and specific process properties. These model libraries can be shared with colleagues and customers, allowing them to achieve the same

design accuracy in their contributions to the design process.

## Next-generation techniques

The advantage of such modeling software is that it is possible to build a global-fitting model of the chosen parameters, handling frequency and geometrical dependencies separately.

Geometric dependencies are modeled using multidimensional polynomial fitting techniques, while frequency dependencies are handled using polynomial fitting techniques. The modeling process does not require any prior knowledge of the circuit under study.

Adaptive algorithms are combined to efficiently fit a model to the parameters, satisfying the predefined accuracy requirements. This process includes the adaptive selection of an optimal number of data samples along the frequency axis, as well as in the geometrical parameter space. It also includes adaptive selection of the optimal order of the multinomial-fitting model. The number of data points is selected to avoid oversampling or undersampling. The algorithm converges when the desired accuracy is reached. The model complexity is automatically adapted to avoid overshoot or ringing, and the model covers the whole parameter and frequency space, making it easily used for optimization purposes.

## Steps for building a model

1. The frequency response of the circuit is calculated at a number of discrete sample points using a full-wave EM simulator. Using adaptive frequency sampling (AFS), a set of frequencies is selected and a rational model for the S-parameters over the desired frequency range is built (see Figure 2).

2. A multinomial is fitted to the S-parameter data at all frequencies (see Figure 3).
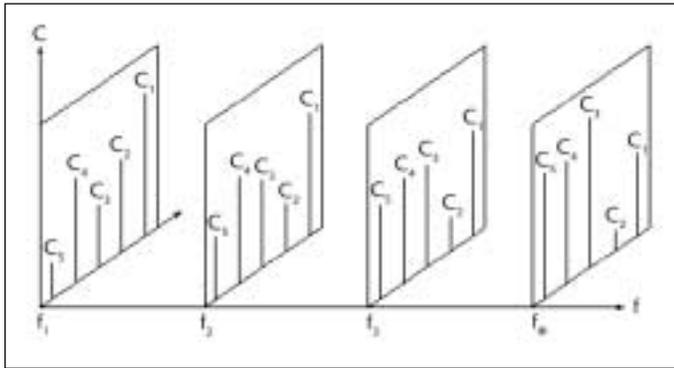
Figure 4. Creation of the coefficients of orthogonal multinomials at discrete frequencies.
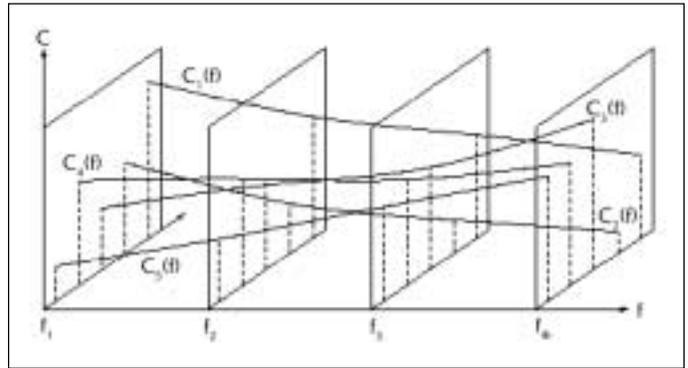


Figure 5. Calculation of coefficients of orthogonal multinomials over the entire frequency range.

3. This model is written as a sum of orthonormal multinomials. The coefficients preceding the orthonormal multinomials in the sum are frequency-dependent (see Figure 4).

4. Using the models built in (1), the coefficients can be calculated over the whole frequency range (see Figure 5). These coefficients, together with the orthonormal multinomials, are stored in a database for use during extraction afterwards.

## Comparing modeling methods

To present a typical procedure, the low-pass filter of Figure 6 is simulated using standard analytical models, a full-wave EM simulation and, finally, a simulation using discontinuities built using a model composer.

The filter incorporates two types of microstrip discontinuities that would benefit from more robust models — a cross and an open. The new model development process begins by using a wizard user
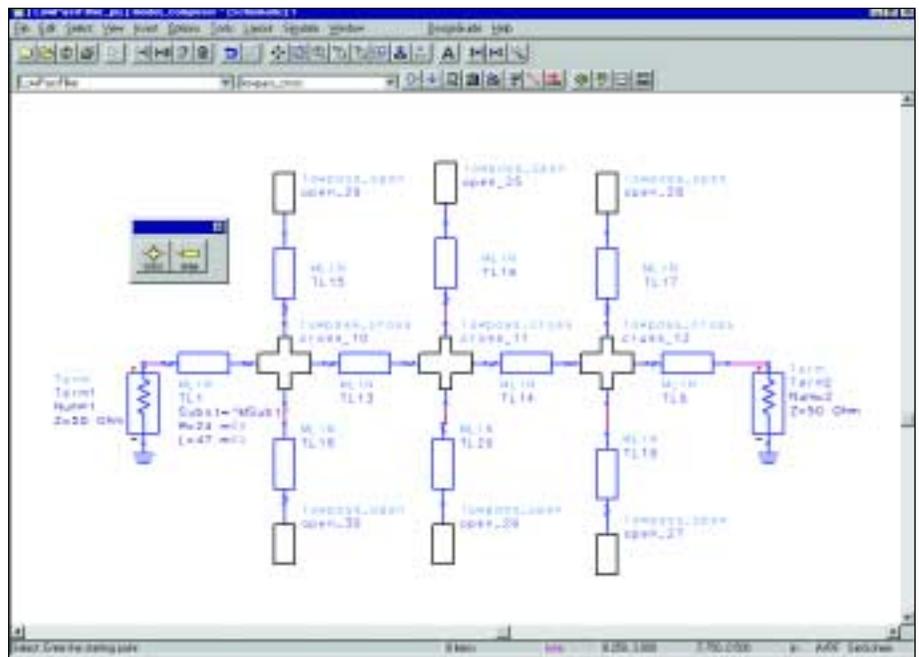


Figure 6. An example lowpass filter design.

| Model | Parameter | Min. | Max. |
|-------|-----------|------|------|
| Cross | Width1 | 20 mil | 45 mil |
| | Width2 | 20 mil | 45 mil |
| | Width3 | 20 mil | 45 mil |
| | Width4 | 20 mil | 45 mil |
| | Frequency | 0 GHz | 20 GHz |
| Open | Width | 20 mil | 45 mil |
| | Frequency | 0 GHz | 20 GHz |

Table 1. The parameters used to define models to be built by the Model Composer.

interface to define the substrate information, model types, frequency range, the required component parameters and their desired range of values. The model information is shown in Table 1.

Once this information is entered via the model composer wizard, the rest of the process is automatic and runs in



Figure 7. New models developed and stored for reference.
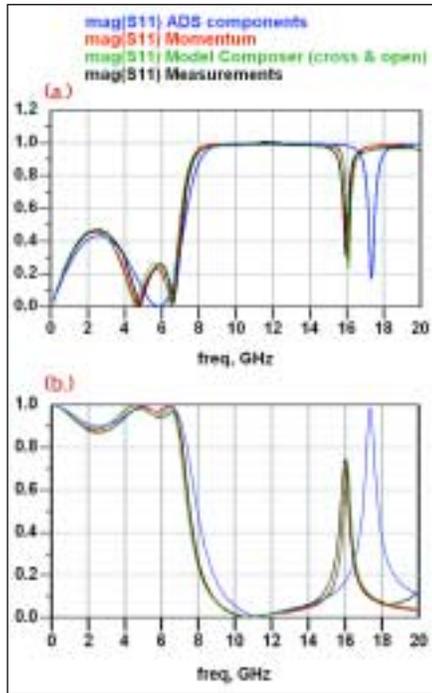
Figure 8a. A comparison of S11 simulations and measurements of the lowpass filter shows that models obtained from Model Composer give results that agree with EM-based simulation and measured data. Figure 8b. This comparison of S21 simulations and measurements illustrates how standard microstrip models deviate from more accurate models (and measurements) at higher frequencies.

the background. The final results are two compact models of the cross and the open, stored in the design kit folder (see Figure 7) with associated electrical models, palette bitmaps, schematic symbols and layout artwork. To verify the model's performance, the filter example was simulated using standard microstrip analytical models, with the EM simulator and with the newly developed models from Model Composer. Results of these simulations are displayed in Figures 8a and 8b, along with measured results.

These figures show that simulation using models generated by such software have an accuracy comparable to both momentum and measured data

### Summary

The simulation speed of analytical models is combined with the accuracy of EM-derived passive models in the latest generation of modeling software.

Using such tools, designers can develop improved models based on specific operational and material properties. These technologies and state-of-

### About the author

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the-art simulators automate the process of accurate model generation.

The low-pass filter example illustrates how simulations using models created in this way maintain both accuracy and speed.

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### References:

[1] "Constrained EM-Based Modeling Of Passive Components" T. Dhaene, J. De Geest and D. De Zutter, IEEE International Microwave Symposium 2002 (IEEE IMS 02)

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