

# Recent Developments in High Frequency Component Modeling

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The ever-growing importance of computer simulation and analysis of high frequency circuits demands high-accuracy models for the components comprising those circuits. Over the past 25 years, those models have evolved from relatively simple equivalent circuits that include only major parasitic elements, to measurement-based or electromagnetic simulation-based behavioral models that may cover a wide range of frequencies, temperature, and operating voltage (or current).

## Commercial Support of EDA Tools

For many years, major component companies have supplied models of their devices, but recently, the number of components in the catalog, the accuracy of the models, and especially the frequency range of their characterization have all increased.

Passive component models from SMT vendors allow even low-cost, high-volume consumer products to have accurate simulation in the design phase. Large-scale suppliers like MuRata, Toko, Coilcraft, Taiyo Yuden, AVX and others, have joined the specialized RF/microwave suppliers that have included *S*-parameter models for many years, and now provide advanced models with greater accuracy.

Active device models have had a similar growth in the number and detail of available component models. All RF and microwave semiconductor suppliers have extensive *S*-parameter files as a minimum level of support, and many provide advanced nonlinear, frequency-dependent models as well.

Process-specific models are essential tools for RFIC and MMIC design, as well as for LTCC (low temperature co-fired ceramic) and recent SoC (system-on-chip) technologies. Foundries providing fabrication services for these devices work closely with all major EDA developers to provide compatible Process Design Kits (PDKs) that include the necessary device, interconnect and other models that will increase the chances of a first-pass design success. Major IC layout tools have recently been seamlessly integrated into RF/microwave EDA tools with joint interface development efforts.

Independent commercial model development has been pursued sporadically for many years, but recently has reached greater importance with the services offered by Modelithics, Inc. This spin-off from the University of South Florida provides measurement-based modeling services to the high frequency industry. The component models provided for major EDA tools include active devices from companies such as Avago, Eudyna, Excelics, Hexawave, Mitsubishi, MIMIX, MWT and NEC. The company also provides passive component models for devices from AVX, American Technical Ceramics, Coilcraft, MuRata, Johanson, KOA, TDK, Toko, Panasonic, and many others. Libraries of these components are offered for major EDA tools such as AWR Corp.'s Microwave Office and Agilent Corporation's Advanced Design System (ADS).

Connector companies also provide simulation and layout models for many high frequency connectors. These may include data for multiple substrates and metallization schemes. The combination of a prescribed method of installation (including mechanical assembly and soldering) with an accurate model for simulation helps designers solve the classic problem of poor prediction of interconnect performance. Samtec provides similar data for a reference layout and computer simulation for high speed digital connectors, which often have had only approximations or design rules to guide engineers.

## Developing Models by Electromagnetic (EM) Simulation

EM simulation vendors such as CST, Agilent, Ansoft, AWR, Sonnet and others place great importance on using their tools to develop behavioral models, not just to simulate a specific circuit.

EM tools have evolved to a high level of accuracy, with well-defined capabilities and limitations. Although it is possible to combine circuit simulation with EM simulation, the large problem size of EM simulation makes this a slow process, relative to circuit simulation alone. Many academic papers and company application notes address the process of developing a behavioral model using EM simulation, then using that model for fast computation in

circuit simulation. This “modular” approach maintains the high accuracy of EM simulation while the engineer enjoys the computation speed of circuit simulation.

It should be noted that accurate EM simulation is not a trivial task. At most companies that employ this type of model development, the best minds on the engineering staff are involved.

### Conventional Measured Model Extraction

Internal efforts by companies like Agilent, which has both EDA and instrument divisions, plus cooperative efforts between independent instrument and EDA vendors, have greatly simplified and sped up the process of parameter extraction. New model development tools aid the efforts of passive and active component manufacturers, as well as those OEMs that choose to develop certain models for their internal use.

Although the general methods are mature, the primary recent advances are in speed, accuracy and flexibility

of operation. Productivity is constantly being addressed by this, and all other, forms of model development.

### New Model Challenges

Advanced models for RFIC/MMIC design are powerful, but there are clear paths to greater accuracy and usability. Allowing a “classic” circuit design engineer to design his or her product as an integrated circuit is still a challenging task, still requiring an experienced chip designer’s assistance. A close interrelationship between circuit design and the physics of IC design has only recently begun to be addressed in depth.

Full-system simulation using physical, EM, circuit and thermal models also has much work yet to be done. Interfacing between combinations of tools has been successful, but like IC design, the models used in the various stages of the process may vary widely in the way they are defined. This “big picture” effort represents a major goal for EDA developers.

## X-Parameters: The Next Step?

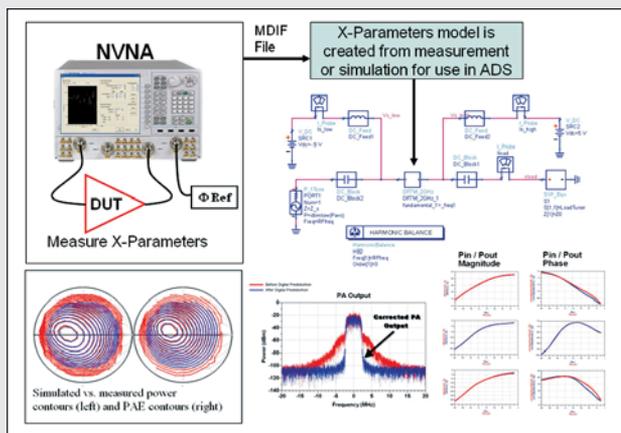
In mid-2008, Agilent Corporation began promoting a new concept, X-parameters, as a natural follow-on to well-known  $S$ -parameters for characterizing active and passive devices at RF and microwave frequencies.

According to Agilent literature, “X-parameters are the mathematically correct superset of  $S$ -parameters, applicable to both large-signal and small-signal conditions, for linear and nonlinear components.”

The X-parameters can be generated either from simulation with the company’s Advanced Design System (ADS) EDA software or from measurements, particularly using Agilent’s Non-Linear Vector Network Analyzer (NVNA).

In the past, designers could not accurately measure, display and simulate the full amplitude and phase information of each spectral component in non-linear designs. As a result, they did not have access to a highly accurate non-linear behavioral model that fully characterizes the non-linear behavior of their devices. Agilent’s new patent-pending X-parameter technology allows designers to capture the non-linear behavior of active components such as amplifiers and transistors in the same manner as obtaining  $S$ -parameters, and save them for use in RF system or circuit designs in ADS.

According to Jason Horn, R&D engineer with Agilent’s High-Frequency Technology Center, and one of the inventors of X-parameter technology, “Literally in five minutes, you can generate a nonlinear X-parameter model from an off-the-shelf amplifier by measuring it with Agilent’s Non-Linear Vector Network Analyzer, and you can start doing non-linear designs with it in ADS immediately.”



Advanced Design System from Agilent’s EEs of EDA division enables X-parameter nonlinear model generation from simulation, allowing design houses to create nonlinear X-parameter models of their RFICs and MMICs, modules and multiport devices such as mixers. X-parameter models protect the intellectual property from which they are generated while retaining the full non-linear characteristics to share with circuit and system design partners.

Users can also generate X-parameter models with load pull characteristics—for accuracy over a wide range of terminating impedances—from ADS simulation or from measurement on an Agilent NVNA using the load-pull system from Maury Microwave Corp.

Nonlinear models have been developed using other methods, but as X-parameters are studied by more engineers and companies, we will see if they become the universal solution for nonlinear device characterization.