# Integrated, Turnkey Modeling & Measurement Systems

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# Integrated, Turnkey Modeling & Measurement Systems

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As companies become more vertically integrated, they take on the greater responsibilities of accurate and robust device modeling, and associated measurements, across multiple product levels (die-level, package-level, IC-level…). With time-to-market as a common organizational goal, the need for a highly-efficient turnkey component- to circuit- to system-level measurement and modeling device characterization solution has never been more critical. To address this growing need, Maury Microwave and AMCAD Engineering have partnered to release a turnkey design flow (figure 1), which includes the instrumentation and software necessary to take measurements, and to extract, validate and refine compact and behavioral models, all from within a single intuitive software platform, IVCAD.

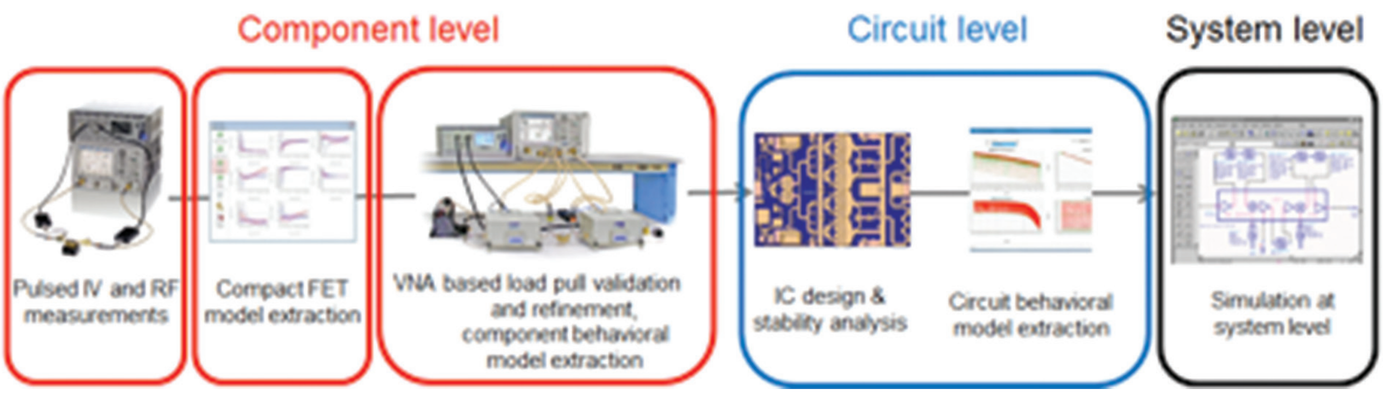


*Figure 1: Design flow to extract component- and circuit-level compact and behavioral models*

The first step in developing a comprehensive line of state-of-the-art transistors is to create highly accurate and reliable compact transistor models. Compact models include elements associated with linear, nonlinear, electro-thermal and trapping circuits and are extracted from synchronized pulsed IV/S-parameter measurements using an AMCAD BILT pulsed IV system, Keysight PNA-X and Maury IVCAD software suite (figure 2).

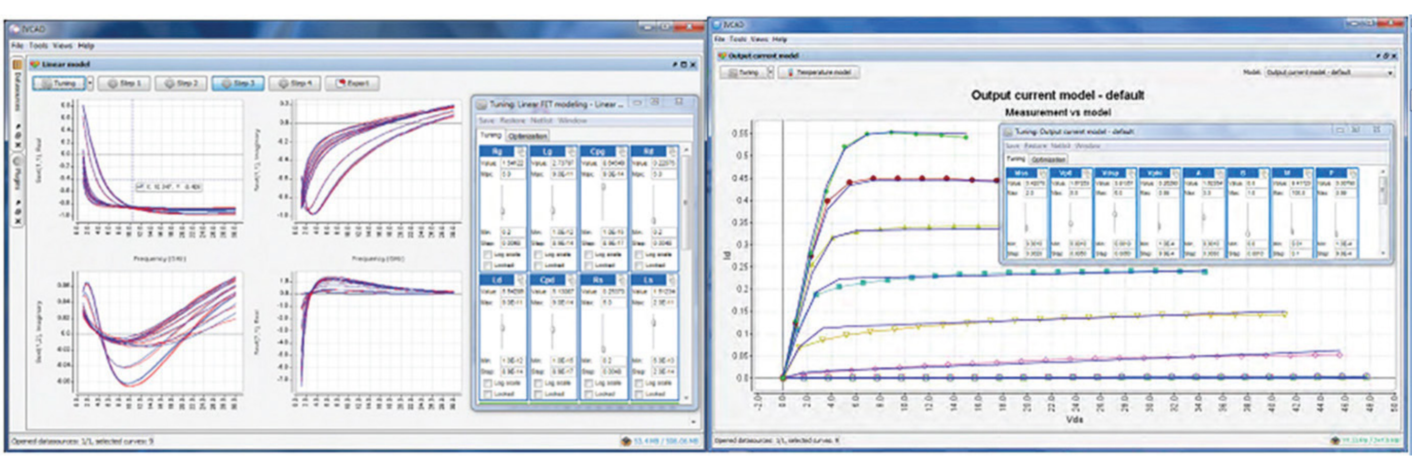


*Figure 2: Linear and nonlinear model extraction optimization in IVCAD*

Linear compact models are extracted using S-parameters to determine the extrinsic parasitic elements, from which the resulting data is used to extract frequency-independent intrinsic parameters.

Nonlinear model extraction uses pulsed IV measurements to study the effects of temperature-dependent performance in safe operating regions and to study the breakdown area of a transistor. Pulse widths and duty cycles are chosen to maintain quasi-isothermal operating conditions. Pulsed IV measurements are used to extract the current diodes, and synchronized pulsed IV/S-parameters to extract the nonlinear capacitance model.

Electro-thermal circuits are used to model transistor performance as a function of device temperature and device self-heating. A transistor's thermal resistance is extracted using the differentiation between continuous and short-pulsed bias conditions. Thermal capacitance is extracted using longer pulses and studying current decrease with time. Thermal impedance is modeled from several thermal resistances and capacitances representing various time constants.

Trapping effects, surface trapping (gate-lag) and buffer-trapping (drain-lag), are modeled from sets of pulsed IV measurements at multiple quiescent bias points. Quiescent bias points are specifically chosen such that the difference between IV characteristics can be entirely attributed to either gate lags or drain lags.

Following the turnkey compact model extraction flow, the 58 electrical equivalent parameters are automatically determined and result in ready-to-use III-V or MOS compact transistor models.

Since the nonlinear compact transistor model was extracted from linear S-parameter measurements, nonlinear vector-receiver load pull (figure 3) can be used to validate and refine the model based on nonlinear fundamental and harmonic load-dependent measurements as a function of impedance, power compression and bias.

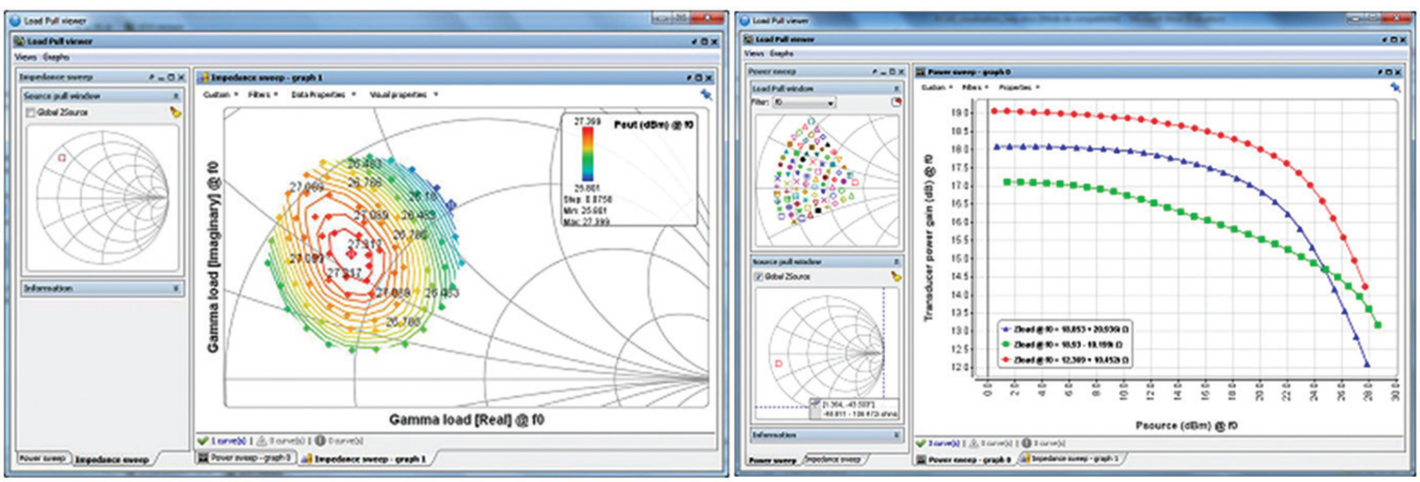

*Figure 3: Load pull iso-contours and gain compression curves under nonlinear operating conditions*

Vector-receiver load pull uses a VNA to measure frequency-selective a- and b-waves from which separate and accurate fundamental and harmonic input and output powers are calculated. Since the large signal input impedance of the transistor is measured in real-time, delivered input power can be calculated as well as operating power gain and gain compression, which are directly related to the intrinsic transistor's performance independent of source match. Vector parameters such as AM/PM and droop, and multi-tone parameters such as intermodulation distortion products and intercept points can be measured and compared against simulated data.

Certain VNAs, such as Keysight PNA-X's, allow for nonlinear NVNA time-domain voltage and current waveforms to be measured. When de-embedded to the intrinsic transistor reference plane, measurements can be compared against simulated data and used to refine and enhance the compact model.

CW and pulsed-RF powers can be swept using programmable signal sources to study the device's performance under small-signal to highly-compressed operating conditions. DC and pulsed biases can be adjusted using programmable power supplies or pulsed-bias (pulsed IV) systems. Impedances can be presented at the fundamental and/or harmonic frequencies using Maury's LXI™-certified passive single or multi-harmonic automated impedance tuners, or active tuning chains, or a combination of both.

Nonlinear vector-receiver load pull plays a critical role in validating any nonlinear model by presenting actual nonlinear operating conditions to the modeled transistor, and is useful for refining the model as needed.

Once a nonlinear compact model has been extracted, or if a compact model is unavailable, it is often useful to have a component-level behavioral model available for circuit design use. Unlike compact models which expose the workings of the transistor, behavioral models are "black-box" and based on a behavioral response to a set of stimuli. Nonlinear load pull measurement data can be converted to various behavioral models, including Keysight X-Parameters and AMCAD Enhanced PHD (EPHD). These models can be used to quickly simulate the behavioral response of a transistor and are useful for circuit design and evaluating the transistor performance versus operating conditions.

Certain behavioral models, such as the AMCAD Multi-Harmonic Vollterra (MHV) model can be useful for system design, taking into account low-frequency and high-frequency memory effects and accurately simulate ACPR and EVM using wideband modulated signals.

Amplifier and MMIC designers will often find that their designs suffer from spurious oscillations, only discovered after a circuit has been fabricated resulting in the necessity of multiple spins. To avoid costly redesigns, stability analysis is an important step in the design flow, and STAN (STability ANalysis) can determine the nature of oscillations under both small signal and large signal operating conditions. Based on the pole-zero identification technique, oscillations are analyzed as a function of bias, power, impedance and manufacturing tolerances at multiple nodes of a circuit. Without a single fabrication, oscillation avoidance using the minimum number of stabilization networks can be compared against RF performance and result in the ideal compromise, leading to first-pass design success.

Without a single software platform covering the entire design flow, one runs the risk of incompatible formatting, missing measurement data and lost time. IVCAD (figure 4) is a single suite which includes modules for synchronized pulsed IV and pulsed s-parameter measurements, compact transistor model extraction for III-V and MOS technologies, passive, active and hybrid-active fundamental and harmonic load pull for model validation, refinement and design, multiple behavioral model extraction techniques, stability analysis of microwave circuits, with advanced visualization and data analysis, full scripting and automation capabilities. IVCAD measurement, compact model and behavioral model file formats are compatible with commercial simulation tools for easy transition from measurement and model to simulation.

*Figure 4: IVCAD measurement and modeling device characterization software suite*

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