IVCAD Advanced Measurement & Modeling Software

DATA SHEET / 4T-022

AMCAD Engineering
Advanced Modeling for Computer-Aided Design

IVCAD SOFTWARE SUITE MODULES:

MT930B1 – IVCAD Basic Visualization
MT930B2 – IVCAD Advanced Visualization Add-On
MT930C – IVCAD Vector-Receiver Load Pull
MT930C1 – IVCAD Vector-Receiver Load Pull Waveguide Add-On
MT930C2 – IVCAD Pre-RF Pulsed IV Load Pull Add-On
MT930D1 – IVCAD Traditional Load Pull
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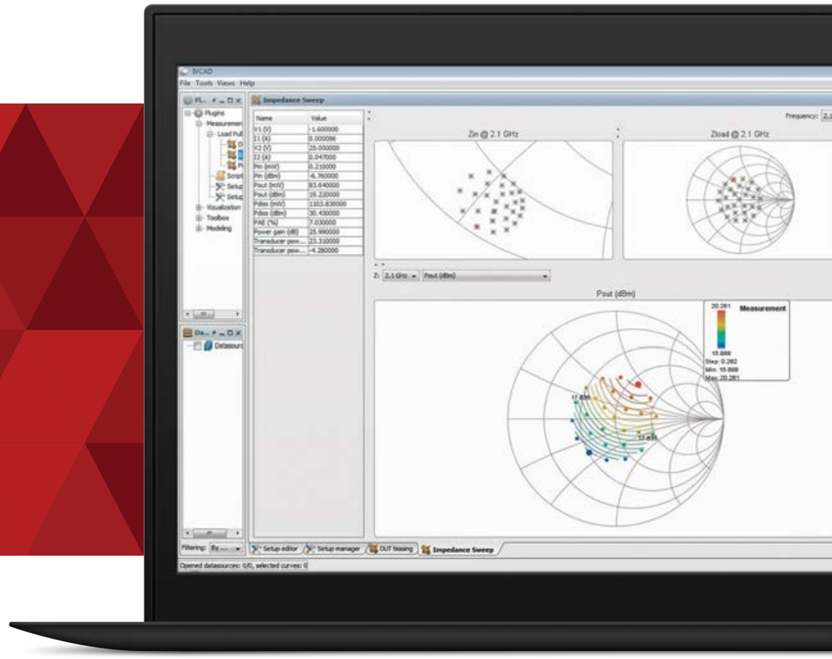
MT930P – IVCAD Measurement Toolbox
MT930Q – IVCAD Stability Analysis Tool (STAN)
MT930R1 – IVCAD EPHD Behavioral Model Extraction



Advanced Measurement & Modeling

The consolidation of industry players and an overall reduction in acceptable time-to-market has led to a demand for streamlined and efficient measurement and modeling device characterization tools. Maury Microwave, along with strategic partner AMCAD Engineering, have succeeded in this challenge by releasing its IVCAD measurement and modeling device characterization software, the most complete commercial solution to cover the design flow from component to circuit to system.

Pulsed IV, Pulsed RF and Compact Transistor Modeling (III-V and LDMOS)

The design flow begins with component-level linear and nonlinear model extraction of popular transistor technologies such as GaN FET and LDMOS.

First, IVCAD, in conjunction with a BILT pulsed-IV system and pulsed-network analyzer will measure synchronized pulsed-IV and pulsed S-parameter data under varying gate and drain bias conditions. Specific pulse widths will be set in order to eliminate self-heating and operate the transistor under quasi-isothermal conditions. The quiescent gate and drain voltages will be set to isolate and model gate-lag and drain-lag trapping phenomena. Measurements can be repeated under varying chuck temperatures, varying pulse widths and quiescent bias points, to extract an electrothermal model component.

AMCAD III-V and LDMOS model extraction is performed within the IVCAD platform; the same tool used to record relevant measurements is also used to extract the complete compact model. The measured S-parameters are used to extract a linear model consisting of extrinsic (pad capacitances, port metallization inductances, port ohmic resistances) and intrinsic parameters (channel capacitances, ohmic resistances, mutual inductance, output capacitance and resistance). Synchronized pulsed IV and pulsed S-parameter are used to extract nonlinear capacitances, voltage controlled output current source, diodes, breakdown generator, thermal and trapping circuits.

Load Pull (Vector-Receiver and Traditional)

Load pull involves varying the load impedance presented to a device-under-test (DUT) at one or more frequencies and measuring its performance, including output power at the fundamental and harmonic frequencies, gain, efficiency, intermodulation distortion… Load pull can be used for amplifier design, model extraction, model validation, performance testing as function of mismatch, and to test the robustness of finished systems, among other things.

Once a nonlinear compact model has been extracted, load pull can be used for model refinement by adjusting nonlinear parameters to better match the nonlinear measurements. Load pull can also be used for model validation by overlaying simulated and measured transistor performance as a function of load impedance presented to the transistor.

IVCAD supports multiple forms of traditional (scalar, modulated) and vector-receiver (VNA-based, real-time) load pull methodologies. Traditional load pull includes CW and pulsed-CW single-tone and two-tone, as well as modulated input signals, fundamental and harmonic impedance control on the source and load, passive impedance generation techniques, under DC and pulsed bias stimulus. Vector-receiver load pull includes CW and pulsed-CW single-tone and two-tone input signals, fundamental and harmonic impedance control on the source and load, passive, active and hybrid-active impedance generation techniques, time-domain waveform NVNA load pull, under DC and pulsed bias stimulus.

Passive load pull allows engineers to use mechanical impedance tuners to vary the source and load impedance presented to the DUT. Passive load pull is available at the fundamental and harmonic frequencies.

Active load pull replaces passive tuners at one or more frequencies with “active tuners”, which use a magnitude and phase controllable source to inject power into the output of the DUT, thereby creating the “reflection” signal needed to vary the impedance presented. Active load pull overcomes the mechanical and VSWR challenges presented by harmonic passive tuners, as well as tuning isolation challenges between the different frequencies related to the combined movement of the tuner’s slugs.

Hybrid-active load pull combines the strengths of active and passive load pull, allowing the passive tuner to act as a prematch, to lower the power required by the “active tuner”, and divide-and-conquer multiple frequencies.

Time-domain NVNA load pull allows for the recording of voltage and current waveforms and load lines in addition to the typical measurement parameters. This additional information can be useful in studying the sensitivity of a transistor as well as class of operation.

Synchronized pulsed-RF pulsed-bias load pull uses the BILT PIV system to bias the DUT for a true pulsed measurement. Pulsing the bias can set the thermal state of the transistor and avoid self-heating. It is also useful to MMIC applications in which the bias will be pulsed.

Behavioral Modeling

Behavioral modeling is a “black-box” modeling technique which models the DUT’s response to a specific set of stimuli (input power, bias, impedance…). Compared with compact models which completely define the characteristics of the transistor, behavioral models define only the “behavior” and static models are valid under the conditions in which they were extracted. Behavioral models are useful in several applications: to hide the details of the transistor specifics while concentrating on its performance and response (ideal for public distribution), to improve the speed of simulation (behavioral models will generally simulate faster than a compact model containing the same data), to model a packaged component, or even a complete circuit or system (incompatible with compact modeling).

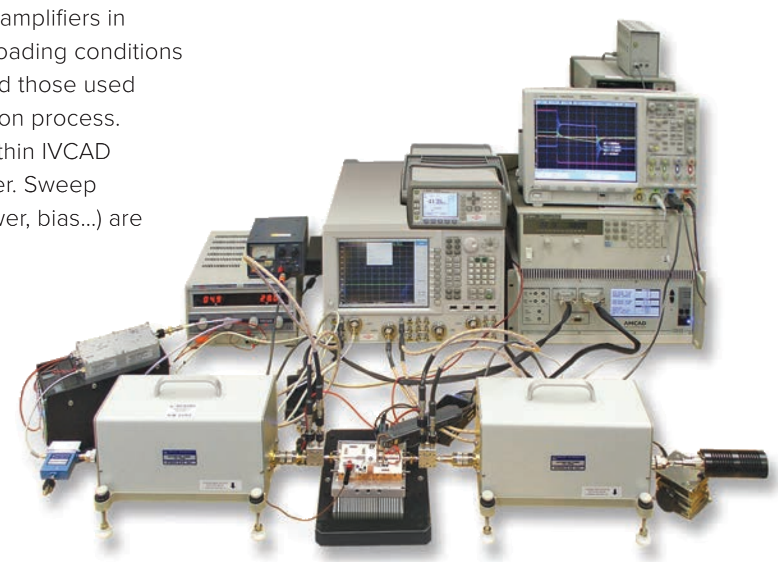
IVCAD supports three behavioral modeling methodologies: Keysight’s X-Parameters and AMCAD’s Multi-Harmonic Volterra (MHV) and Enhanced PHD. X-Parameters are the result of poly-harmonic distortion methodology (harmonic superposition) which uses harmonic extraction tones to quantify the harmonic nonlinearities of a DUT. The MHV modeling technique is based on harmonic superposition combined with dynamic Volterra theory resulting in a model that can handle both low frequency and high frequency memory effects. The strength of MHV modeling is that it enables accurate and reliable simulations in commercial RF circuit or system simulators, even when using complex modulated wideband signals. Thanks to this accuracy, the most important figures of merit of RF systems can be analyzed safely (e.g., EVM, ACPR, IM3, etc.).

Enhanced PHD (EPHD) is ideal for behavioral modeling of amplifiers in which extrapolation of loading conditions may be required beyond those used in the modeling extraction process. Behavioral modeling within IVCAD is transparent to the user. Sweep plans (impedances, power, bias…) are defined and the measurement is run as normal, however the software will communicate with the relevant model extraction application and present a completed model upon completion of the measurement routine.

Stability Analysis of Circuits

Once an amplifier or integrated circuit has been designed on a circuit simulator, it is critical to test the design for low- and high-frequency oscillations. IVCAD offers a Stability Analysis module (STAN) which is compatible with commercial circuit simulation tools. Single-node and multi-node analysis identifies the cause and localization of oscillations. Parametric analysis determines oscillations as a function of varying input power, bias, load impedance and stabilization network parameters (resistance values). Monte Carlo analysis discovers oscillations as a function of manufacturing dispersions and tolerances.

Whether being used for a single purpose or across multiple modeling, design and production groups, IVCAD measurement and modeling device characterization software suite offers an intuitive, methodical and efficient solution for first-pass design success and quickest time to market.



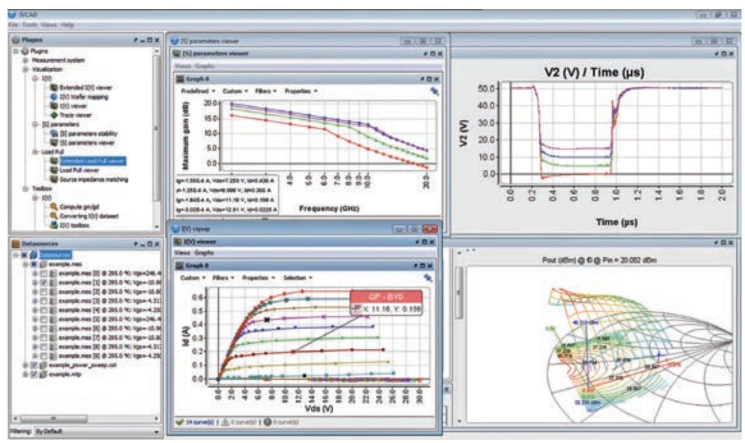
MT930B1 IVCAD Basic Visualization

IVCAD offers a modern and intuitive basic visualization package for IV, S-Parameters and Load Pull data.

- Basic I(V) Viewer plots IV curves of Vd, Vg, Id and Ig
- IV Trace Viewer
- Basic S Parameter Viewer plots S-parameters in standard and custom formats including log magnitude, linear magnitude, phase, polar, and Smith Chart
- Basic Load Pull Viewer plots impedance sweeps and power sweeps with advanced filtering capabilities

Dockable windows allow users to create and save custom IVCAD environments. Templates allow users to save their preferred visualization graphs and recall or share with colleagues. Data Editor allows users to create new parameters based on equations and visualize alongside measurement data. Export allows users to save graphs and plots as JPG or PDF files for reporting. Visualization is compatible with Maury Microwave and common commercial data formats.

Visualization of S-Parameters, IV Curves, Pulse Shape and 3D Load Pull Contour



MT930B2 IVCAD Advanced Visualization Add-On

MT930B2 is an add-on module for MT930B1 which enables advanced visualization capabilities including:

> Extended IV Viewer

> I(V) Wafer Mapping

> S parameter stability analysis

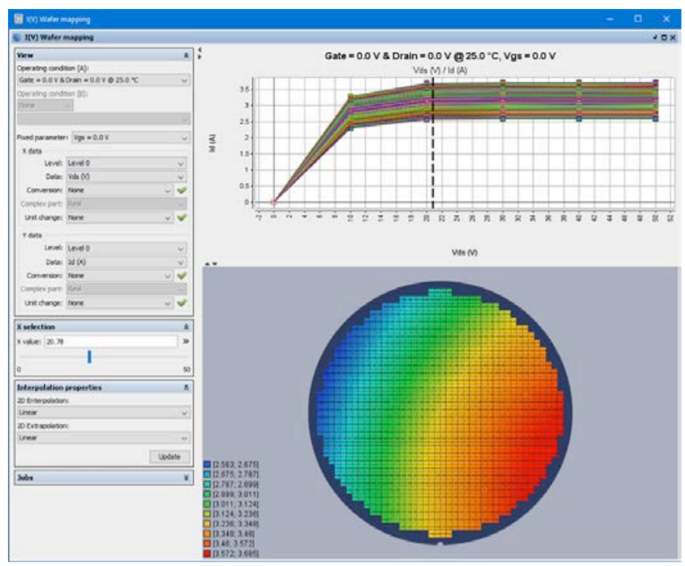
> Extended Load Pull Viewer

> Load Pull time domain visualization

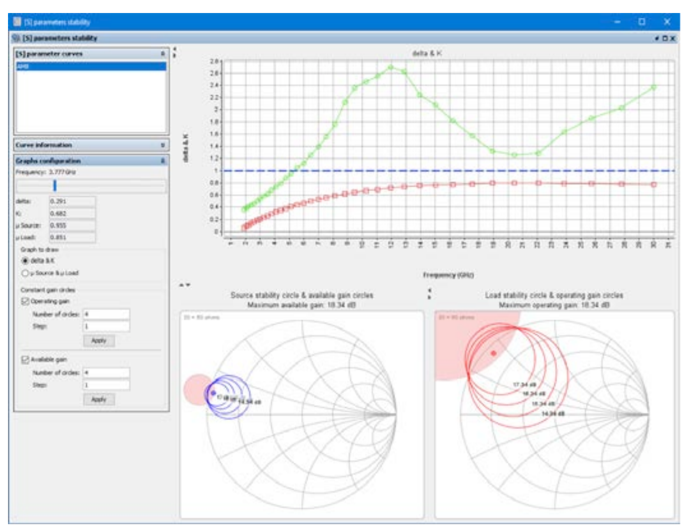
> Magic Source Pull

Extended IV Viewer – enables users to visualize a transistor's pulsed IV characteristics versus time. This is useful in observing dynamic self-heating in the saturated region while moving different time markers. A second use is to determine the ideal measurement windows, i.e. the steady-state measurement area, so that the measurement data is not recorded in an area of overshoot or ringing. This is critical in defining the minimum pulse width for any given measurement, since the ideal value is tied to transistor size, bias tees, cables, etc, and can only be determined by visualizing the shape of the pulse over time.

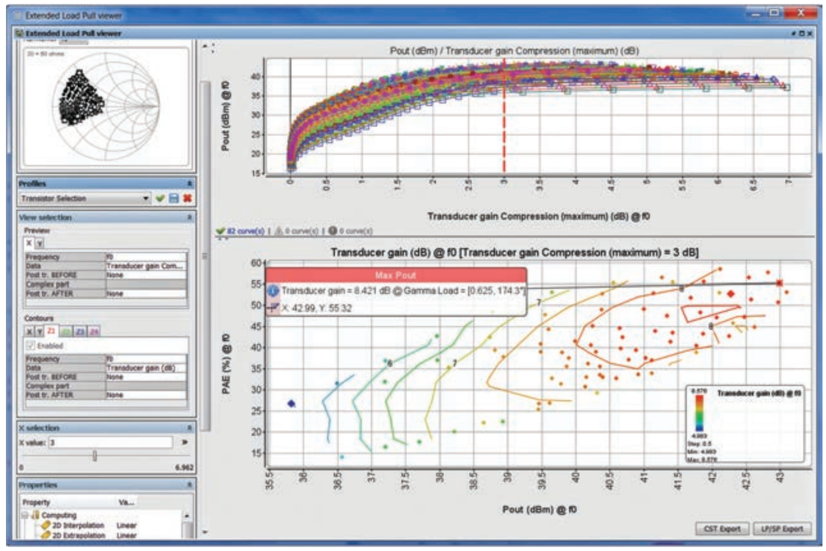
I(V) Wafer Mapping – makes use of IVCAD's automated probe station control for step-and-repeat IV measurements and plots critical IV characteristics as a function of transistor over the wafer. DC Gm and Gd characteristics can be dynamically observed, as well as Gate Lag and Drain Lag over the wafer.



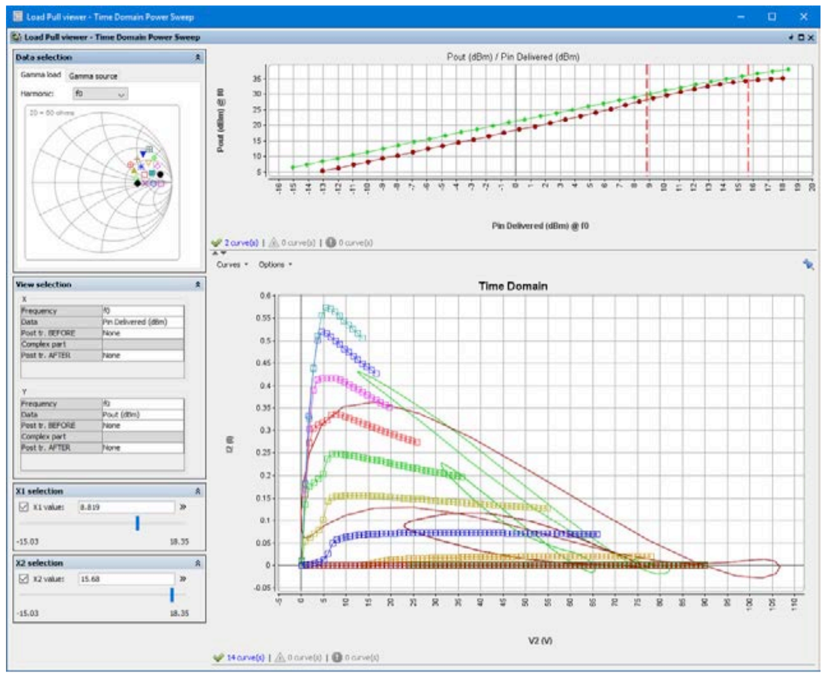
S-parameter stability analysis – allows users to visualize source and load stability circles extracted from linear S parameter measurements. Constant available gain and operating gain circles are also plotted and updated in real-time as a function of frequency.



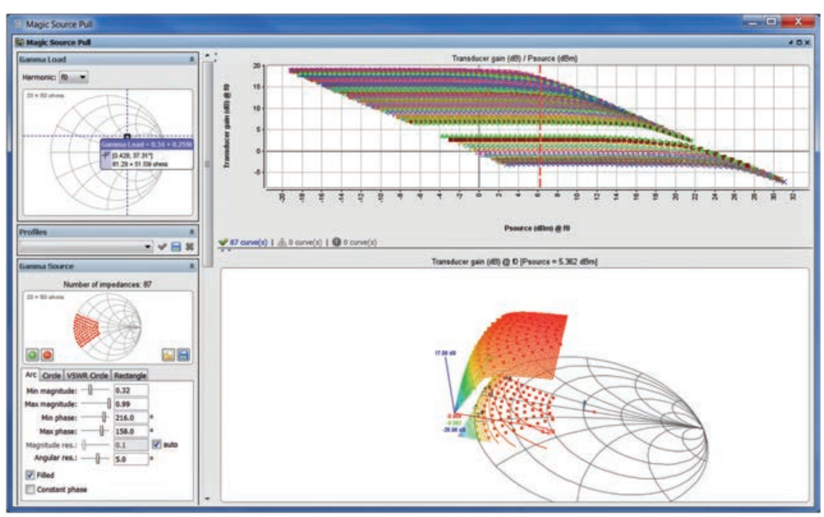
Extended Load Pull viewer – enables users to dynamically plot XY graphs and Smith Chart contours based on a dependency variable, such as input power, output power, gain compression, efficiency or EVM. The viewer links two independent plots, such that the first plot is used to determine the dependency value, while the second plot is automatically updated as a function of the dependency value, and can be customized on the fly. Extended Load Pull viewer is invaluable when sorting through large sets of measurement data, such as nested measurements (i.e. load pull over a region of the Smith Chart, while sweeping power at each load).



Load Pull Time Domain visualization – enables the plotting of voltage and current waveforms and load lines measured using the MT930G IVCAD Time-Domain Waveforms add-on module for MT930C IVCAD Vector-Receiver Load Pull. In addition, linear models extracted using MT930M1 IVCAD Linear Model Extraction can be used to de-embed the time-domain waveforms to the intrinsic transistor reference plane, and intrinsic RF load lines can be superimposed with Pulsed IV plots to give valued information regarding high efficiency operating classes (i.e. Class F, Inverse Class F…). Markers can be placed at different powers to visualize the effects of gain compressions on load line saturation.



Magic Source Pull (Source Pull Converter) – Large signal input impedance can be found by measuring DUT a- and b-waves at the DUT reference plane. A patented technique simulates source matching, without varying the source impedance. Even under extremely mismatched conditions this “virtual source matching” is highly reliable, provided the DUT is sufficiently unilateral (S21~ >S12+50dB). Simulated source contours are drawn, and trade-offs between maximum gain, efficiency and other parameters can be viewed in real-time without multiple source-load measurement iterations. Direct computation of the input VSWR versus source power and source impedance is also enabled.

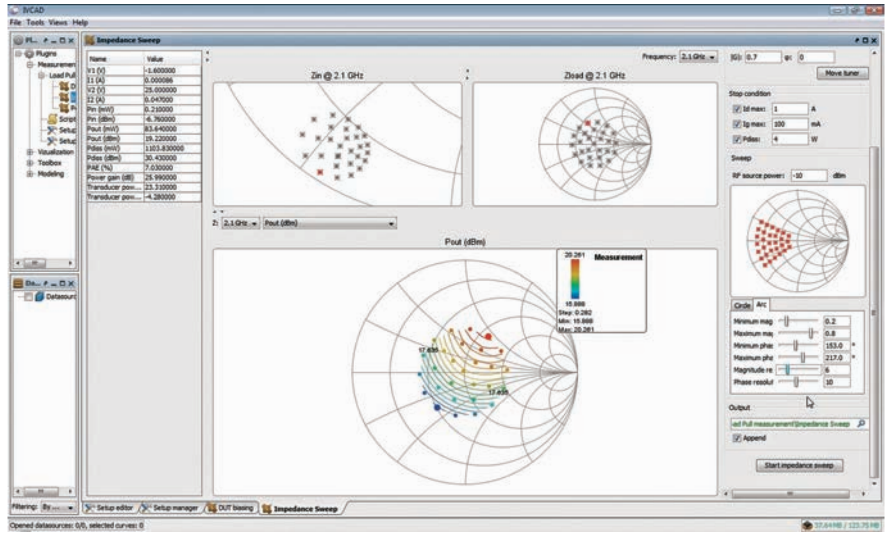


MT930C IVCAD Vector-Receiver Load Pull and MT930C1 IVCAD Vector-Receiver Load Pull Waveguide Add-On

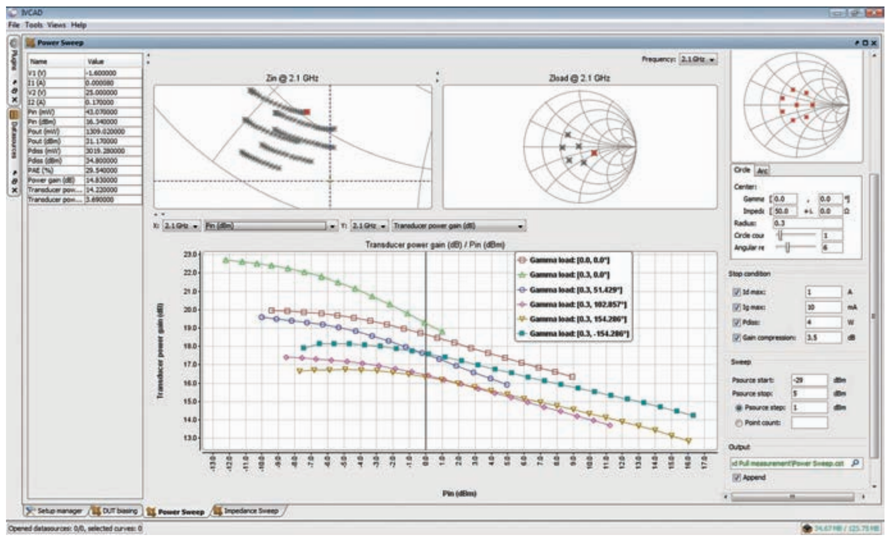
IVCAD offers a modern, efficient methodology for load pull measurements, with low-loss couplers between the tuners and DUT. Connecting the couplers to a VNA allows real-time measurement of a- and b-waves at the DUT reference plane, presenting vector information not normally made available. IVCAD measures the actual impedances presented to the DUT without assumptions of pre-characterized tuner positioning or losses. Extremely accurate transistor's input impedance derived from the a- and b-waves results in properly-defined delivered input power, true power added efficiency and true power gain measurements. Output powers at each frequency, fundamental and multiple harmonics, are made available as are multi-tone carrier and intermodulation powers.

Key Features:

- > Supports single-tone and two-tone CW and pulsed-CW drive signals
- > Fundamental and harmonic impedance control on source and load
- > Automatically measures and calculates available parameters based on instrumentation
- > DC and pulsed bias with interactive bias control
- > Measure Zin in real-time to determine Pin,delivered
- > Automatically tune the source tuner to the complex conjugate match of Zin for maximum power delivered to the DUT
- > Measure actual Zl load impedances presented to DUT
- > Two-tone IMD load pull using PNA-X
- > Automatically de-embed and correct S-parameters of components between tuner and DUT
- > Advanced peak search algorithm determines the region of maximum performance
- > Real-time visualization of load contours and power sweeps
- > Integrate VRLP and TLP in one setup
- > Export data to CSV or MDF



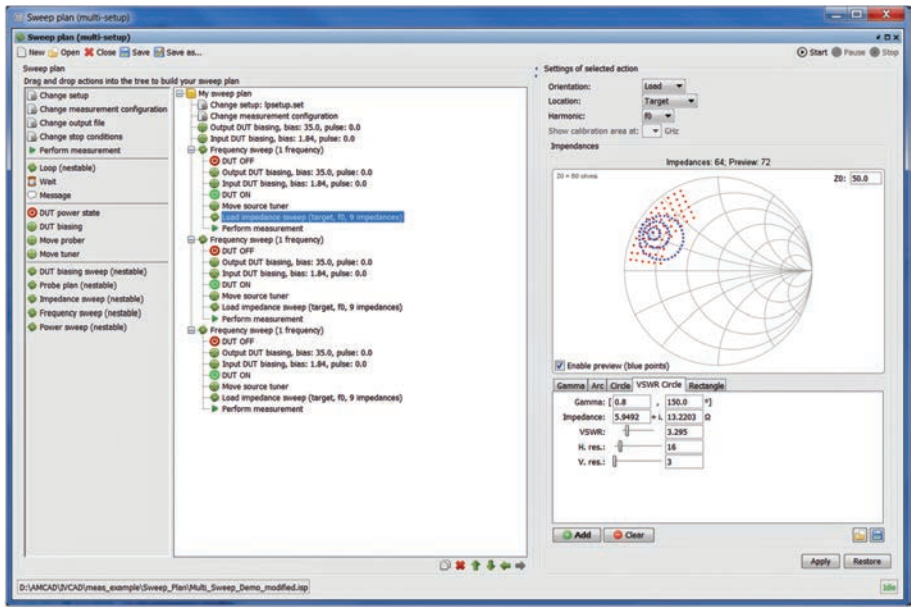
Impedance Sweep at Fixed Power



Power Sweep at Multiple Impedances

MT930C1 — is an add-on module for MT930C which enables vector-receiver load pull measurements using waveguide tuners and waveguide frequency extender modules.

Advanced Sweep Plan – available with both MT930C and MT930D1; by performing sweeps at multiple impedances, sufficient data is gathered that target parameters can be changed post-measurement without the need for additional measurement iterations. The same data set can be used to plot selected parameters at a constant input power, parameters at a constant output power, and parameters at constant compression level. This process greatly reduces total measurement time by gathering sufficient data first-pass, and shifting capabilities towards data visualization and analysis. Sweep parameters include DUT biasing, probe map, impedance sweep, frequency sweep, and power Sweep. Advanced capabilities include changing setup File, measurement configuration, output File During Sweep and stop conditions throughout the plan, as well as adding nestable loops, wait times and messages.



Advanced Sweep Plan Varying Bias, Impedance and Power

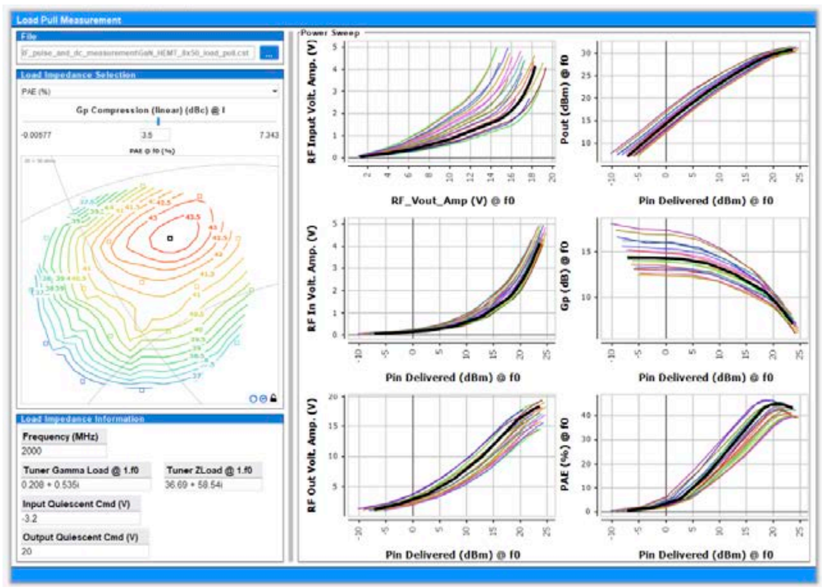
MT930C2 Pre-RF Pulsed IV Load Pull Add-On

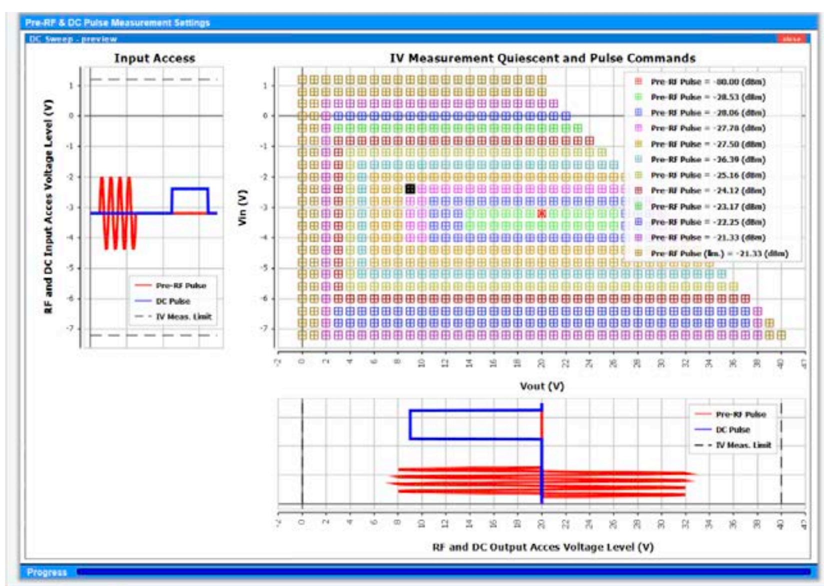
MT930C2 is an add-on software module for MT930C Vector-Receiver Load Pull and MT930J Pulsed IV Curves which measures the I-V characteristic of GaN HEMT transistors in pulse mode by considering the "real" state of charge of the traps, i.e., the one imposed by the component's environment in its final application. The measurement involves applying a RF pre-pulse before each IV measurement point which conditions the charge of the traps at a level determined by the I-V area and is varied throughout the measurement to represent the signal envelope's evolution. The solution uses vector-receiver load pull measurements to set the impedance states to match the final application and set the load lines appropriately.

MT930C2 has been developed to create a more accurate compact transistor model and to speed-up the model extraction and validation process. MT930C2 simplifies the trap models development and embeds non-50ohm measurements into the model extraction process.

Key Features

- I-V measurements are taken in non-50 Ω environment with dynamic trapping effects
- Automatic power configuration of the RF pre-pulse
- Real-time visualization of the I-V network under varying pre-pulse power levels





MT930D1 Traditional Load Pull and MT930D2 Harmonic, Spectrum and Vector Analyzer Add-On

IVCAD offers a flexible solution for traditional load pull based on power meters and optional spectrum or vector signal analyzers. In its simplest configuration, IVCAD can use a single signal source and power meter to measure power, gain, and efficiency. Adding an optional second power meter will enable input signal monitoring or reflection power measurements, or powers at harmonically separated frequencies when combined with a multiplexer. Adding an optional spectrum analyzer will enable the measurement of power at fundamental and harmonic frequencies. Adding an optional second source and spectrum analyzer will enable the measurement of two-tone IMD products. Adding an optional vector signal source and vector spectrum analyzer will enable the measurement of ACPR and EVM for modulated signals. IVCAD uniquely enables multiple calibration techniques including S-parameter calibration and power calibration with and without input power meters.

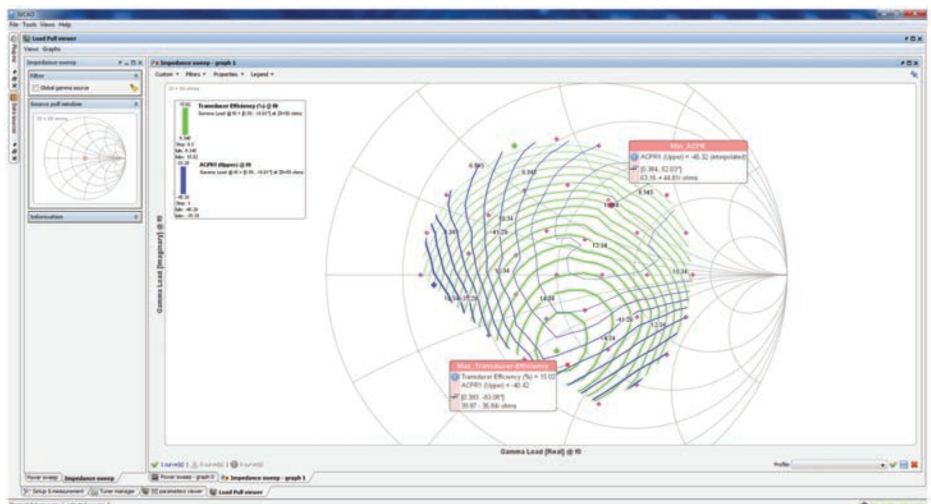
MT930D1 – includes CW and pulsed-CW single tone load pull using a power meter to measure output power

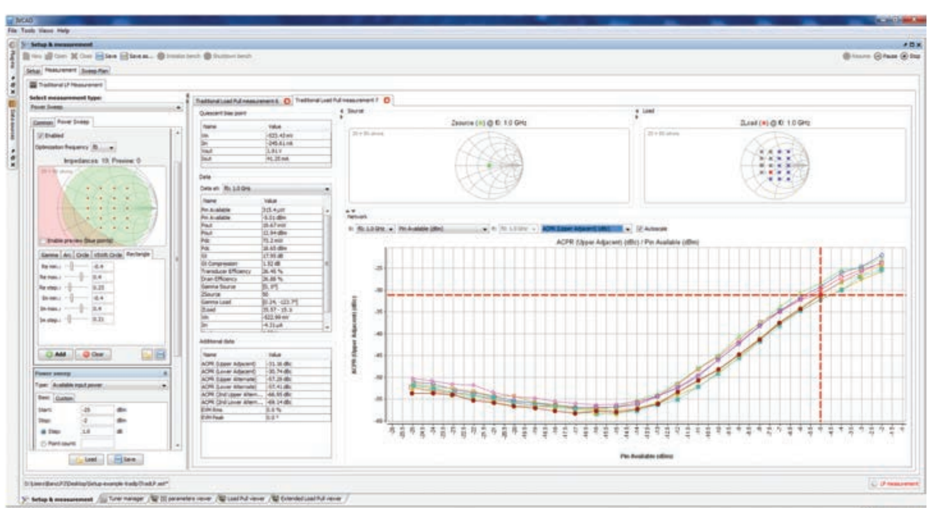
MT930D2 – is an add-on module for MT930D1 and enables the addition of a multiplexer with multiple power meters for harmonic power measurements, a spectrum analyzer for harmonic power measurements and two-tone IMD measurements (when paired with a second or two-tone signal source), a vector analyzer for modulated signal measurements of ACPR and EVM (when paired with a vector signal generator), and harmonic load pull (when paired with compatible impedance tuners.)

Advanced Sweep Plan – See Advanced Sweep Plan description in MT930C.

Key Features

- Supports single-tone and two-tone CW and pulsed-CW and modulated drive signals
- Fundamental and harmonic impedance control on source and load
- Automatically measures and calculates available parameters based on instrumentation
- DC and pulsed bias with interactive bias control
- S-parameter and power calibration methodologies
- Harmonic load pull using power meters or spectrum analyzers
- Two-tone IMD load pull using spectrum analyzers
- Modulated load pull using vector analyzers
- Real-time visualization of load contours and power sweeps
- Integrate VRLP and TLP in one setup
- Export data to CSV or MDF



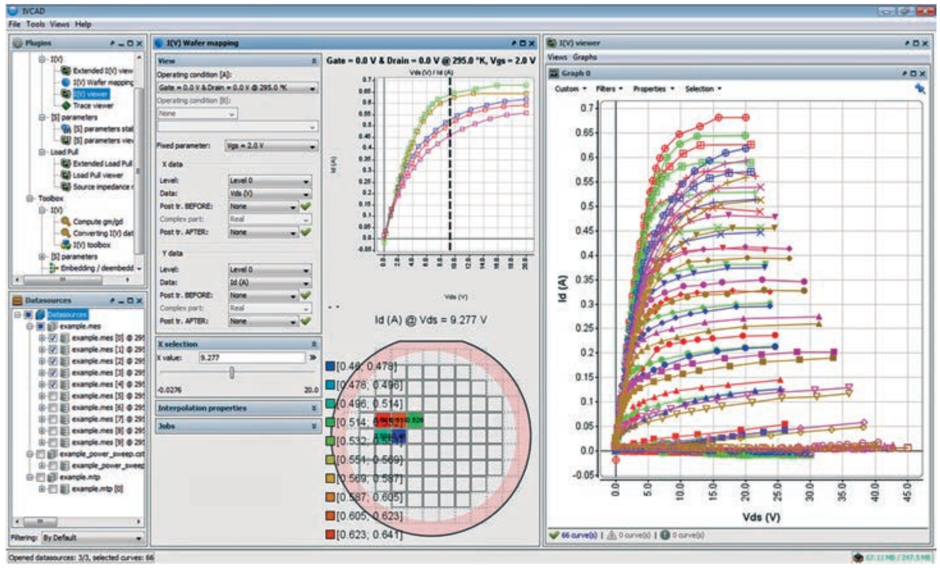


MT930E IVCAD IV Curves

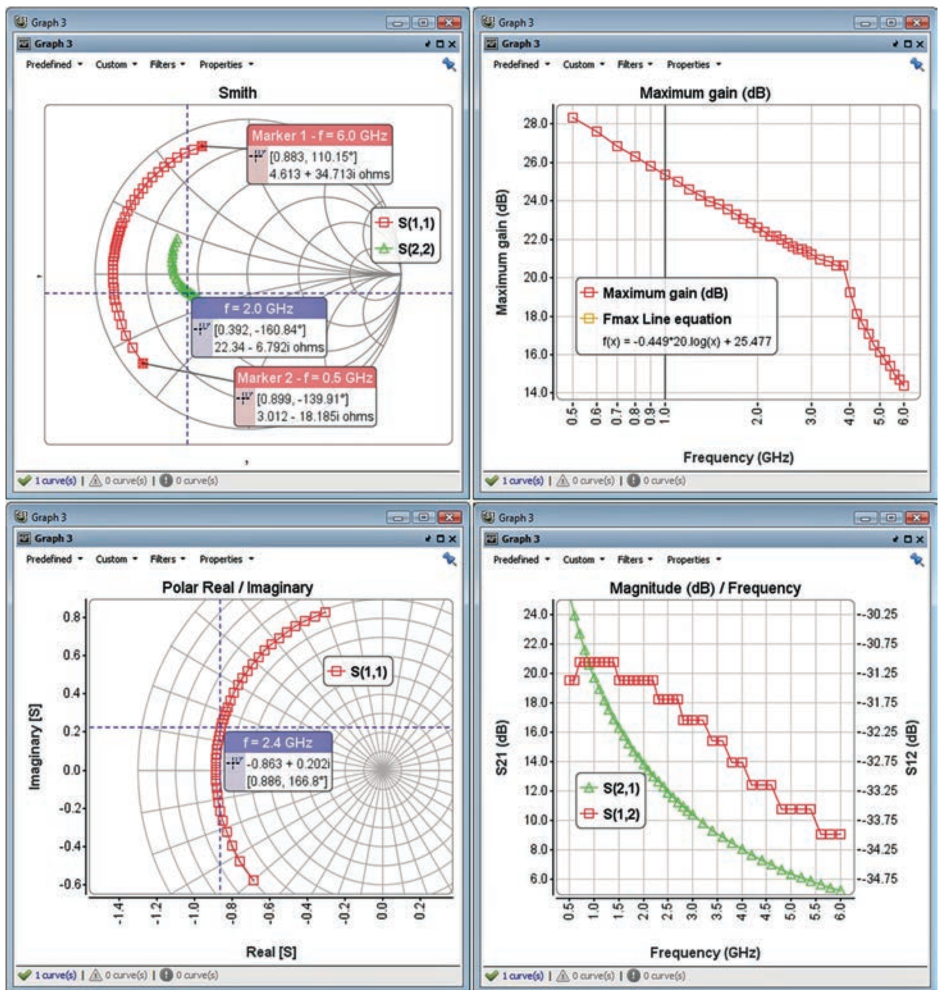
MT930E is a standalone module which enables DC-IV curves to be generated for a list of drain and gate voltages.

MT930F IVCAD CW S-Parameters

MT930F is an add-on module for MT930E which enables CW S-parameters to be measured at each DC IV bias point.



IV Curves at Various Wafer Positions



S-Parameters Plotted on Smith Chart, Maximum Gain, Polar, and Magnitude

MT930GA IVCAD Time-Domain LSA Add-On

MT930GA is an add-on module for MT930C Vector-Receiver Load Pull which enables time-domain large signal analysis and waveform reconstruction when used with supported VNAs and comb generators (harmonic phase references), and does not require third-party nonlinear VNA software. The LSA add-on records the phase dependency of harmonic content and allows a- and b-waves, voltage and current waveforms, and load lines to be displayed for each measurement state (impedance/power/bias) and can be de-embedded to the device reference plane.

Time-domain analysis, or Waveform Engineering, allows the analysis of currents and voltages at the device input and output terminals in order to identify the DUT's mode of operation. This tool is useful in the study and design of advanced amplifier classes of operation including E, F, J and K and their inverses.

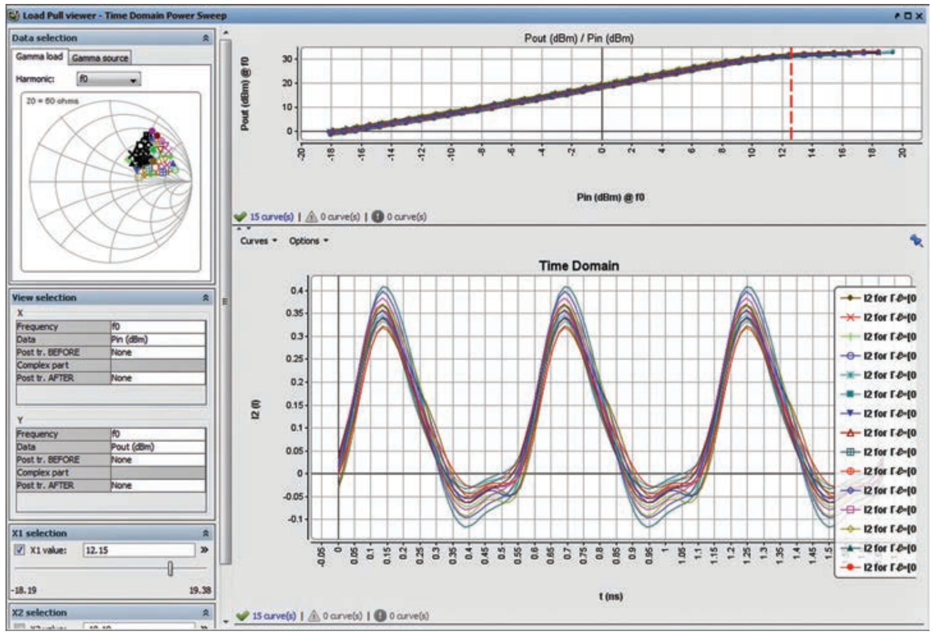
When used in combination with MT930R1 IVCAD EPHD Behavioral Model Extraction, an enhanced Poly- Harmonic Distortion behavioral model can be extracted for each measurement state with no significant addition of time.

MT930GB IVCAD Keysight NVNA Support Add-On

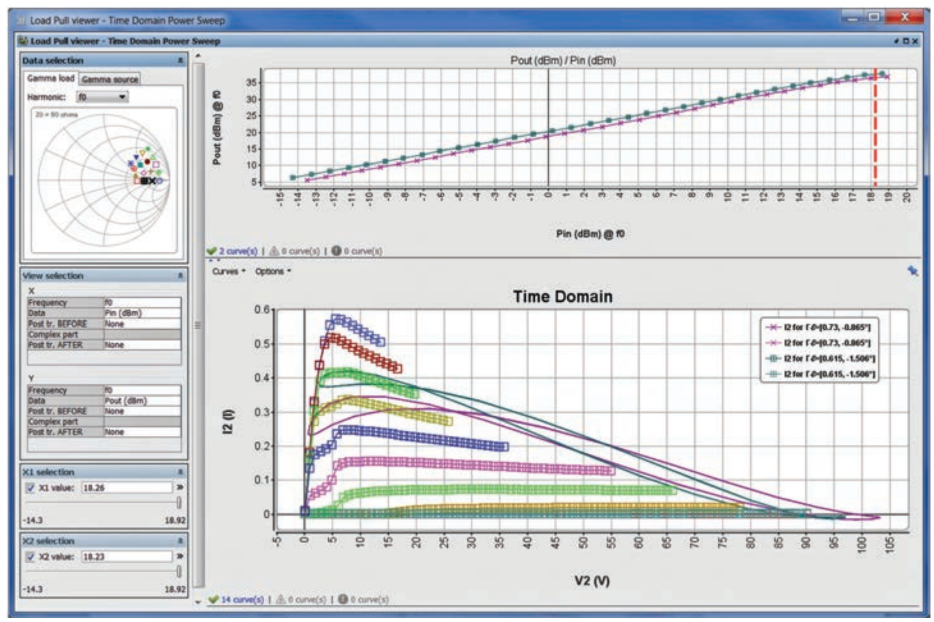
MT930GB is an add-on module for MT930C Vector-Receiver Load Pull which enables time-domain large signal analysis and waveform reconstruction in conjunction with Keysight PNA-X network analyzer with NVNA software option enabled.

MT930GB relies on the NVNA application to measure the phase dependency of harmonic content and allows a- and b-waves, voltage and current waveforms, and load lines to be displayed for each measurement state (impedance/power/bias) and can be de-embedded to the device reference plane.

With the appropriate PNA-X options, MT930GB also enables the extraction of X-parameters behavioral models.



Output Current Waveforms at Constant Input Power Under Varying Load Impedances



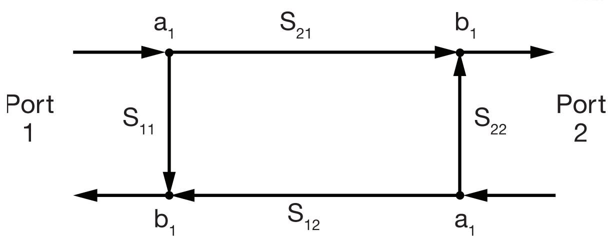
DC and RF Load Lines at Constant Input Power Under Varying Load Impedances

Key Features

- Enhanced active load pull algorithm for faster and safer convergence

MT930H IVCAD Active Load Pull and MT930H1 IVCAD Active Load Pull Waveguide Add-On

MT930H is an add-on module for MT930C Vector -Receiver Load Pull which enables active load pull in conjunction with internal and external sources for fundamental and harmonic load pull measurements. Considering our DUT as a two-port device shown below, Γ_L is nothing more than a_2/b_2, or the ratio between the reflected- and forward-traveling waves. A generalized form of the formula can be written as $\Gamma_{x,n}(f_n)=\frac{a_{x,n}(f_n)}{b_{x,n}(f_n)}$

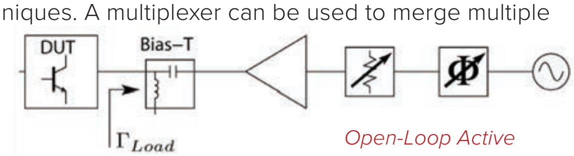


Two-port Scattering Parameter Model.

A closer examination of the formula $\Gamma_L=a_2/b_2$ reveals that there is no limitation on separating the sources of a_2 and b_2. It is obvious that b_2 is the wave coming from the device, of which we have no direct control; however a_2 need not be a reflected version of b_2 but can be a new signal entirely!

Active Load Pull – Active injection load pull, more commonly referred to as active load pull, relies on external sources to inject a signal into the output of the DUT, thereby creating a_2. Because a_2 is no longer limited to a fraction of the original reflected signal, as is the case with the traditional passive mechanical tuner, external amplifiers may be used to increase a_2 nearly indefinitely so that Γ_L can achieve unity. The simple active tuning chain consists of a signal source, a variable phase shifter and a variable gain stage, shown in the diagram below. Common signal generators that have built-in amplitude and phase control of the injected signal are ideal for active load pull.

Harmonic load pull, or tuning impedances at multiple frequencies simultaneously, becomes simple when using active load pull techniques. A multiplexer can be used to merge multiple active tuning paths, one per frequency,



Open-Loop Active Tuning Block Diagram.

so that $\Gamma_{x,n}(f_n)=\frac{a_{x,n}(f_n)}{b_{x,n}(f_n)}$ is satisfied.

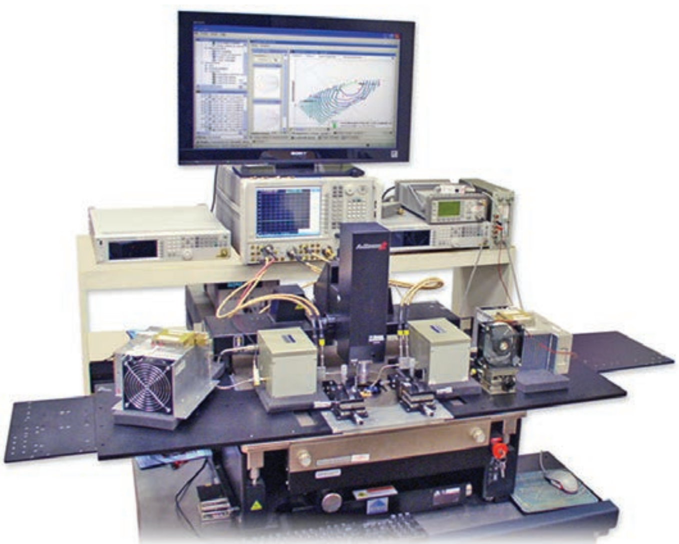
Any loses inherent to multiplexers are easily overcome by the amplifiers used in each active tuning chain.

Hybrid-Active Load Pull – Both traditional passive mechanical tuner systems and active injection load pull systems have their advantages and disadvantages. While mechanical tuners are simple, less expensive and can handle high power, there is no physical way to overcome the losses involved with the system that limit achievable Γ_L. While active load pull systems are extremely quick, capable of Γ_L=1 and easily integrated for harmonic measurements on-wafer, high-power setups require more-expensive band-limited amplifiers.

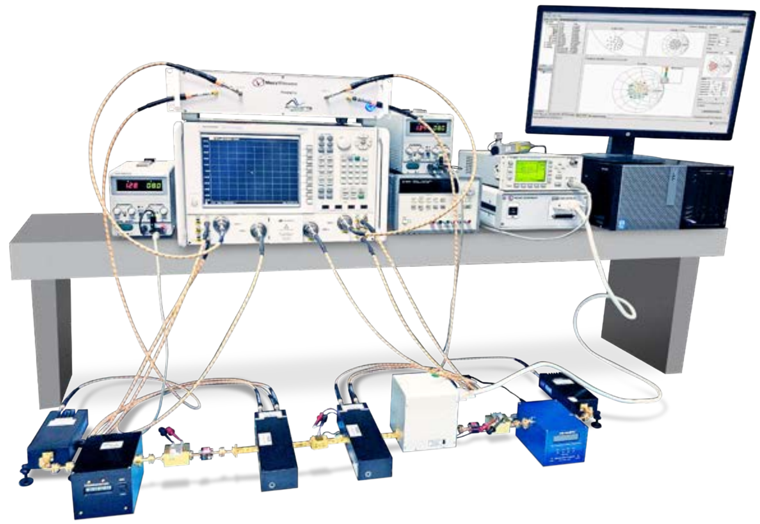
It is possible to obtain the advantages of both systems while minimizing the disadvantages, using a technique referred to as hybrid load pull. Hybrid load pull refers to a combination of active and passive tuning in the same system. Traditional passive mechanical tuners can be used to reflect high power at the fundamental frequency allowing a much smaller active injection signal, using much smaller amplifiers, to overcome losses and achieve Γ_L=1. Additionally, since the powers at harmonic frequencies are often well below the power of the fundamental signal, less-expensive wideband amplifiers may be used with active tuning to accomplish active harmonic load pull with $\Gamma_{L,nf}$=1. In both cases, only a low power is required for active tuning.

MT930H IVCAD Active Load Pull (continued)

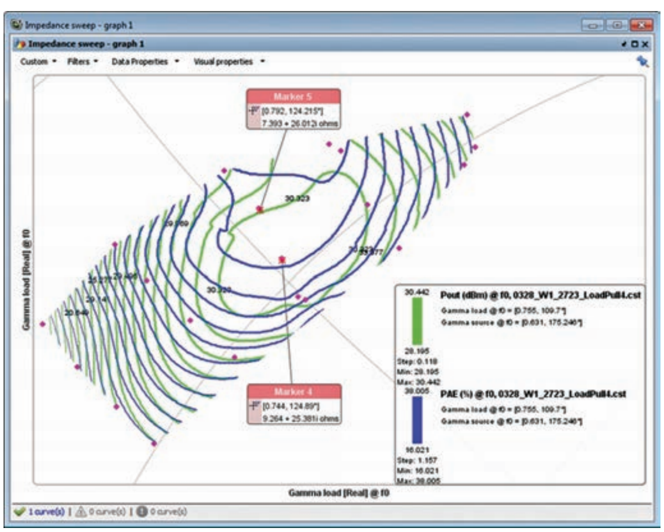
MT930H1 — is an add-on module for MT930H which enables active and hybrid-active load pull measurements using waveguide tuners and waveguide frequency extender modules



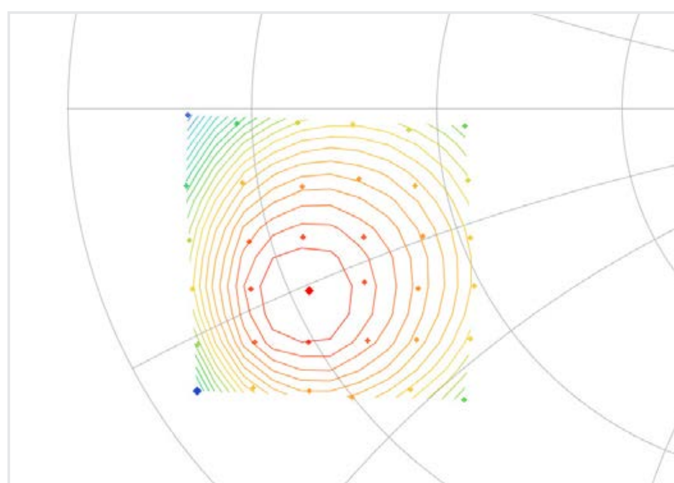
Hybrid-Active Load Pull at 30–50 GHz



Hybrid-active load pull system with WR12 automated impedance tuner, low-loss couplers and waveguide extenders covering 60-90 GHz



Output Power and PAE Contours at High-Gamma Enabled by Hybrid-Active Load Pull



Characterization of HBT transistor at 80 GHz with Pout=15dBm, optimum efficiency at Γ =0.68 and closed contours at Γ =0.92

MT930J IVCAD Pulsed IV Curves

MT930J is a stand-alone module for advanced Pulsed IV measurements using dedicated pulsing hardware (e.g., AMCAD's BILT Pulsed IV system).

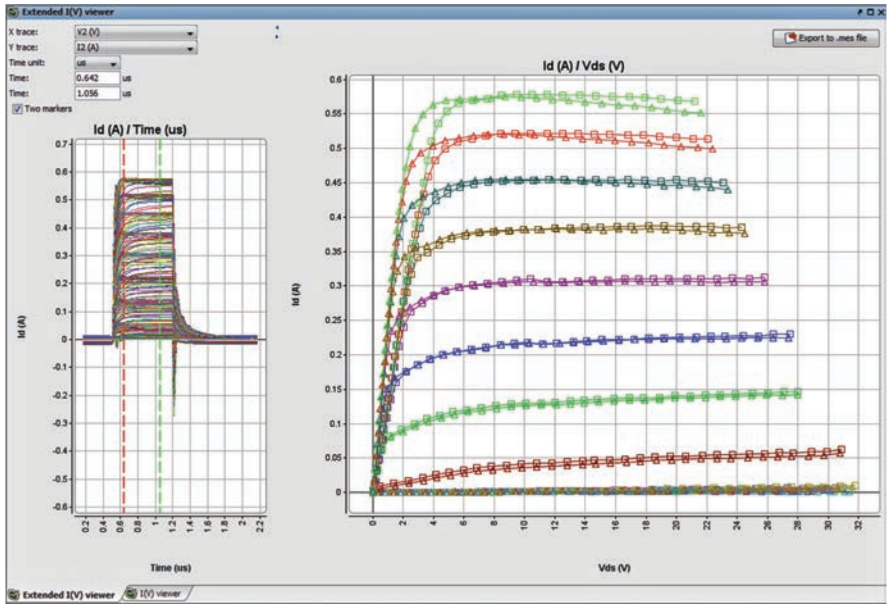
Current-voltage (IV) measurements are used to describe the relationship between the input and output currents and voltages of a device. Standard GaN Field Effect Transistors (FETs) are characterized by measuring the output current as a function of output voltage for swept input voltages. Because GaN devices tend to self-heat and are susceptible to trapping effects, it is important to pulse voltages between a quiescent and hot value and define appropriate pulse-widths. By pulsing the voltage, a lower average power will be delivered to the device thereby reducing self-heating. Such a measurement allows for near-isothermal performance.

IVCAD enables the visualization of trapping phenomena, gate lag and drain lag, on GaN transistors. It is a simple task to view trapping effects as a function of varying quiescent bias.

IVCAD has implemented full wafer control by interfacing with Cascade Nucleus software.

Key Features:

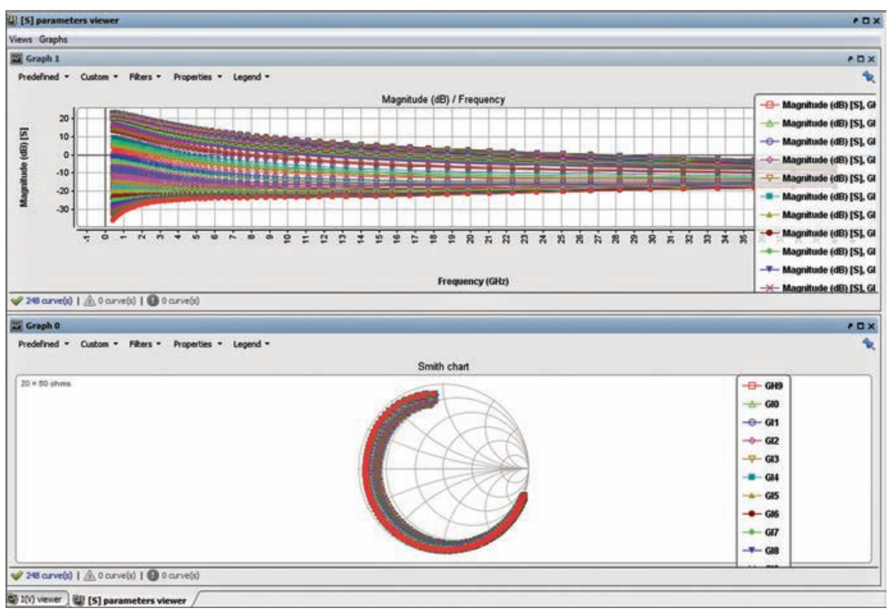
- Pulsed configuration and calibration of all instruments (including PIV system and VNA) controlled by IVCAD
- Graphical pulsed chronogram easily defines gate, drain, RF source and measurement windows
- Sweep input or output voltages in linear, adaptive and custom voltage steps
- IV trace screenshot visualizes IV waveform without the need for an oscilloscope
- VNA operated in NBW for enhanced accuracy S-parameters
- Multiple stop conditions for voltages, currents, powers and temperatures
- Automated probe station control
- Export data to ICCAP, ADS and Microwave Office



Pulsed IV Curves Plotted at Different Times with Pulse

MT930K IVCAD Pulsed S-Parameters

MT930K is an add-on module to MT930J which enables synchronized Pulsed S-Parameter measurement in conjunction with Pulsed IV.



Pulsed S-Parameters Under Varying Bias Conditions

MT930L IVCAD Scripting Language

MT930L is an add-on module to MT930C/D/J/K which enables complex test sequencing through a dedicated scripting language.

Scripting is available both internally to IVCAD and as an external script server. The script server allows users to run IVCAD as slave software, controlled by an external application, through TCP/IP sockets.

TCP/IP sockets allow programs to talk through a network, but a communication between two programs on the same computer can also be established.

Internal scripting is managed by the script editor, which includes functions divided into several categories:

Concurrency – functions related to threading

User interfaces – functions related to creating windows, docking windows, fonts, labels, 2D and 3D graphs, wafer maps

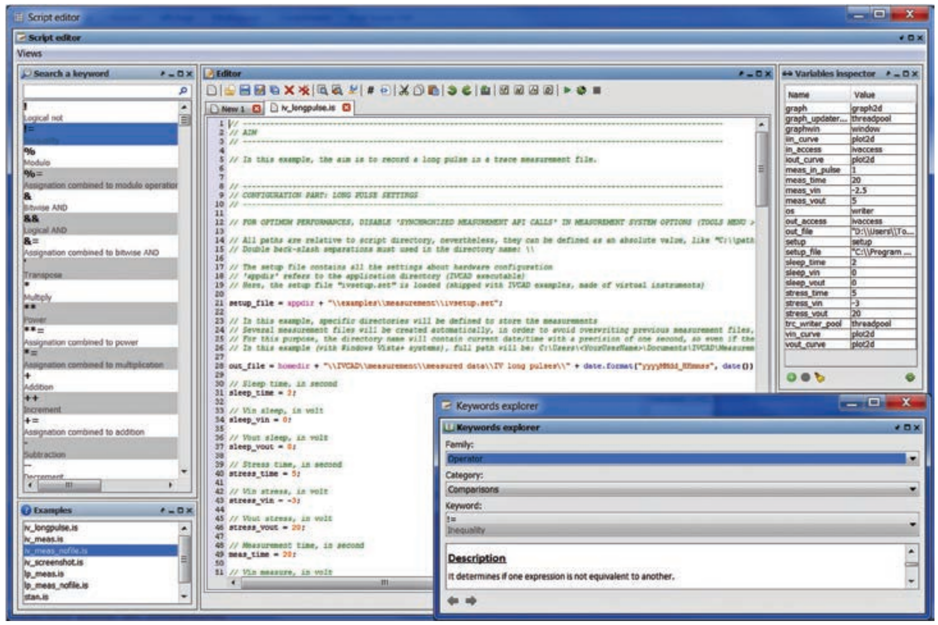
I/O – functions related to logging events, printing messages, reading and writing characters, managing files and directories

Math – functions related to math, values, vectors, arrays, rows, factorial operations, complex numbers, conversions, exponents, interpolation, trigonometry

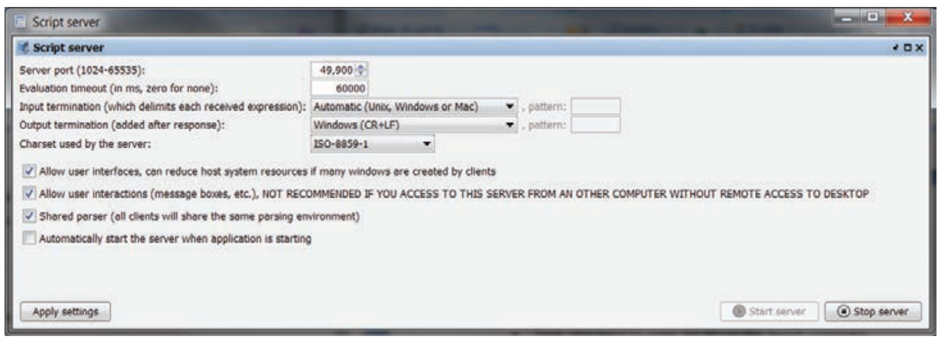
Measurements – functions related to impedance control, IV control, probe station control, tuner control, setup management

Scripting – functions related to loops, conditions, if/else

SQL – functions related to database management



Script File Tuning Source and Load Within IVCAD



Script Server

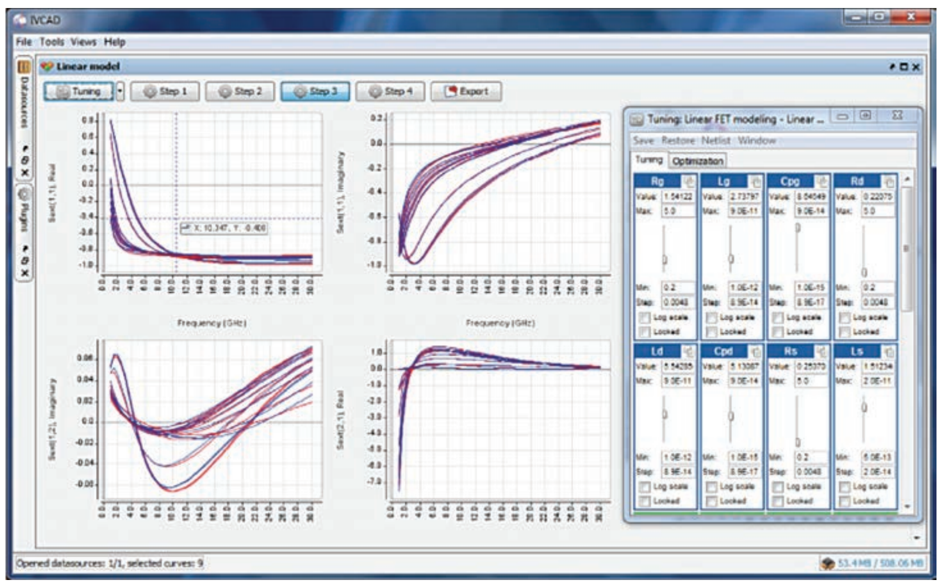
MT930M1 IVCAD Linear Model Extraction

MT930M1 is an add-on module to MT930J and MT930K for Linear Model Extraction.

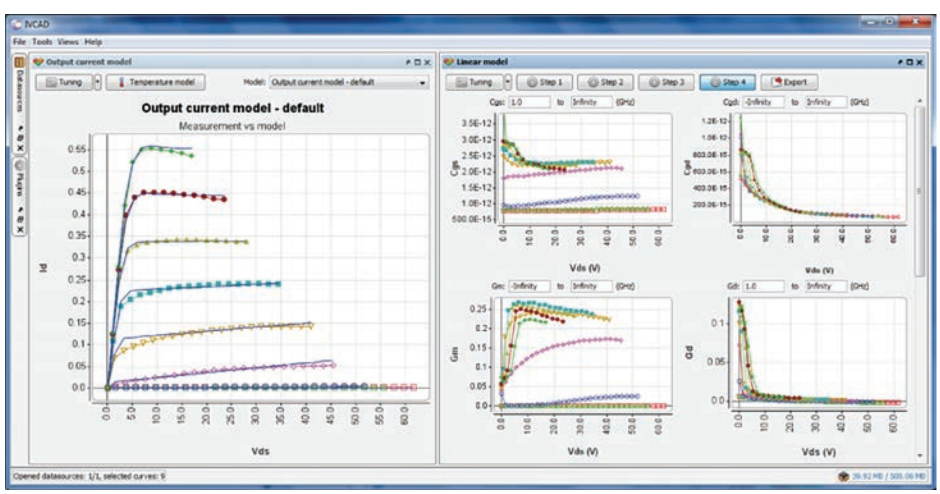
Linear Model Extraction is used to determine the extrinsic parameters (parasitic elements) and intrinsic parameters of III-V and LDMOS transistors. Linear modeling fits measured data to linear model equations, and can be automatically optimized or manually tuned to solve for values of the extrinsic (Rg, Lg, Cpg, Rd, Ld, Cpd, Rs, Ls) and intrinsic parameters.

Linear model extraction is a critical first step in the transistor modeling process, and any errors resulting from linear model inaccuracies will prevent the extraction of nonlinear models. A wizard guides users through a step-by- step process in order to eliminate user errors and ensure first-pass linear model extraction success. Validation is provided by comparing intrinsic elements through a multi-bias extraction. Netlist export is available at each level of the linear model extraction process.

The resulting linear model can be used with MT930M2A and MT930M2B to generate nonlinear models, or exported to commercial circuit simulators. The linear model can also be used to de-embed time-domain load pull data to the intrinsic device reference plane, and visualize intrinsic load lines for advanced amplifier classes.



Linear Model Comparing Measured And Optimized Data



Multi-Bias Capacitances and Transconductance Model Extraction

MT930M2A IVCAD Nonlinear Model Extraction, III-V

MT930M2A is an add-on module to MT930M1 for Nonlinear Model Extraction of III-V device technologies. The extrinsic parameters measured through linear modeling (MT930M1) are used to extract intrinsic parameters.

In quasi-isothermal conditions, MT930M2 uses synchronized pulsed IV/RF measurements to extract the parameters of the AMCAD nonlinear equations that describe the nonlinear capacitances, diodes, and current sources of the transistor. Pulse widths are kept sufficiently short in order to avoid a strong temperature variation during the pulse duration and the duty cycle is kept sufficiently low in order to avoid a mean variation of the temperature, so that the transistor's pulsed IV measurements are obtained under quasi-isothermal operating conditions. S-parameters are measured in the steady-state region of the signal.

Nonlinear Capacitance Model Extraction – For III-V or LDMOS transistors, thanks to a selection of the IV plots close to the expected RF load line, the capacitance values will be extracted according to the instantaneous Vgs and Vds values. In order to extract an accurate and robust model regarding the convergence of the simulation, the nonlinear models will be provided under the form of a "one dimension" formulation. Thus Cgd will be a function of intrinsic Vgd while Cgs will be a function of the intrinsic Vgs voltage. The comprehensive parameters of these equations can be tuned manually or optimized automatically. For III-V transistors Cds is provided as a linear model; for LDMOS transistors Cds is provided as a nonlinear capacitance model.

Diode Parameter Extraction – For III-V transistors, the gate current will be accurately modeled by two diodes (Dgs and Dgd), biased in forward mode.

The manual or automatic tuning of the diode's parameters provides an accurate fit of the positive gate current at low Vds and high Vgs voltages. The negative gate current for high Vds voltages in pinch-off conditions is provided by a breakdown generator.

Output Current Extraction – A specific algorithm is used to extract the output current source model, which provides a reliable description of the Ids current for different Vds and Vgs voltages.

The formulation used enables an accurate description of the output current sources and its derivatives (gm, gd). The comprehensive parameters of these equations can be tuned manually or optimized automatically.

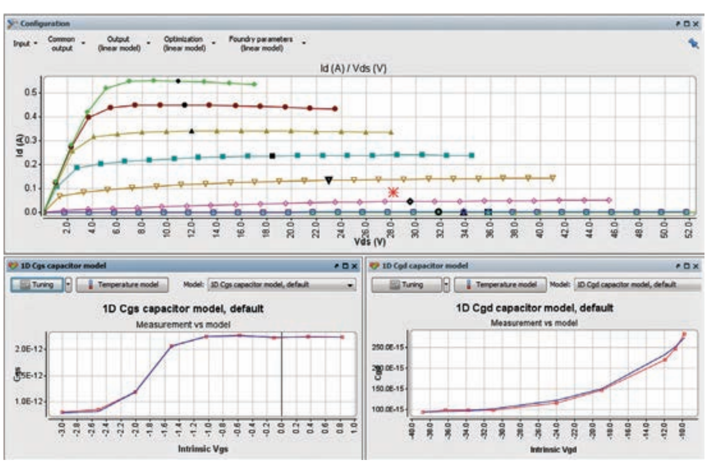
MT930M2A uses a modified Tajima current source model for III-V transistors.

IVCAD employs a comprehensive library and flexible formula editor which allows users to create custom model parameters and parameter extraction equations. Users can implement proprietary equations based on their own experiences and expertise, and benefit from IVCAD's optimization algorithms and GUIs.

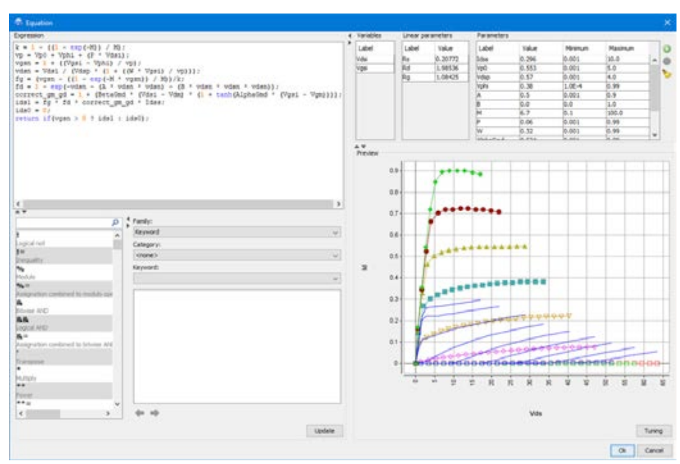
MT930M2B IVCAD Nonlinear Model Extraction, LDMOS

MT930M2B is an add-on module to MT930M1 for Nonlinear Model Extraction of LDMOS transistors. The extrinsic parameters measured through linear modeling (MT930M1) are used to extract intrinsic parameters.

MT930M2B uses a proprietary AMCAD current source model for LDMOS transistors.

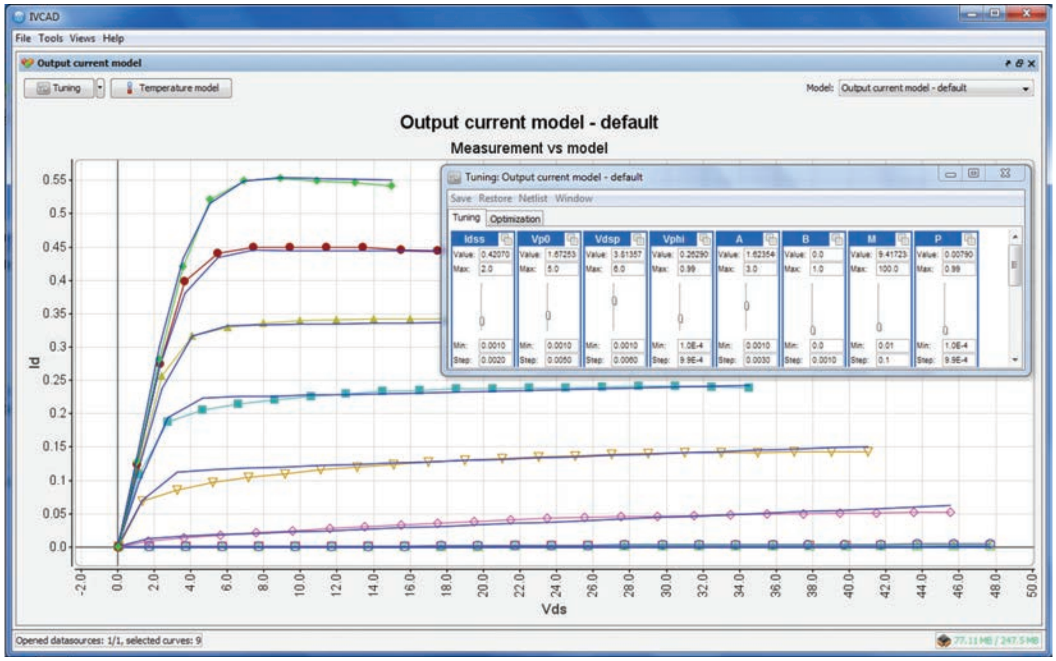


Capacitance Model Extraction Showing Excellent Match Between Measurement and Modeled Data

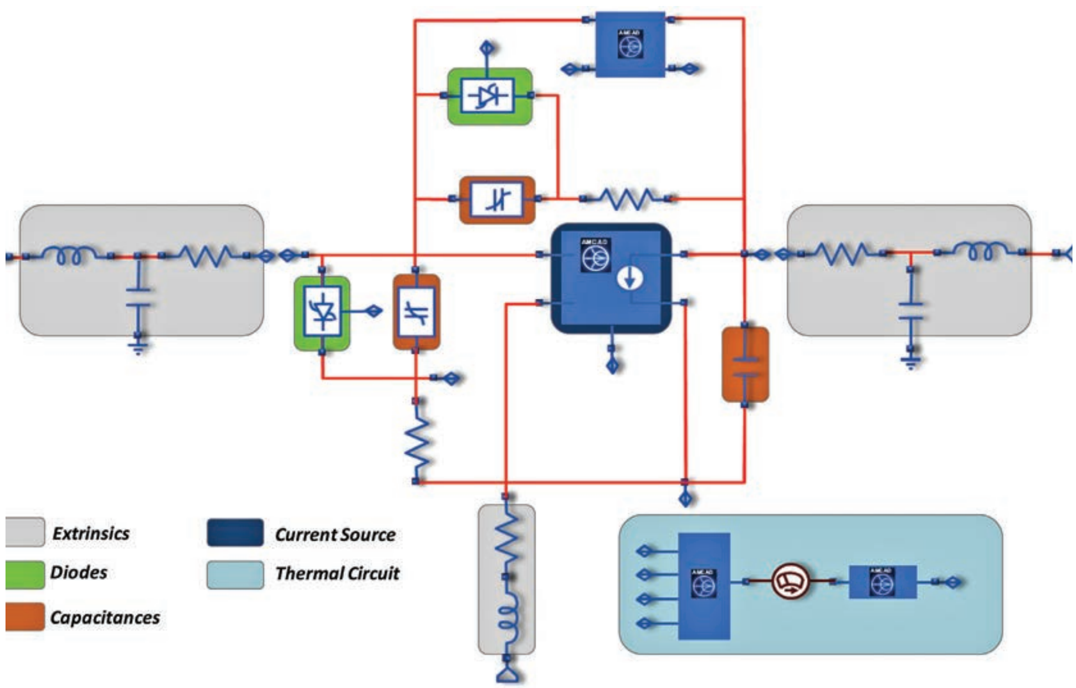


Equation Editor for Nonlinear Model Extraction

Current Source Extraction Showing Excellent Match Between Measured And Modeled Data



AMCAD III-V Model Template



MT930P Toolbox

MT930P is a stand-alone module which enables useful mathematical tools post-measurement.

> IV Tools – compute gm/gd, convert IV data sets, interpolate/extrapolate IV points.

> S-parameters – TRL fixture extraction, interpolate/extrapolate S-parameters.

> De-embedding – de-embedding S-parameters, intrinsic de-embedding of S-parameters based on linear model.

> Converter – mathematical calculator for converting phase, power, VSWR, impedance.

MT930Q IVCAD Stability Analysis Tool

Stability Analysis Tool (STAN) is a revolutionary stability analysis technique for microwave circuits, which is valid for both small-signal and large-signal regimes. This tool is able to detect and determine the nature of oscillations, such as parametric oscillations in power amplifiers, that may be functions of the input drive signal. Knowledge of the type of oscillation mode facilitates the insertion of stabilization networks, with a better balance between the required oscillation avoidance and maintaining the original circuit performances.

The STAN approach calculates a single-input, single-output (SISO) transfer function for a circuit of interest linearized around a given steady state. A simulated frequency response of the linearized circuit is fitted to a rational polynomial transfer function by means of frequency-domain identification algorithm. If no poles on the right-half plane (RHP) are found, it is considered stable.

Key Features:

> Single-node analysis

> Multi-node analysis

> Parametric analysis under varying load impedances

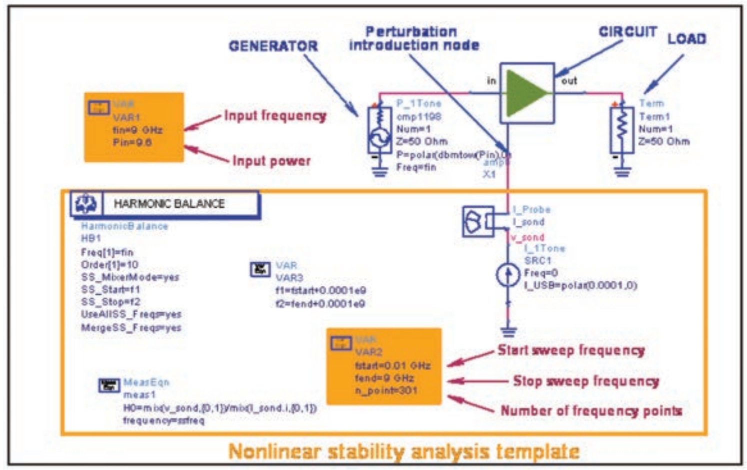
> Parametric analysis under varying input signal power

> Monte Carlo analysis

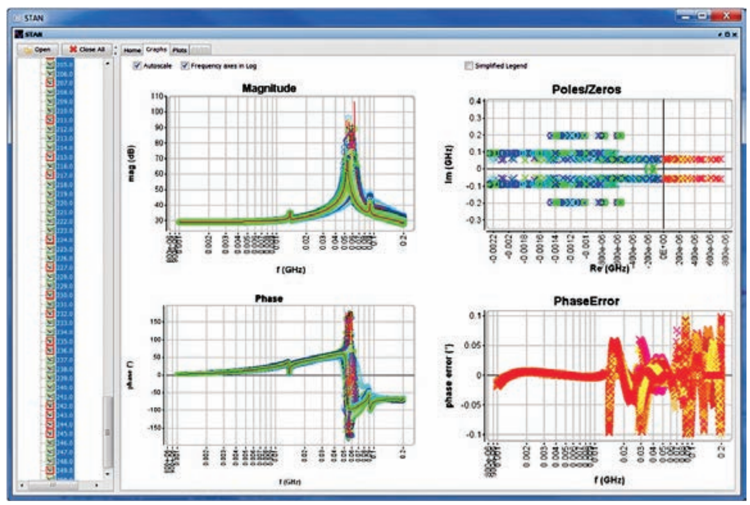
> Compatible with IC, MMIC and hybrid-amplifier designs

> Templates supplied

STAN is compatible with major commercial circuit simulator tools.



Nonlinear Stability Analysis Template



STAN Tool Graphical User Interface

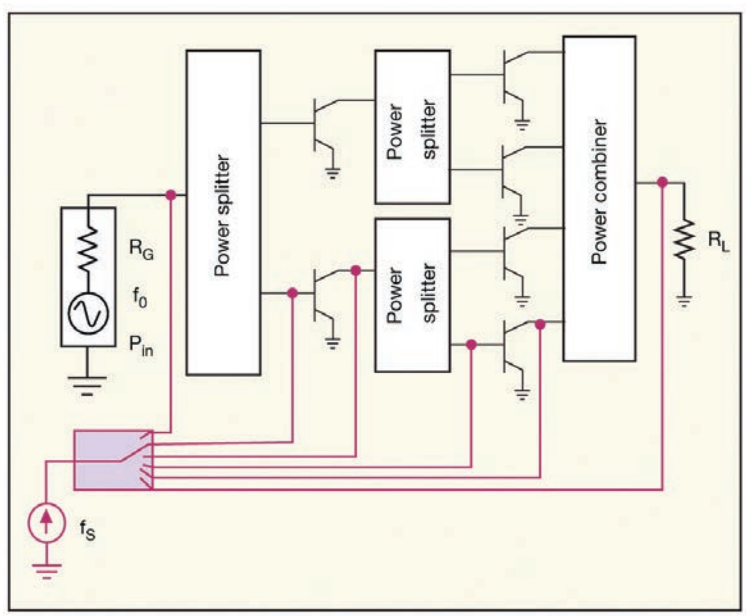


Diagram Showing a Multinode Stability Analysis of an RF/microwave Amplifier

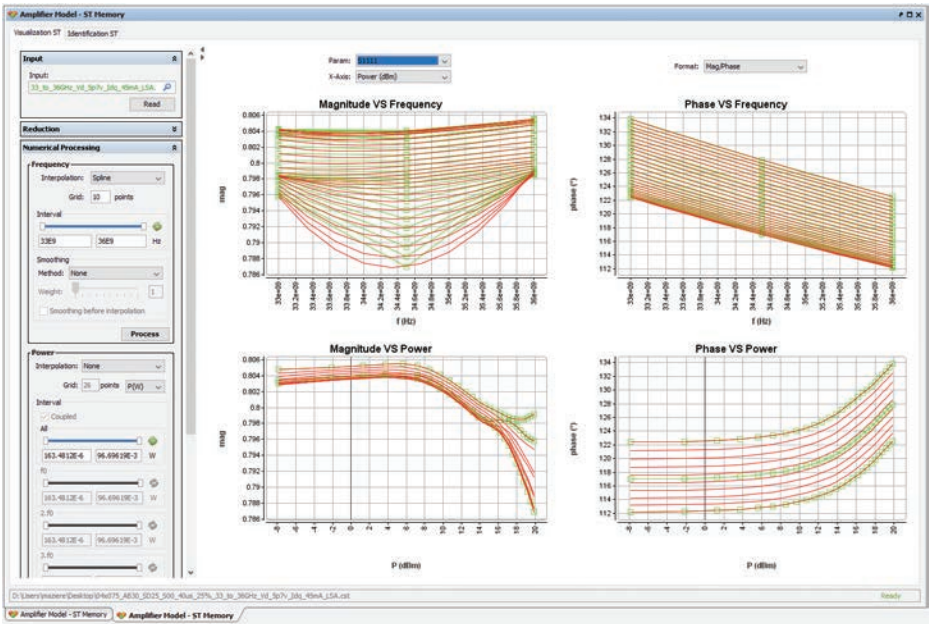
MT930R1 IVCAD EPHD Behavioral Model Extraction

MT930R1 is a stand-alone module for Enhanced PHD (EPHD) behavioral model extraction directly from Vector-Receiver Load Pull measurement data.

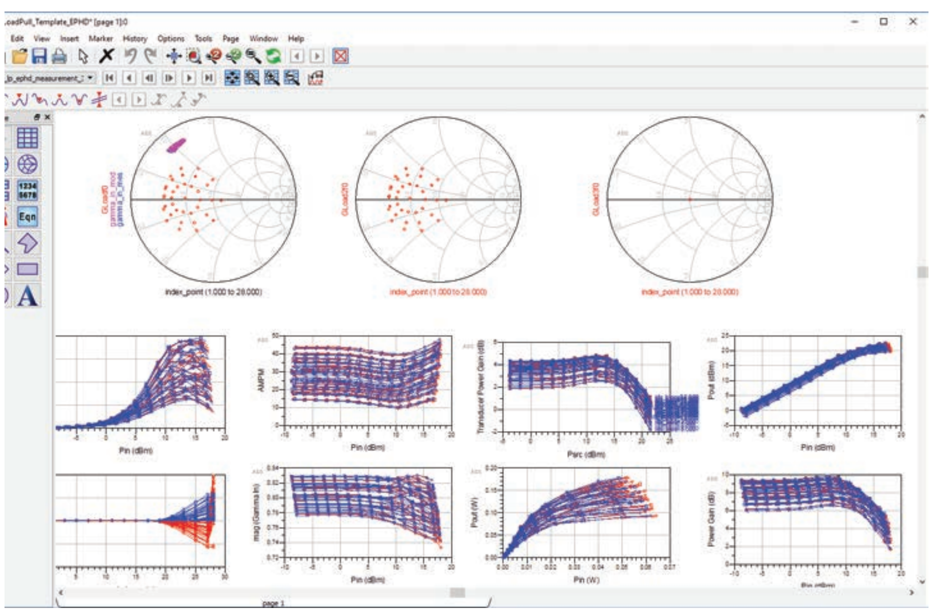
The EPHD Model is based on Poly-Harmonic Distortion theory with a dynamic power expansion order. The methodology has been designed for simulation requirements where loading conditions are significantly different than those used during the measurement, and accurate interpolation and/or extrapolation is required.

Based on successful industry implementation, the EPHD behavioral model has been proven to show excellent robustness and convergence even when a DUT sees a dynamic load impedance modulation, which is typical in the case of highly nonlinear classes of operation (i.e. Class C).

MT930R1 is especially useful for the behavioral model extraction of packaged transistors to be used in the design of power amplifier circuits.



Visualization of Behavioral Model Terms



ADS Comparison of Measured and Modeled Performance Parameters

Recommended Reading

The following literature is recommended for those who wish to learn more about the IVCAD Advanced Measurement & Modeling Software Suite and the test and measurement applications it supports.

5A-069 VNA Based Load Pull Harmonic Measurement De-embedding Dedicated to Waveform Engineering

Abstract – This paper presents a simple methodology to observe the RF waveforms at the drain source current reference plane of the transistor, without using a complete nonlinear model. The aim is to allow Power Amplifier designers starting their work using VNA based harmonic and time domain load pull measurements, and S parameter measurements. The later measurements will be used to extract a linear model first. Then the parameters of the linear model will be used to deembed the load pull measurements directly at the voltage controlled current source plane, in order to enable waveform engineering. Because of the well know theoretic conditions that enable optimum efficiency, this methodology can also be used to avoid time consuming multi-harmonic load pull measurements. Harmonic impedances can be defined accordingly to the knowledge of the operating class addressed, while load pull optimization can be addressed to refine the fundamental matching only.

5A-067 A multi-harmonic model taking into account coupling effects of long- and short-term memory in SSPAs

Abstract – This paper presents a new macro modeling methodology for solid-state power amplifiers (SSPAs) and packaged transistors used in communication systems. The model topology is based on the principle of harmonic superposition recently introduced by Keysight Technologies' X-parameters™ combined with dynamic Volterra theory. The resulting multi-harmonic bilateral model takes into account the coupling effects of both short- and long-term memory in SSPAs. In this work, the behavioral model was developed from time-domain load pull and used to simulate the amplifier's response to a 16-QAM signal with specific regards to ACPR and IM3.

5A-066 Behavioral Power Amplifier Model considering Memory Effects dedicated to radar system simulation

Abstract – In radar systems, where pulsed RF signals are used, one of the main concern is the spurious emission. Such spurious are emissions of frequencies outside the bandwidth of interest. The spurious level must be kept under a Aaaaa level to be compliant with the specifications. In order to check all these specifications, system level simulation can be used, but accuracy and reliability of the simulation results will depend on the circuit model reliability, especially for the Power Amplifier (PA) which is a critical element. Such model must take into account the different memory effects. This paper proposes a complete and practical methodology to extract a Behavioral PA model dedicated to radar applications. A specific attention is paid on the coupling effects between short and long term memory dynamics.

5A-065 High Efficiency Doherty Power Amplifier Design using Enhanced Poly-Harmonic Distortion Model

Abstract – This application note presents new identification methodologies dedicated to packaged transistor behavioral modeling. Using the background of the Poly-Harmonic Distortion (PHD) model formalism, the extension of the model kernels description up to the third order makes the behavioral model more robust and accurate for a wide range of impedance loading conditions, which is a primordial when designing a High Power Added Efficiency Doherty Amplifier, where a load impedance variation can be observed as a function of the power level. In this paper, a model of a 15 W GaN Packaged Transistor has been extracted from Load Pull measurements for Class AB and Class C conditions. This new Enhanced PHD model (EPHD) and the original PHD model are benchmarked against Load Pull measurements in order to check the new formulation. An advanced validation at the circuit level was done in order to verify the ability of the EPHD model to predict the overall Doherty Amplifier performances.

5A-063 Selecting the Node: Understanding and overcoming pole-zero quasi-cancellations

Abstract – This application note provides the fundamentals to understand the origin of pole-zero quasi-cancellations and the tips to get a reliable analysis that unambiguously decides on the stability/ instability of the circuit in the presence of quasi-cancellations.

5A-061 Multiharmonic Volterra (MHV) Model Dedicated to the Design of Wideband and Highly Efficient GaN Power Amplifiers

Abstract – This paper presents a complete validation of the new behavioral model called the multiharmonic Volterra (MHV)model for designing wideband and highly efficient power amplifiers with packaged transistors in computer-aided design (CAD) software. The proposed model topology is based on the principle of the harmonic superposition introduced by the Keysight X-parameters, which is combined with the dynamic Volterra theory to give an MHV model that can handle short-term memory effects. The MHV models of 10- and 100-W packaged GaN transistors have been extracted from time-domain load–pull measurements under continuous wave and pulsed modes, respectively. Both MHV models have been implemented into CAD software to design 10- and 85-W power amplifiers in - and -bands. Finally, the first power amplifier exhibited mean measured values of 10-W output power and 65% power-added efficiency over 36% bandwidth centered at 2.2 GHz, while the second one exhibited 85-W output power and 65% drain efficiency over 50% bandwidth centered at 1.6 GHz.

5A-057 Assets of Source Pull for NVNA Based Load Pull Measurements

Abstract – This study deals with Vector Network Analyzer based source/load-pull measurements. While a lot of papers demonstrated the influence of harmonic load impedances on PAE performances and time domain RF waveforms shaping, the harmonic source-pull topic has been a little bit less addressed. When using a traditional power meter based source/load-pull bench, source pull measurements are mandatory. Indeed, for a fixed power level and a given set of load impedances, the source pull optimization highlights the conditions to match the transistor's input access. Nowadays, modern Vector Network Analyzer based source-load pull systems provide the direct measurements of the transistor input impedance. Thus, from the theoretical definition of any arbitrary source impedance, the mismatch calculus between input and source impedances is possible. It gives rise to a new kind of virtual source pull measurements. Some of us have called this method "magic source pull". This traditional source pull and Vector Network Analyzer based "magic source pull" will be provided.

5A-054 Software Simplifies Stability Analysis

Abstract – Stability analysis software helps to reveal any unwanted oscillations in an amplifier or other high-frequency design before committing the design to an expensive foundry run. Stability can be difficult to achieve in microwave circuits with gain (nonlinear behavior), such as amplifiers and oscillators. Amplifier designers, for example, have long dreaded the appearance of oscillations in a carefully considered circuit. When that circuit is in monolithic-microwave-integrated-circuit (MMIC) form, a "fix" requires another foundry run. But help in achieving microwave circuit stability has arrived, by way of the stability analysis (STAN) software developed by AMCAD Engineering and sold by Maury Microwave Corporation.

5A-052 Compact Transistor Models: The Road Map to First-Pass Amplifier Design Success

Abstract – Amplifier designers have been making use of modern transistor models since their first appearance in the mid-1970s. Models have allowed engineers to create advanced designs with first-pass success, without the need for multiple prototypes and design iterations. But with so many different modeling techniques, how does one select which one to use? The three most common types of models used in industry today are: physical models, compact models and behavioral models.

5A-051 Vector-Receiver Load Pull Measurement

Abstract – The following special report considers the improvements in large-signal device characterization brought on by a new class of vector receiver load pull systems compared to older scalar techniques using calibrated automated load pull tuners. Recent improvements to nonlinear device measurement systems have greatly enhanced load pull characterization, which in turn impacts RF board level circuit design, particularly power amplifiers using discrete transistors.

5A-050 Tracing The Evolution of Load-Pull Methods

Abstract – The evolution of load-pull tuning has led to hybrid and mixed-signal approaches that use the best features of mechanical and active tuners to speed measurements on nonlinear devices.

5A-043 Pulse-Bias Pulsed-RF Harmonic Load Pull for Gallium Nitride (GaN) and Wide Band-Gap (WBG) Devices

Abstract – For the first time ever, a commercially available pulse -bias pulsed-RF harmonic load pull system is being offered for high power and wide band-gap devices. Pulsing DC bias in conjunction with pulsing RF reduces slow (long-term) memory effects by minimizing self-heating and trapping, giving a more realistic observance of transistor operating conditions. IV, S-Parameter and Load Pull measurements taken under pulsed-bias pulsed-RF conditions give more accurate and meaningful results for high-power pulsed applications.

SEE THE IVCAD MEASUREMENT & MODELING DEVICE CHARACTERIZATION SOFTWARE SUITE IN ACTION!

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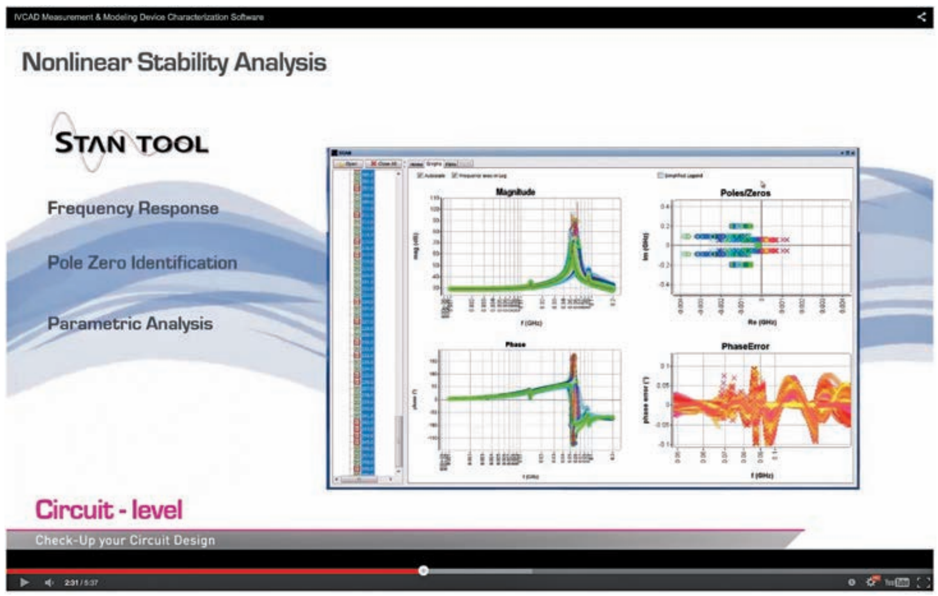

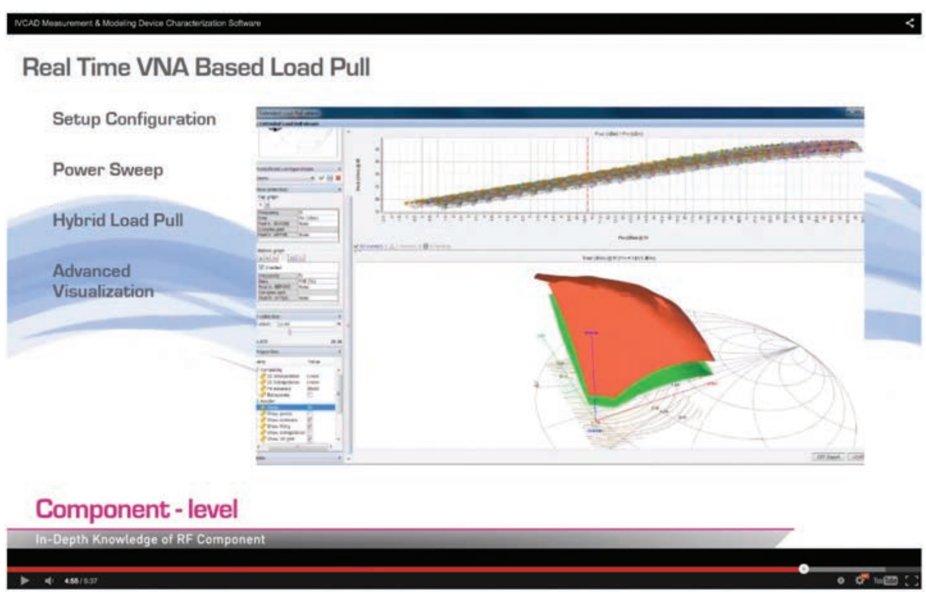

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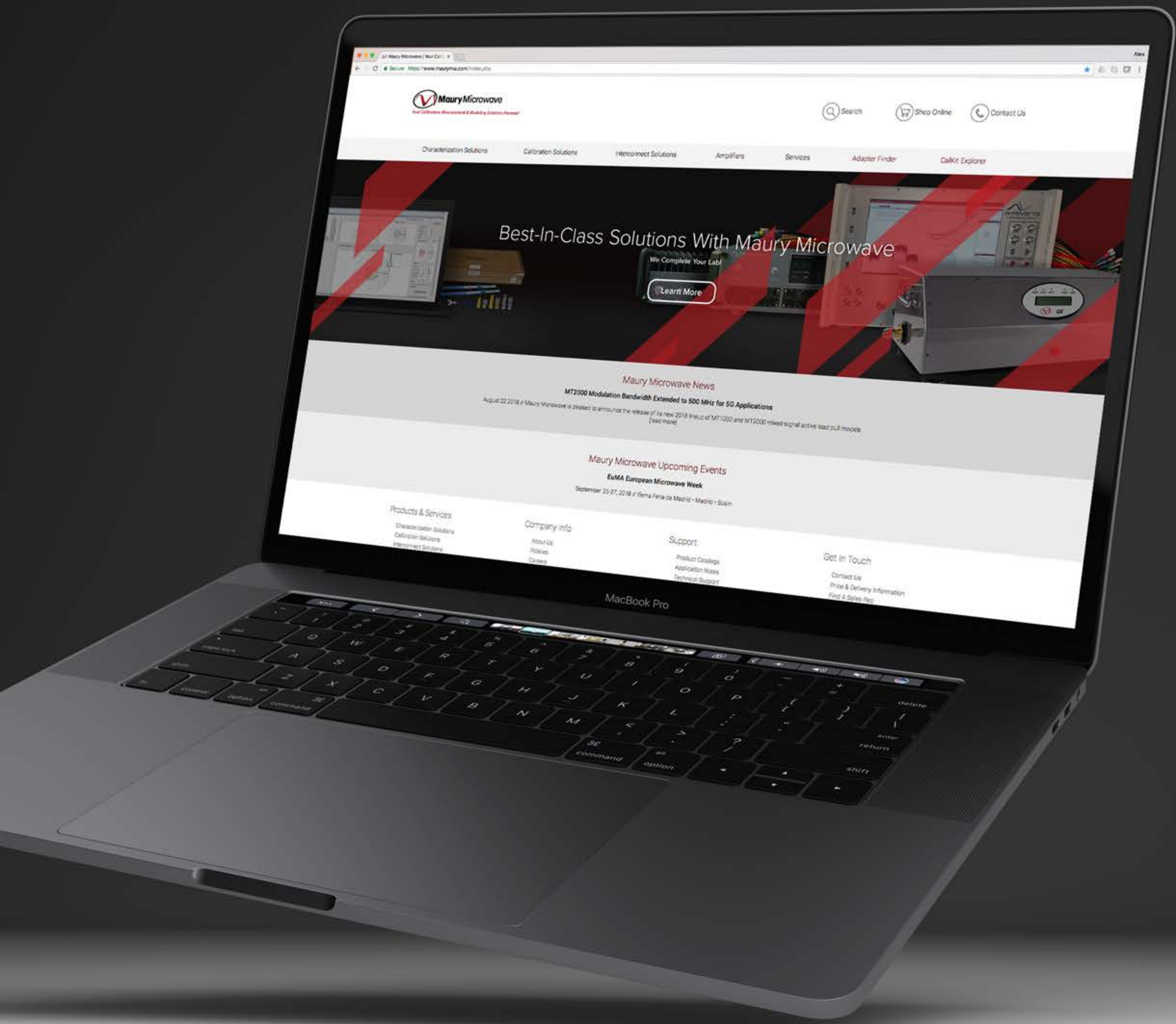

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CONTACT US:
W / maurymw.com
E / maury@maurymw.com
P / +1-909-987-4715
F / +1-909-987-1112
2900 Inland Empire Blvd
Ontario, CA 91764