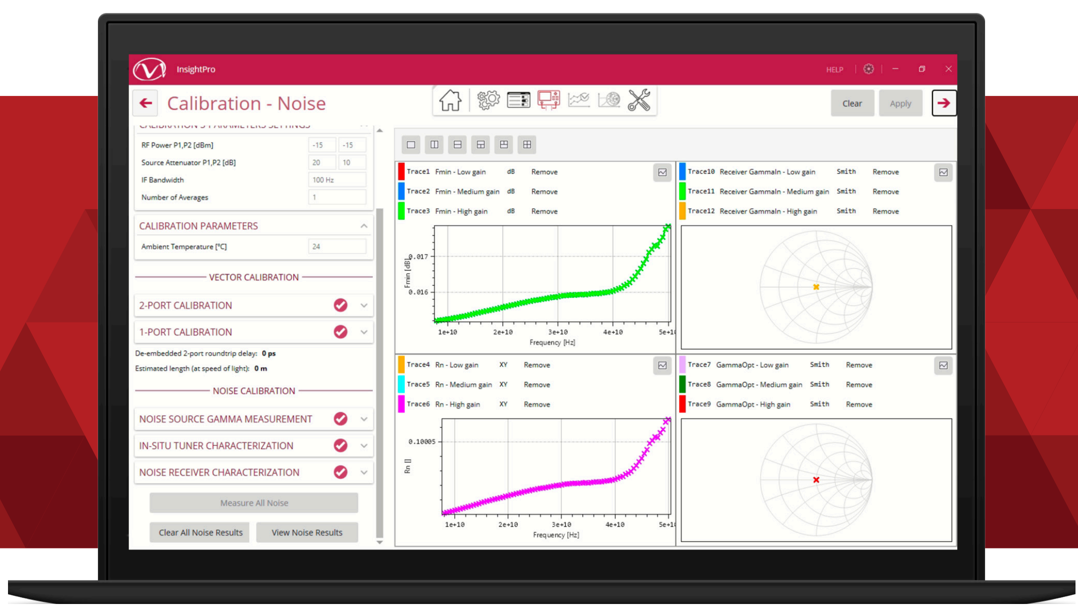
Measurement and Modeling Device Characterization Suite

DATA SHEET / 4T-026

InsightPro™

INSIGHTPRO SOFTWARE SUITE MODULES:

IP-VIS – Data visualization and analysis
IP-MEA-SPA – S-parameters / CW & pulsed small signal measurements
IP-MEA-POW – Power / large signal measurements
IP-MEA-MOD – Modulated signal measurements
IP-MEA-TD – Time domain analysis / nonlinear measurements
IP-MEA-NF – Noise figure measurements
IP-MEA-PIV – Pulsed IV measurements
IP-IMP-PAS – Passive impedance control
IP-IMP-ACT – Active impedance control
IP-IMP-WID – Wideband impedance control
IP-IMP-BB – Baseband impedance control
IP-MDL-BM – Behavioral model extraction



Maury Microwave

// APRIL 2025

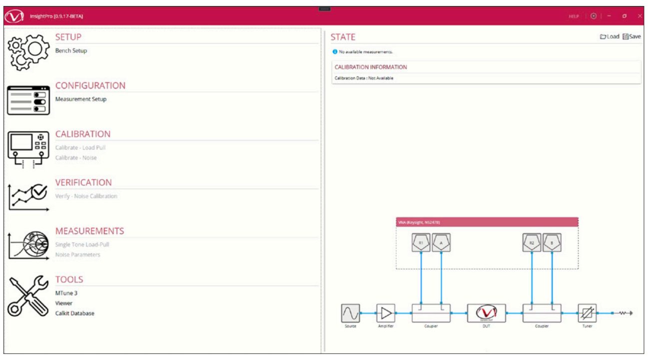
Introducing InsightPro™ – The Ultimate Measurement & Modeling Solution

In the fast-paced world of wireless technology development, precision, efficiency, and confidence in measurement data are critical to success. InsightPro™ is the industry's premier unified software suite, designed to accelerate the component and sub-system measurement and model extraction workflow for R&D, design verification, and small-scale production testing.

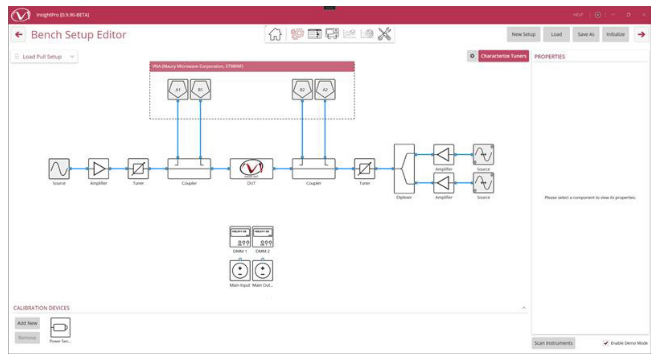
Built with a measurement-first approach, InsightPro™ serves as the primary software interface for instrument-agnostic small-signal and large-signal characterization in both 50Ω and non-50Ω environments. By streamlining data collection, management, and analysis, it enables engineers and researchers to make informed decisions with confidence.

With a DUT-centric wizard for ease of use and advanced automation tools, InsightPro™ enhances efficiency, ensuring seamless integration into existing workflows. Designed for the world's leading manufacturers, it helps companies bring high-performance wireless products to market faster—empowering innovation at every stage of development.

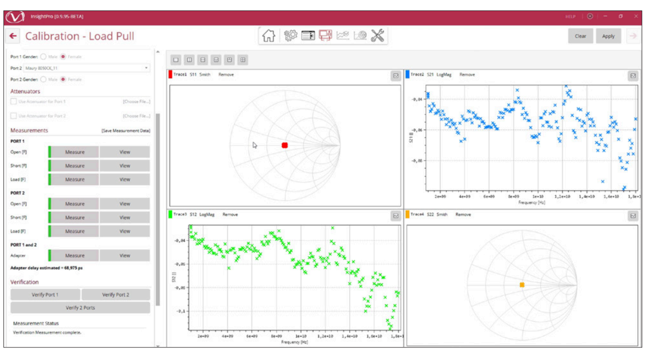
Experience the next generation of measurement and modeling with InsightPro™.



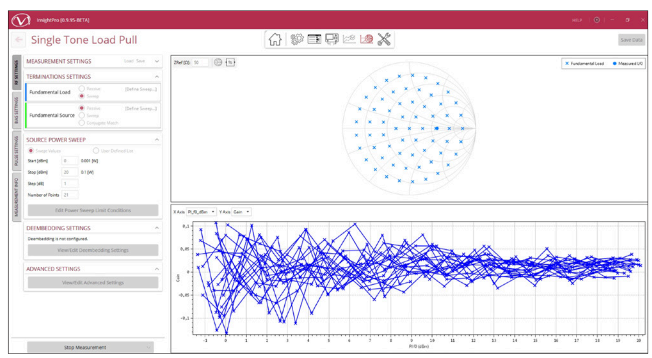
Intuitive easy-to-use graphic interface



Flexible bench setup



Robust calibration



Intuitive validation and measurement

Measurement Overview

The development of an RF or microwave amplifier begins with transistor characterization, where **pulsed IV and pulsed S-parameter** measurements are used to extract intrinsic device behavior while avoiding self-heating and trapping effects. **Load pull measurements** are then performed to determine the optimal impedance conditions for power, efficiency, and linearity, enabling the creation of accurate large-signal and behavioral models. These models are integrated into circuit simulators to design and optimize the amplifier's matching networks, biasing, and stability. Once the design is finalized, a prototype is fabricated and tested, where power, gain, efficiency, and distortion metrics (e.g., P1dB, ACPR, EVM) are validated under real-world conditions using modulated signals and wideband load pull. The design goes through an **amplifier characterization** sequence which allows for tuning and optimization before the design is finalized. The final amplifier undergoes reliability testing, regulatory compliance checks, and system integration, ensuring it meets the required performance standards for commercial or military applications before production.

InsightPro™ has been optimized for the following 50Ω and non-50Ω measurement methodologies:

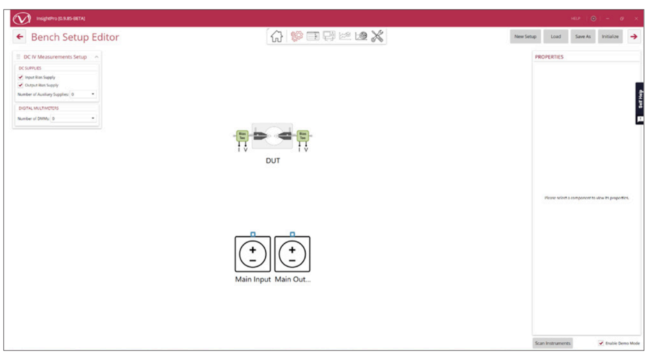
- **Pulsed IV and Pulsed S-Parameters Measurements**
- **Traditional Passive Load Pull**
  - Fundamental and/or harmonic impedance control
  - Single-tone, two-tone or modulated input drive signal
  - DC and/or pulsed bias
- **Vector-Receiver Load Pull**
  - Fundamental and/or harmonic impedance control
  - Passive, active and hybrid-active impedance synthesis
  - Wideband impedance control
  - Baseband impedance control
  - Single-tone, two-tone or modulated input drive signal
  - DC and/or pulsed bias
  - Time domain analysis, large signal analysis
  - ANN behavioral model extraction
- **Noise Figure/Parameter Characterization**

Pulsed IV and Pulsed S-Parameters Measurements

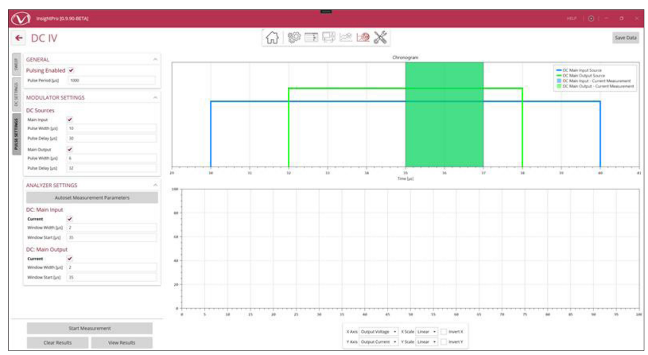
Pulsed IV (Current-Voltage) measurements are a technique used to characterize the electrical behavior of semiconductor devices under pulsed biasing conditions rather than traditional DC biasing. In pulsed IV testing, short-duration voltage or current pulses are applied to the device under test (DUT) while avoiding self-heating and charge trapping effects that can distort the true behavior of the device. Pulsed S-Parameter measurements extend pulsed IV techniques by measuring the scattering parameters (S-parameters) of a device under pulsed conditions. This approach provides frequency-domain characterization while still avoiding thermal and trapping effects.

Pulsed IV measurements are useful for:

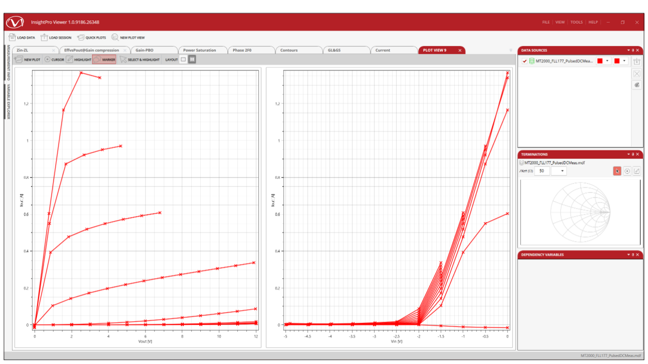
- Avoiding Self-Heating Effects - Power devices and RF transistors generate significant heat under DC bias, which affects their electrical characteristics. Pulsed IV measurements apply short pulses to prevent excessivej unction heating, providing more accurate intrinsic device characteristics.
- Eliminating Trapping Effects - In GaN, LDMOS, and other high-power devices, charge carriers can become trapped in deep energy states, altering IV characteristics over time. Pulsed IV helps characterize such phenomena allowing a more accurate model.
- More Accurate Large-Signal Device Modeling - Many RF and microwave devices operate under high-power pulsed conditions (e.g., radar, 5G, satellite communications). Pulsed IV provides better large-signal modeling than DC measurements, ensuring that models accurately predict real-world device behavior.
- Improved Device Reliability Testing - Pulsed IV can help study bias-stress effects, breakdown voltages, and transient behavior, making it useful for reliability assessments in power and RF electronics.



Bench setup editor - Pulsed IV



Pulsed measurement chronogram / timing setup



Exemplary Pulsed IV measurements

Please refer to the Configuration Guide on page 16 to configure your license of InsightPro™ for pulsed IV and pulsed IV with pulsed S-parameters measurements.

Traditional Passive Load Pull

Passive load pull is a widely used technique in RF and microwave engineering that modifies the impedance presented to a device under test (DUT) to evaluate its performance under different load conditions. This is achieved using mechanical impedance tuners, such as slide-screw tuners, which reflect a portion of the RF signal back to the DUT to create a controlled impedance environment.

By systematically adjusting the tuner's settings, engineers can optimize for key parameters such as output power, efficiency, gain, and linearity, allowing them to identify the best matching conditions for their designs. Passive load pull is commonly applied in power amplifier (PA) design, model validation, and device ruggedness testing.

Key Components in Passive Load Pull Measurements

- **Signal Sources** - A continuous wave (CW) signal generator is typically used as the RF source in passive load pull systems. For traditional scalar load pull, these sources usually generate single-tone CW signals or pulsed-CW signals for evaluating power and efficiency under controlled conditions.

- **Power Meters** - Power meters are used to measure the DUT's output power and efficiency. Since passive load pull involves reflecting RF signals back to the DUT, the measured power must be de-embedded from the sensor reference plane to the DUT reference plane. This is done by accounting for tuner and fixture losses, ensuring accurate calculations of delivered power and transducer gain. Scalar power meters provide broadband power measurements, integrating all frequency components (fundamental and harmonics), whereas frequency-selective power sensors can be used to measure specific frequency components.

- **Spectrum Analyzers** - A spectrum analyzer is used in passive load pull setups to evaluate harmonics and intermodulation distortion (IMD). Since power meters measure total RF power, spectrum analyzers allow for a frequency-specific breakdown of the output signal, providing insight into harmonic content and unwanted emissions. This is particularly useful for ensuring that a power amplifier meets linearity requirements and regulatory spectral masks.

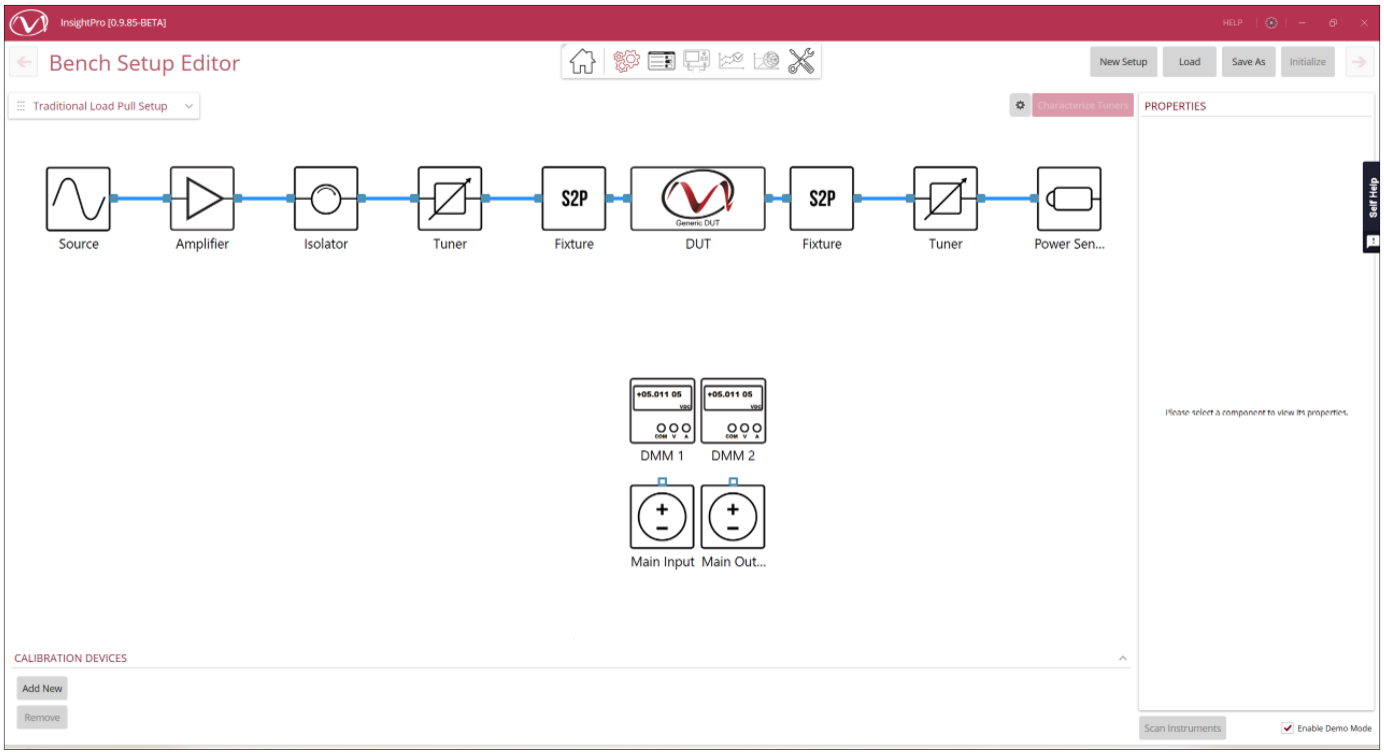
While passive load pull traditionally uses CW signals, modern wireless applications require testing under complex modulated conditions. This is where vector signal generators (VSGs) and vector signal analyzers (VSAs) come into play.

- **Vector Signal Generator (VSG)** - A VSG replaces a traditional CW signal source, generating realistic communication signals such as QPSK, QAM, and OFDM signals used in modern wireless standards (5G, Wi-Fi, LTE). By using a modulated stimulus, engineers can evaluate how a DUT performs under actual operating conditions rather than idealized CW excitation.

- **Vector Signal Analyzer (VSA)** - A VSA extends load pull measurements beyond simple power and gain, providing detailed analysis of signal quality and spectral performance. It enables key measurements such as:
  - **Adjacent Channel Power Ratio (ACPR)** – Determines the level of unwanted emissions in adjacent frequency channels, a critical metric for wireless compliance.
  - **Error Vector Magnitude (EVM)** – Evaluates modulation accuracy by measuring the deviation between the ideal and actual transmitted signal.

In passive load pull, a single-carriage passive impedance tuner is used to control the impedance presented to the device under test (DUT) at a single frequency, typically the fundamental frequency (F_0). This is achieved by adjusting the position of a metallic probe (or tuning element) within the tuner's slabline structure, which reflects a portion of the signal back toward the DUT, modifying the magnitude and phase of the impedance seen at F_0. This allows engineers to systematically vary the impedance and optimize parameters such as output power, gain, and efficiency at the fundamental frequency.

A multi-carriage passive impedance tuner, consisting of two or more independent tuning elements, extends this capability by enabling harmonic load pull, where the impedances at multiple frequencies—typically F_0 and its harmonics ($2F_0$, $3F_0$, etc.)—are controlled simultaneously. By using multiple probes that interact with the signal at different locations along the slabline, each tuning element can be adjusted independently to achieve the desired impedance at its corresponding frequency.



Bench setup editor – traditional load pull

Please refer to the Configuration Guide on page 16 to configure your license of InsightPro™ for traditional passive load pull measurements.

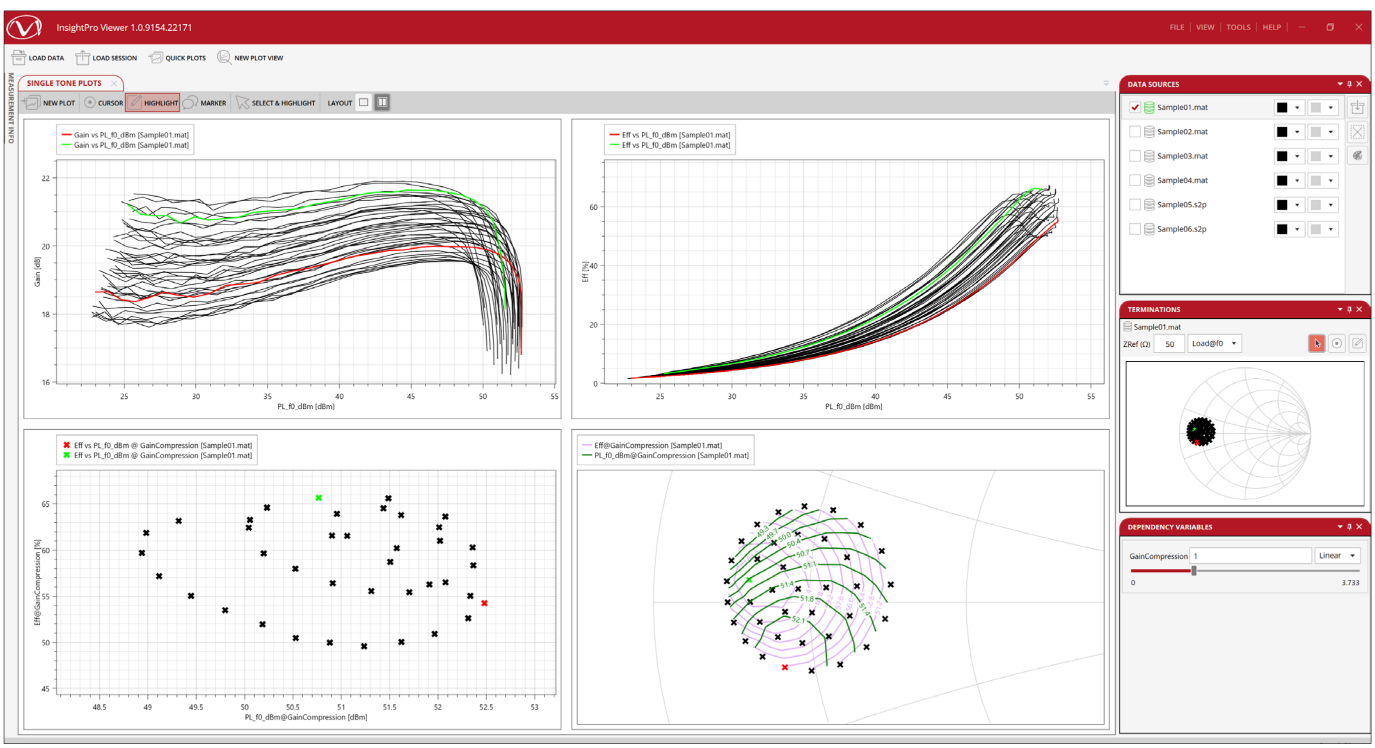
Vector-Receiver Passive Load Pull

Vector Receiver Load Pull (VRLP) is an advanced impedance tuning technique that utilizes a Vector Network Analyzer (VNA) or other vector-receiver-based system to directly measure both magnitude and phase of RF signals at the device under test (DUT) reference plane. Unlike traditional scalar load pull, which only measures power levels, VRLP provides full complex wave information, enabling more precise and insightful analysis of device performance under varying impedance conditions.

Advantages of Vector Receiver Load Pull

- **Eliminates Potential De-Embedding Errors** – Since measurements are taken directly at the DUT reference plane, VRLP removes uncertainties from passive system losses.
- **Real-Time Impedance Measurement** – Unlike traditional methods that assume impedance values based on pre-calibrated tuner settings, VRLP allows for live monitoring and verification of presented impedance.
- **Oscillation Detection & Stability Analysis** – Since VRLP captures a-waves and b-waves, it can detect oscillations and unstable DUT behavior, a critical advantage in high-power amplifier design.
- **Enhanced Harmonic Load Pull** – VRLP extends traditional load pull by enabling direct harmonic frequency measurements, improving efficiency optimization in power amplifiers.
- **More Accurate Power & Efficiency Measurements** – By directly capturing incident and reflected waveforms, VRLP calculates delivered power and gain with higher precision, reducing measurement uncertainty.

Load pull measurements can be performed on a fixtured Device Under Test (DUT) using coaxial or waveguide connections, or on-wafer using a probe station with wafer probes. For on-wafer load pull, Maury Microwave has collaborated with FormFactor and MPI to develop standardized, proven integrated solutions that seamlessly adapt Maury's load pull systems for on-wafer characterization. These solutions include optimized impedance tuners, probe stations designed to support tuners, and low-loss wafer probes that enhance tuning performance at high frequencies. Additionally, many Maury impedance tuners are designed for direct connection to the probe tip, eliminating unnecessary interconnects and maximizing performance in on-wafer load pull measurements.



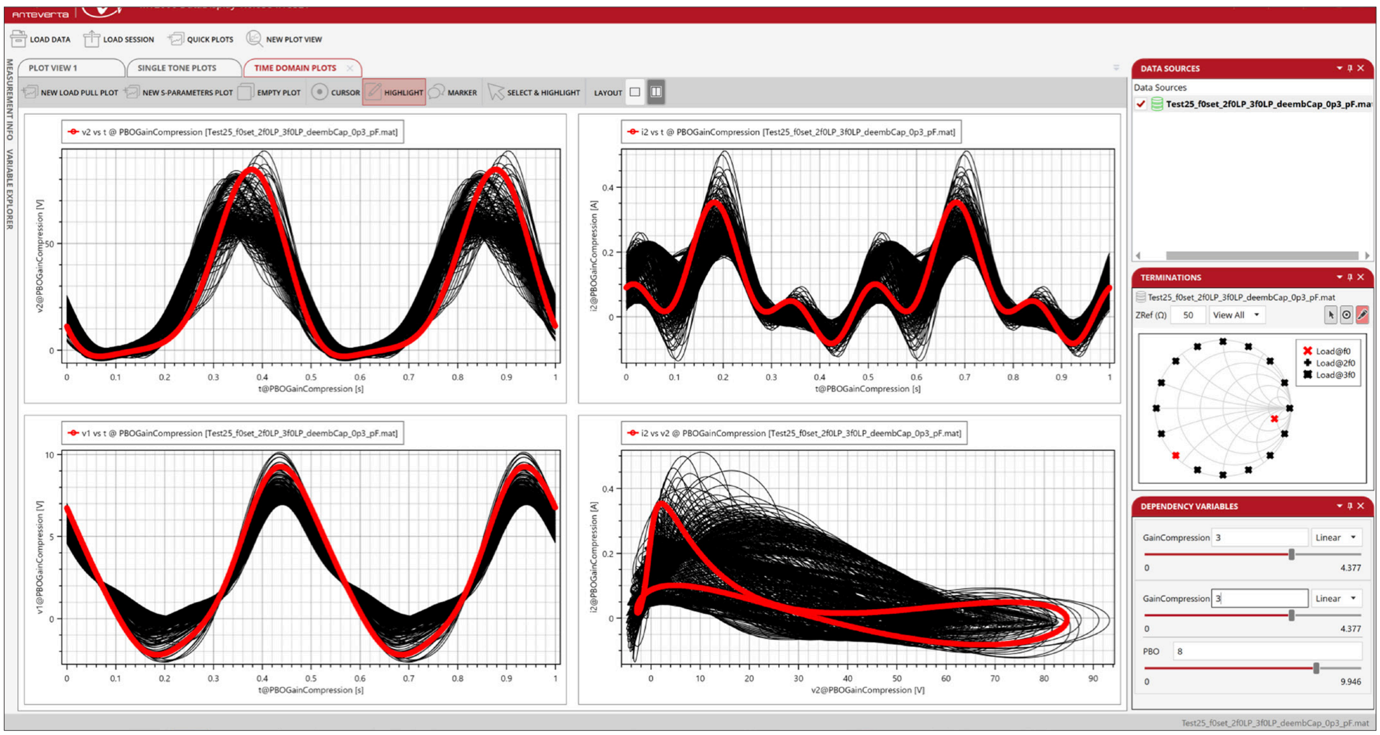
Exemplary vector-receiver load pull measurements

Please refer to the Configuration Guide on page 16 to configure your license of InsightPro™ for vector receiver passive load pull measurements.

Vector-Receiver Passive Load Pull and Time Domain Analysis

One of the key advantages of Vector Receiver Load Pull (VRLP) is its ability to enable time-domain analysis, also known as large-signal analysis or Nonlinear Vector Network Analysis (NVNA). Traditional scalar and even vector-based frequency-domain load pull methods focus on measuring power, gain, efficiency, and impedance, but do not provide insight into the actual voltage and current waveforms at the device under test (DUT). VRLP, when combined with a time-domain capable measurement system, allows engineers to reconstruct time-domain voltage and current waveforms, unlocking critical insights into the large-signal behavior of RF and microwave devices.

Using Fourier analysis, the frequency-domain data collected in VRLP can be transformed into time-domain voltage and current waveforms, revealing the DUT's instantaneous voltage and current behavior over the RF cycle. With both voltage and current waveforms, engineers can plot load lines, directly visualizing how the DUT behaves across its nonlinear operating regions, such as saturation, compression, and breakdown. By analyzing the time-domain signal, engineers can optimize harmonic terminations to shape the voltage and current waveforms, improving power efficiency and linearity in power amplifiers.



Exemplary vector-receiver load pull measurements with time domain analysis

Please refer to the Configuration Guide on page 16 to configure your license of InsightPro™ for vector receiver passive load pull measurements with time domain analysis.

Vector-Receiver Passive Load Pull and Behavioral Model Extraction

Behavioral models can be used in circuit simulations, allowing engineers to predict how the device will behave in different circuit environments.

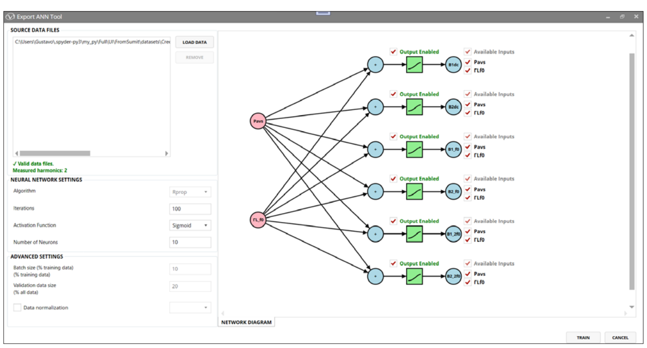
Behavioral model extraction is the process of creating a mathematical model that represents the input-output behavior of a device under test (DUT) based on measured load pull data. Instead of relying on complex physics-based models (such as transistor-level models), a behavioral model characterizes how the device responds to different impedances, power levels, and frequencies using empirical data.

This process involves:

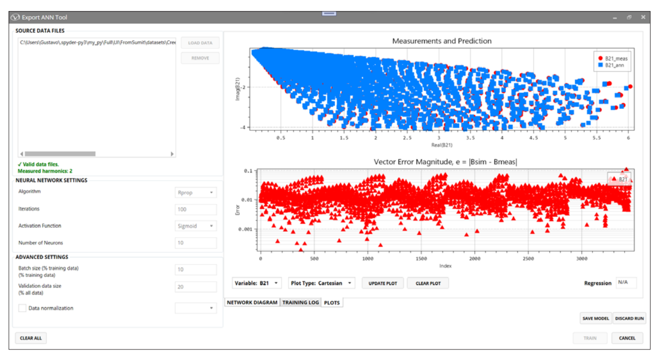
- Performing load pull measurements at multiple impedance states to capture variations in power, gain, efficiency, linearity, and other parameters.
- Using mathematical algorithms to fit the measured data to a predictive model that can describe DUT performance over a range of operating conditions.

An Artificial Neural Network (ANN) is a machine learning approach that can be used to create highly accurate, nonlinear behavioral models from load pull data. In this context, an ANN-based behavioral model works by:

- Learning complex relationships between input variables (power, impedance, frequency, bias, etc.) and output variables (gain, efficiency, ACPR, etc.).
- Interpolating between measured data points to generate a smooth, continuous model that can predict DUT behavior beyond discrete measured values.
- Handling large, multi-dimensional datasets, making it ideal for modeling wideband and nonlinear devices with complex dependencies.
- Providing fast and efficient simulations, significantly reducing computation time compared to traditional equation-based models.



ANN settings and network



ANN behavioral model export

Please refer to the Configuration Guide on page 16 to configure your license of InsightPro™ for vector receiver passive load pull measurements with behavioral model extraction.

Active and Hybrid-Active Load Pull

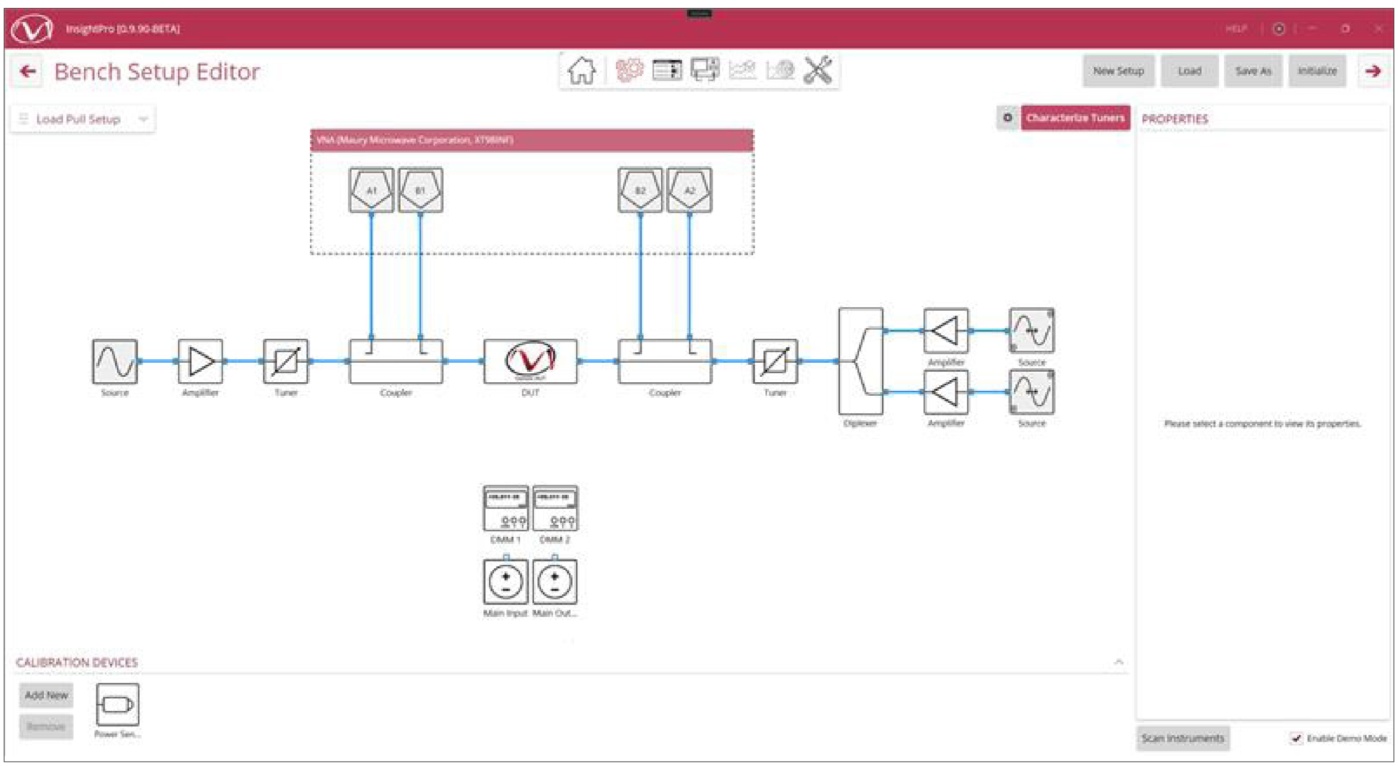
Active Load Pull is an advanced impedance tuning technique that replaces a passive impedance tuner with an "active tuner", actively injecting a controlled RF signal back toward the device under test (DUT) instead of relying solely on passive reflection. This is typically achieved using sources with amplitude and phase control, and amplifiers, to generate a desired reflection coefficient (Γ) at the DUT reference plane, providing precise control over the magnitude and phase of the impedance.

Hybrid Active Load Pull combines passive impedance tuners with active signal injections to achieve high reflection coefficients without the requirement of large amplifiers. In this method, a passive tuner provides a pre-match, while an active injection loop enhances the impedance tuning range. Hybrid-active load pull can also be configured to use passive impedance tuners at one frequency, and active impedance control at different frequencies, such as the second and/or third harmonic, to enable harmonic load pull measurements.

In addition to the advantages outlined in vector receiver load pull, active and hybrid-active load pull offer:

- **Frequency agnostic operation:** Purely active load pull systems can be used over the entire frequency range of the vector network analyzer, and is not limited by the passive impedance tuner's operating frequency.
- **Higher Reflection Coefficients (Γ):** The active loop boosts the reflection coefficient beyond what the passive tuner can achieve alone for hybrid-active load pull.
- **Easy expansion to harmonic load pull:** By using multiple active tuning loops, engineers can independently control the impedance at fundamental and harmonic frequencies, optimizing efficiency and linearity.

As a type of vector receiver load pull, active and hybrid-active load pull can be used with time domain analysis and behavior model extraction.



Bench setup editor – hybrid active load pull measurements

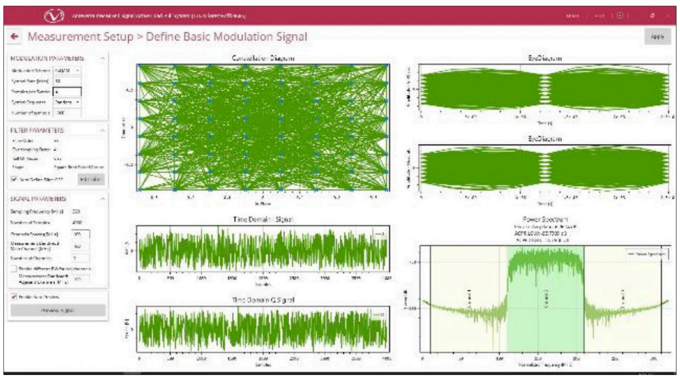
Please refer to the Configuration Guide on page 16 to configure your license of InsightPro™ for active and hybrid-active load pull measurements.

Mixed-Signal Active and Hybrid-Active Load Pull

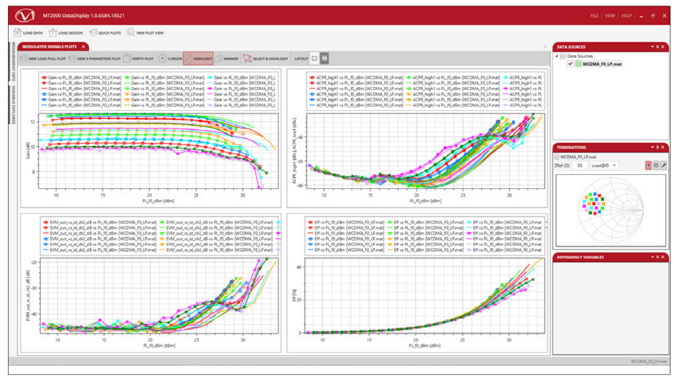
Mixed-Signal Active Load Pull (MSALP) is an advanced impedance tuning technique that extends active load pull beyond single-frequency control, allowing for wideband impedance control over modulated signals. Unlike traditional active load pull, which typically adjusts impedance at discrete frequencies (e.g., fundamental and harmonics), mixed-signal active load pull enables real-time impedance shaping across a broad bandwidth, making it ideal for modern wireless communication systems such as 5G, Wi-Fi, and satellite networks.

Instead of relying on analog sources to control impedance, mixed-signal active load pull uses high-speed digital signal processing (DSP) and arbitrary waveform generation (AWG) to actively synthesize the desired reflection coefficient (Γ) across the entire modulation bandwidth of the signal. This allows engineers to study real-world operating conditions of RF devices under complex modulated waveforms rather than just continuous-wave (CW) signals.

As a type of vector receiver load pull, active and hybrid-active load pull can be used with time domain analysis and behavior model extraction.



Modulated signal definition



Exemplary mixed-signal active load pull measurements

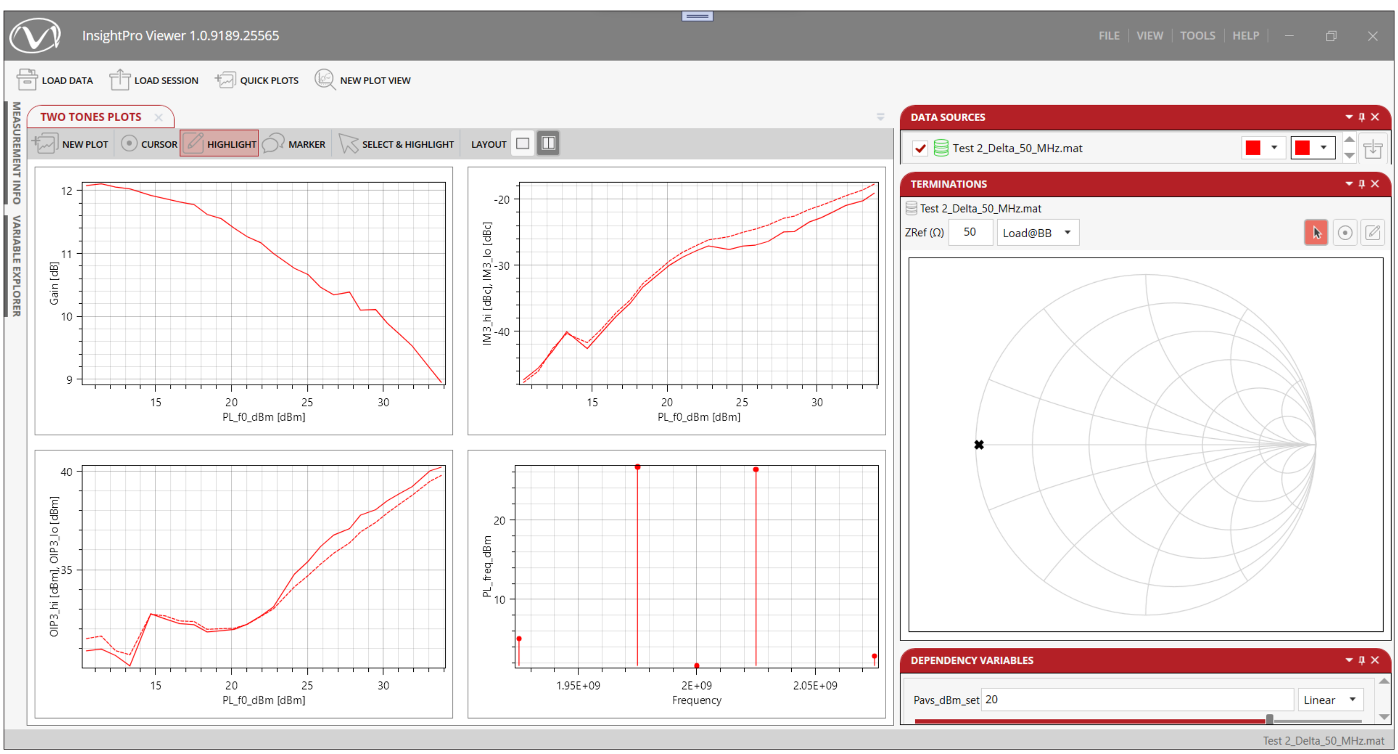
Mixed-Signal Active Load Pull with Baseband Impedance Control

Mixed-Signal Active Load Pull (MSALP) with Baseband Impedance Control is an advanced impedance tuning technique that allows engineers to manipulate not only the RF impedance at fundamental and harmonic frequencies but also the baseband impedance, which plays a critical role in the behavior of nonlinear RF devices.

Traditional passive and active load pull focuses on impedance tuning at discrete RF frequencies, typically the fundamental and harmonics. However, modern wideband RF systems—such as 5G, Wi-Fi, and satellite communications—experience strong interactions between the RF and baseband (low-frequency) signals due to envelope modulation effects, memory effects, and nonlinear distortion. Baseband impedance control in mixed-signal active load pull enables engineers to directly influence these effects, leading to improved power amplifier efficiency, linearity, and spectral performance.

Key Benefits of Baseband Impedance Control in Mixed-Signal Active Load Pull:

- **Improved Power Amplifier Linearity & ACPR Performance** - Baseband impedance strongly affects memory effects and envelope shaping, which influence adjacent channel power ratio (ACPR) and distortion. By tuning the low-frequency impedance, engineers can minimize intermodulation distortion (IMD) and spectral regrowth, leading to cleaner transmitted signals.
- **Enhanced Power Amplifier Efficiency & Waveform Engineering** - The interaction between baseband and RF signals impacts the waveform shape, affecting drain efficiency and power-added efficiency (PAE). Optimizing baseband impedance conditions can lead to more efficient PA operation, reducing power consumption and heat generation.
- **Understanding & Mitigating Memory Effects** - Many RF devices exhibit memory effects, where past input signals affect future behavior. These effects are influenced by baseband impedance interactions. By actively tuning the baseband impedance, engineers can better characterize and compensate for memory effects, leading to more accurate nonlinear models and improved device performance.
- **Optimizing Wideband Modulated Signal Performance** - For 5G and broadband RF applications, controlling impedance over a wide frequency range is crucial. Baseband impedance control ensures that power amplifiers and RF front-end components operate optimally across their entire bandwidth, reducing distortion and improving efficiency.



Exemplary mixed-signal active load pull measurements with baseband impedance control

Noise Figure/Parameter Characterization

Noise Figure is a measure of how much noise a device (like an amplifier, mixer, or receiver) adds to a signal, relative to an ideal, noiseless device. It quantifies the degradation in the signal-to-noise ratio (SNR) as a signal passes through a system.

- **Definition**: Noise figure (NF) is defined as the ratio of the input signal-to-noise ratio (SNR) to the output SNR:

$$NF = \frac{SNR_{\text{in}}}{SNR_{\text{out}}}$$

Since noise figure is usually expressed in decibels (dB), it is calculated as:

$$NF(db) = 10\log_{10}(\frac{SNR_{\text{in}}}{SNR_{\text{out}}})$$

- **Explanation**: A lower noise figure means the device adds less noise to the signal, while a higher noise figure means the device introduces more noise.

Noise Parameters

Noise parameters are a set of values that describe the noise performance of a device, typically for different operating conditions such as frequency, input impedance, and temperature. The four key noise parameters often used are:

1. ***Fmin***: The minimum noise figure (minimum NF a device can achieve under optimal conditions).

2. **Rn**: The equivalent noise resistance, which describes how the noise figure degrades as the input impedance deviates from the optimal source impedance.

3. **|Γopt|**: The magnitude of the reflection coefficient of the optimal source impedance for minimum noise

4. **Γopt<:** The phase of the reflection coefficient of the optimal source impedance for minimum noise

Together, these parameters describe how the noise figure of a device changes with varying source impedance.

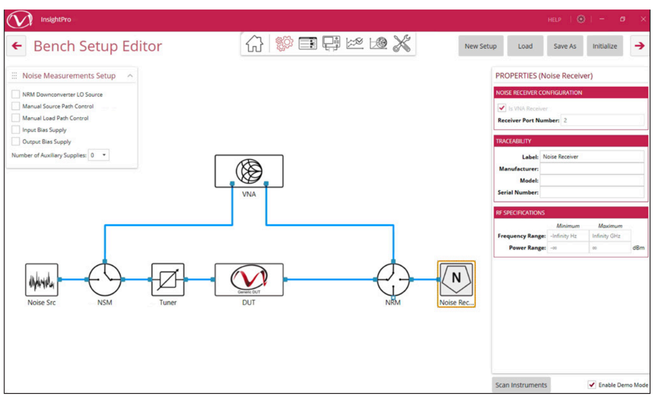
Measuring Noise Figure and Noise Parameters

InsightPro is a cutting-edge, wizard-driven software platform developed by engineers for engineers, specifically designed to simplify and enhance the extraction of noise parameters, including noise figure. With its intuitive interface and step-by-step guidance, InsightPro ensures seamless operation from setup to results, empowering users to effortlessly extract accurate noise parameters across a broad frequency range.

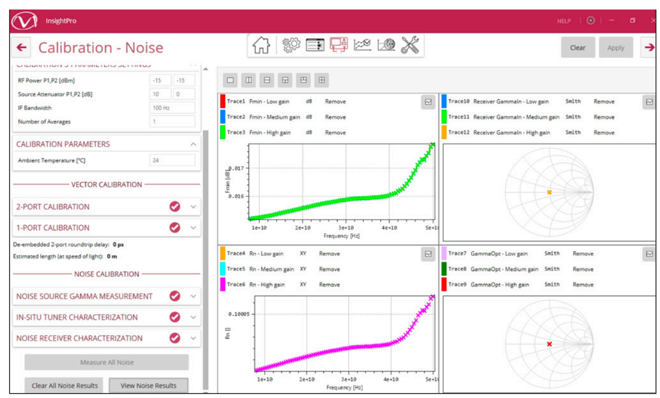
Designed with ease of use in mind, InsightPro guides customers through every phase of the process:

- **Instrument Bench Setup**: InsightPro simplifies your setup with an interactive block diagram, making sure all instruments are correctly configured.
- **System Calibration**: The software leads you through a complete calibration process, ensuring your system is optimized for accurate measurements.
- **Calibration Verification**: After calibration, InsightPro provides tools to verify the accuracy, so you can trust your setup is delivering precise data.
- **Noise Parameter Extraction**: Using Maury's state-of-the-art automated impedance tuners, InsightPro extracts noise parameters from your Device Under Test (DUT) across wide frequency bandwidths with unparalleled accuracy.

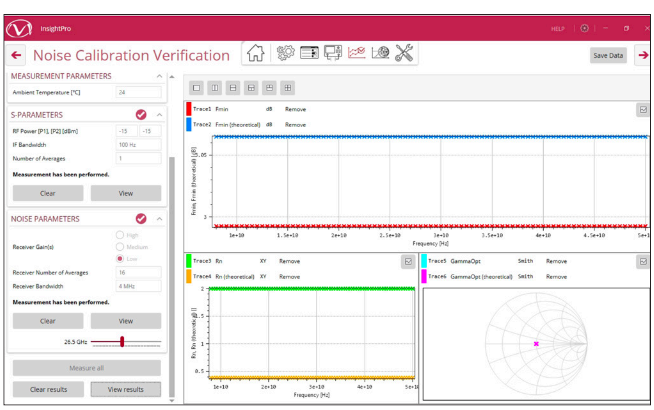
InsightPro is designed to work seamlessly with common instruments from major manufacturers, including **Keysight Technologies, Rohde & Schwarz**, and others. Whether you're working with coaxial or waveguide setups, or require connectorized or on-wafer solutions, InsightPro is an integral part of complete, turnkey noise parameter measurement systems.



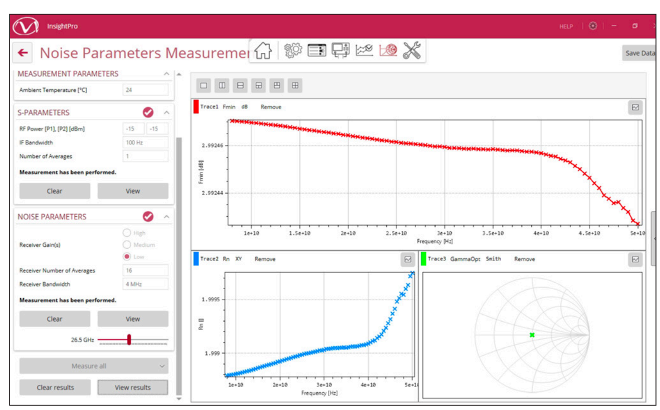
Instrument Bench setup



System Calibration



Calibration Verification



Noise Parameters Extraction

Configuration Guide

InsightPro™ consists of visualization, measurement, impedance control and modeling software modules that can be configured to build over 20 different measurement solutions, as follows:

- **IP-VIS** Data visualization and analysis
- **IP-MEA-SPA** S-parameters / small signal measurements
- **IP-MEA-POW** Power / large signal measurements
- **IP-MEA-MOD** Modulated signal measurements
- **IP-MEA-TD** Time domain analysis / nonlinear measurements
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- **IP-MDL-BM** Behavioral model extraction

Typical Configurations	Visualization	S-Parameters	Power Measurements	Modulation Measurements	Time Domain Measurements	Noise Figure/ Parameter Measurements	Passive impedance control	Active impedance control	Wideband impedance control	Baseband impedance control	PIV	Behavioral modeling
	IP-VIS	IP-MEA-SPA	IP-MEA-POW	IP-MEA-MOD	IP-MEA-TD	IP-MEA-NF	IP-IMP-PAS	IP-IMP-ACT	IP-IMP-WID	IP-IMP-BB	IP-MEA-PIV	IP-MDL-BM
S-parameters measurements	x	x										
Passive traditional load pull	x	x	x				x					
Passive vector-receiver load pull	x	x	x				x					
Active load pull	x	x	x					x				
Hybrid-active load pull	x	x	x				x	x				
Modulated passive load pull	x	x	x	x			x					
Modulated active load pull	x	x	x	x				x	x			
Modulated hybrid-active load pull	x	x	x	x			x	x	x			
Time domain passive load pull	x	x	x		x		x					
Time domain active load pull	x	x	x		x			x				
Time domain hybrid active load pull	x	x	x		x		x	x				
Modulated active load pull with baseband impedance control	x	x	x	x				x	x	x		
Behavioral modeling with passive load pull	x	x	x		x		x					x
Behavioral modeling with active load pull	x	x	x		x			x				
Noise figure and noise parameters measurements	x	x				x	x					
Pulsed IV measurements	x										x	
Pulsed IV and Pulsed S-parameters measurements	x	x									x	
50ohm power measurements	x	x	x									
50ohm power measurements with modulation	x	x	x	x								

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