MAURY

RF Device Characterization Systems

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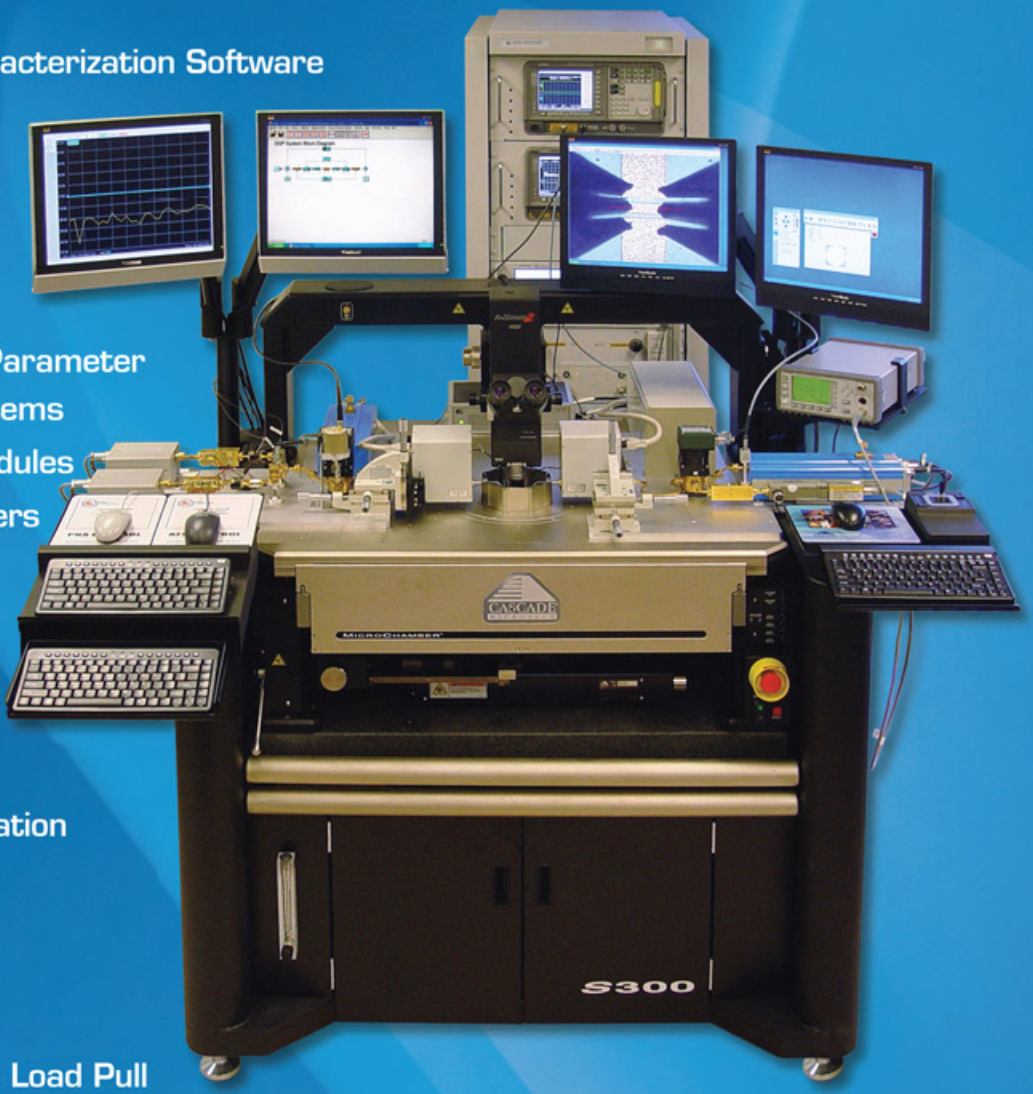

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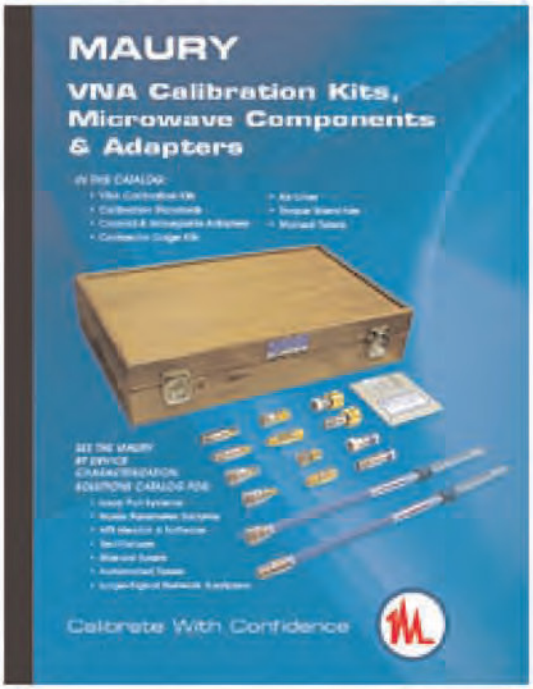

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Maury Device Characterization Systems

Maury Microwave Has the Most Complete Selection of Load Pull Solutions! We Are Your Complete Measurement & Modeling Solutions Partner!

In This Volume:

RF Device Characterization Methods

Accurate de-embedded performance evaluation of the power, intermodulation distortion, adjacent channel power, noise and network (S-parameter) characteristics of packaged or on-wafer devices under various conditions of impedance matching is the foundation of successful design, manufacture, and use of RF and microwave devices. Maury device characterization systems support the best industry-recognized test and measurement methods.

Pitfalls To Avoid When Purchasing A Device Characterization System

An automated device characterization system can greatly simplify test and measurement operations and quickly provide reliable empirically-based data for design and modeling of new products. But finding the right system is not simple. There are mistakes to be avoided if you are to maximize return on investment, achieve your test and measurement goals, and get your products to market. Here is some valuable advice from the experts at Maury.

Device Characterization Software (IVCAD, ATSv5 and AMTSv2)

Maury IVCAD software is the newest and most advanced measurement and modeling software in the market. It supports multiple load pull techniques, performs noise parameter, DC-IV and pulsed-IV measurements, and incorporates sophisticated device modeling tools. Maury's ATS software (ATSv5) includes a comprehensive set of upgrades, improvements, and additions to the classic ATS test and measurement tools.
Maury's Automated Mobile Test System software (AMTSv2) is designed specifically to automate the testing of mobile phones in transmit and receive modes, for output power and sensitivity. It now includes support for GSM, WCDMA and CDMA2000.

Load Pull and Noise Parameter Systems

Maury offers fully integrated, automated tuner-based systems configured to operate from 0.25 to110 GHz. These complete turnkey systems can be customized to support Basic (power, gain and PAE) and Advanced Load Pull characterization (modulation, optimal ACPR, CDP, and Harmonic LP). Maury Noise Parameter systems are available in electromechanical and solid state versions that can be customized to perform on-wafer or in-fixture noise parameter characterization at frequencies from 0.25 to 110 GHz.

Automated Tuners, Controllers And Hubs

Maury USB-controlled automated tuners and hubs are described in detail, with their respective specifications and applications.

Accessories

Maury offers a number of accessories to support your test bench needs, including automated tuner controllers, noise receiver modules, diplexers and triplexers, pre-matching probe mounts, manual tuners, and automated sliding shorts.

Advanced Device Characterization Systems

Maury now offers Mixed-Signal Active Load Pull systems, and the AMCAD Engineering PIV/PLP family of Pulsed IV systems.

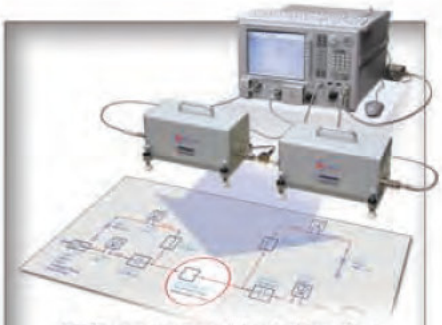
You Have Load Pull Needs – We Have You Covered!

Maury Microwave Has the Most Complete Selection of Load Pull Solutions

MAURY's Mixed-Signal Active Load Pull Allows Wideband Modulated Impedance Control for Base Station PAs

Active and Hybrid Load Pull Using PNA-X Simplifies Harmonic Tuning with Gamma = 1

Pulsed-Bias Pulsed-RF Harmonic Load Pull for GaN and Wide Band-Gap Devices



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Ultra-Fast Noise Parameter Method Gives More Accurate Results in Less Than 1/100th the Time to 110 GHz!

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ADVANCED RF DEVICE CHARACTERIZATION SYSTEMS

SOLID-STATE ELECTRONIC TUNER SYSTEMS

AMCAD ENGINEERING PULSED IV SYSTEMS

ATSv5 Automated Tuner System Software

MT993 Series

Introduction

The Maury Automated Tuner System Software (ATSv5) is the easiest-to-use, yet most advanced, and most powerful device characterization software in the world. It brings together a comprehensive suite of software tools that greatly simplifies device characterization applications. The advanced development of this software has made it a must-have part of any modern test and measurement lab. For a growing community of RF and Microwave engineers and designers, ATS software has truly become the brain behind their device characterization operations.

What ATSv5 Software Can Do For You

Maury ATSv5 makes it possible to accurately measure power, gain, efficiency, IMD, ACPR, EVM, harmonics, noise parameters and many other characteristics of a device under test (DUT). Measured data from the ATSv5 software can be imported with ease into Agilent's ADS software environment for simulation of device models or PA/LNA designs. Optionally, using ATSv5 with the Maury DLL library gives users the accuracy and repeatability of the Maury ATS hardware with the flexibility to write their own custom test and measurement applications.

ATSv5 builds upon the legendary reliability and robustness of ATSv4 which was the most comprehensive upgrade and improvement to ATS since the Windows™ release in 2000. The central features include an all new and significantly improved

GUI API for direct tuner control (eliminating the need for the legacy tuner controller object) and the availability of a comprehensive DLL kit.

But perhaps the most exciting feature of ATSv5 is the addition of a powerful new method of cascaded harmonic load pull that eliminates the need for diplexers/triplexers.

In addition, this release of ATS has undergone extensive QA testing, including comprehensive regression analysis for algorithmic integrity evaluation, a rigorous automated analysis to identify, document and correct defects, and live hardware evaluation in Maury's device characterization laboratory.

ATSv5 is designed to run under Microsoft® Windows™ XP, and Windows™ 7.

Support and Upgrades

The Maury ATS is continually being improved and upgraded. At least one formal software upgrade is produced each year. A software support agreement is available to ensure that your system remains current with the latest features and improvements in measurement capability.

ATSv5 Software Suite Models

- MT993A – Power Parameters, Power Measurement Mode, Swept Power Display, Load/Source Pull Contour Display
- MT993B – Noise Parameters, Interactive Noise Measurement Mode, Swept Noise Display, Noise Statistics Display
- MT993B01 – Ultra-Fast Noise Characterization Using PNA-X
- MT993C – Combines MT993A and MT993B
- MT993D – Intermod Distortion (IMD), Adjacent Channel Power (ACP), and Error Vector Magnitude (EVM)
- MT993D03 – PNA-X NVNA (Load Pull + NVNA + X-Parameters)
- MT993D04 – Active Load Pull
- MT993E – Programmers Edition
- MT993F – System Control Option
- MT993G – DC IV Curve Option
- MT993H – Harmonic Source/Load Pull Option (Supports Triplexer/Diplexer and Cascaded Tuner Techniques)
- MT993J – Fixture Characterization Option
- MT993N06 – Tuner Characterization Option
- MT993V01 – Tuner Interpolation dll Option
- MT993V04 – Tuner Movement dll Option

MT993A – Power Characterization Application Software

General

The MT993A power characterization application software is designed to operate with the Maury Automated Tuner System (ATS) to determine the optimum load and source termination conditions for improving device performance. This software is provided as part of an ATS system specified for power characterization; either separately as model MT993A, or combined with the MT993B noise characterization software as model MT993C.

Power Parameters

In large signal amplifier design, power output is a complex function of the input power level, terminating impedances, and DC bias conditions.

A load pull bench, operating with the Maury power application software can provide fast accurate measurements of power output, transducer gain, power gain, power-added efficiency and measured input and output voltages and currents. The program also permits display of up to 10 harmonic source and load impedances simultaneously. A unique feature of the Maury software allows the user to define up to 35 user functions. These functions can be used to develop specific output parameters (e.g., simple efficiency, VSWR), or to control instruments (e.g., to control the turn-on/ turn-off sequence of a high power signal source). The program also has a built-in general purpose S-parameter measurement program that allows for fixed or swept bias conditions. The software provides for both data and graphical hard copy outputs.

Power Measurement Mode

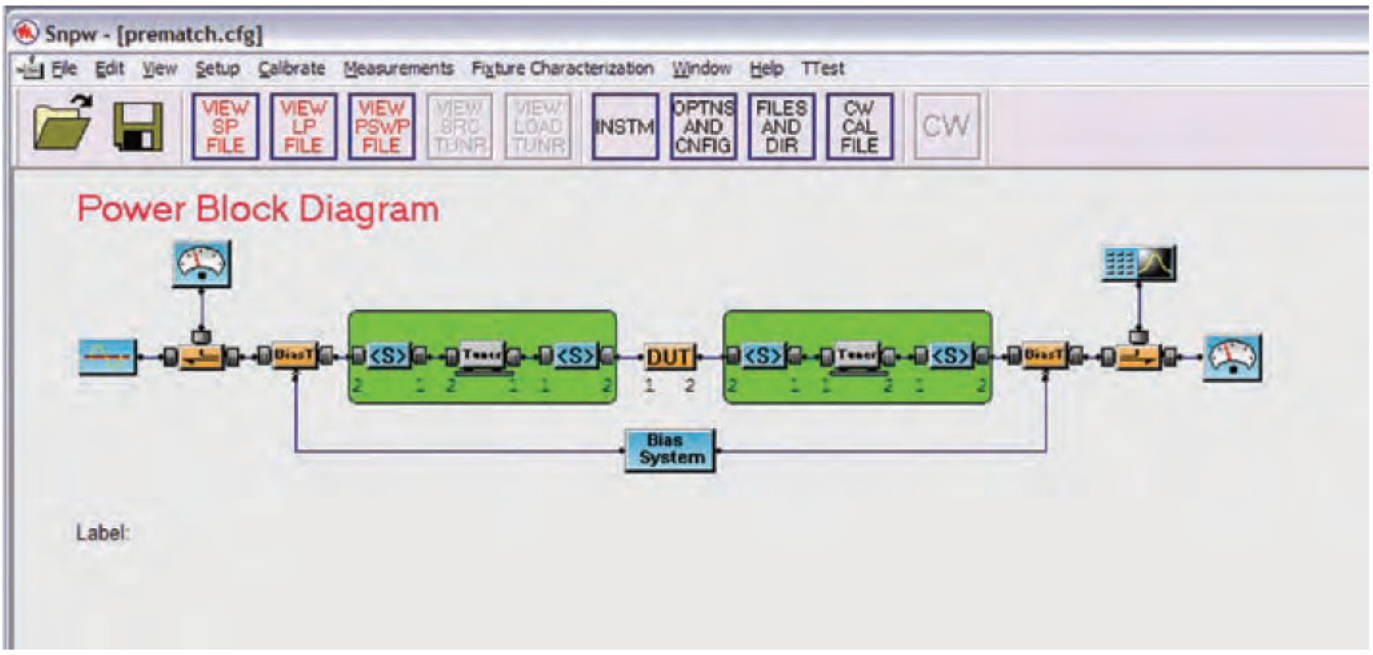
This is a single frequency display that permits the user to select the measured device parameters at a single input power or over a range of powers at any available source or load impedance. The frequency and impedances for load or source pull and sweep plan measurements can also be selected from this display. This is an active measurement screen which allows the operator to move the source and/or load tuners to any available position, and measure all active parameters. If the S-parameter option is exercised, stability circles S11* and S22* are also displayed.

Swept Power Display

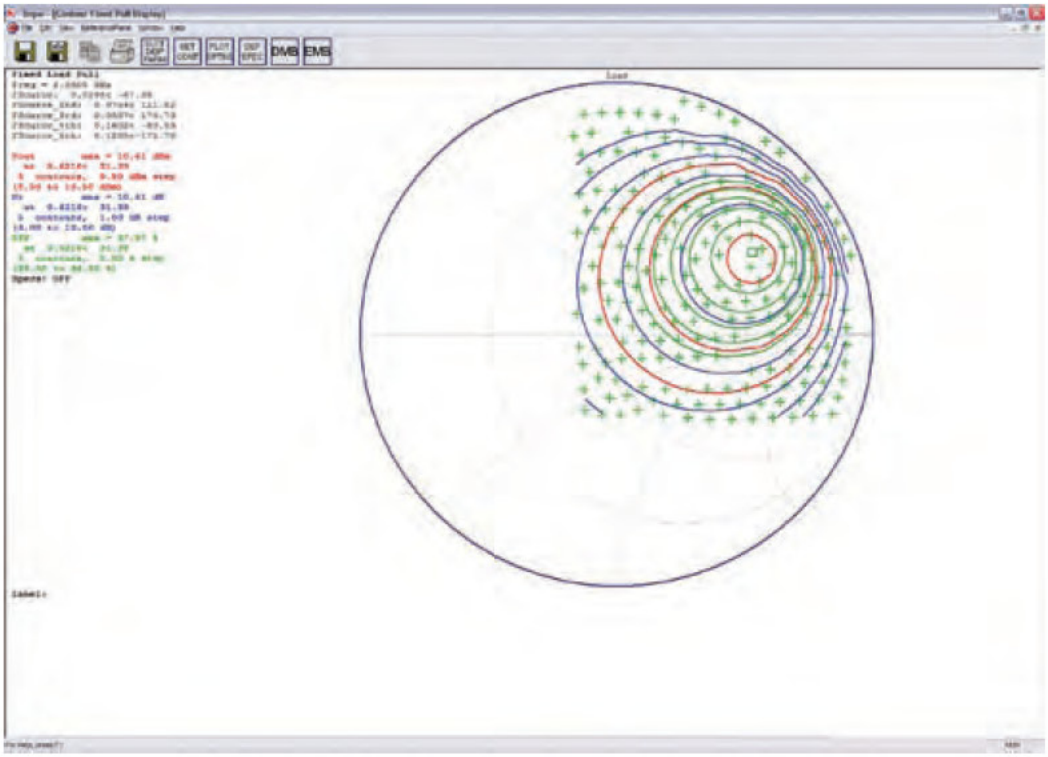
Up to five of the measured parameters can be simultaneously displayed versus available input power. A mouse or cursor key controlled marker provides for readouts at measured or interpolated points. Graphics scales are user-controlled. All measured parameters are tabulated below the plots and are available for printout.

Load/Source Pull Contour Display

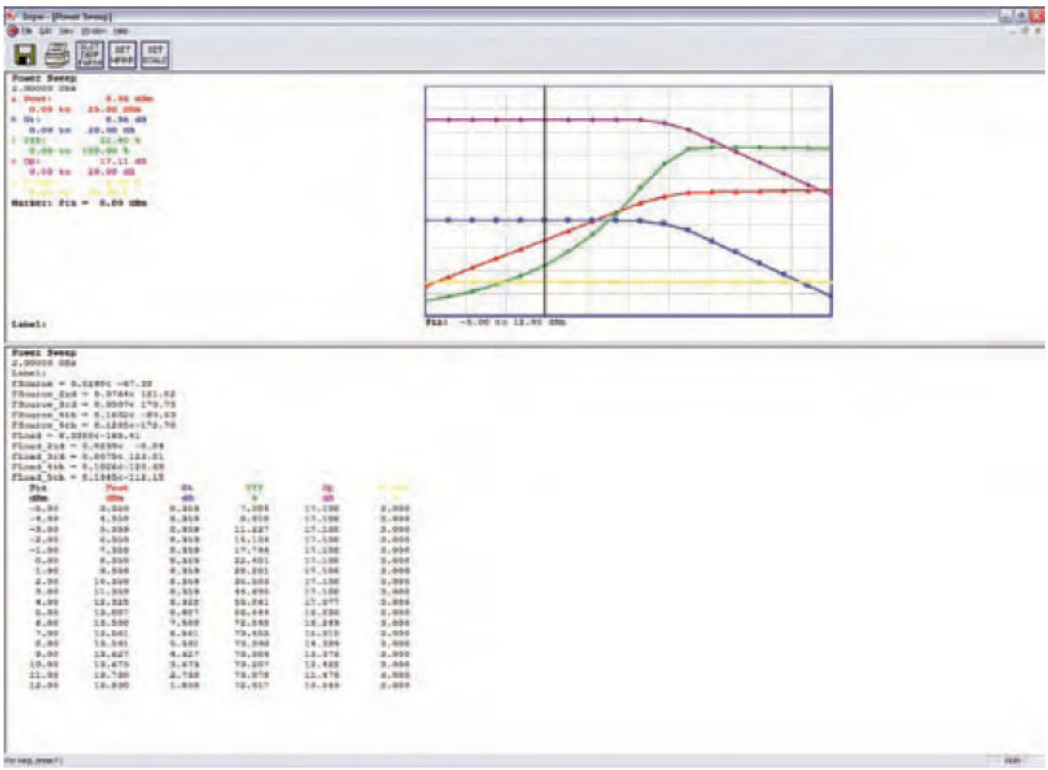
This single frequency display plots constant measured parameter contours on the impedance plane and the impedance(s) for maximum or minimum values. Contours of up to three parameters can be simultaneously displayed. The number of contours displayed, as well as the increment between contours, are user controlled. Output data at any tuner position can also be user controlled. The contour data can be converted to spreadsheet format with a single keystroke.



Typical setup for performing simultaneous load pull and source pull measurements.



Typical load pull contour display.



Typical swept power display.

MT993B – Noise Characterization Application Software

General

The MT993B noise characterization application software is designed to operate with ATS tuners and determine the noise parameters of a linear device, module or sub-assembly. The program is provided as part of an ATS system specified for noise characterization separately as model MT993B, or combined with the power characterization software as model MT993C.

Noise Parameters

Good noise performance is a critical element of most receiving systems. Knowledge of the noise parameters which define the noise performance of a device can be an invaluable aid to the receiver/amplifier designer by saving hours of design time and reducing, or even eliminating "cut-and-try" iterations.

An ATS system, operating with the Maury noise application software, can provide fast accurate measurements of minimum noise figure, optimum source reflection coefficient, and equivalent noise resistance. The program will also provide the gain parameters of the device and has a built-in general purpose S-parameter measurement program. All measurements can be de-embedded to the device input and output planes. The software provides for both data and graphical hard copy outputs.

Interactive Measurement Mode

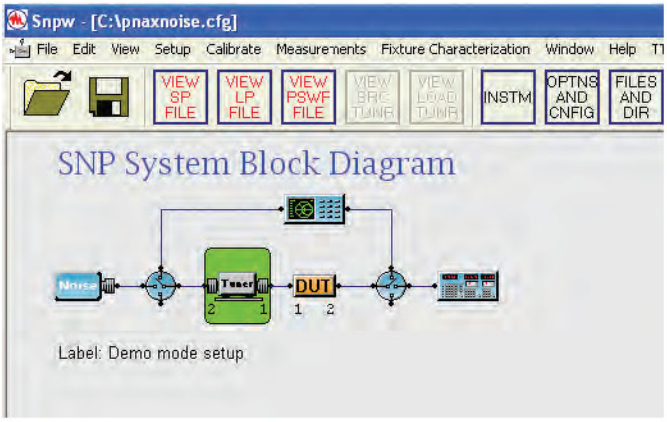
This is a single frequency display that permits the user to: a) measure the device noise parameters; b) measure noise figure and gain at any available source impedance; c) select the noise parameter measurement method; and, d) select the impedances used in the noise parameter determination or let the software determine these automatically. Constant noise figure and gain circles can also be plotted on the source impedance Smith chart. An advanced sweep plan is available to define fully-automated, multi-frequency, multi-bias noise characterization projects.

Swept Noise Display

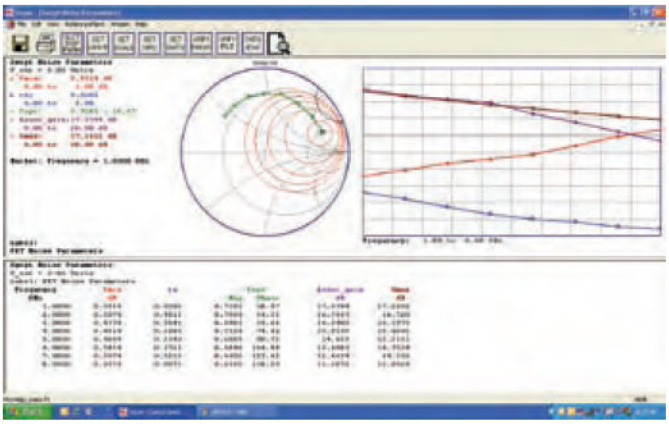
The measured parameters can be simultaneously displayed versus frequency and bias. A mouse or cursor key controlled marker provides for readouts at measured or interpolated points. Data smoothing (1st or 2nd order) is available, and graphics scales are user-controlled. Noise parameters as well as maximum gain, associated gain and stability factor (k) are tabulated and available for printout below the plots.

Noise Statistics Display

This is a statistics window screen which shows agreement between the noise parameter solution and individual points. The noise parameter solution is also displayed so the effect of changing options can be immediately seen. This display may be toggled between calibration and DUT measurement data so the effect of calibration options can be seen on the measured DUT data.



Typical setup for performing noise characterization measurements.



Typical swept noise display.

MT993B01 – High Speed Noise Parameter Measurement Option

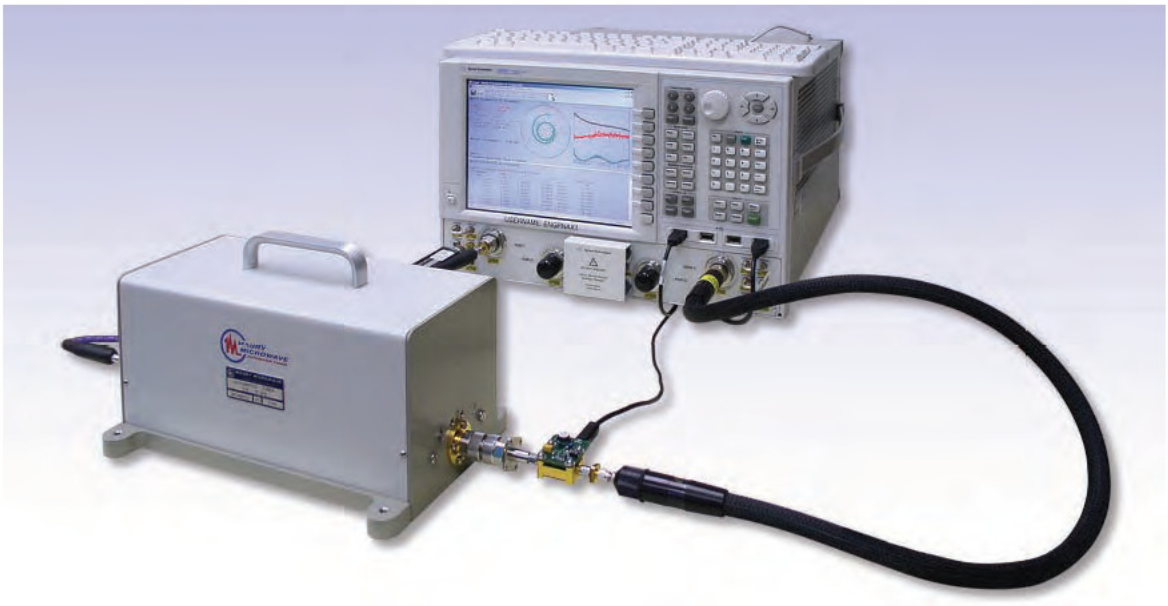
General

The MT993B01 high speed noise parameter measurement option (patent pending) operates with the MT993B noise characterization application software and Agilent's PNA-X to take advantage of the built-in noise receiver and fast sweep capability of the analyzer. This typically speeds up the calibration and measurement time by 200X – 400X; making it practical to sweep a much larger frequency set. Typical test bench setups are simplified (as shown in the photograph below), which reduces the number of cables and connections, thus helping to stabilize the setup. This setup produces data that is smoother and has less scatter than traditional methods of noise measurement. The fast measurement speed eliminates temperature drift, and using a VNA with an internal noise receiver simplifies the setup and makes it much more stable and consistent.

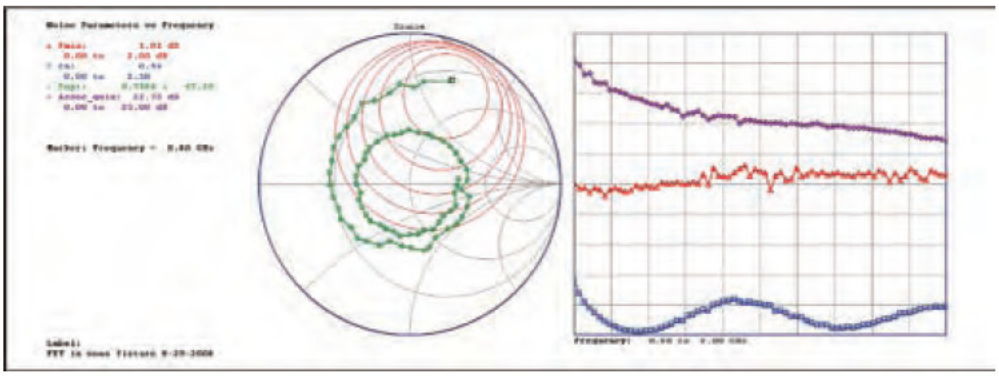
Benefits and Features

The MT993B01 option includes two key features that contribute to the breakthrough speed improvement: 1) The ATS tuner is characterized with one set of states (physical tuner positions) that are selected to give a reasonable impedance spread over the frequency band of interest; and 2) the noise power measurement is swept over the frequency range at each state, so that the tuner only moves to each position once; thereby minimizing tuner movement.

The much higher speed makes it practical to always do a full in-situ calibration to minimize errors, and to measure more frequencies to get a better view of scatter and cyclical errors, and to be able to use smoothing with more confidence. The higher frequency density also enhances accuracy by reducing shifts due to aliasing.



Typical setup for performing high speed noise parameter measurements.



Measured noise parameter data using MT993B01 (no smoothing).

MT993D – Intermod Distortion (IMD) and Adjacent Channel Power (ACP) Application Software

General

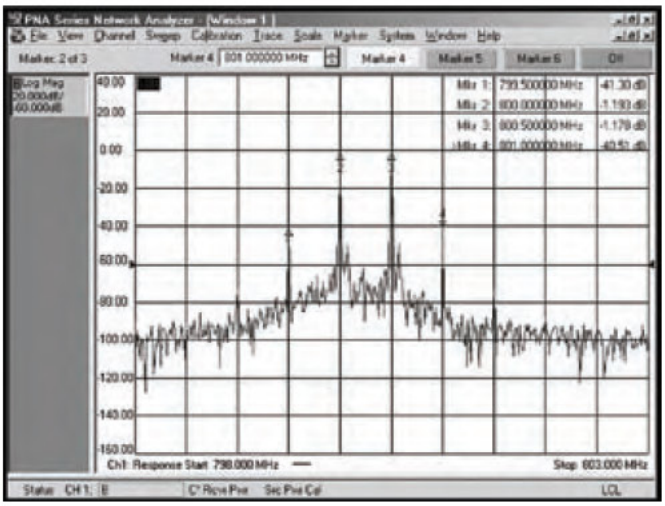
The MT993D IMD/ACP application software requires the MT993A power characterization application software or MT993C power and noise characterization application software to operate with the Maury automated tuner system (ATS).

IMD/ACP Parameters

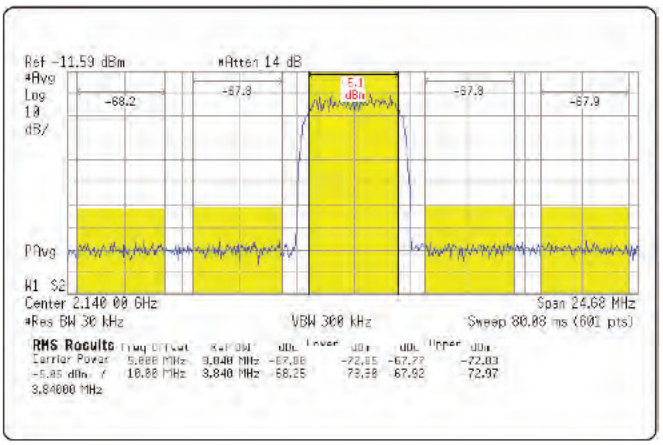
When two signals are simultaneously present, device non-linearity can cause frequency mixing. Odd order mixing (e.g., the fundamental of one signal mixing with the second harmonic of the other) results in a pair of mixing products which straddle the original pair and are displaced by the separation between the two tones. The magnitude of these products is a measure of the device non-linearity.

An ATS, operating with the Maury power and IMD/ACP application software, can provide fast, accurate measurements of the power parameters and the additional functions: 3rd through 7th order IMD power, carrier power, C/I ratio, intercept point, and first and second upper and lower adjacent channel power.

Adjacent channel power usually refers to the "spill-over" of a signal – typically, digitally modulated – into the adjacent or next adjacent communications channel. Knowledge of the magnitude of these products and other related parameters, as well as the termination conditions for minimizing or maximizing them, can be of significant help to the amplifier and system designer.



Typical IMD measurement data.



Typical ACP measurement data.

MT993D03 – Enhanced Time-Domain and X-Parameters Load Pull Application Software

General

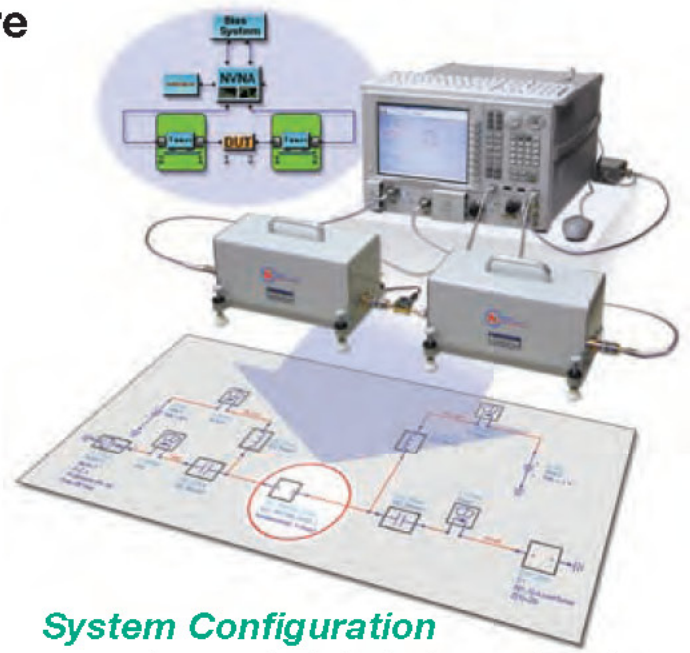
The MT993D03 enhanced time-domain and X-parameter application software is an automated application for combining a nonlinear vector network analyzer (NVNA) with load pull measurements to extend the measurement and extraction of X-parameters over the entire Smith Chart. The augmented X-parameter data include magnitude and phase as nonlinear functions of power, bias, and load, at each harmonic generated by the device and measured by the NVNA. The X-parameters can be immediately used in a nonlinear simulator for complex microwave circuit analysis and design. This capability extends the applicability of measurement-based X-parameters to highly mismatched environments, such as high-power and multi-stage amplifiers, and power transistors designed to work far from 50 ohms. It provides a powerful and general technology-independent alternative, with improved accuracy and speed, to traditional large-signal device models which are slow to develop and typically extrapolate large-signal operation from small-signal and DC measurements.

Load Pull with X-Parameters

Combining load pull with NVNA measurements of X-parameters and the PHD framework provides a simple and direct way to develop a large signal model for analysis of complex power amplifier circuits. The load pull measurement creates an X-parameter file which can be loaded directly into a non-linear simulator to be used as the PHD component. The data can be used immediately for analysis of complex power amplifier circuits. The load-dependent X-parameters enable full waveforms to be predicted – calibrated to the device terminals – even under high degrees of compression, and over all impedance environments. The user selects an impedance range of interest, possibly over the entire Smith chart, then uses the PHD model as a circuit element in a non-linear analysis. Because it is based on measurement at the actual operating conditions of the device this model can be used with great confidence.

The load pull X-parameter measurement can include a complete sweep plan. Stimulus variables can include impedance, power drive, bias, and frequency. This can extend the applicability of the PHD model over a much wider range of validity – over the range of actual applications for many high-power and multi-stage PA designs.

This process is a major simplification over past practice. It provides the simplicity of using load pull and NVNA data directly for simple power amplifier design, but with the ability to analyze complex circuits that require a large signal model. It is not limited to characterizing a single device, but applies equally to modeling an amplifier section. The entire process is independent of the device technology. Extracting full load-dependent X-parameters at multiple harmonics is significantly more automated and repeatable than extracting a standard "compact" transistor model. This makes it ideal for use with new technologies and new amplifier realizations before any detailed physics-based compact models or accurate circuit-level models are available.



System Configuration

Compared to a typical scalar load pull system, the combination of MT993D03 enhanced time-domain and X-parameter application software and a nonlinear network analyzer, like the Agilent PNA-X with NVNA and X-Parameter options, results in a simplified setup with fewer components, an easier use model, and faster measurements.

The centerpiece of the measurement setup is the PNA-X with NVNA and X-parameter options. The MT993D03 software can run directly on the analyzer for maximum interoperability and speed, eliminating the need for a dedicated measurement computer, and serves as a time domain measurement system with 26 GHz of bandwidth.

All couplers, bias tees, and RF sources are included in the PNA-X, so connecting the system is simple. The USB-controlled tuner plugs directly into the analyzer, and the DC instruments are controlled through the built-in GPIB interface. Since both the NVNA firmware and MT993D03 software have built-in support for external instrument control through GPIB, bias sweeps are easy to set up and measurement synchronization is automatically handled.

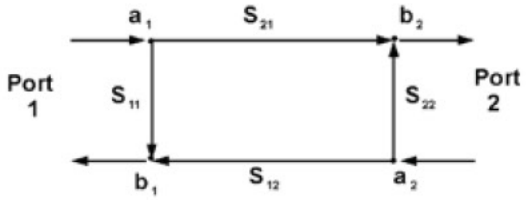
The user interface is primarily handled through Maury's ATS software, with the NVNA firmware used for calibration and made available for advanced settings (configuring internal switches and attenuators, utilizing advanced features of the PNA-X such as pulse modulation or triggering, etc.). Measurement configuration through the GUI is similar to standard load pull configuration, but uses a simpler block diagram with the NVNA replacing several instruments. The measurement parameter "X-Params" is available when the NVNA is included in the setup. When it is not selected, time-domain load pull measurements (load dependent waveforms) are taken. When "X-Params" is selected, the X-parameters of the DUT are also measured as a function of load and any swept bias conditions. The resulting X-parameters are written to a single file at the end of the measurement and are immediately ready to be imported into ADS and used in simulation and design.

MT993D04 – Active Load Pull

General

Considering our DUT as a two-port device shown in Figure 1, 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 ($\Gamma_L>1$ is theoretically possible but has no practical consideration).

The simple active tuning chain consists of a signal source, a variable phase shifter and a variable gain stage, shown in Figure 2. Common signal generators, such as the Agilent ESG, PSG or MXG, have built-in amplitude and phase control of the injected signal and 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, 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 Passive-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 $\Gamma_L=1$ 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 $\Gamma_L=1$. 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.

Optional Software Features

System Control Option (MT993F)

MT993F is an option that extends the capability of the MT993A or MT993C power measurement application software to provide automated switching between noise, power, Intermod Distortion (IMD), Adjacent Channel Power (ACP), DC I-V curves, and S-parameter measurements from a single setup. A special S-parameters, noise, and power (SNP) calibration is also possible with this option.

A further advantage of this option is that the RF switching reduces system cost by allowing sharing of equipment. This can save the cost of up to two RF sources.

DC I-V Curve Option (MT993G)

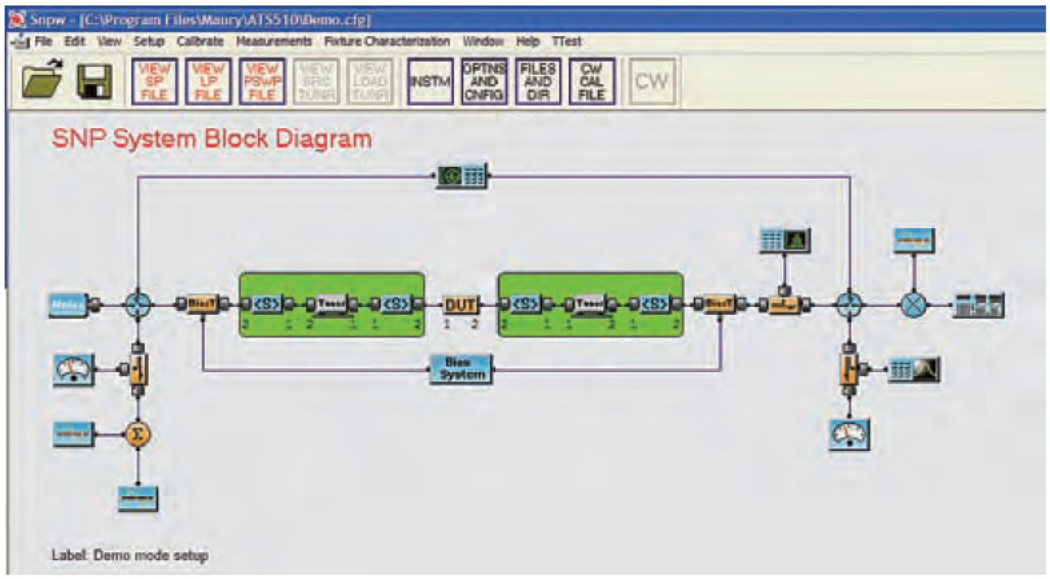
MT993G is an option that extends the capability of MT993A, MT993B or MT993C power measurement application software to provide for automatic measurement and display of device DC current-voltage curves. For FET devices, the measurement display is a family of output current versus output voltage curves with input voltage as the parameter. For bipolar devices, the measured display is a family of output current versus output voltage curves with input current as the parameter. A maximum dissipation value can be entered which will cause each sweep to terminate when that condition is reached.

Harmonic Source/Load Pull Option (MT993H)

MT993H is an option that extends the capability of the MT993A or MT993C power measurement application software to allow load/source pull measurements to be done independently at the fundamental, 2nd harmonic, and 3rd harmonic frequencies. Harmonic load pull is achieved by using a diplexer/triplexer to separate tuned frequencies, or by cascading tuners in-series and using advanced algorithms to set tuner positions. Harmonic tuning will generally improve power-added efficiency (PAE) for compressed amplifiers and lower error-vector magnitude (EVM) for modulated signals.

Fixture Characterization Option (MT993J)

MT993J is a standalone option that enables the S-Parameters of a test fixture or probe setup to be determined from two network analyzer calibrations. First, a 2-port calibration at the coaxial cable reference plane (or similar) is performed; second, a 2-port calibration at the DUT reference plane is performed. The resulting calibrations are mathematically compared and two separate S-Parameter files, each one representing a fixture half, are generated.



Typical setup for performing SNP measurements

MT993 DLL Library – User Functions & Custom Instrument Drivers

General

A unique feature of the Maury ATS software is the availability of the instrument driver source code. Users can write their own function for a specified measurement routine and the software will carry out what is involved in that function. Similarly, when faced with the need to use a non-supported piece of equipment, the user can open and copy the file for a similar instrument and modify the copied version (under a different file name) for the specific non-supported instrument. ATS software is written with Microsoft® Visual C++, so some familiarity with C programming is helpful, and a Microsoft® Visual C++ compiler is required.

Tuner Movement dll (MT993V04)

The Tuner Movement dll, MT993V04, can be used for tuner initiation, setup and control with options for interpolation and de-embedding. It is also available with Interpolation as MT993V01.

The Tuner Movement Dynamic Link Library (dll) can be used to control:

- All Maury USB Tuners
- MT986A, MT986B, & MT986C tuner controllers
- MT1020B & MT1020C Hubs
- Solid State NP, LP Mainframe Controllers

This library contains over 26 functions providing basic tuner control with an option for tuner impedance interpolation. The package has been designed to provide an easy way of controlling Maury tuners from within another proprietary software application.

This library package comes as a self-extracting, executable file that can be installed on Windows® 98, 2000, and XP equipped PCs. Included in the install package are programming examples for Visual Basic, Agilent VEE and LabView, and a sample executable program. All drivers are provide for the Maury Controllers and National Instruments GPIB cards.

Tuner Characterization dll (MT993N06)

The Tuner Characterization dll, MT993N06, provides the ability to characterize tuners without the need for external control, through the SNPW GUI. The tuner characterization files generated with this option are in the format used by the Maury Tuner Movement dll and the SNPW software.

SNPW Programmers Edition (MT993E)

Over 250 functions are available to be called by third party software, enabling users to do step-and-repeat measurements. Most other measurements available through the main software GUI are available to be called. Interactive mode allow users to write specialized tests without the need to develop all of the code necessary for calibration and setup. Users need only to start the interactive mode, setup the system through the SNPW GUI and then call the desired functions through the executive software.

Tuner Automation Environment dll (MT993R)

This package bundles together the Tuner Movement dll (MT993V04) with the Interpolation dll (MT993V01) and Tuner Characterization GUI (MT993N06).

Table of Products, Features & Options.

Software Package	Uses	Models
Tuner Movement dll	Controls Tuner Movement	MT993V04
Tuner Movement dll with Interpolation	Interpolation Between Tuner Points & De-embeding	MT993V04 with V01
Tuner Characterization dll (External Control)	Characterize Tuners Through The Interface	MT993E with MT993N06
Tuner Characterization SNPW GUI	Characterize Tuners Through The SNPW GUI	MT993N06
SNPW Programmers Edition	Depending On Key Options, Most SNPW Functions Are Available	SNPW Measurement Options with MT993E
Tuner Automation Environment	Bundled Package	MT993R (MT993V01, MT993V04 & MT993N06)