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LARGE-SIGNAL NETWORK ANALYZER TECHNOLOGY
Preliminary Product Overview

Maury Microwave's MT4463A Large-Signal Network Analyzer (shown here with the Maury MT982E30 automated tuner system) is the first commercial product to be based on Agilent's large-signal network analyzer (LSNA) technology as licensed to Maury.

The New Frontier ...
Beyond S-Parameters

The trend in modern communications applications is towards higher power drive levels and more complex modulation schemes. These large-signal conditions cause devices and components to exhibit nonlinear behavior, significantly degrading system level performance.

Today's designers face considerable challenges when trying to measure, model, and design devices and systems that operate under large-signal conditions. Many design iterations are necessary, and design verification has become a large portion of the overall development time. Researchers are looking for reliable cause and effect information, which requires testing under realistic stimulus and load conditions. Accurate and efficient measurements, which truly characterize nonlinear devices, are needed to get insight in the operation of devices, components and subsystems. Such measurements will also help to create and improve nonlinear device models. Current tools, such as vector network analyzers, spectrum analyzers, digitizing scopes, microwave transition analyzers and load pull measurement systems, each analyze only certain aspects of a nonlinear behavior. They do not provide fully calibrated characterization under large signal conditions.

The Maury/NMDG large-signal network analyzer allows researchers to view an accurate representation of the actual voltage and current waveforms at the device terminals. It measures magnitude and phase of incident and reflected waves at fundamental, harmonic and modulation frequencies. These measurements are fully calibrated and traceable, providing more complete device characterization under the given stimulus.

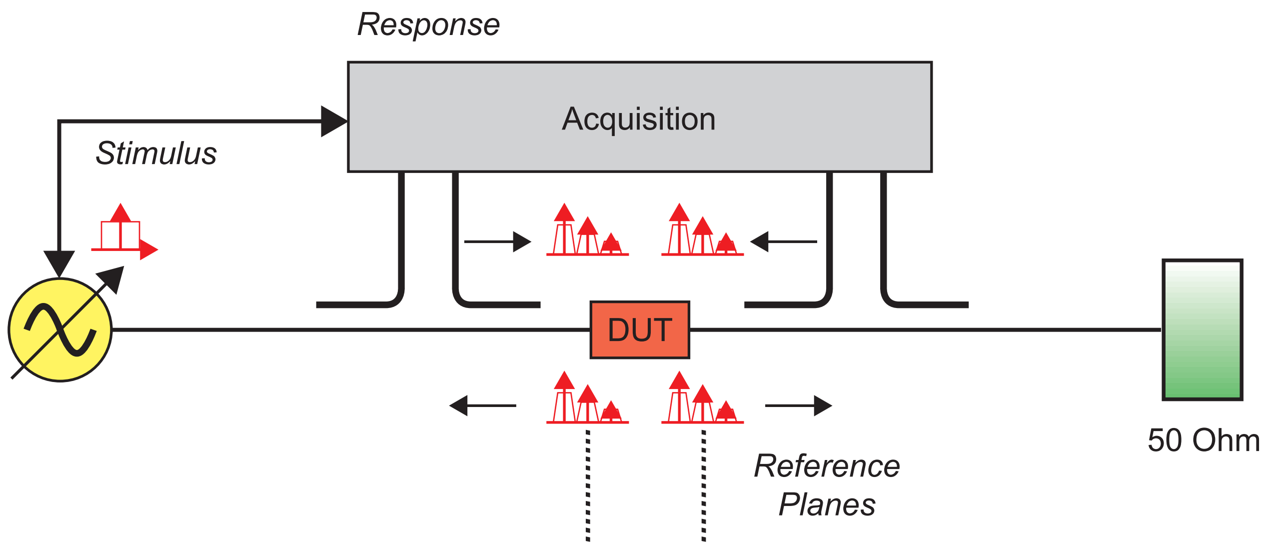
The measurement results can be displayed in frequency, time or frequency-time domain. They enable the user to study nonlinear device behavior, to verify their designs and to improve device models at the circuit level. An open architecture provides expert research designers and modelers with maximum flexibility.

What is Large-Signal Analysis?

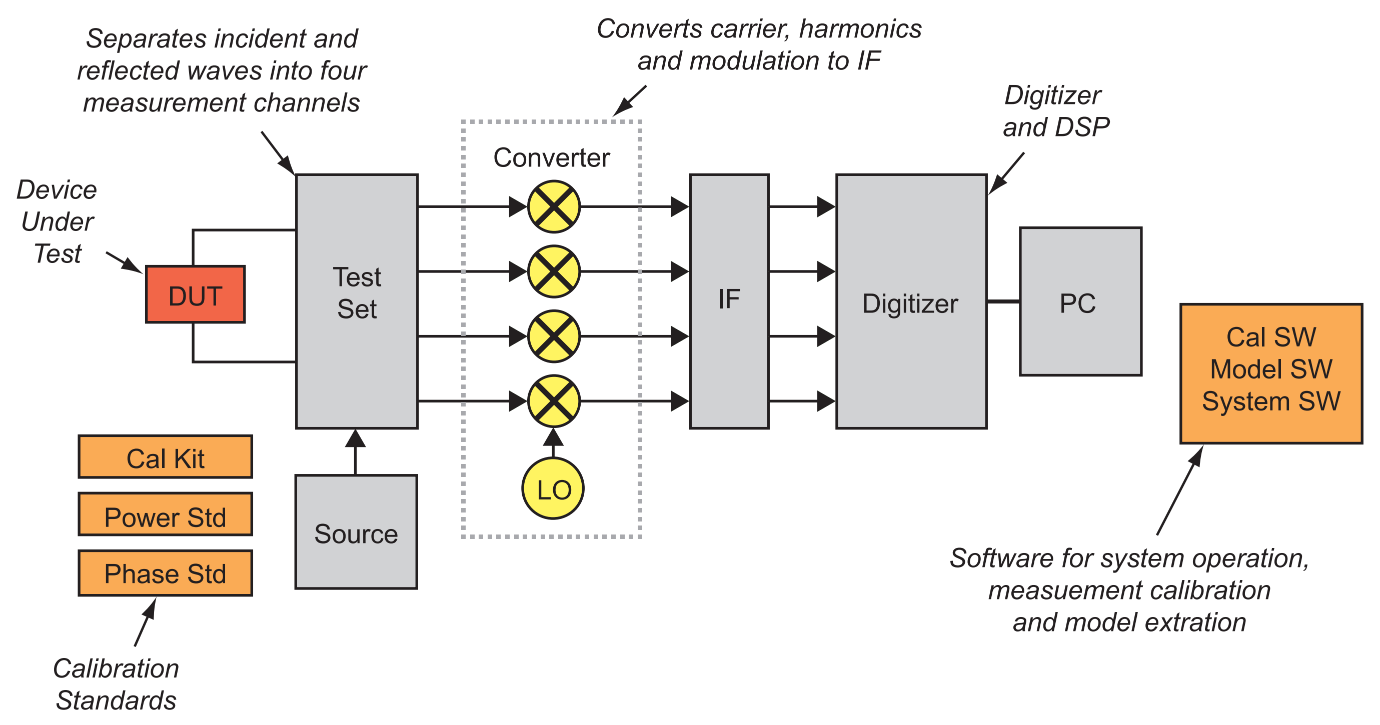
S-parameters are commonly used to describe small signal device behavior. They are extremely valuable as they offer a mathematical representation of linear device behavior. The application of s-parameters allows circuit designers and modelers to achieve excellent correlation between simulation and measurement. However, s-parameters only apply to linear devices and systems, where the superposition principle is valid. Large-signal environments usually push devices into their nonlinear operating regions, and s-parameters and the superposition principle no longer apply.

Researchers and design engineers face a significant problem when trying to translate high level system specifications such as spectral regrowth, adjacent channel power ratio (ACPR) and third order intercept (IP3) into concrete device and process parameters. There is an urgent need for a framework which deals with large-signal behavior from device to system level in a coherent way, that can be applied to measurements, modeling and simulation. Imagine the increase of productivity in the design flow, if process engineers could work with circuit designers and system level engineers based on the same measurement tools and methods.

A long term cooperative effort between NMDG Engineering, Maury Microwave and several research institutions is under way with the goal of developing a new analysis framework for large-signal RF and microwave design process. With its strong presence in device characterization, modeling and simulation, Maury and NMDG are uniquely positioned to lead this effort. The large-signal network analyzer has allowed participating researchers to gain new insight into their device's behavior under large signal conditions. Now, for the first time, this measurement system is being made available to Maury and NMDG's customers.



The large-signal network analyzer measures incident and reflected waves at fundamental, harmonic and modulation frequencies.



Functional block diagram of the large-signal network analyzer.

Voltage and current relationships are the fundamental information used by computer aided engineering (CAE) tools and device level models. What has been missing is a way to accurately measure voltages and currents at the device under test's (DUT's) ports under realistic stimulus and load conditions. The large-signal network analyzer takes a first step towards bridging the gap between measurement, modeling and simulation, from device level to system level.

The Large-Signal Network Analyzer

The large-signal network analyzer is a 4-channel data acquisition system, operating from 600 MHz to 20 GHz. The system provides calibrated measurements on a given frequency grid[1] at the DUT ports. The RF source is optional but is required during the calibration process. Therefore only a limited set of sources is supported. For a 1-tone measurement, the system synthesizer generates the RF signal needed to stimulate the DUT. The signal passes through the test set to the DUT. The test set is similar to that of a traditional network analyzer and separates the incident and reflected voltage waves. The coupled waves are then sent to the down converter which uses harmonic sampling to compress all four channels simultaneously into four IF signals. The signals are then digitized and sent to the PC for error correction and formatting. Connection to Agilent's Advanced Design System (ADS) is made possible by data output in CITIfile format.

The open system architecture makes future addition of hardware components possible. This will allow the user to optimize the measurement system for specific applications. A bias supply is optional, and bias tees are built into the test set. An amplifier and/or attenuator can be added to the source path. A second source can be added for 2-tone measurements, or to add periodic modulation. The system can easily accommodate on-wafer measurements using a probe station. Tuners can be added by the user to vary the source or load impedance.

To fully realize the powerful potential of this system, the user needs to have a strong foundation in network analysis or RF and microwave concepts. In addition, a working knowledge of Mathematica will also need to be acquired. However, the system does supply a Graphical User Interface (GUI), which will lead a novice user through basic calibration and common measurements.

Calibration

The calibration of the large-signal network analyzer consists of three steps: a traditional network analyzer calibration, a power calibration and a phase calibration. The phase calibration is a unique contribution of Agilent's large-signal network analyzer. Calibration data is generated at the fundamental frequency and its harmonics (or, if applicable, over a range of fundamental frequencies and their harmonics).

A traditional network analyzer calibration is used to correct for systematic errors contributed by the measurement system, since the system itself is linear. This establishes the correct ratios between input and output signals at the DUT. Coaxial measurements will use an open-short-load calibration. For on-wafer measurements a line-reflect-reflect-match calibration is supported.

The power calibration is necessary to establish an absolute power reference. It is accomplished by connecting a power meter to one of the ports of the signal separation module. The power measured by the data acquisition is compared to the power measured by the power meter as the RF source is stepped through the frequency grid of interest.

Finally, a phase calibration is needed to link the phases of the multiple harmonic components of the measured signal to the fundamental. A phase reference generates a comb of frequencies, which is accurately characterized during the manufacture of the system. The characterization process is traceable to an NMDG and Agilent in-house standard, and NMDG continues to work with National Standards Laboratories to provide measurement integrity and traceability.

For on-wafer measurements, the power meter and the phase reference are connected to the AUX cal port on the test set, and the system is able to move the reference planes to the probe tips.

Software

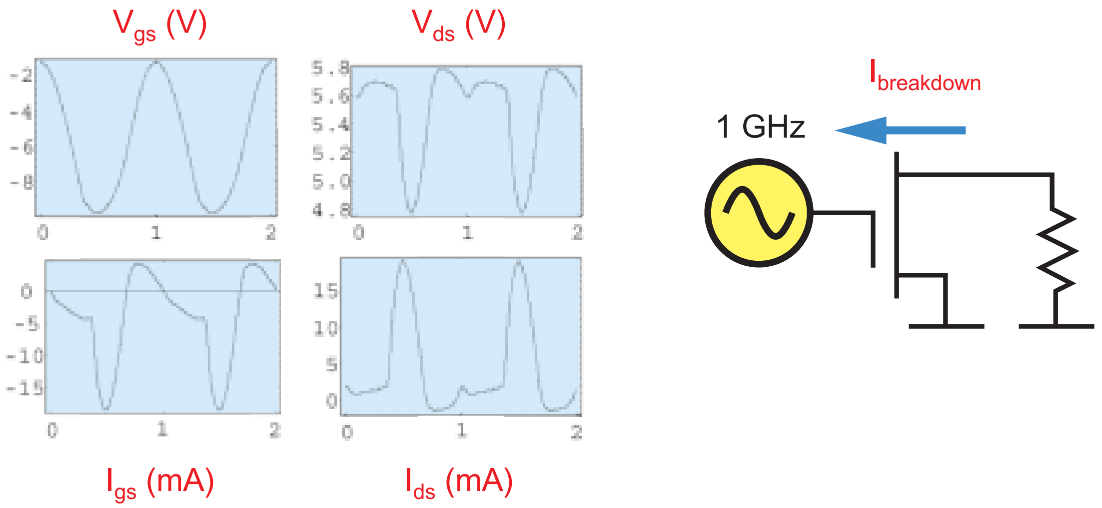
The Large-Signal Network Analyzer provides an open software architecture with a powerful scripting language based on Mathematica. A Graphical User Interface, which guides the user through basic calibration and measurement procedures is available to help new users learn and use the system.

The LSNA can be controlled from Mathematica and also a limited set of sources and DC supplies. All of the measurement and calibration functionality is implemented in Mathematica as well.

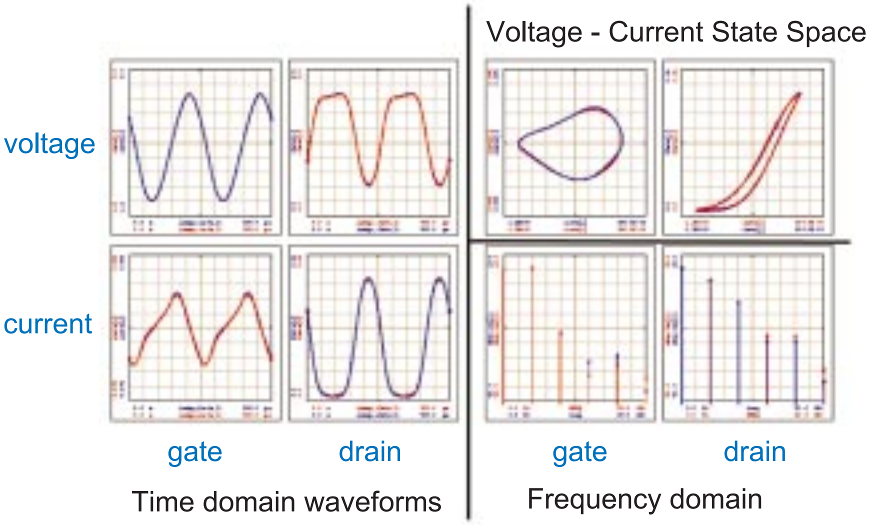
Mathematica has long been one of the prime software choices for scientists working at the frontiers of research and modeling. It puts the largest collection of mathematical knowledge at the fingertips of its user. The open software structure with Mathematica as the scripting language allows for user adaptation of the system to an unlimited number of applications. Mathematica training can be included with the purchase of the large-signal network analyzer.

Application Examples

The large-signal network analyzer is a powerful tool. It offers many different representations of the acquired data. The best choice depends on the specific application. Transistor designers can view their devices in the voltage — current format that they are most familiar with. Power amplifier designers usually prefer traveling waveforms and load lines. Researchers and designers will be able to verify the accuracy the device models used by their simulation package. Model parameters can be optimized through the import of real voltage and current measurement data into a commercial simulator package. The correlation of measurements and simulations should significantly improve as modelers and designers start using the large-signal network analyzer.



This example shows the voltage and current time domain waveforms as they appear at the gate and drain of a FET transistor. The measurements were performed applying an excitation signal of 1 GHz at the gate. The signal amplitude was increased until the breakdown current was observed. It is visible as a negative peak (20mA) for the gate current, and as an equal amplitude positive peak at the drain. The current flows from the drain towards the gate. This kind of operating condition deteriorates the transistor and is a typical cause of transistor failure.



A GaAs HEMT is shown in voltage and current time domain view, as well as in voltage-current state space and frequency domain.

Device reliability is an important concern for power amplifier designers. Currently the breakdown characteristics of a transistor are determined under DC bias conditions. However, designers want to push their devices to the limit, and the limits established at DC are too conservative under large-signal high frequency conditions. The large-signal network analyzer's ability to directly measure transistor breakdown currents under realistic operating conditions enables designers to fully exploit their device potential.

The concept of dynamic loadline is very useful for microwave power amplifier designers. The dynamic loadline represents current versus voltage at the output of a transistor for the fundamental and harmonics, under given bias conditions and input and output match. Once the dynamic loadline is determined, the designer can easily tune bias parameters, input power and output impedance to optimize output power or power added efficiency (PAE). Up to now, dynamic loadline information was only available from advanced simulators, and depended therefore on the accuracy of the large-signal models of the device. The large-signal network analyzer makes it possible for the first time to accurately measure the dynamic loadline directly, without the dependence on accurate models. This allows faster and more efficient design cycles.

Footnotes

[1] A frequency grid consists of all the measurement frequencies of interest plus the frequencies of their significant harmonics. The large-signal network analyzer is fully calibrated for all points on the frequency grid.

Preliminary Characteristics and Typical Specifications

The measurement system consists of the following components:

- A test set for signal routing and signal separation, also contains bias tees.
- A down converter which converts high frequency signals into IF signals.
- A VXI data acquisition system for digitizing the IF signals.

A power meter to perform calibration of the harmonics.

- A phase reference is used as the phase standard for measured harmonics.
- A PC to control the measurement system and display the data.

Optional are:

- A limited set of microwave sources.
- A limited set of DC monitor and force sources.
- Modulation source: ESG.

Installation and training are also included with each system.

Measurement Frequency Range: 600 MHz to 20 GHz.

Maximum Power into Test Ports: 10 watts (+40 dBm).

Maximum Stimulus Power from Test Port: +7 dBm (Maximum stimulus power from test port can be increased to +30 dBm with external amplifier).

Measurement Dynamic Range: 60 dB

Modulation Measurement Bandwidth: 8 MHz

This document contains preliminary information and is under development. Subject to changes without notice.

Contact Information

Please contact your nearest Maury Representative or our Sales Department at:

2900 Inland Empire Blvd.
Ontario, California 91764 USA
Telephone: (909) 987-4715
Fax: (909) 987-1112

International —

Surinder Bali (sbali@maurymw.com)
Cell Phone (UK) 44 77 641 93425

Domestic —

Roy Zohrabian (rzohrabian@maurymw.com)
Telephone: (909) 987-4715 extension 311

Don't Forget to Visit our Web Site at
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