Nonlinear Vector Network Analyzer (NVNA)

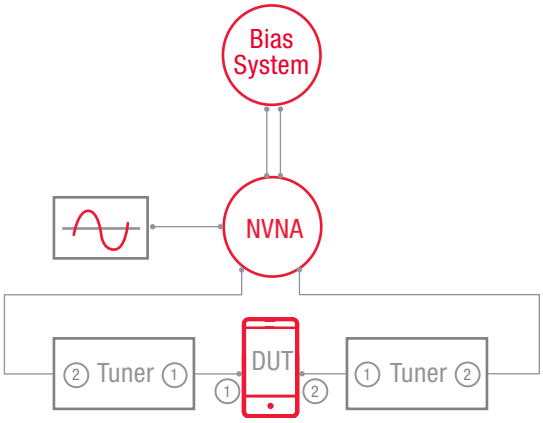
Breakthrough Technology for Nonlinear Vector Network Analysis from 10 MHz to 67 GHz

KEYSIGHT TECHNOLOGIES

Keysight Technologies, Inc. Can Help You Meet Challenges with the Award-Winning NVNA…

Designed specifically for:

- Semiconductor foundries and IC designers
- Base station power ampliier designers
- Active device military component designers
- Research centers and universities



"I know my amplifier gain is changing with output match, but "Hot S22" measurements don't give me the correct answer. When I cascade individual stages of my power ampliier, the composite output does not perform to my expectations. What's going on? I need new tools that can expand my insight into the nonlinear behavior of my devices.

Much of my time is spent designing matching circuits by trial and error. What I really want is the amplitude and phase of the full frequency spectra of my devices."

– Customer Quote

Innovative Technology to Go Beyond Linear S-parameters

NVNA provides the critical leap in technology to go beyond linear S-parameters, allowing you to efficiently and accurately analyze and design active devices under real world operating conditions.

Nonlinear component characterization

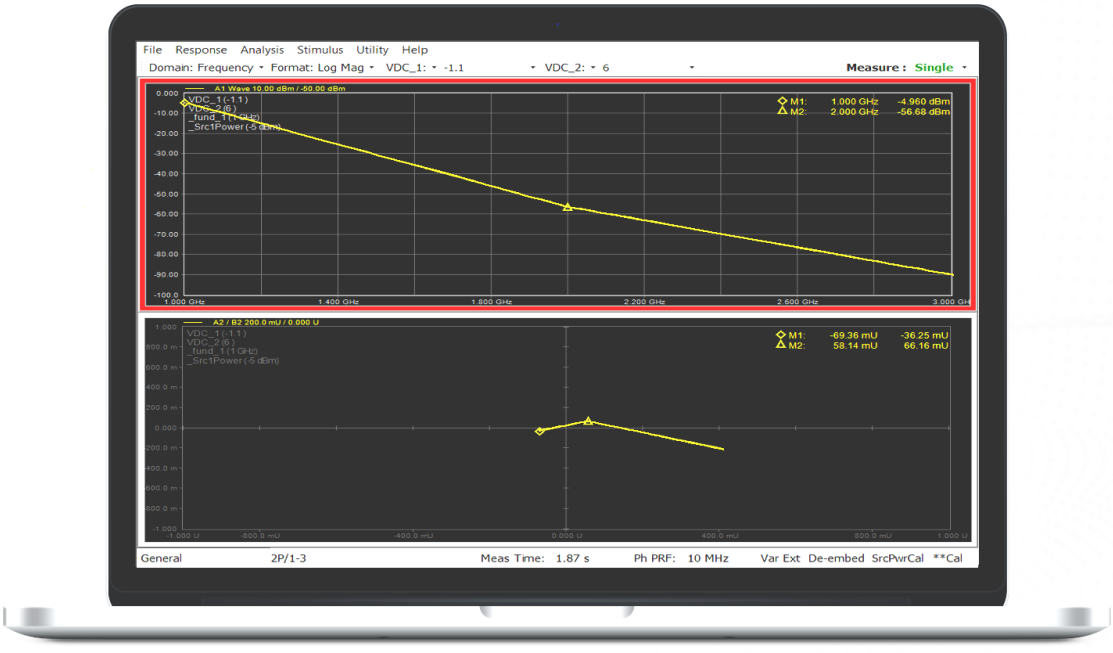
Nonlinear component characterization provides strong insight into the nonlinear behavior of your device under test (DUT). Now you can quickly and easily measure and display the calibrated, vector corrected waveforms of the incident, reflected and transmitted waves of the DUT. With this capability, you can know explicitly the amplitude and phase of each distortion product of interest. All measured spectra is traceable to the National Institute of Science and Technology (NIST).

Easily move between domains

Displayed data can be represented in frequency, time or power domains to fully analyze and develop a deeper understanding of device behaviors. Each domain provides its unique insight into what is contributing to the current state of the device operation so that designs can be optimized. Absolute amplitude and relative cross frequency phase of all the measured spectra enables you to tell which spectral components are creating problems so you can design matching circuits to cancel these signals.

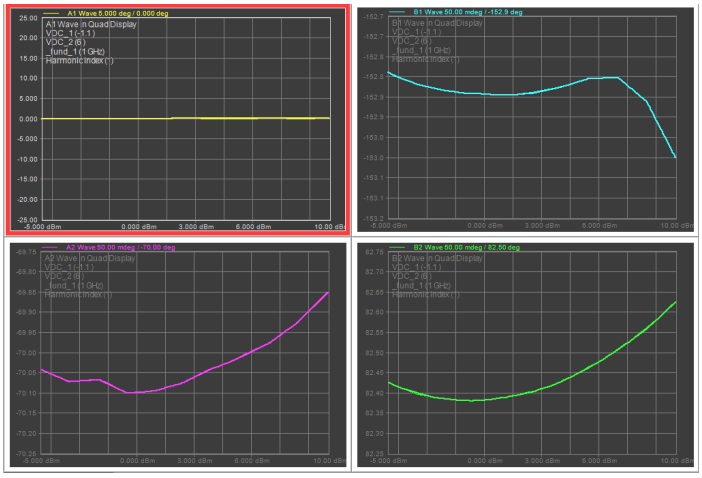
The Keysight NVNA provides fast and powerful measurement capabilities. Six nonlinear options are available to help solve your toughest problems:

- Nonlinear component characterization
- Nonlinear X-parameters[4]
- Nonlinear pulse envelope domain
- Arbitrary load X-parameters
- Arbitrary load control X-parameters
- Arbitrary load control device characterization

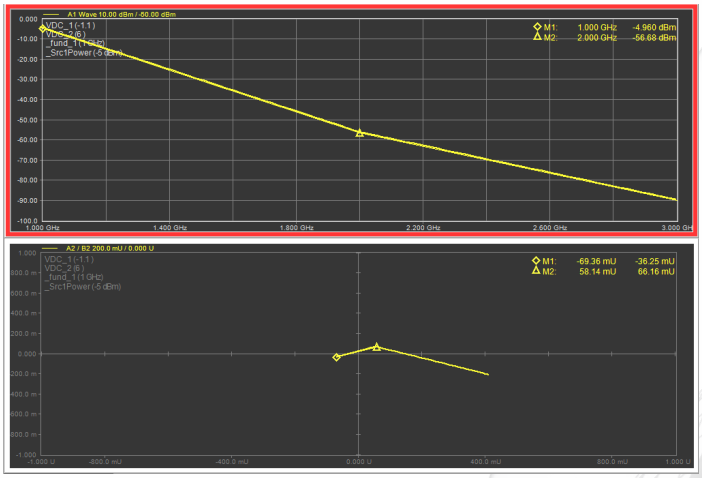


Easily Move Between Domains

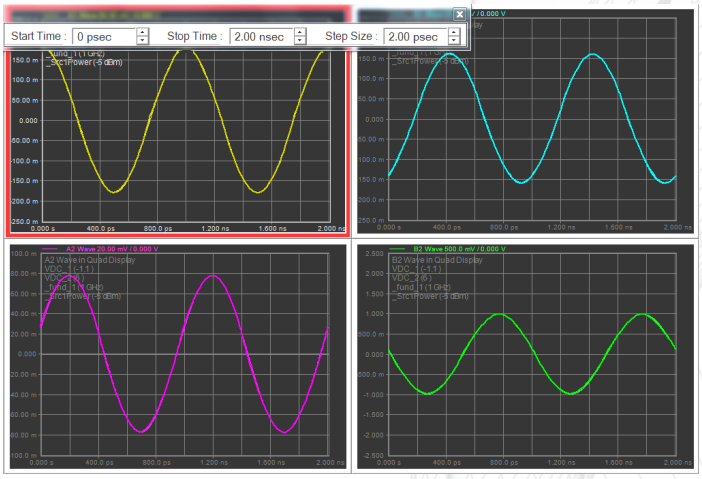
Easily move between domains and create custom displays



View input and output waves in frequency and power domains



Customized view of output load impedance



View input and output waves in time domain

NVNA component characterization additionally enables you to:

- Create user-defined parametric displays such as dynamic I/V curves
- Extract full input and output wave data for building user-defined models
- Quickly and easily set up and make measurements using the front panel Graphical User Interface (GUI) and remote programming interface

Introducing X-Parameters: The “New S-parameters” for Nonlinear Components

Nonlinear X-parameters

X-parameters are the mathematically correct extension of S-parameters to large-signal conditions. This provides a device independent, black-box framework whose coefficients are identifiable from a simple set of physical measurements on the device under test.

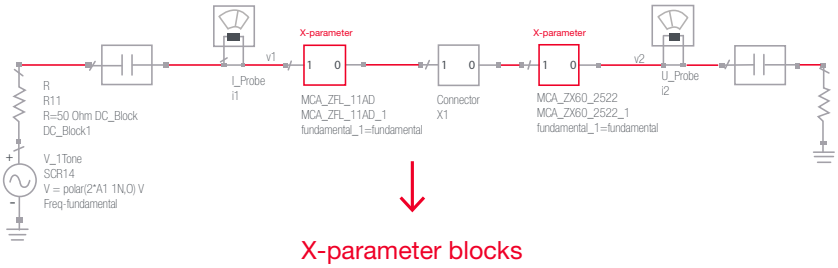
X-parameters are a fully nonlinear framework that provides both the magnitude and phase of the fundamental and harmonics. They can be cascaded in simulation and produce the correct behavior in mismatched environments. Researchers and designers can now measure match, gain, group delay and more for driven components.

X-parameters in conjunction with ADS design and simulation tools minimize design iterations, speed simulation and deterministically model the nonlinear behavior of your active components. This can significantly reduce the time to market for component, module, and system design. Additionally, because Keysight’s X-parameters are a measurement-based, black-box representation of the DUT, they can be used to distribute more complete device operating characteristics than traditional datasheets, and at the same time protect the device IP.

X-parameter process flow

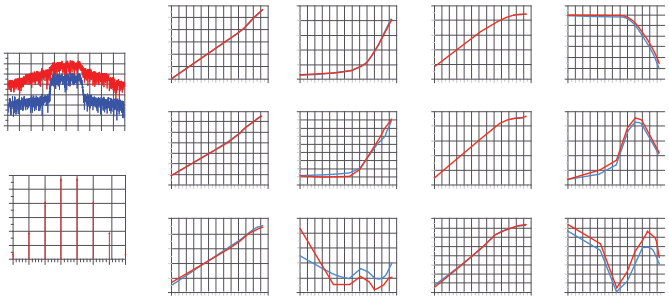
NVNA nonlinear measurements

ADS simulation and design



X-parameter blocks

X-parameters enable accurate nonlinear simulation under arbitrary matching conditions.



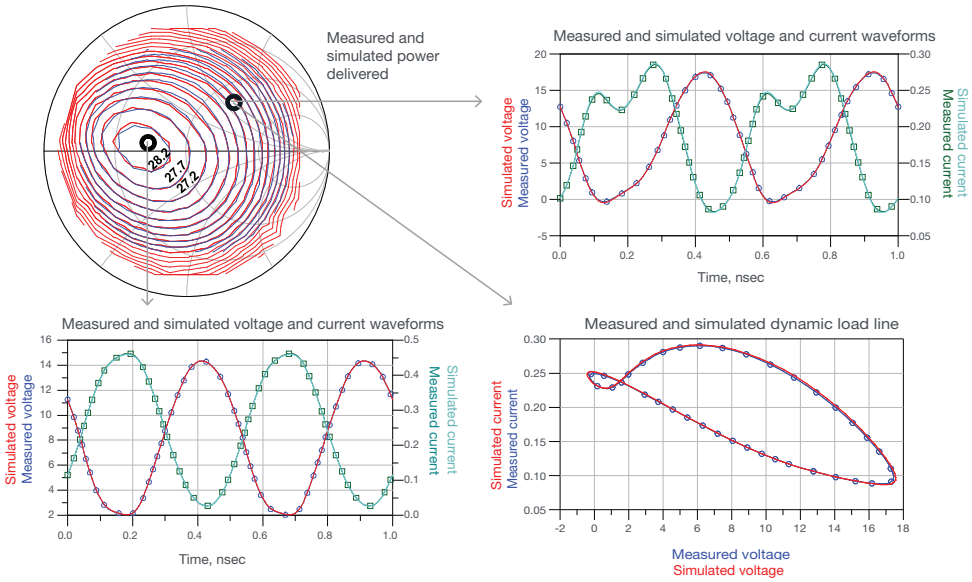
This allows prediction of component behavior in complicated nonlinear circuits.

Capture Complete Nonlinear Behavior at All Load Impedances

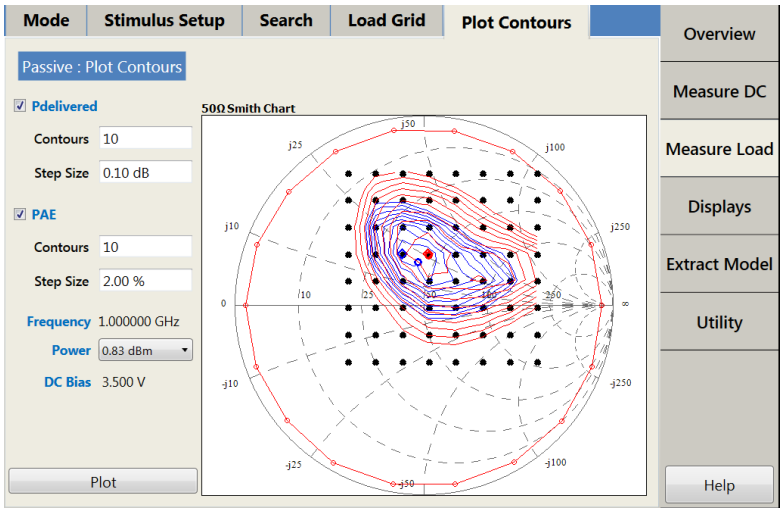
X-parameters with arbitrary load impedances

X-parameters provide a powerful, yet simple and automated process for capturing nonlinear component behavior over arbitrary complex impedances, input powers, input frequencies, DC biases, and more. X-parameters fundamentally unify, for the first time, scattering parameters, scalar and vector load-pull data, and device generated harmonics. Full load-dependence also enables immediate X-parameter applications to transistor characterization, modeling, and circuit design.

- Reduce design cycles by 50 percent using real nonlinear data
- Extend X-parameter cascadability to arbitrarily large load mismatch
- Model devices and design multi-stage, Doherty, or other complex amplifier circuits with the drag and drop simplicity of Keysight's Advanced Design System (ADS)
- Measure and predict dynamic load-lines at input and output ports under arbitrary loading conditions, even under very large compression



Measure nonlinear behavior with Keysight's NVNA and view simulated waveforms in Keysight's ADS; X-parameters give contours and waveforms at any loading condition including cascaded systems

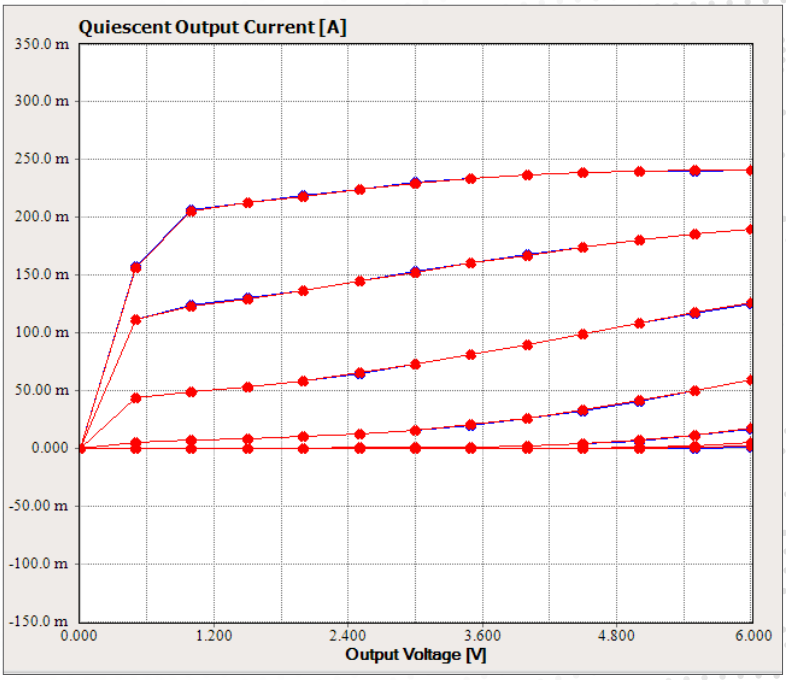


Keysight arbitray load control application using passive, active, or hybrid loadpull

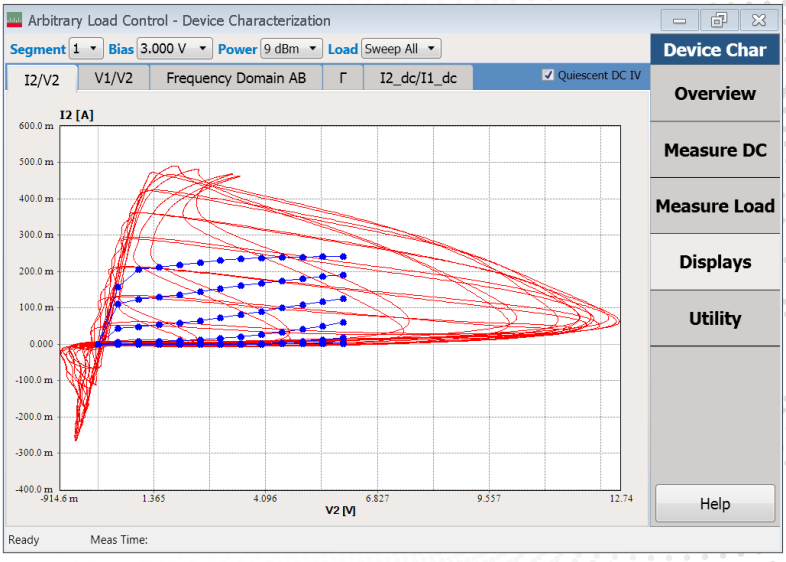
Capture Large Signal Waveforms Under Active Loads for Compact Model Generation

Arbitrary load control-device characterization

- For modeling, design and validation scientists/engineers who work with 2-port nonlinear active devices with optimal output impedances far from 50 Ohms, (predominantly power transistors)
- Simplified, integrated interface to setup and measure large signal waveforms for device modeling. Active source control of RF stimulation and dc bias at both input and output ports simultaneously.
- Interactive NVNA GUI optimizes measured data in NVNA. Generated data can be passed to ICcap to extract Keysight's powerful DynaFET compact model. Model contains RF and DC behavior including memory effects and load sensitivity. Model can then be used in ADS to optimize circuit design.
- Alternatively, NVNA large signal data can be used to generate customers own compact models.
- Additionally, you can use data to fit any existing compact model to the large signal waveforms.



Measure and analyze device dc characteristics

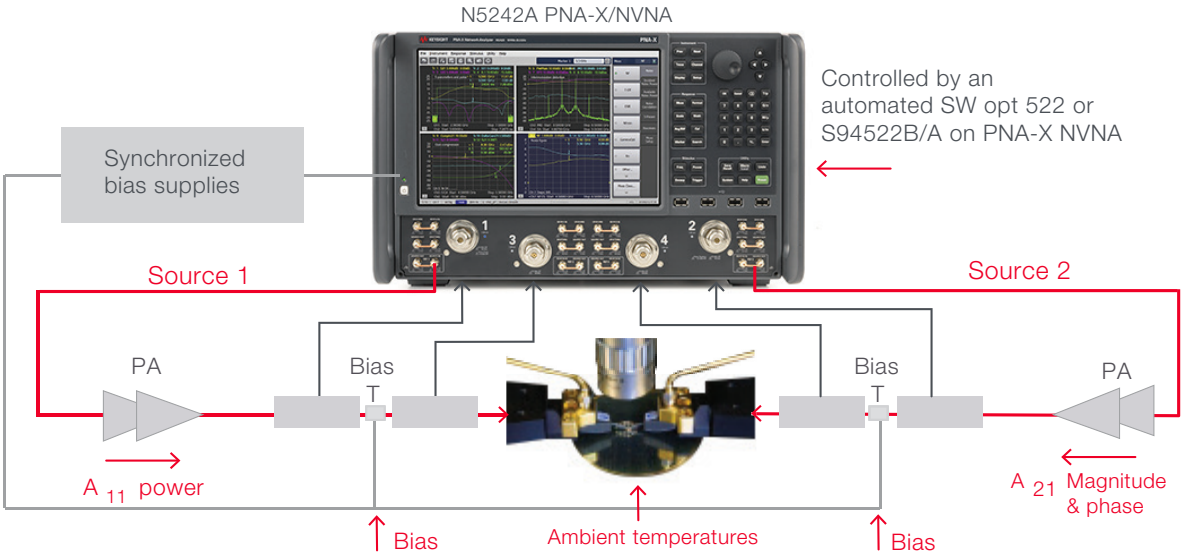


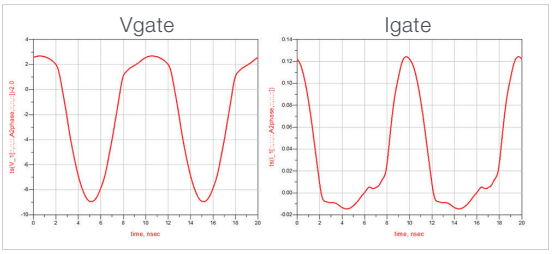
RF I/V response to large signal stimulus

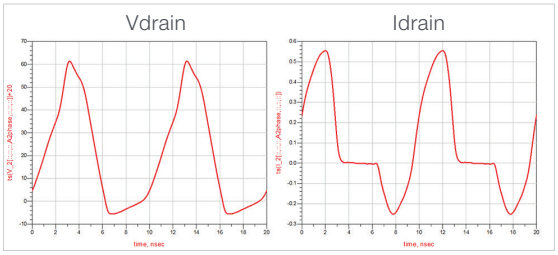
Device characterization (ALC) setup

The device characterization application provides a powerful, yet simple and automated process for capturing nonlinear device behavior over active, arbitrary complex load impedances, input powers and DC biases. When used for Keysight's DynaFET compact model extraction, the measured device data must be for on-wafer III – V semiconductor FET transistors, GaN and GaAs. On-wafer power should be limited to 5 watts or less due to CW RF stimulus. For general use, the large signal waveforms can be measured for any 2-port device. Available on both the "A" and "B" model PNA-X running NVNA.

Device Characterization (ALC) Setup





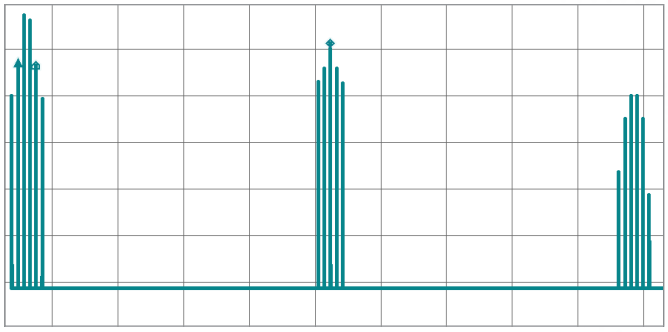


Two-Tone X-Parameter Measurements

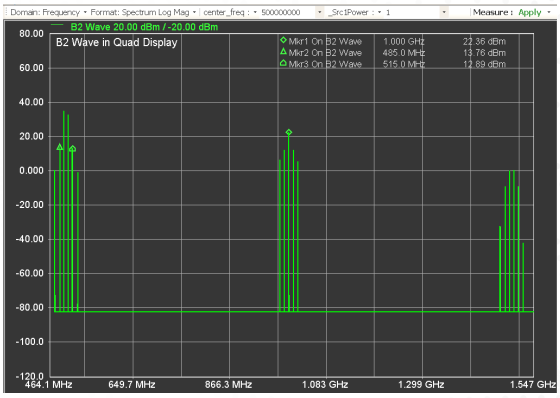
Extract X-parameters with two-tone stimuli

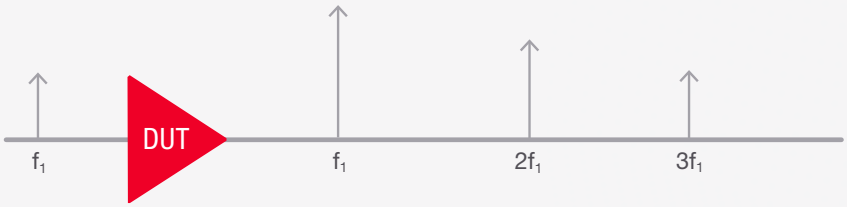
X-parameter measurements have been expanded to include two-tone large signal stimuli to a device. When a two-tone signal is applied to a nonlinear device, it produces a number of mixing products which occur around the fundamental frequency as well as the harmonics. The NVNA has the ability to measure all these mixing products providing a much richer characterization of the device's nonlinear behavior.

Once the two-tone stimulus X-parameters have been captured, the component's behavior can be imported into ADS, and cascaded with other components, providing powerful design and analysis capabilities to be modeled and analyzed under two-tone stimulus conditions. A two-tone stimulus can also provide additional insight about bandwidth dependencies and inferences about a device's possible memory effects.

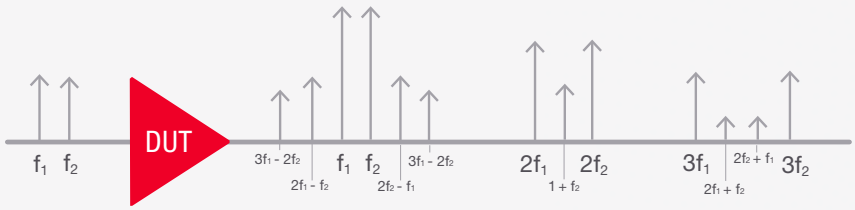


Accurately measure amplitude and relative phase of two-tone mixing products to deterministically design matching circuits





A single tone stimulus signal produces harmonics

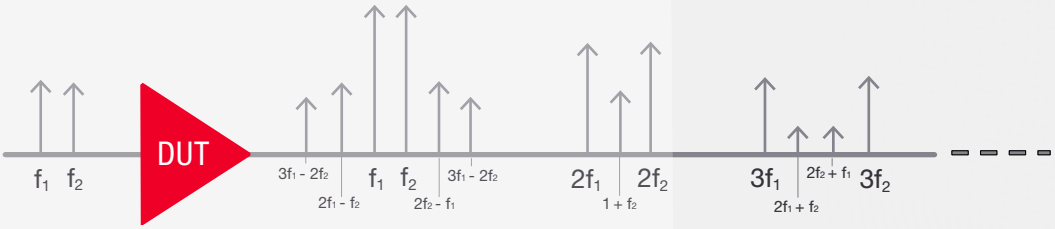


A two-tone stimulus signal produces inter-modulation products around each of the harmonic frequencies

Multi-Tone Waveform Measurement and Analysis

Evaluate device behavior with multiple large signal stimuli

An arbitrary number of large signal stimuli can be applied to a device for waveform measurement and analysis. Any multi-tone stimuli ranging from a simple two-tone stimulus to an arbitrary number of large signal tones can be applied to the DUT to simulate conditions analogous to a variety of modulation stimuli. This allows analyzing a device's behavior under conditions very similar to modulated signals.



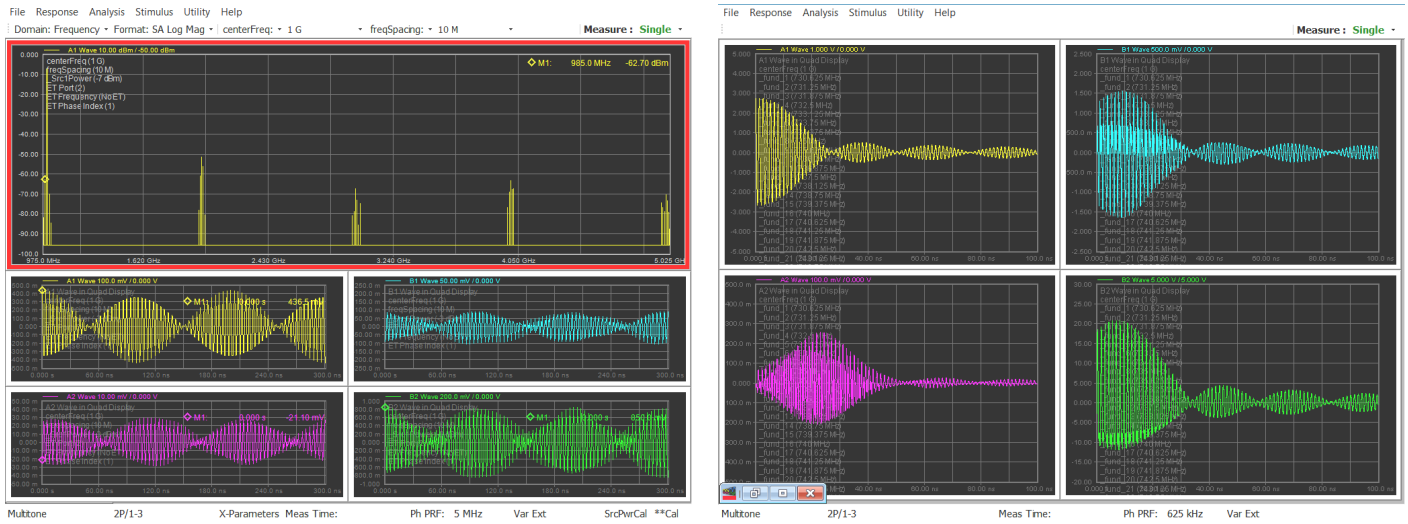
A two-tone signal produces multiple mixing products

A multi-tone signal into an amplifier produces many complex mixing products

Simulate complex modulation signals

Since many system designs operate with complex modulation signals, it is desirable to evaluate components and system designs with complex signals that are similar to these modulation signals. An external arbitrary waveform generator and microwave source can be utilized to generate a desired complex multi-tone signal to stimulate the device.

When a multi-tone signal is applied to a nonlinear device, a variety of mixing products from all the tones appear at the output of the device. The NVNA has the ability to measure the amplitude and phase of each of these mixing products, and characterize the behavior of the device to this complex multi-tone signal. This type of information can provide insight into the behavior of the device or system under complex modulation conditions.



NVNA display showing an input signal with 64 frequency tones spaced 80 kHz apart centered at 2 GHz, and the corresponding composite output waveform from the DUT

Mixer and Converter Measurements

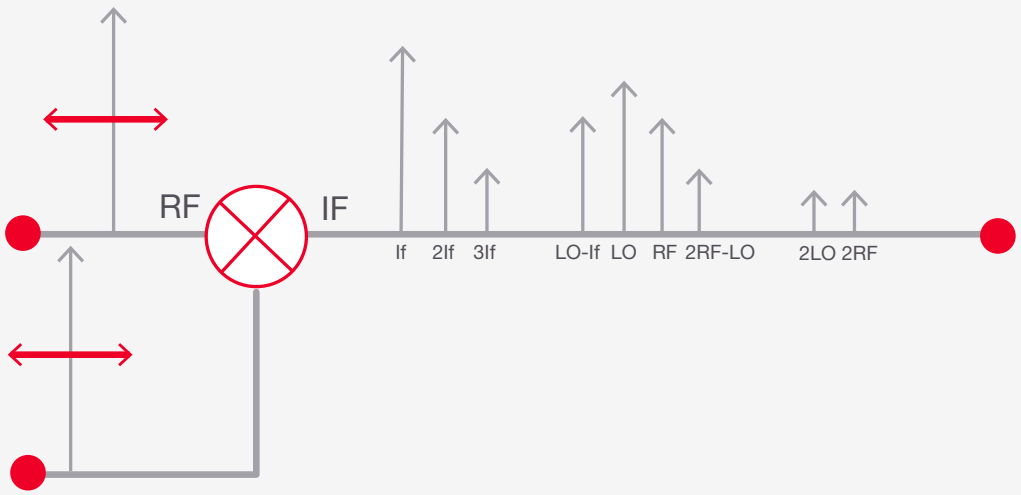
Characterizing three-port devices

The NVNA has the ability to characterize three-port devices such as mixers or downconverters. A drive tone RF signal is provided to the RF port of a mixer, and an LO signal with a different frequency and amplitude is presented to the LO port of the mixer. The RF signal presented to the mixer can be varied in power level to provide a variety of large signal conditions. The NVNA has the ability to measure and characterize the amplitude and phase of all the mixing products on the mixer's RF, LO, and IF ports. This enables characterizing the nonlinear behavior of a three-port device, and extracting a three-port X-parameter file.

With this three-port measurement capability, there is flexibility in characterizing a mixer or converter. The RF and LO frequencies can be swept simultaneously, providing a fixed IF output, or a swept RF and fixed LO can be utilized, providing a swept IF frequency output.

Accurate system design simulation

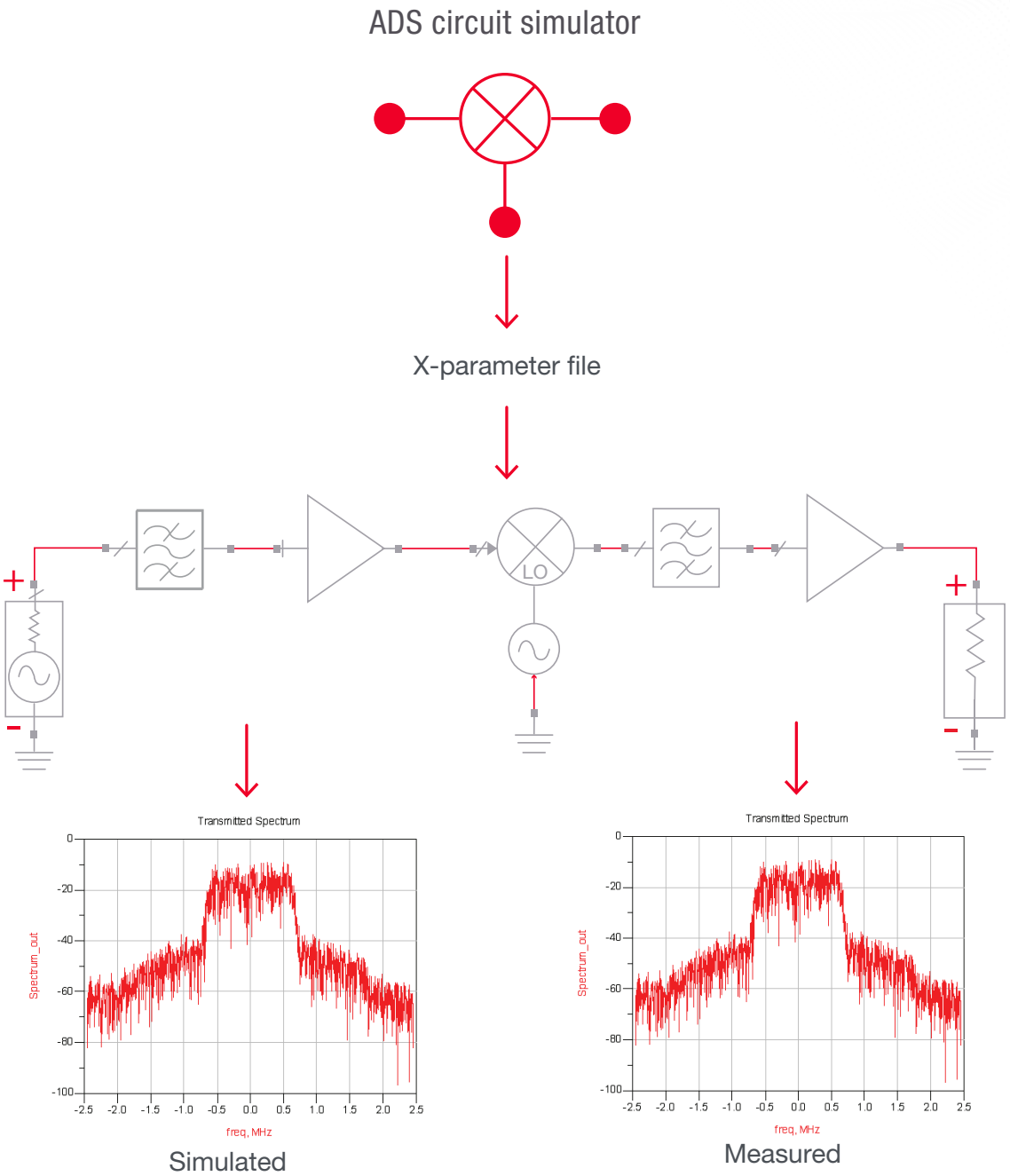
With the capability to measure and extract the nonlinear behavior of a mixer or converter, a three-port X-parameter file can be imported into an ADS design simulator to provide accurate simulations for system designers.



Characterize mixer nonlinear behavior

Three-port X-parameter measurement capability enables:

- Characterizing the nonlinear behavior of mixers and converters
- Accurate three-port X-parameter models that can be imported into ADS simulators
- Cascading both amplifiers and mixers in system designs
- Accurate simulation results for system designs

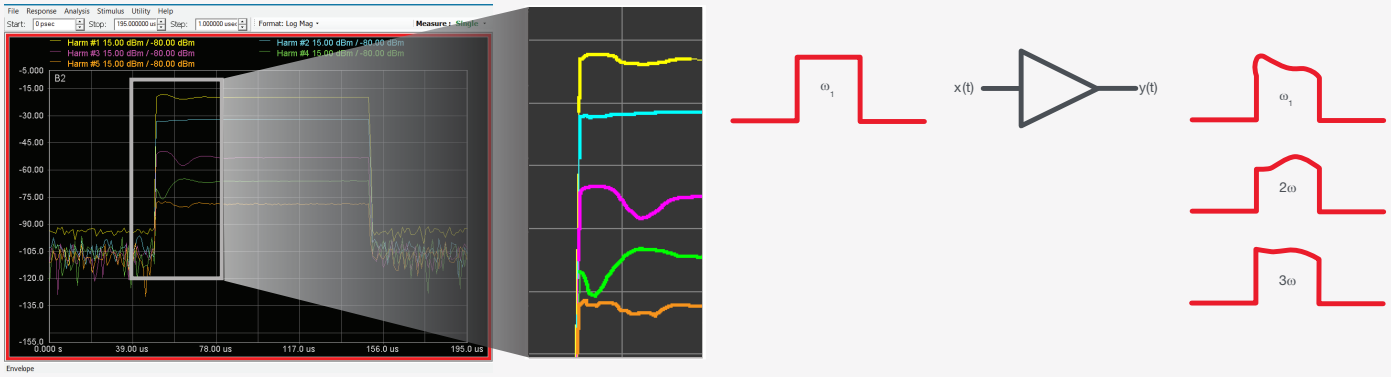


Simulated system performance will closely match measured performance

Explore the Power of Pulse Envelope Domain

Nonlinear pulse envelope domain

Gain key insights into understanding memory effects in active nonlinear devices. Low frequency effects from thermal/heating or contributions from biasing circuits to high frequency effects from frequency limiting matching circuits can complicate analyzing component behaviors. NVNA pulse envelope domain measures the vector corrected amplitude and phase of the fundamental and harmonic pulse envelopes of your DUT. Displayed data indicates how the nonlinear behaviors of your device are changing over time, giving you a powerful tool in analyzing the nonlinear root issues and then validating the design changes.



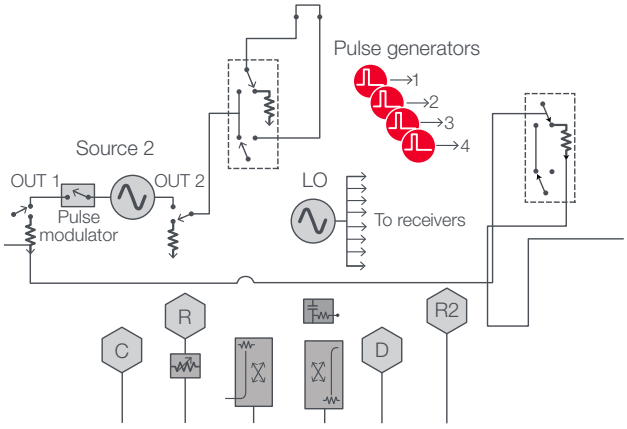
Screen capture

Detailed view

Multiple frequency envelopes with time varying phase and amplitude

Output (b2) multi-envelope waveforms — each harmonic has a unique time varying envelope signature

NVNA takes full advantage of the PNA-X optional internal pulse modulators and generators to provide fast, accurate and easily configured nonlinear pulse envelope domain measurements. This high level of integration greatly simplifies setup while maximizing efficient, accurate measurements.



PNA-X integrated pulse generators and modulators

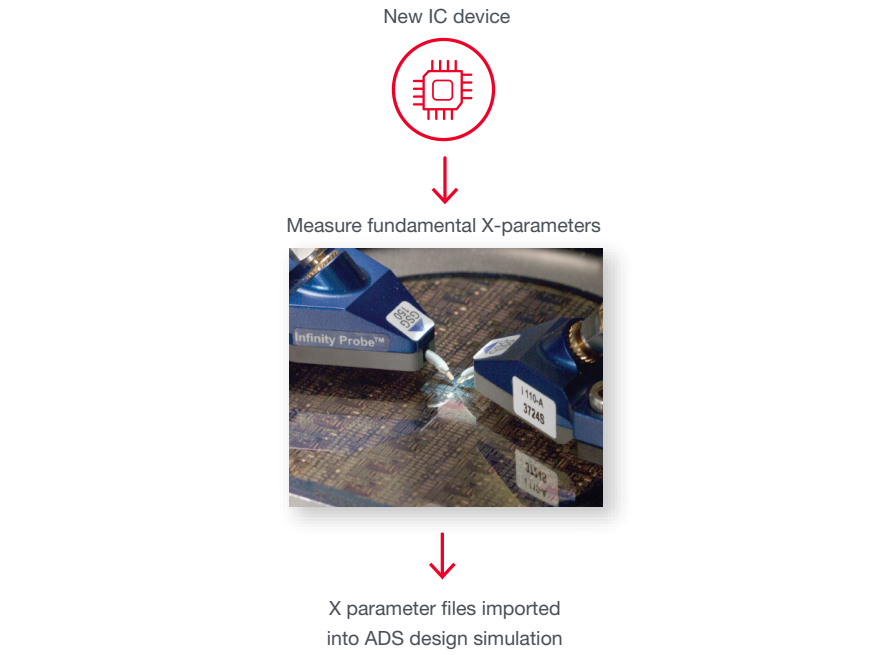
Fundamental Only X-Parameters

Measuring X-parameters at only the fundamental frequency for certain devices, it may be difficult or not important to measure the device's harmonic energy. Many narrowband devices would not have meaningful harmonic responses, and certain high frequency devices may be difficult to measure the device's harmonic energy. For example, a 34-GHz device would need a network analyzer with a frequency range of over 100 GHz to characterize the energy at the third harmonic.

The NVNA has the capability to measure and characterize these types of devices at their fundamental frequencies only, and extract an X-parameter model that includes the device's behavior at a desired large signal operating point, and can also include power level, bias, source, and load dependencies. The fundamental only X-parameter model can be imported into an ADS design simulation, where its associated dependencies can be used in simulation like any other device model.

When the NVNA is used solely as a fundamental only measurement instrument, the calibration and measurement phase references are not required. Thus, lower cost and less complicated measurement systems can be configured.

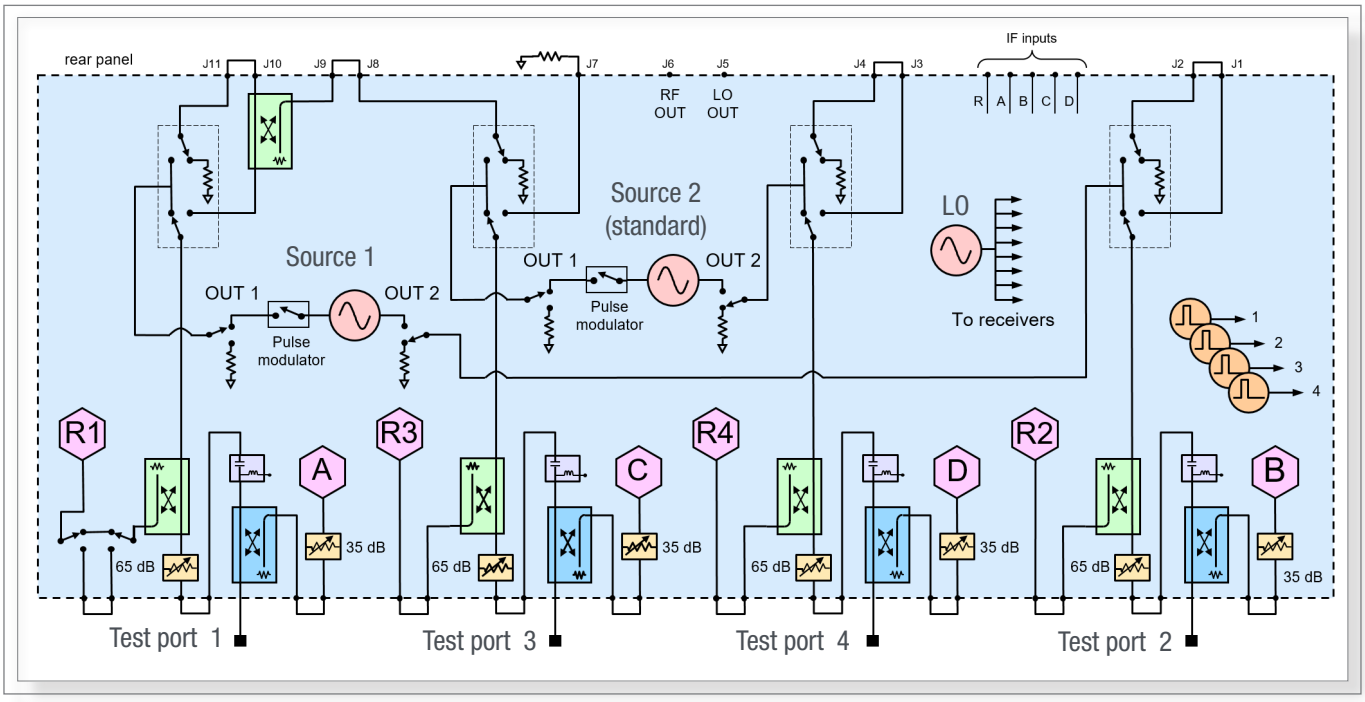
Measure fundamental X-parameters



NVNA: A Highly Integrated Extension of the Premier-Performance PNA-X Microwave Network Analyzer

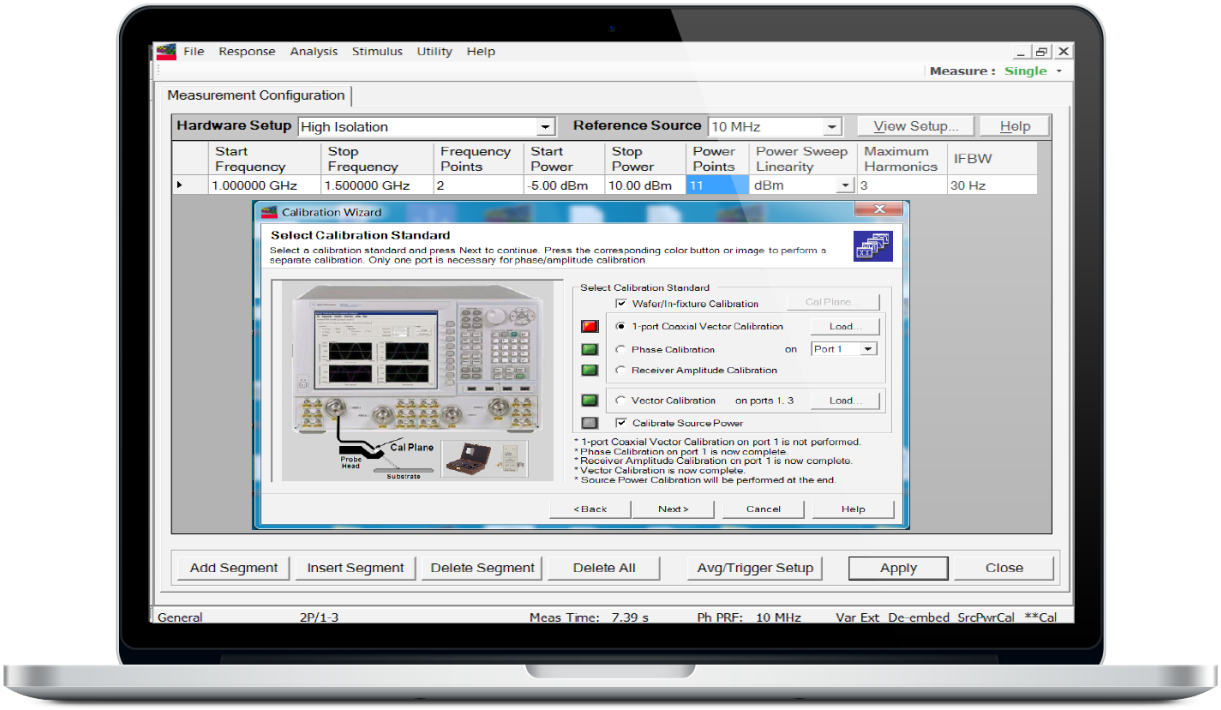
The industry-leading performance and highly integrated configurable nature of the PNA-X make it the ideal solution to address active device measurement challenges. High quality sources with excellent harmonic performance, sensitive and linear receivers, exceptional flexibility and a friendly user interface combine to create a winning combination. The PNA-X with NVNA enables engineers to stay on the leading edge of component design and test.

PNA-X block diagram



NVNA: PNA-X Microwave Network Analyzer

The standard PNA-X is transformed into the NVNA with a minimum of external accessories and the nonlinear firmware options. Core to this transformation is the nonlinear calibration process. Trust in the measured data is as important as the data itself. NVNA's state-of-the-art nonlinear calibration process provides vector calibrated amplitude and phase data traceable to the National Institute of Science and Technology (NIST). A simple three-step calibration process is driven by a graphical calibration wizard to remove any systematic errors and maximize accuracy.



NVNA guided calibration wizard - vector, phase and amplitude calibrations

Phase calibration with Keysight's new performance comb generator

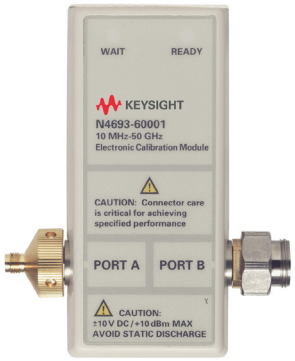
Keysight's U9391C/F/G Comb Generators are used as the NVNA's harmonic phase reference and provides exceptional performance, frequency range and ease of use. The comb generator plays a key role in making calibrated phase measurements at the spectral components of interest and offers:

- Low sensitivity to temperature, input power, and drive frequency
- 10 MHz to 67 GHz frequency range
- Wide dynamic range

U9391F/G comb generator
10 MHz to 50 GHz or 67 GHz

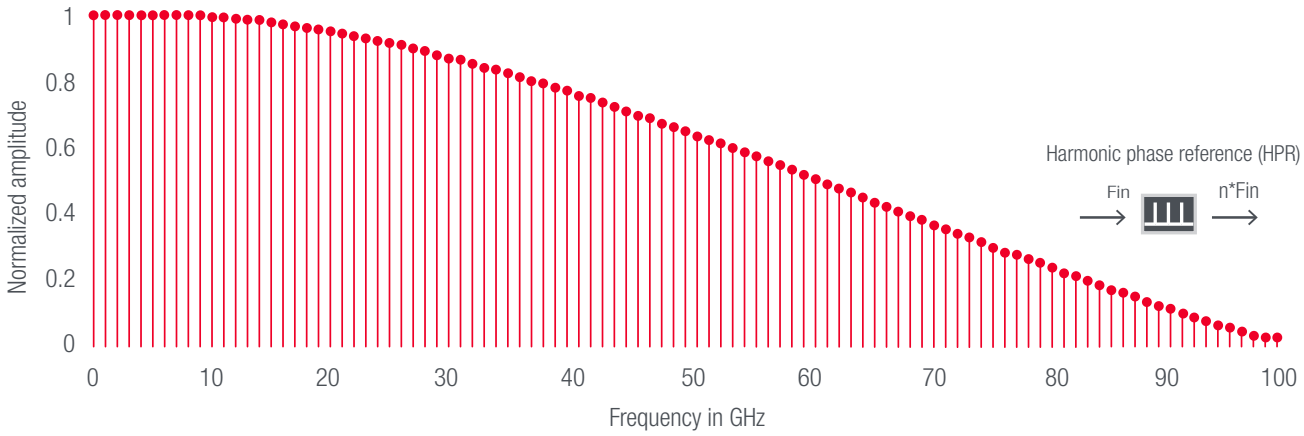
U9391C comb generator
10 MHz to 26.5 GHz

USB power sensor - amplitude calibration with Keysight's power meter or USB sensor



Calibration module - vector calibration with Keysight's standard electronic or mechanical calibration kits

Phase reference output



Phase reference output provides wide frequency coverage with less than 1 MHz tone spacing

Ordering Information

Keysight Nonlinear Vector Network Analyzer (NVNA)

The NVNA is built on the high-performance PNA-X platform. Go to www.keysight.com/find/pna PNA-X Data Sheets for technical specifications.

PNA-X Family of network analyzers
N5249B, 900Hz/10 MHz to 8.5 GHz[11]
N5241B, 900Hz/10 MHz to 13.5 GHz[11]
N5242B, 900Hz/10 MHz to 26.5 GHz[11]
N5244B, 900Hz/10 MHz to 43.5 GHz[11]
N5245B, 900Hz/10 MHz to 50 GHz[11]
N5247B, 900Hz/10 MHz to 67 GHz[11]

Nonlinear vector network analysis[1]	For PNA-X Series	For PNA Series	For PNA-L Series	Additional information
Nonlinear component characterization	S94510B/A[2]	n/a	n/a	Requires test set option 41x or 42x
Nonlinear component characterization	S94511B/A[2]	n/a	n/a	Export-control version. Requires test set option 41x or 42x
Nonlinear X-parameters[3, 4]	S94514B/A[5]	n/a	n/a	Requires test set option 42x and application software S94510B/A or S94511B/A
Nonlinear pulse-envelope domain	S94518B/A	n/a	n/a	Requires hardware option 021 and application software S94510A or S94511A and S93025B or S93026B
Arbitrary load-impedance X-paramters[3, 4, 7]	S94520B/A	n/a	n/a	Requires application software S94514B/A
Arbitrary load-control X-parameters[3, 4, 10]	S94521B/A	n/a	n/a	Requires application software S94520B/A
Arbitrary load-control device characterization[8, 9, 10]	S94522B/A	n/a	n/a	Requires application software S94510B/A or S94511B/A

Ordering Information

Phase Reference Comb Generators[6]	
U9391C	10 MHz to 26.5 GHz Phase reference comb generator
U9391F	10 MHz to 50 GHz Phase reference comb generator
U9391G	10 MHz to 67 GHz Phase reference comb generator (Requires a +15 VDC, 2A)
DC power supply for comb generators: Recommend N6705B with appropriate modules or equivalent. Go to http://literature.cdn.keysight.com/litweb/pdf/5989-7619EN.pdf for the Keysight U9391C/F/G Comb Generators Technical Overview.	
Required Nonlinear Accessories	
Keysight power meter and sensor or USB power sensor Keysight vector calibration standards, mechanical or ECal Optionally an Keysight source such as a MXG or PSG can be used in place of the 10 MHz reference from the PNA-X as the drive signal for the phase reference comb generator if a tone spacing different from 10 MHz is desired.	

1. A fully configured NVNA system requires two comb generators with power supplies, Keysight calibration kits (mechanical or Ecal), and a power meter and sensor or USB power sensor.
2. Pulse capability requires option 021 and S93025B or S93026B.
3. Requires EXG, MXG, or PSG signal generator for X-parameter extraction (the PNA-X's 10 MHz reference output can be used for 10 MHz tone-spacing applications).
4. X-parameters is a trademark and registered trademark of Keysight Technologies in the U.S., Europe, Japan, and elsewhere. The X-parameters format and underlying equations are open and documented. For more information, visit www.keysight.com/find/eesof-x-parameters-info.
5. Pulse capability requires option 021, 022 and S93025B or S93026B.
6. Two phase reference comb generators are required for nonlinear measurements; fundamental only X-parameters measurements do not require phase reference comb generators.
7. Requires additional load control application: Keysight S94521B/A or Maury Microwave or Focus Microwave applications.
8. Currently CW stimulus only
9. Use of this application will generally require external sources, couplers attenuators, wafer probe station and more to complete system configuration. Please work with your local Keysight application engineer for details.
10. Requires Win 7 OS or above.
11. The lowest frequency of the NVNA application is limited to 10 MHz even with the low frequency extension (LFE) option to 900 Hz.

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