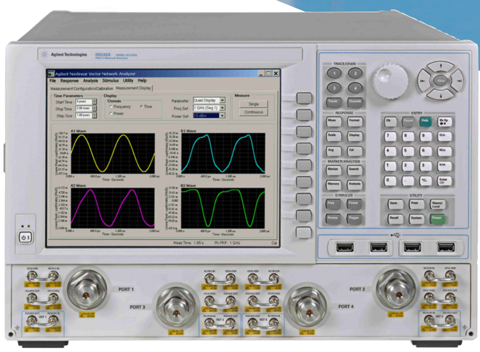
Solutions for

Characterizing High-Power Devices

Using X-Parameters to Make Nonlinear Measurements of High-Power Amplifiers

Application Note



The PNA-X network analyzer, with NVNA software, can be used to measure the linear and nonlinear behavior of high-power components.

Overview

High-power devices are common building blocks in RF and microwave communication systems. One such device, the high-power amplifier, plays an especially critical role in today's mobile phones, base stations for cellular and mobile wireless infrastructure and satellite communication systems. In the base station market, for example, high power amplifiers approaching 100 watts are typical. To obtain the most power from these devices, engineers are forced to push them to their limit, often driving them into the nonlinear region of operation. Such nonlinear behavior can be problematic to the amplifier and is typically a contributing factor in wasted frequency spectrum in communication applications. Accurately characterizing and understanding this behavior is critical to enabling today's engineer to design and verify efficient high-power devices like amplifiers.

Problem

Testing a high-power amplifier is no easy task, requiring that the engineer measure the component's linear and nonlinear behavior using a high-power test system. With no such test system available today, this poses quite a challenge. Perhaps even more challenging is dealing with the component's nonlinear behavior. Typically, engineers make a set of constrained linear measurements at high power levels and then just assume the amplifier is linear, all the while hoping it isn't so nonlinear that their assumption will create a problem. In an ideal world, the engineer would measure the amplifier and then use the results in a simulator to determine the amplifier's performance when connected to other devices. But, if the amplifier's nonlinear behavior is measured using a linear assumption, then the result of the simulation will be wrong. While engineers may live with this inaccuracy, it invariably results in extensive and costly empirical-based iterations of the design, adding substantial time and cost to the design and verification process. Testing today's high-power devices demands an alternate solution—one that quickly and accurately characterizes the device's nonlinear behavior and that is capable of dealing with its high power level.

Solution

The linear and nonlinear behavior of devices like high-power amplifiers can now be quickly and accurately measured using X-parameters* and a network analyzer that has been modified with external components to create a high-power test setup. X-parameters represent a new category of nonlinear network parameters for deterministic, high-frequency design and are used to characterize a components' nonlinear behavior. They are measured using a network analyzer and are used to create X-parameter models that can be imported into a simulator for design verification.

Because network analyzers don't typically operate above 100 milliwatts, they must be modified in order to measure the nonlinear behavior of high-power devices and to deal with the high power levels of such a measurement.

Some of the key reasons for modifying the network analyzer include:

- Stimulus and extraction-tone sources may need to provide more power than it can supply;
- its inputs may need to be protected from costly damage due to high power (e.g., pushing the instrument beyond its maximum input power limits);
- receiver levels may need to be attenuated to avoid compression effects; and
- the device under test (DUT) may require special load characteristics to avoid oscillation.

The external components that can be added to the network analyzer to avoid these issues include: attenuators, couplers, isolators, tuners, and pre-amplifiers.

Attenuators and couplers can be used to improve the network analyzer's power handling capability, while pre-amplifiers are used when the DUT requires more input power than the network analyzer's maximum output levels. Of course, adding any external component to the network analyzer setup may compromise its performance (e.g., measurement noise and calibration drift may increase, and the calibration procedure may become more complicated). Careful consideration must therefore be taken when selecting an external component for the high-power test configuration. Additionally, the engineer must know the network analyzer's power limitations and path losses.

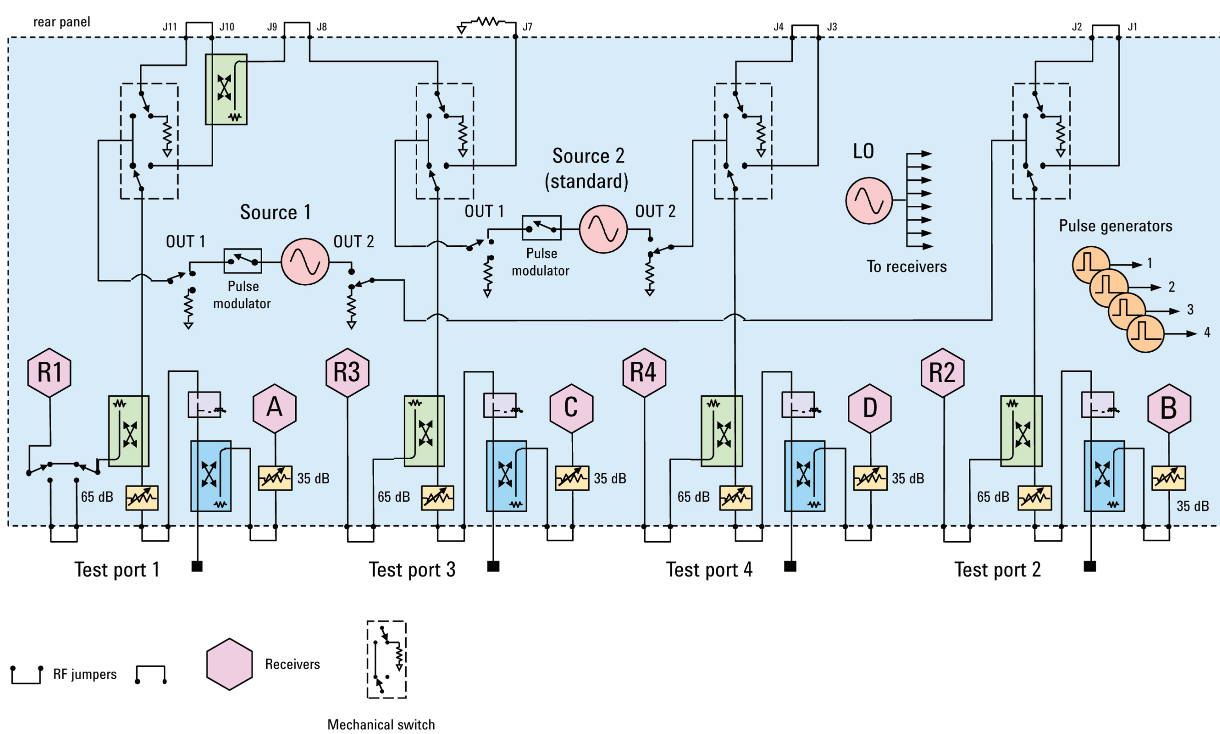


FIGURE 1: *Block diagram of the PNA-X N5242A Option 423 RF test set.*

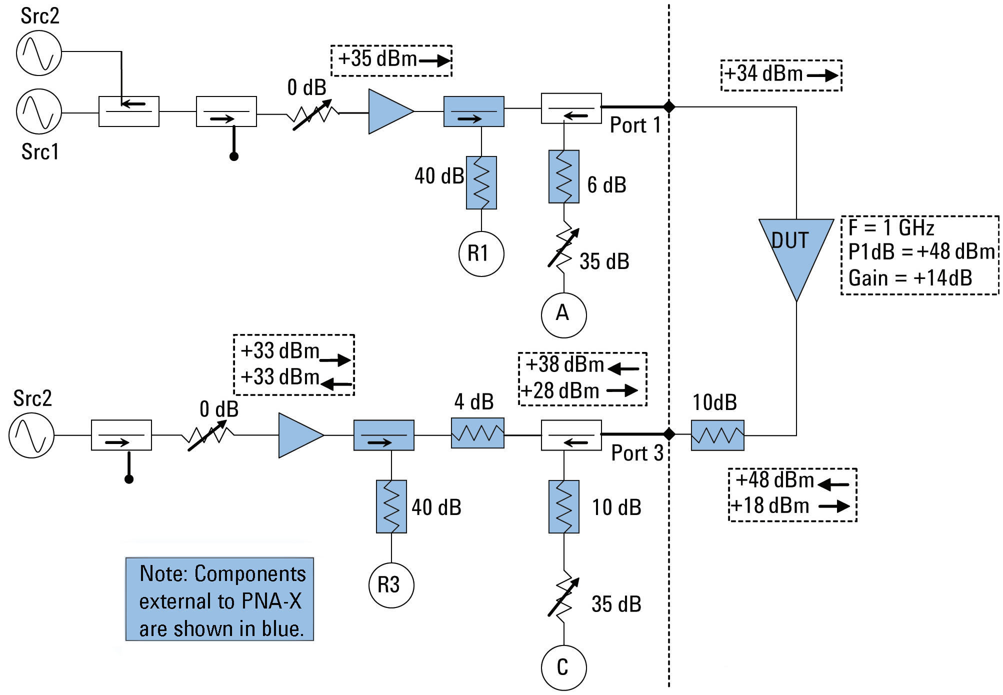


FIGURE 2: *Block diagram modifications for testing +48 dBm amplifier.*

Making Nonlinear Measurements

The Agilent PNA-X Series network analyzer is a modern vector network analyzer that can be easily modified to quickly and accurately characterize the linear and nonlinear performance of high-power amplifiers from 10 MHz to 50 GHz. X-parameters are measured using Agilent's Nonlinear Vector Network Analyzer (NVNA) software running on the PNA-X. The resulting X-parameter models can be imported into Agilent's Advanced Design System (ADS) simulator where it can be used to simulate actual linear and nonlinear component behavior.

Figure 1 shows a block diagram of a PNA-X which identifies the RF test set components. These components include: four ports, two independent RF sources, source attenuators, receiver attenuators, bias tees, internal combiner, and mechanical port switches. When the DUT requires more input power than the PNA-X's maximum output levels, external pre-amplifiers must be added. External attenuators and couplers are added when the power levels of the DUT test setup exceed the damage levels of the PNA-X.

Example: +48 dBm Power Amplifier

Using the PNA-X network analyzer running the NVNA software to measure a high-power component's X-parameters is a fairly straightforward process. As an example, consider an amplifier with a 1-GHz frequency, 14-dB gain and a maximum output power of +48 dBm. The high-power test set used to measure this amplifier is shown in Figure 2. It requires two pre-amplifiers, two high-power couplers and six attenuators. By ordering special option H85, the PNA-X's bias tees have been removed, so the test port couplers may be operated at higher power levels.

The components used in this modified PNA-X test set were chosen with the following constraints in mind:

- Two PNA-X reference couplers were replaced with external high-power couplers having a damage level of +43 dBm (similar to the test port couplers).
- Attenuation levels were set in the A, C, R1 and R3 receiver paths to minimize distortion by ensuring receiver operation below -20 dBm.
- Port 1 output power was boosted by a +35-dBm pre-amplifier.
- A high-power 10-dB attenuator is added between the DUT output and PNA-X Port 3 to protect the test port coupler.
- A pre-amplifier with +33-dBm output power was added to PNA-X port 3.
- A 4-dB attenuator (able to withstand + 39 dBm) was added between the PNA-X Port 3 couplers to protect the pre-amplifier from over power.
- A 10-dB attenuator (able to withstand +49 dBm) was added between the DUT output and PNA-X Port 3 test coupler to protect the test coupler from over-power.
- The extraction tone at PNA-X Port 3 is +18 dBm (assuming that the couplers have 0.5-dB loss each at 1 GHz). This tone is 30 dB below the main tone level (+48 dBm) and should be sufficiently large.

Helpful Measurement Tips

When making high-power amplifier measurements, there are a number of things the engineer needs to keep in mind. First is calibration—a crucial factor in ensuring the accuracy and repeatability of any measurement. Calibrating a high-power test set can pose a number of complications that the engineer must be aware of. For example, pre-amplifiers added to the test set may compress or damage the calibration standards, while attenuators added to improve power handling capability may result in a noisy calibration.

While it may be advantageous to calibrate the test system without any pre-amplifiers, doing so may result in a noisy calibration. With the PNA-X, pre-amplifiers can be added after a complete NVNA calibration—assuming they are located between the RF source and reference coupler. If the test setup includes tuners located between the DUT and the PNA-X test ports, the NVNA calibration (consisting of vector, phase and power calibration) must be performed without the tuners in place. External software can be used to characterize the tuners, de-embed the results and perform automated load-pull measurements.

Secondarily, engineers must use caution to avoid damaging the network analyzer, test components and the DUT. Some important things to watch out for include:

- The DC damage level of some ports is 0 V.
- The RF power applied to the ports should be at least 3 dB below the RF damage levels of those ports and ideally, 6 dB lower.
- When calculating power levels at a given point in the test setup, first determine the worst-case levels by assuming that signals add as voltages rather than as powers.
- The DUT and pre-amplifiers may have specific input and output load match requirements which must be met before being powered-up to avoid oscillation or damage. Beware of open-circuit conditions.
- The DUT and pre-amplifiers may be sensitive to power-on sequencing. Know the pre-amplifier and DUT requirements before turning on the system.
- Beware presetting the network analyzer. If there are high-power parts in the test set, presetting may preset to some level that will destroy the parts.

Summary of Results

With active components continuing to be driven into nonlinear operation, the need for fast and accurate measurement of that nonlinear behavior becomes all the more urgent. As a logical extension of S-parameters to include nonlinear effects, accurate and robust X-parameters represent the ideal solution to this dilemma. Whether created from measurement or ADS simulation, they offer speed and convenience analogous to the well-known linear S-parameters. Resulting X-parameter-based behavioral models can be quickly and easily dropped into simulation and used to deterministically design the most robust components and systems in the shortest amount of time and with the highest degree of accuracy.

For more information on X-parameters refer to the following Agilent application notes: Solutions for Securing Successful First-pass Component Design and High Power Amplifier Measurements Using Agilent's Nonlinear Vector Network Analyzer

The Power of X

The Agilent PNA-X Microwave Network Analyzer with the NVNA software and X-parameters are key products in Agilent's comprehensive Power of X suite of products. These products grant engineers the power to gain greater design insight, speed manufacturing processes, solve tough measurement problems, and get to market ahead of the competition.

Offering the best combination of speed and scalability, and created and supported by renowned worldwide measurement experts, Agilent's X products are helping engineers bring innovative, higher performing products to emerging markets around the globe.

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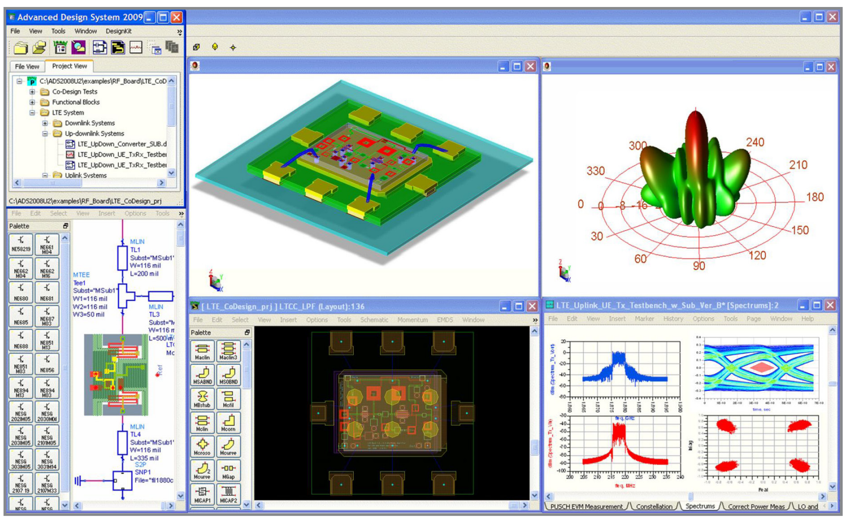

W2200 ADS Core

* X-parameters is a registered trademark of Agilent Technologies. The X-parameter format and underlying equations are open and documented. For more information, visit **http://www.agilent.com/find/eesof-x-parameters-info**

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