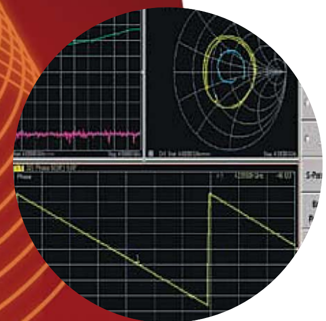
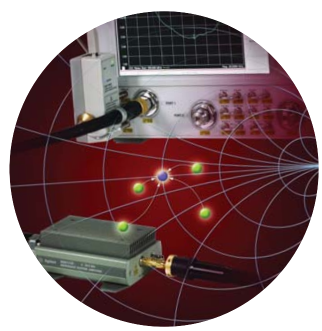




Agilent PNA-X Series

The premier-performance microwave network analyzers

- Single connection, multiple measurements
- 10 MHz to 13.5/26.5/43.5/50 GHz
- 2- and 4-ports
- Two built-in high-performance signal sources
- One-box pulsed-RF test solutions
- Internal combiner and mechanical switches
- Advanced calibration technology
- 10.4-inch touch screen

Agilent Technologies

Welcome to the World of PNA-X

The premier-performance microwave network analyzers

The PNA-X offers breakthrough speed, accuracy, performance, and multi-function capabilities compared to traditional microwave network analyzers. Rather than just a pure network analyzer, the PNA-X is also a platform or test system. Adding options to the platform provides the user with functionality that in the past required a combination of standalone signal sources, a spectrum analyzer and a noise figure analyzer.

With the PNA-X, single-connection, multiple-measurements are easy. Following calibration and connection of the DUT to the PNA-X, users can measure nearly all of the necessary parameters of the DUT. For amplifiers, for example, input and output match gain, harmonics, 1 dB compression points, AM-to-PM conversion, third-order intercept (TOI), and noise figure can all be measured simultaneously. The PNA-X Series is designed for measurements of active components, such as power amplifiers, low-noise amplifiers, mixers, converters, T/R modules, and antennas.

New applications/measurement functions

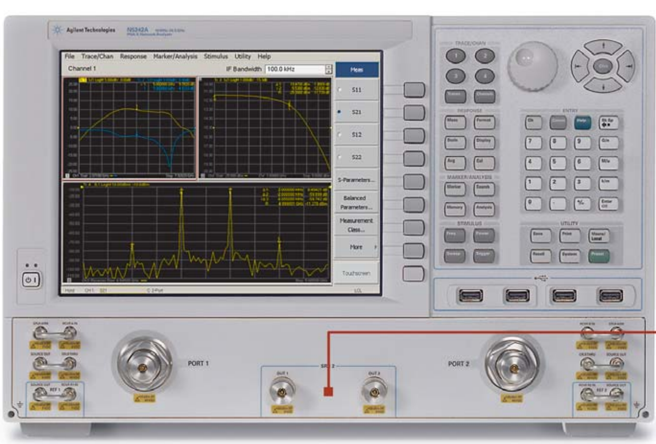
- **Noise figure measurements:** Source-corrected measurements with the highest accuracy in the industry
- **Nonlinear X-parameter measurements:** Breakthrough technology to analyze nonlinear behaviors of active devices
- **Embedded-LO converter measurements:** Accurately measure relative phase and absolute group delay
- **Gain compression measurements:** Measure linear and compression gain, input and output powers at compression, and deviation from linear phase across frequency
- **Pulsed-RF measurements:** The world's first one-box pulsed-RF network analyzer with internal pulse modulators and pulse signal generators
- **True differential measurements:** Provide true-differential stimulation for balanced components
- **Scalar mixer measurements:** Transfer the accuracy of a power meter to conversion gain/loss measurements
- **Vector mixer measurements:** Enables the measurement of absolute group delay for mixers and converters
- **Intermodulation and harmonic distortion measurements:** Make swept distortion measurements versus frequency or power, without external components

The PNA-X covers all existing applications of the PNA/PNA-L, up to 50 GHz

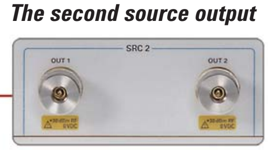
The latest calibration technology

- **QSOLT (Quick SOLT) calibration:** Improve efficiency by significantly reducing the number of calibration standards required for multiport setups
- **Enhanced frequency-response calibration:** Simplify calibration for high-power amplifier measurements

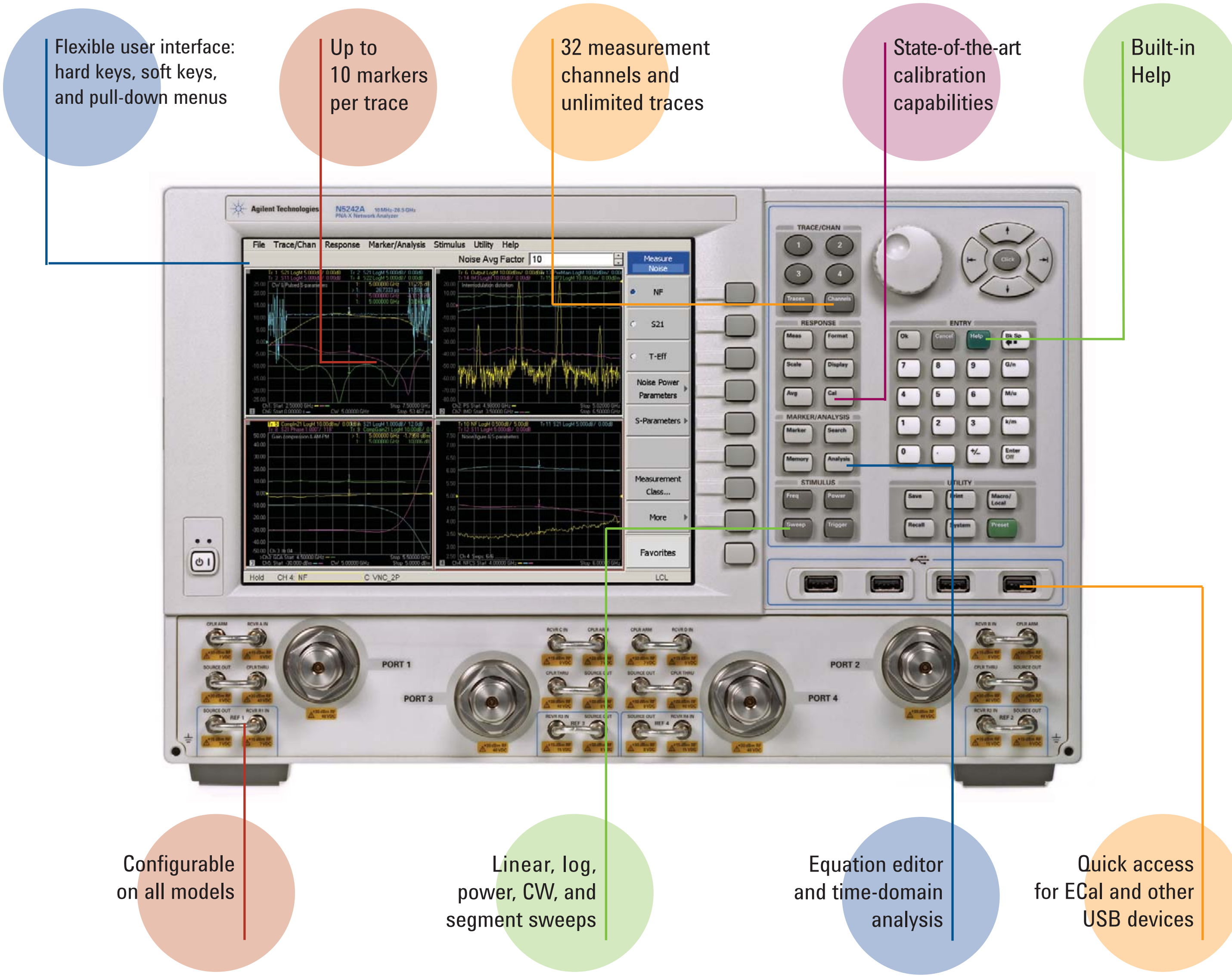
The PNA-X covers all calibration technologies of the PNA/PNA-L, up to 50 GHz



The second source output



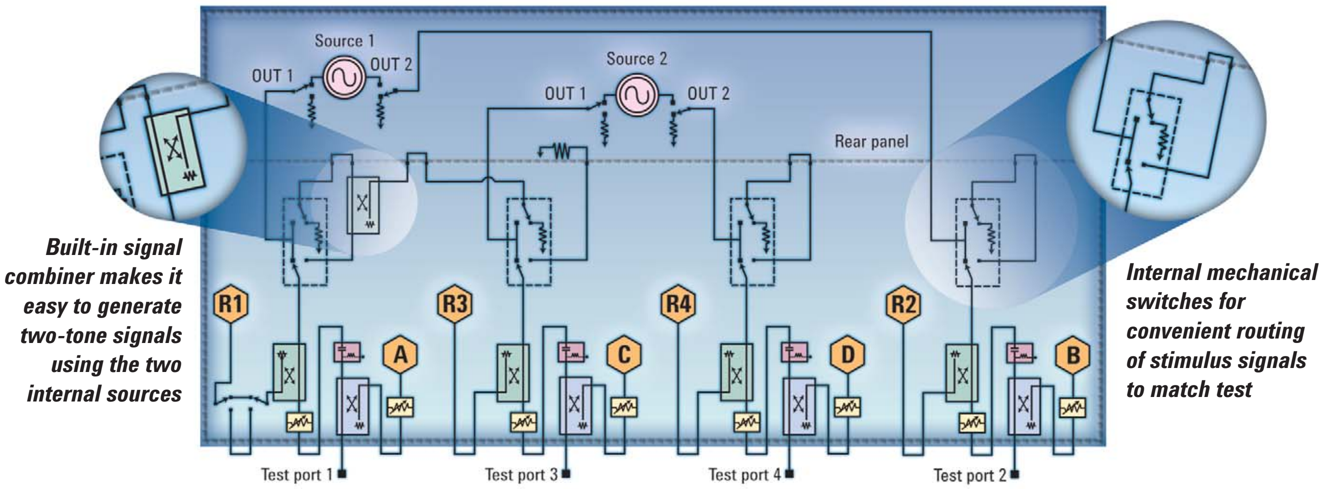
Intuitive Operation Makes Complex Measurements Quickly



The PNA-X integrates a 10.4-inch high-resolution display with a touch screen, which provides a crisp view and easy access to all data and traces. This enhanced user interface allows intuitive operation and helps you set up complex measurements quickly.

The Premier-Performance Microwave Network Analyzers

The industry-leading performance and highly integrated configurable nature of the PNA-X make it the ideal solution to address active device measurement challenges.
The PNA-X enables engineers to stay on the leading edge of component testing.



PNA-X block diagram (shown with Options 400, 419, and 423).

High-performance sources

- 10 MHz to 13.5/26.5/43.5/50 GHz
- Internal second source for intermodulation distortion measurements, hot-S_{22}, and high-speed swept-LO measurements
- Output power up to +22 dBm and power sweep range of 48 dB
- Excellent harmonic performance (≤ -60 dBc) for accurate harmonic distortion and intermodulation distortion (IMD) measurements

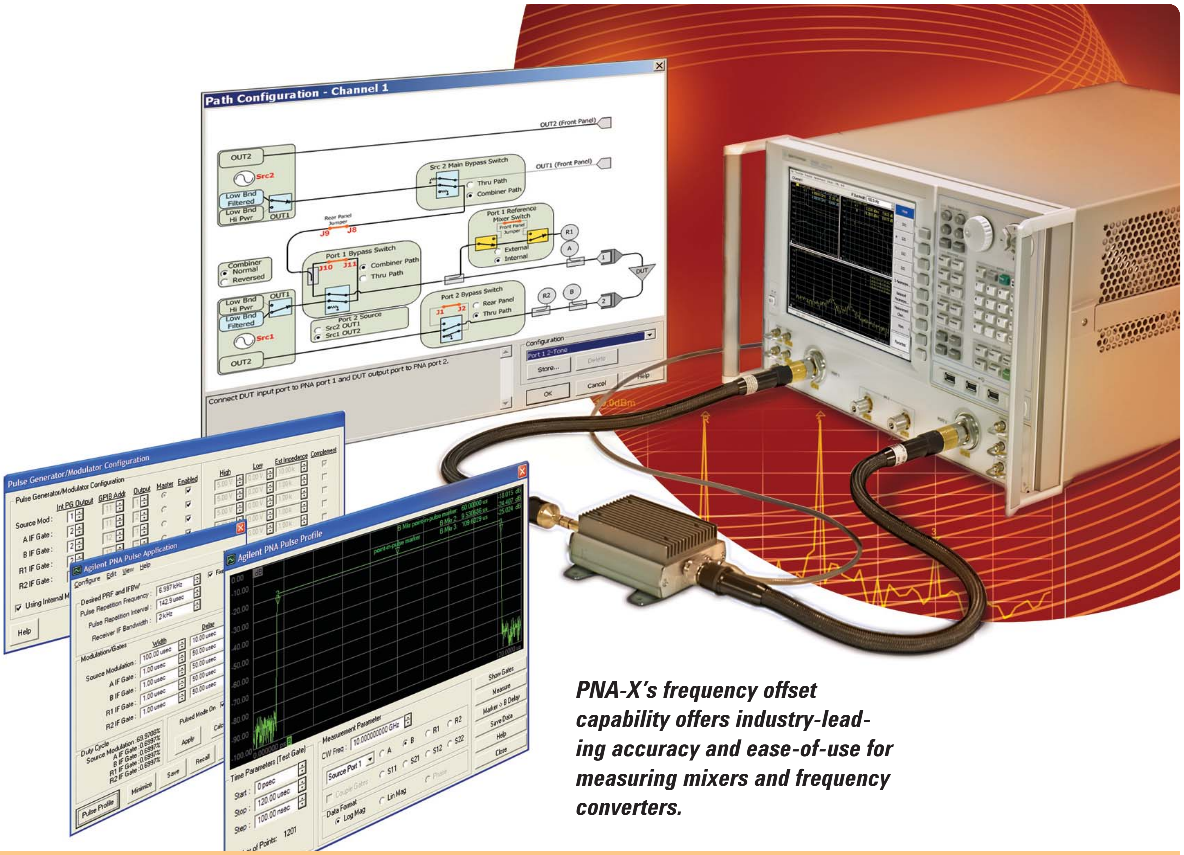
Sensitive and linear receivers

- Receivers with 0.1 dB compression points at +13 dBm, for higher dynamic accuracy
- Higher sensitivity for pulsed S-parameter measurements compared to the PNA
- Low noise floor of -130 dBm at 10 Hz IFBW
- Standard configuration includes 5 MHz IF bandwidth for measurement of narrow pulses (down to 250 ns)

Exceptional flexibility

- Built-in signal combiner for easy IMD and hot-S_{22} measurements
- Built-in pulse modulators and pulse generators for convenient measurements of pulsed S-parameters
- Internal mechanical switches enable flexible signal routing for single-connection, multiple-measurements – external filters, amplifiers and test equipment (e.g., signal source and spectrum analyzer) can be added as needed
- Noise figure measurement capability up to 26.5 GHz extends the suite of measurements available with a single connection, and offers industry's highest accuracy
- Front-panel jumpers offer direct access to internal directional couplers and receivers
- Source and receiver attenuators with 5 dB increments for better measurement optimization
- Built-in bias-tees simplify amplifier evaluations
- Three sets of triggers on rear panel enable easy instrument synchronization in complex systems

The Industry's First One-Box Pulsed-RF Test Solution



PNA-X's frequency offset capability offers industry-leading accuracy and ease-of-use for measuring mixers and frequency converters.

Features of PNA-X pulsed-RF test solutions

- Built-in bi-directional pulse modulation and four-channel pulse generator
- 5 MHz IF bandwidth for measurements with narrow pulses (≥ 250 ns) in wideband mode and 133 ns time resolution for pulse profile measurements
- Narrowband mode provides stimulus to ≥ 33 ns (20 ns typical), and 33 ns (20 ns typical) time resolution for pulse profile measurements
- Integrated pulse solution for point-in-pulse, pulse profile and average pulse measurements in wideband or narrowband modes. Pulse-to-pulse measurements available in wideband mode.
- Dramatic dynamic range increase in narrowband mode, compared to PNA, thanks to a combination of crystal filters, hardware gating, and Agilent's patented spectral-nulling and software-gating technology
- Free, wideband-mode application program simplifies pulsed-RF measurement set up, significantly improving test efficiency
- PNA-X can be synchronized with external pulse modulators and pulse generators for applications requiring complex timing
- Pulsed-RF capability is available for use in far-field antenna-measurement systems
- Pulsed-RF capability is available for use with PNA-X-based millimeter-wave systems
- Full 2-port and enhanced-response calibrations available in pulsed mode

Industry challenges for pulse test

With the rapid development of radar technology and applications, there is a growing need for much narrower pulsed-RF signals.

When using wideband pulse detection (resulting in the fastest measurements), the narrower the pulse, the wider the required IF bandwidth. Therefore, the minimum pulse width that can be measured by the network analyzer is limited by its IF bandwidth. For traditional network analyzers, the IF bandwidth is below several tens or hundreds of kHz—far from satisfying industry needs. By expanding its IF bandwidth the 5 MHz, the PNA-X can make pulsed S-parameter measurements in wideband mode with narrow pulses (pulse width ≥ 250 ns). Bandwidths beyond this are not practical, since the receiver noise floor increases with larger IF bandwidths, resulting in reduced signal-to-noise ratio and lower measurement accuracy.

Narrowband detection uses a narrow IF filter to eliminate unwanted pulse spectral lines, leaving only the central spectral line (see Agilent Application Note 1408-12 for more information). Adopting this technology, the pulse width is not limited, but measurement dynamic range is greatly decreased at low pulse duty cycles. Without advanced signal processing, this dynamic range loss is related to duty cycle by:

Dynamic Range Loss (dB) = -20*Log (Pulse Duty Cycle)

For every factor of 10 decrease in duty cycle, the dynamic range is reduced by 20 dB. While some improvement in dynamic range can be achieved by further narrowing the IF bandwidth, measurement speed is slowed as a result and measurement efficiency is reduced. To address these problems, the PNA-X applies many innovative and patented technologies to improve measurement accuracy and speed.

Innovative and patented technologies for narrowband pulsed-RF test

Patented technology: Spectral nulling

Most narrowband technology applies extremely narrow IF filters. To reject the unwanted pulsed spectrum lines, the filter width is typically set to between 0.1% and 1% of the pulse-repetition frequency (PRF). The rejection is about 70 to 80 dB. However, extremely narrow filters significantly reduce the measurement speed. The PNA-X applies patented spectral-nulling technology to optimize these limiting factors (see Figure 1).

In Figure 1, the blue curve represents the 500 Hz IF filter frequency response, while the red lines represent the pulse spectrum with a 1.7 kHz PRF. The red dotted lines correspond to unwanted pulse spectral components, while the red solid line is the wanted center spectrum line. With proper selection of the PNA-X's filter bandwidth, the nulls of the IF filter align with the undesired spectral lines, leaving only the desired center signal. In the example shown, the PNA-X is actually using every third null of the filter to filter out unwanted pulse spectral lines with more than 120 dB of rejection.

Using spectral nulling in this example, the IF bandwidth is 29.4% of the PRF. Using traditional IF filter technology, the IF bandwidth would need to be 1% (or smaller) of the PRF, or less than 17 Hz, resulting in very slow measurements. The PNA-X therefore, with its patented spectral-nulling technology, delivers increased measurement speed as well as better measurement accuracy.

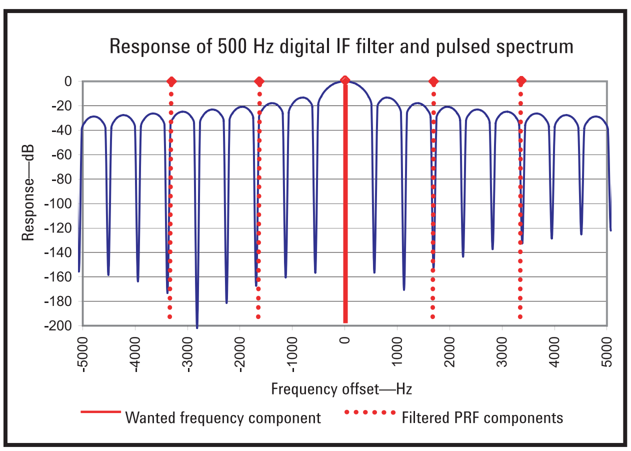


Figure 1. Spectral nulling

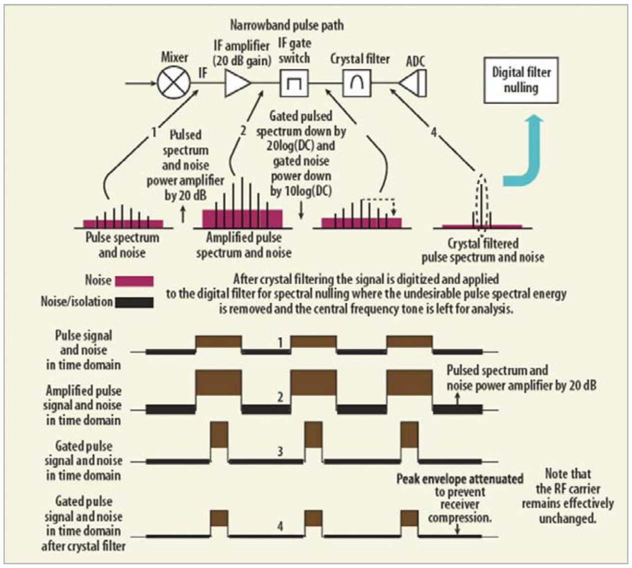


Figure 2. Unique narrowband signal processing technology

Technology innovation: unique narrowband signal processing technology

One disadvantage of traditional narrowband detection is that it is limited by the duty cycle of the stimulus. For every factor of 10 decrease in duty cycle, dynamic range is reduced by 20 dB. With a .001% duty, for example, the corresponding degradation in dynamic range is 100 dB, according to -20*log(0.001%). Agilent's solution to this limitation is to employ unique narrow-band signal processing technology in the PNA-X Series (see Figure 2).

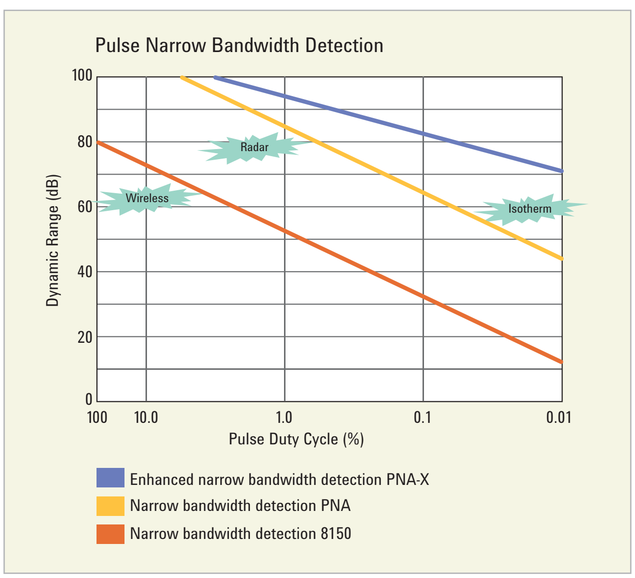


Figure 3. Narrowband detection performance comparison

Figure 3 presents a visual comparison of the PNA-X and other traditional solutions. The improvement in dynamic range versus duty cycle for the PNA-X is readily apparent, compared to older 8510 or PNA-based solutions.

Patented technology: receiver software gate technology

Advances in receiver gate technology are a result of Agilent's unique innovation—the PNA-X hardware gating as shown in Figure 4. Hardware gating is required for point-in-pulse measurements, but it cannot eliminate the noise and crosstalk outside the gate.

The PNA-X also utilizes Agilent's patented software gate technology. After passing through the hardware gate, the IF signals are digitized and passed through a software gate, as shown in Figure 5. The software gate reduces the noise and crosstalk signals outside the hardware gate, thereby approaching ideal noise and isolation conditions. This technique substantially increases measurement sensitivity.

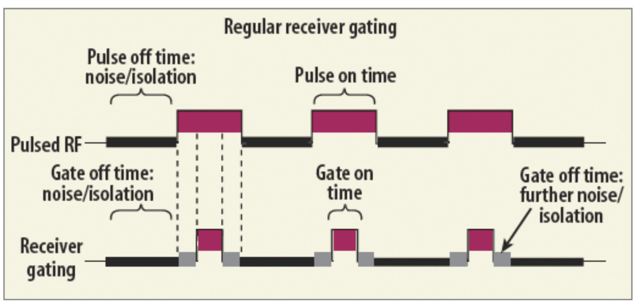


Figure 4. Regular receiver gate technology

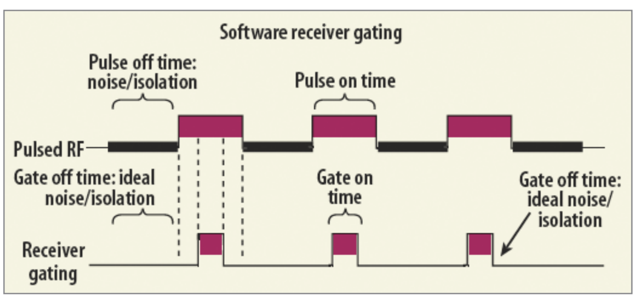


Figure 5. Software receiver gate technology

Pulse performance: PNA-X versus PNA

While the PNA is an industry-proven standard for meeting the challenges in pulse test, the PNA-X moves pulse test to a higher level by combining the enhanced hardware and software gate technologies. Figure 6 shows a comparison of the PNA-X and PNA with a real measurement when the duty cycle is 0.001%. Compared to the PNA, the noise floor of the PNA-X decreases by 20 dB due to the advanced IF hardware. It decreases by an additional 20 dB due to software gating, for a total improvement of 40 dB. The PNA-X's measured dynamic range is still 60 dB, even when the pulse duty cycle is 0.001%.

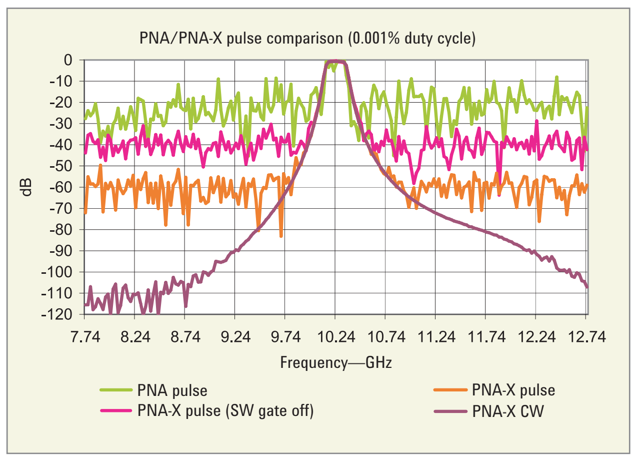


Figure 6. Pulse performance comparison of the PNA-X and PNA

Mixer/Converter Solutions with Advanced Calibration Technology

Features of PNA-X mixer/converter measurement solutions

- Second internal source eliminates the need for an external signal source to generate LO signals
- Up to 35 times faster than using an external source for swept-LO/fixed-IF applications
- Absolute group delay and phase measurements
- Conversion loss/gain measurements
- Input match, output match and LO match measurements
- IMD measurements for frequency-conversion components
- LO power calibration
- Output power of internal source up to +20 dBm
- Industry's best solution for absolute group delay measurements of embedded-LO conversion components
- Advanced, patented calibration technology
  - Vector Mixer Calibration (VMC) for the most accurate measurements of absolute group delay
  - Scalar Mixer Calibration (SMC) for power-meter-corrected measurements of conversion loss/gain
  - Both techniques feature input and output match correction for transmission measurements, greatly reducing ripple while increasing measurement accuracy

Industry challenges for frequency-conversion component test

Mixer and conversion devices lay at the heart of radar, satellite and wireless communication systems. With the rapid development of signal format diversification and complex modulation, requirements on the frequency response and phase linearity of these conversion devices are increasing. The two most important factors are in-band conversion-loss flatness and group-delay flatness.

Measuring frequency-conversion devices is a challenge in the RF industry, especially for group delay measurements. The technology challenges include:

1. **How do you eliminate** the ripple in conversion-loss measurements caused by port-match errors? The traditional method is to measure the conversion loss by using the source and receiver power calibration function of the network analyzer. Because this technique does not correct for port-match errors, attenuators are added at the test port to optimize matching.

2. **How do you measure** the absolute group delay of frequency-conversion devices? Two common approaches are the three-mixer technique and modulation technique, both of which have limitations. With the three-mixer technique, the match error between the two mixers cannot be eliminated, in turn affecting the measurement accuracy. Also, a filter is needed to eliminate the unwanted mixed frequency between the two mixers, so that filter's effect must be removed. In addition, one of the three mixers should be reciprocal. One problem with the modulation technique is that its measurement accuracy is limited to 5 to 10 ns, typically.

3. **The LO of many receivers** used in satellite and radar systems is internal and cannot be connected to an external clock. The frequency of the LO in these devices is a function of time and temperature, often resulting in unusable group delay measurements since the LO frequency drifts during the course of the measurement.

PNA-X solutions are designed for frequency-conversion devices

Scalar Mixer Calibration (SMC)

Agilent's SMC combines two-port calibration and power calibration to address the first technical problem mentioned above. First, a source power calibration is made with a power meter to ensure that accurate power is coming out of the test cable connected to the network analyzer. The calibrated source is then used to calibrate the analyzer's measurement receivers. Next, a two-port calibration is done to measure the other systematic errors that affect reflection and transmission measurements. Specifically, mismatch errors are removed during conversion loss/gain measurements, resulting in decreased ripple.

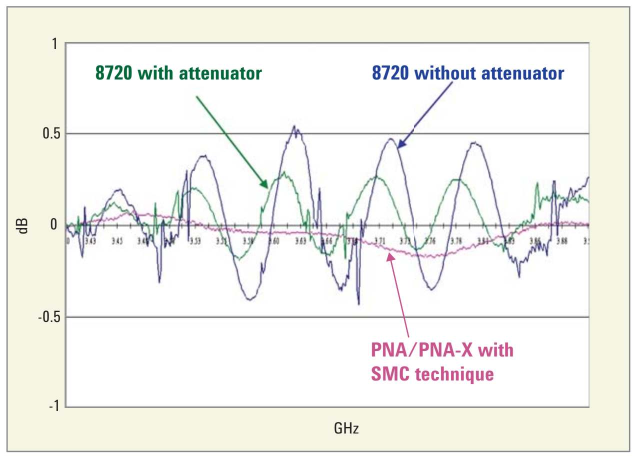


Figure 7. Comparison of conversion loss results

The setup for SMC is shown in Figure 8 on page 11. Using an Agilent U2000 Series USB power sensor to make the power calibration eliminates the need for an external power meter.

Figure 7 (above) shows comparisons of conversion loss measurements using SMC and traditional techniques. The traditional technique uses an attenuator to improve port match, but the ripple is still large. The PNA-X solves this problem by using SMC's port match correction.

The need for reference and calibration mixers

Vector Mixer Calibration (VMC)

To measure group delay, the phase of S_{21} must be measured. Since S_{21} is a ratio of two receivers (B/R1), it is necessary to ensure that the frequencies of the test receiver B and the reference receiver R1 are the same. If they are at different frequencies, the result is pure noise. When measuring frequency-translating devices, R1 works at the input frequency and B works at the output frequency. Consequently, the input signal sent to R1 must be converted to the output frequency to make R1 and B equal in frequency. A reference mixer is therefore required to supply a signal with the correct frequency to the reference receiver. The reference mixer is supplied by the user. The setup is shown in Figure 9.

For the calibration, two-port calibrations are used to measure the one-port error terms associated with each test port (at the corresponding input and output frequencies), as well as the load match of port two. To measure the transmission response term, a calibration mixer (also supplied by the user) is introduced as a characterized through standard. The calibration mixer, along with a filter to select the desired sum or difference product, is characterized by making three reflection measurements using an open, short and load as a termination.

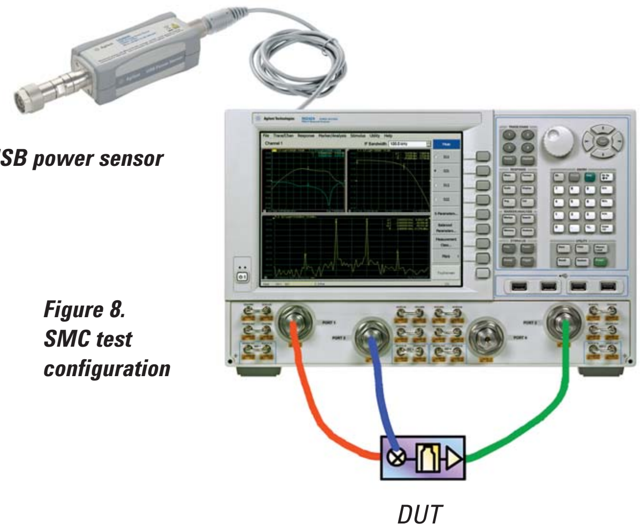


Figure 8. SMC test configuration

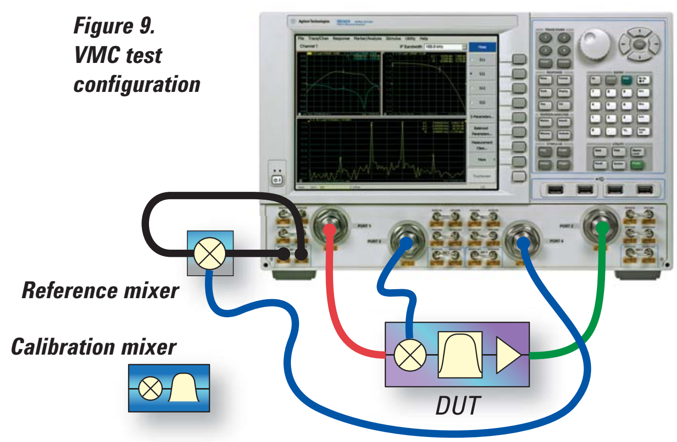


Figure 9. VMC test configuration

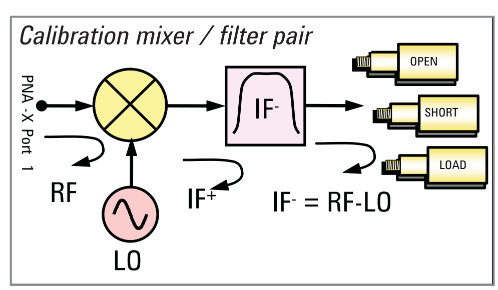


Figure 10. The calibration mixer is characterized by three reflection measurements, each with a different termination.

VMC calibration

While many engineers believe that VMC calibration is sophisticated and difficult to understand, it is really an easy process that requires only three steps.

Step 1: Perform a two-port calibration at ports one and two. Data is collected at both the input and output frequencies.

Step 2: Characterize the calibration mixer/filter pair as shown in Figure 10.

Step 3: Use the calibration mixer/filter as a through standard to measure the transmission response of the overall test system

VMC measurement

Following calibration, the engineer simply connects to a DUT to perform the VMC measurement. VMC measurements can also be used to measure more complicated components like multi-channel mixers and converters, or I/Q modulators that contain mixers.

Figure 11 shows the measured results comparing Agilent's VMC method to the traditional three-mixer approach. Note that the VMC measurement shows much less ripple and noise.

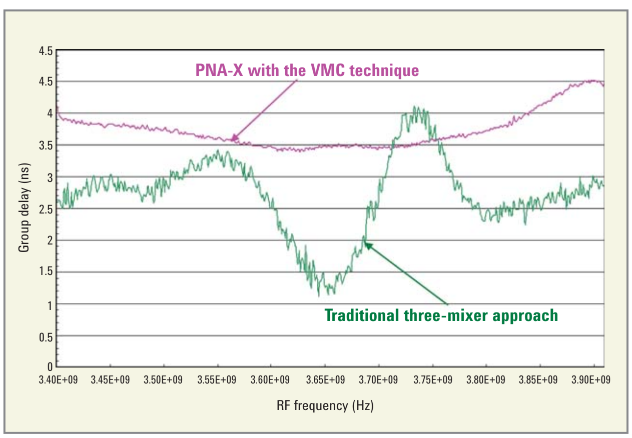


Figure 11. Measurement comparison for group delay

Intermodulation Distortion Measurements of Converters

Agilent's Intermodulation Distortion (IMD) Application (Option 087) makes it very easy to set up and calibrate swept-IMD measurements of frequency converters. The application controls the two internal sources of the PNA-X and an external source, which can be used either as the second stimulus signal or as the LO signal to the DUT. For a more complete description of this application, see page 20.

What is an Embedded-LO Converter?

Embedded-LO frequency converters contain an internal local oscillator (LO) that cannot be locked to an external time base and cannot be replaced by an external LO signal. This conversion device is widely used in satellite and large radar systems. Figure 12 shows an example.

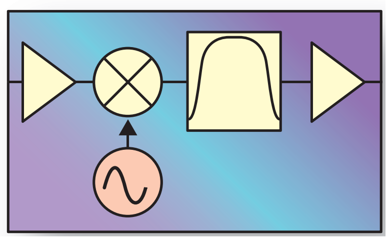


Figure 12. Embedded-LO conversion device

Absolute Group Delay Challenge for Embedded-LO Converters

When measuring an embedded-LO converter, the actual working frequency of the LO is unknown to the network analyzer. While the nominal LO frequency is known, there is always some deviation that can be as little as a few Hz or as large as several kHz. Plus, the LO frequency drifts as a function of time and temperature. During measurements, the input RF signals are supplied by the network analyzer source, so they are known precisely. Since the LO signal is unknown, the analyzer is tuned to a frequency that is offset from the actual IF output signal. This makes it difficult or impossible to measure group delay. Group delay measurements of embedded-LO converters are an important benchmark for satellite and radar systems.

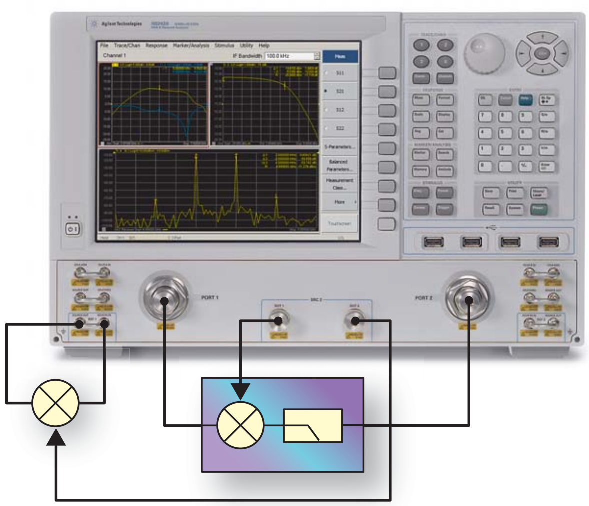


Figure 13. Calibration for embedded-LO converter

Absolute Group Delay Solution for Embedded-LO Converters

To solve this difficult measurement challenge, Agilent has unveiled a new solution, Option 084, which builds on the VMC measurement technique.

The measurement connections for an embedded-LO converter are shown in Figure 14. The first step is to measure the frequency of the actual IF signal. From this measurement, and knowing the input RF signal, the LO frequency can be calculated. This step requires two sweeps of the network analyzer. The first sweep is broadband, where a rough measurement of the embedded-LO frequency is made over a selectable frequency span (Figure 15). In this example, the nominal frequency is 5 GHz, and the specification for the maximum deviation of the LO frequency is less than +/-500 kHz. So, the center frequency of the receiver is set to 5 GHz, with a span of 1 MHz. Since 200 points are used for this measurement, the frequency resolution is 1 MHz/200 = 5 kHz. However, the analyzer needs a more precise determination of the LO frequency to make group delay measurements. The second sweep gives the analyzer the necessary precision. It is a sweep of phase versus time, as shown in Figure 16. From this sweep, the frequency deviation can be determined as $\Delta F = -\Delta\Phi/(360^*\Delta T)$.

From the results of the broadband and precise sweeps, the working frequency of the LO can be determined accurately enough to make a valid group delay measurement.

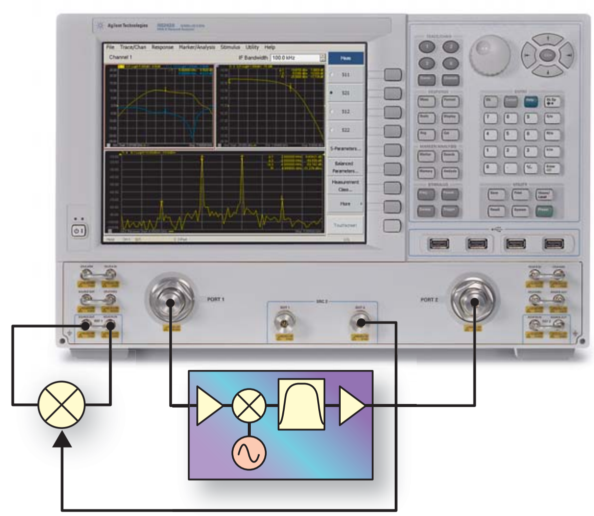


Figure 14. Measurement of embedded-LO converter

Calibration and measurement for embedded-LO converters

Agilent's VMC technology can also be applied to calibration of an embedded-LO converter. An example of just such a connection is shown in Figure 13.

Before each measurement, background sweeps (broadband and precise sweeps) are made to determine the frequency of the embedded LO. The LO frequency of the reference mixer is adjusted to be consistent with the actual LO frequency of the DUT. In this way, the reference and test receivers have signals at near identical frequencies which are necessary for group delay measurements.

The accuracy of this method can be demonstrated by comparing the results of measuring a converter with an LO under locked and unlocked conditions, as shown in Figure 17. Here, the red trace is the result of sharing a common 10 MHz time base between the LO source and the PNA-X. The yellow trace is the result of an LO source that is completely independent from the PNA-X and uses the embedded-LO measurement technique described above. Because the results are nearly identical it is clear that this solution can effectively address the challenge of measuring the absolute group delay of embedded-LO converters.

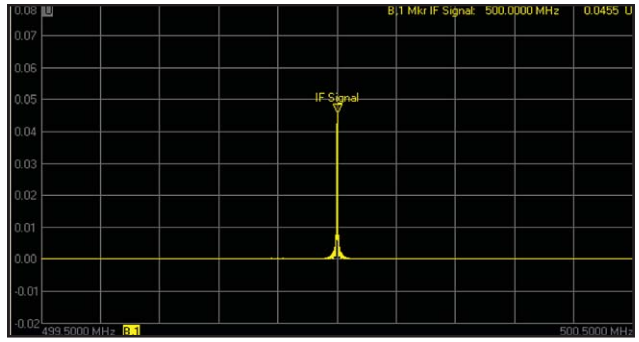


Figure 15. Broadband sweep results

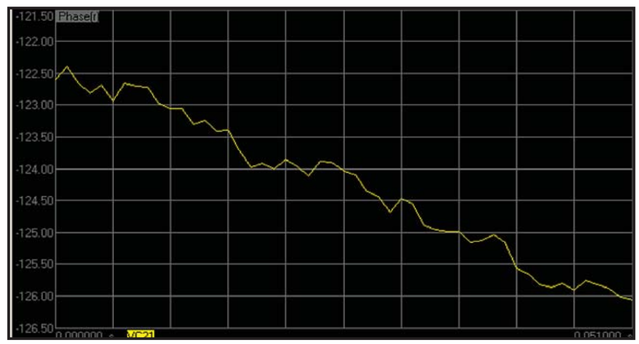


Figure 16. Precise sweep results

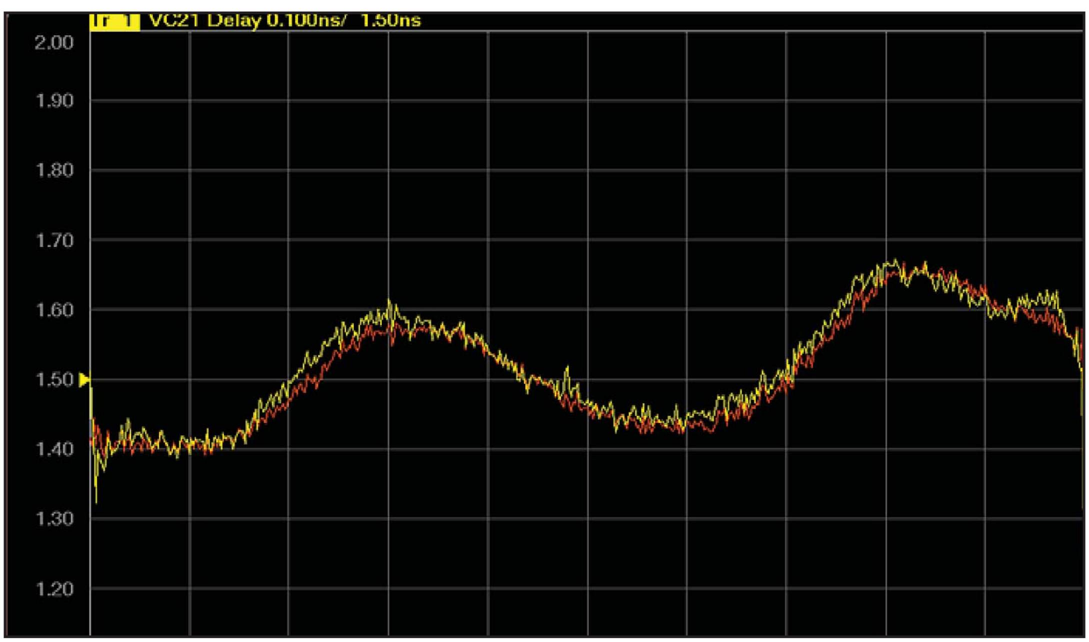
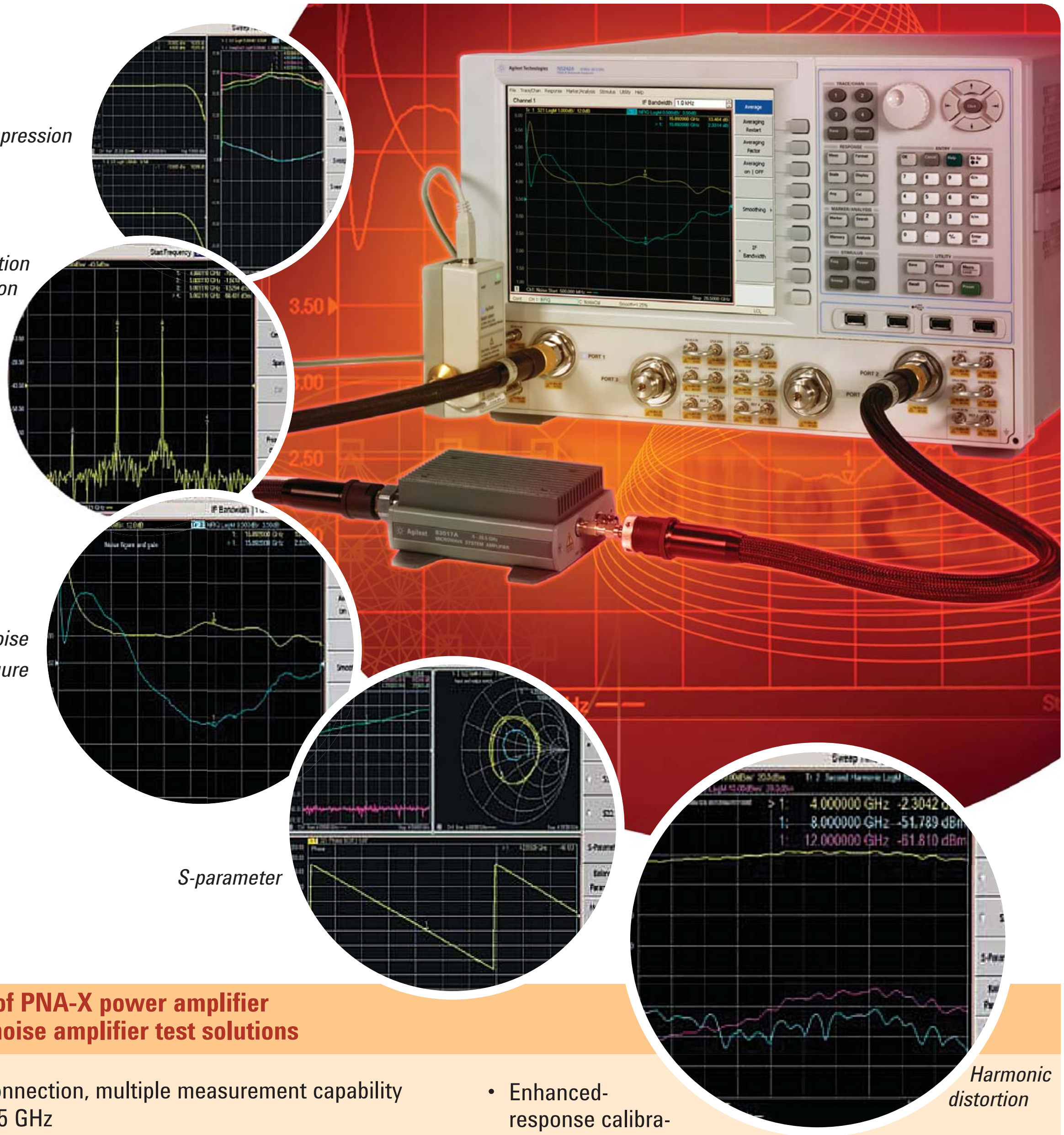


Figure 17. Absolute group delay results comparing a converter with a locked and unlocked LO. The results are nearly identical.

The Industry's First Comprehensive One-Box Solution for Amplifier Test



Features of PNA-X power amplifier and low-noise amplifier test solutions

- Single connection, multiple measurement capability up to 26.5 GHz
- Cold-source-based noise figure measurements featuring advanced source correction for high accuracy. Supports high-gain amplifiers (> 30 dB)
- Two-dimensional scans of gain compression versus frequency
- Swept-frequency and swept-power IMD measurements
- Swept harmonic measurements
- Power-added efficiency measurements
- Hot-S_{22} measurements
- One-box, pulsed S-parameter measurements
- True-differential stimulus measurements
- Enhanced-response calibration for power amplifier measurements
- Max output power ≥ +20 dBm
- Max power sweep range ≥ 40 dB
- Two signal sources with best harmonics (≤ -60 dBc)
- High receiver 0.1 dB compression points (> +13 dBm)
- Expanded test capability by connecting vector-signal sources and vector-signal analyzers to rear-panel RF access points for EVM, ACPR, CCDF, and more

Noise figure measurements using the *new industry standard!*

Industry challenges for noise figure measurements

Low-noise amplifiers (LNAs) are core components in the front-end of RF and microwave receivers. They are used to amplify weak signals from a receiving antenna while minimizing added noise. The sensitivity of the receiver depends on the quality of the LNA (characterized by its gain and noise figure). When the transmitter and receiver are balanced to optimize the size, weight, cost, and performance of a system, high-sensitivity receivers can be used to decrease the transmitter's output power, resulting in smaller, lower power amplifiers. Since the LNA noise figure is typically small, measurement accuracy is the primary challenge.

Traveling-wave-tube amplifiers (TWTA) are common high-power amplifiers widely used in radar and satellite systems. The TWTA noise figure tends to be higher than 30 dB. Using conventional techniques, which are limited by the excess-noise ratio of the noise source, today's instruments cannot easily measure noise figures greater than 30 dB.

Noise figure measurement techniques

Two main methods are used today to measure noise figure. The most prevalent method is called the Y-factor or hot/cold source technique, as shown in Figure 18A. It relies on a noise source that is placed at the input of the amplifier under test (AUT). The output of the AUT is connected to a noise receiver. The noise source can be turned on and off to create "hot" and "cold" states. The noise source's off state represents a "cold" source impedance that is equivalent to a load at room temperature. The on state represents the excess noise generated above the room temperature noise and is equivalent to a load at an elevated temperature. By measuring the resulting noise powers at the output of the AUT from the two states, the noise figure can be calculated.

The Y-factor technique is considered the standard for noise figure measurement. It is today incorporated in Agilent's Noise Figure Analyzer (NFA) and spectrum analyzer-based noise figure solutions.

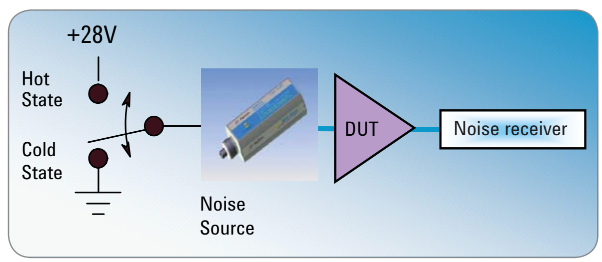


Figure 18A. Y-factor technology

A second method for measuring noise figure is called the cold-source technique. A noise source is not required at the input of the amplifier for hot or cold states. Rather, this method uses a single-input termination at room temperature as shown in Figure 18B. The cold source technique requires an independent measurement of the DUT's gain. This technique is well suited for use with network analyzers because they can measure gain extremely accurately by utilizing vector error correction. The advantage of the cold-source method is that it enables single-connection, multiple-measurement solutions like the PNA-X.

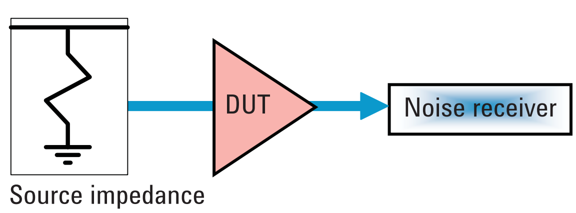


Figure 18B. Cold noise technology

Problems using the Y-factor method

Accurate noise figure measurements using the Y-factor method are challenging for two reasons. First, connecting to the AUT can be difficult. Secondly, when the noise source is not connected directly to the input of the AUT, the resulting accuracy degradation is significant.

There are several situations where it is impossible to connect a noise source directly to the amplifier's input:

- **Transmit/receive modules** with microstrip interfaces (for phased-array radars) require test fixtures to interface to the VNA
- **On-wafer testing** of microwave integrated circuits requires coaxial-to-coplanar test probes (Figure 19)
- **Automated-test environments** where a switch matrix is used between the test equipment and the AUT (Figure 20)

The addition of cables, switches, test fixtures, and/or probes causes degradation of the test system's effective source match. This impairment causes two types of noise figure measurement errors. One is the classic error due to mismatch which arises from non-ideal system source match and amplifier input match. The effect of this mismatch shows up as a classic ripple pattern in the test results when the frequency span is wide enough to show one or more cycles. Often times the ripple is not viewable because the frequency span of the measurement is too narrow; nevertheless, the error is still in the measurement.

The other type of noise figure error introduced by imperfect system source match is due to the noise coming out of the input of the AUT. The noise reflects off the system source match and reenters the amplifier. It causes the noise figure of the AUT to change, depending on the phase of the reflected noise power and the correlation among the various noise generators within the amplifier. Thus, the measured noise figure varies as a function of the system source impedance. This behavior can be characterized in terms of the LNA's noise parameters. When measuring noise figure, the variation of the test system's source impedance around 50 ohms will cause the measured noise figure of the AUT to vary as well, inducing measurement error. This effect also causes ripple in the measured results which are indistinguishable from the ripple caused by mismatch.

PNA-X based noise figure measurement solution

The PNA-X eliminates the need for a noise source by using the cold-source method. The accuracy problems of the Y-factor method are overcome by two techniques. Firstly, vector-error correction is used to compensate for the mismatch effects caused by imperfect system source and load match, as well as for system frequency-response errors. Secondly, noise-parameter-induced errors are overcome by using a standard Agilent ECal module as a variable impedance tuner to vary the source match of the test system for each of the desired measurement frequency points. At each source impedance, a corresponding noise power measurement is made with the AUT in place. None of the source impedances presented to the AUT are exactly 50 ohms, but from the set of impedance and noise power measurements, the 50 ohm noise figure can be accurately calculated. In this manner, the effect of switches, cables, fixtures, or probes can be fully removed from the test results, delivering the highest noise figure measurement accuracy of any commercial test system available today.

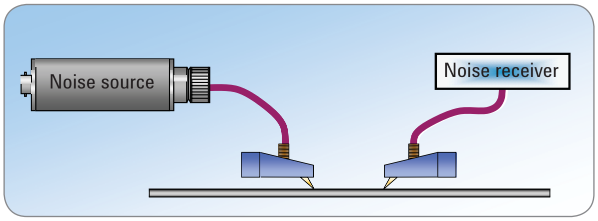


Figure 19. On-wafer component test

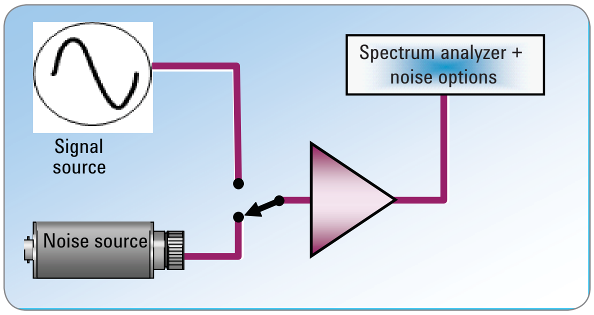


Figure 20. Automated test system

PNA-X based noise figure measurement solution cont.

Figure 21 shows the block diagram of a two-port PNA-X with the noise figure option. The ECal module, used as an impedance tuner, is connected to Port 1 via a front-panel RF link. The noise source is only used during the calibration process, but not during amplifier measurements.

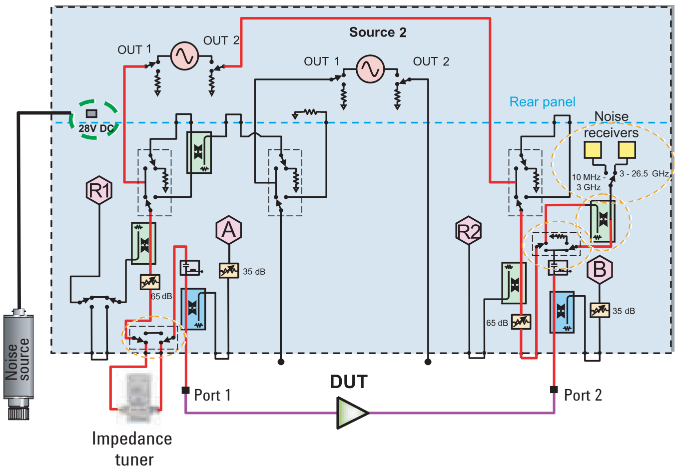


Figure 21. PNA-X-based noise figure solution (up to 26.5 GHz)

Comparison of noise figure measurement uncertainty

Figure 22 compares on-wafer noise figure measurement uncertainty between the Y-factor method and the PNA-X's method. For the Y-factor method, the uncertainty is calculated in two different ways. In one way the noise source is connected via a probe to the DUT. In the other way, an electrical network simulating the switches and cables from an automated-test-equipment (ATE) setup is placed between the noise source and the probe.

The PNA-X example includes the probes and ATE network. Using the PNA-X-based noise figure solution, the uncertainty is approximately 0.3 dB.

Using a Y-factor-based solution, the uncertainty is about 0.75 dB without the ATE network. Combining the probes and the ATE network degrades the measurement uncertainty to about 1.1 dB. In addition to the accuracy improvement provided by the PNA-X, it also makes noise figure measurements 4 to 10 times faster than a noise figure analyzer.

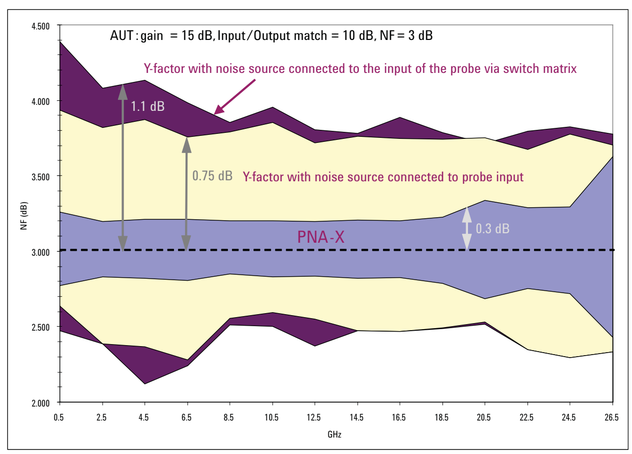


Figure 22. Comparison of noise figure uncertainties

Two-dimensional gain compression measurements

The industry's most comprehensive measurement application for swept-frequency gain compression

Industry requirements for gain compression measurement

The most common measurement of amplifier compression is the 1 dB compression point (Figure 23). This is defined as the input (or output) power which results in a 1 dB decrease in amplifier gain. This measurement is commonly done on a network analyzer by performing a power sweep at a fixed frequency value. The power sweep is usually repeated at several different CW frequencies. This approach is much faster than stepping a signal generator, but gain compression versus frequency cannot be displayed directly on the VNA, and most of the underlying power sweep data is not needed.

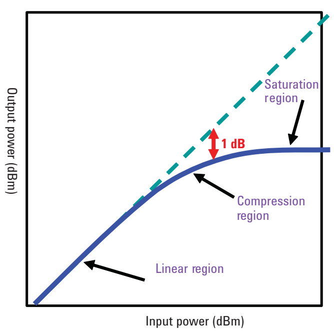


Figure 23. Gain compression concept

Fast, accurate, gain compression measurements

To meet industry requirements, Agilent offers a gain compression application (Option 086) for swept-frequency gain compression measurements. The analyzer automatically performs a power sweep at each frequency point, and displays the gain compression versus frequency. Figure 24 shows three sweep approaches. Smart Sweep uses an adaptive power sweep which greatly increases sweep speed. The other two methods are true two-dimensional sweeps, sweep frequency per power and sweep power per frequency. Figure 25 shows the results of a swept gain-compression measurement.

Variety of two-dimensional sweeps

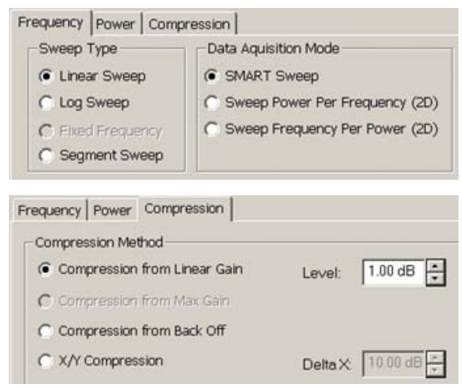


Figure 24. Setup dialog box for the gain compression application (Option 086)

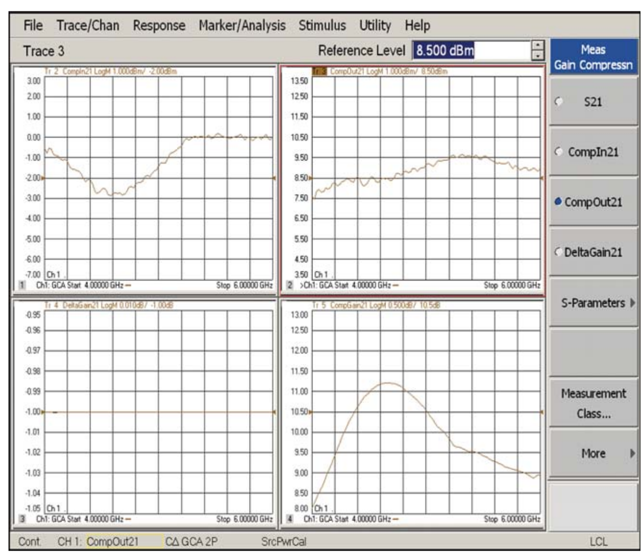


Figure 25. Results of a swept gain-compression measurement

One-box solution for amplifier test

CONTINUED

Intermodulation/harmonics distortion measurement

Frequency sweep and power sweep

The challenges of intermodulation and harmonic distortion for traditional network analyzers

Using traditional network analyzers for intermodulation or harmonic distortion measurements, the results contain three components. The first is induced by harmonics of the source, the second by the DUT's characteristics, and the third by receiver compression. However, only the second component is desired. The first component causes serious errors since the harmonics of a traditional network analyzer are around -20 dBc. The 0.1 dB compression points of traditional network analyzers are around –5 dBm; thus receiver compression can be easily introduced by the DUT. Another problem for the traditional approach is that an external combiner needs to be supplied by the user. Also, external switches are needed to build an automated test system.

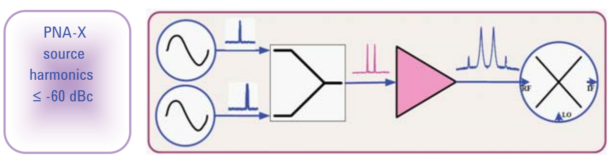


Figure 26. Intermodulation distortion measurement

Solutions and test results

To solve these problems, the PNA-X is designed with superior performance. The harmonics of the two internal sources are below -60 dBc, and the 0.1 dB compression points of the receivers are around +12 dBm. The PNA-X has a built-in, switchable combiner. Figure 27 shows the block diagram for IMD measurements. The intermodulation distortion results are measured by receiver B. With this arrangement, both one and two source measurements can be made.

Agilent's IMD application (Option 087) makes it very easy to set up and calibrate swept-IMD measurements. It controls the built-in second source and internal combiner of the PNA-X. The user can sweep either the center frequency of the two stimulus signals, the frequency spacing of the two stimulus signals about a fixed center frequency, or the power of one or both stimulus signals. The analyzer can measure intermodulation distortion products of order 2, 3, 5, 7, or 9, and can display the associated intercept points. In addition, an IM spectrum mode gives a spectrum-analyzer-like display

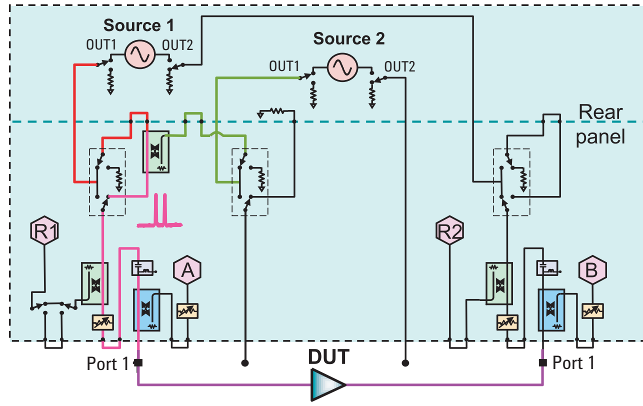


Figure 27. PNA-X intermodulation distortion measurement block diagram

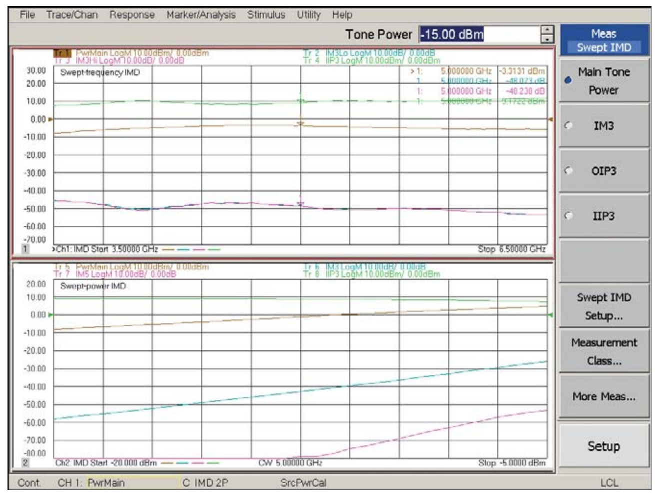


Figure 28A. PNA-X swept intermodulation distortion measurement results

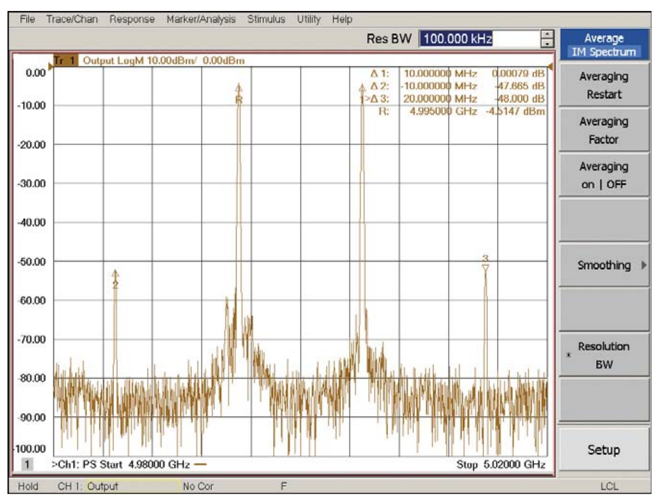


Figure 28B. PNA-X IM spectrum mode, showing spectrum-analyzer-like display of signals

for confirming or trouble-shooting measurements. Figure 28A is an actual measurement of swept-frequency and swept-power IMD. Figure 28B shows the IMD test signals and products using the IM spectrum mode available in Option 087.

True differential stimulus measurements

Measure the performance of balanced components in compression

Traditional measurement approach and problems for balanced components

In many RF and microwave applications, balanced components are widely used for their excellent EMI behavior and ability to process low-level signals. Differential S-parameters are an important parameter for characterizing these devices. The traditional approach for measuring the performance of balanced components in compression uses a single-ended stimulus signal and calculates balanced performance mathematically. While this approach works well for linear devices like filters, it is not suitable for active components operating in their nonlinear region. These devices require true differential input signals.

Often, designers use external baluns to generate differential signals. However, the quality of these signals can suffer due to non-ideal balun performance. Also, it is difficult to calibrate the test system when the balun is in place.

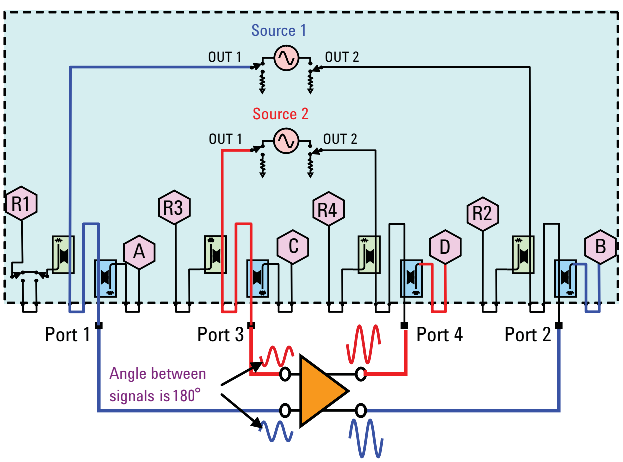


Figure 29. True differential stimulus measurements

Measurement comparisons

Agilent offers an integrated true-mode stimulus application, Option 460, for four-port PNA-X instruments which solves the problems previously mentioned. The fundamental principle for measurement is shown in Figure 29. The PNA-X provides very accurate results because the magnitude and phase of the two sources are adjusted at each frequency point to ensure true differential signals, even with poorly matched devices. Figure 30 shows the measurement results using single-ended (with computed differential response) and true-differential stimulus. The results show that the two methods deviate as the device is driven into compression. Only true differential stimulus can provide the right answer when testing at large signal levels in this example.

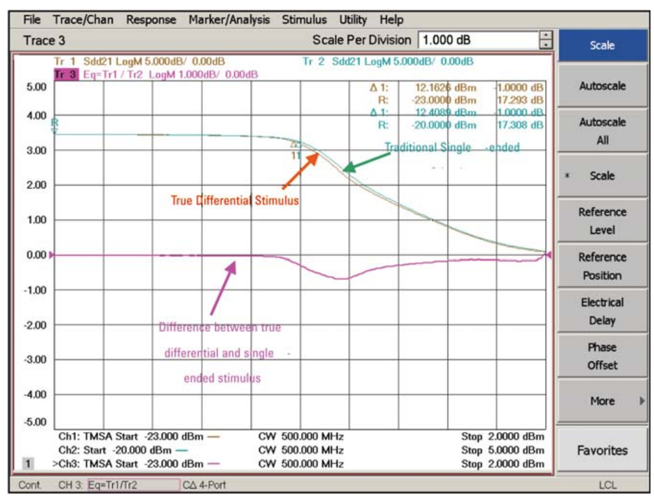


Figure 30. Measurement results comparing single-ended and true-differential stimulus using a power sweep

PAE measurements

Calculate the efficiency of RF power amplifiers by adding DC measurements

Fundamental concept of power-added efficiency measurement

Power-added efficiency (PAE) refers to how efficiently the amplifier converts DC power to amplifier output power. Ideally, all of the DC power supplied to the amplifier would be converted to RF output power. In the real world however, some of the DC power is wasted in the form of heat. PAE is a key factor for evaluating the performance of an RF amplifier and is defined as:

$$PAE = \frac{Power_{RF\_OUT} - Power_{RF\_IN}}{Power_{DC}} * 100\%$$

Amplifier designers need to measure PAE on their devices to determine the input power levels that provide the best balance between low distortion and high efficiency. Often, the trade-off is frequency dependent.

PAE power efficiency measurement solution

Measuring the input and output RF power of an amplifier is a standard network analyzer measurement. In order to calculate PAE, the analyzer also needs to measure the supply voltage and current of the amplifier. Agilent's PNA-X network analyzer has two DC voltage inputs that can be displayed on the instrument's screen. By using a simple resistive network and some simple math, both voltage and current can be measured. Figure 31 shows the measurement setup. A power supply supplies the amplifier with power through a sense resistor with a known value. Figure 32 shows the equation used to calculate PAE based on the measurement results of RF and DC power. The measured data and calculated PAE versus frequency are shown in Figure 33.

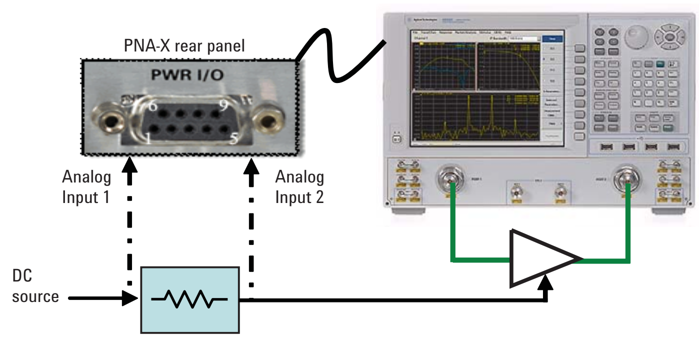


Figure 31. PAE measurement configuration

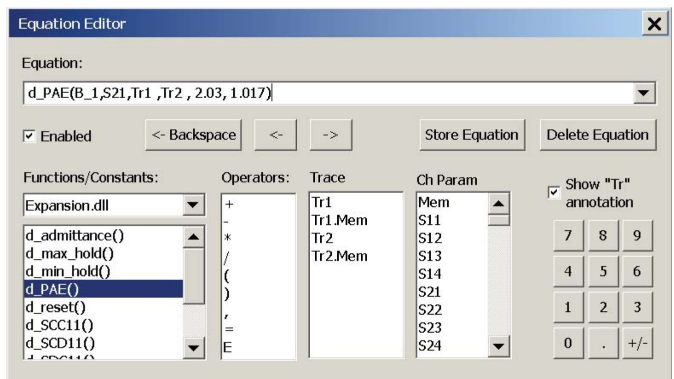


Figure 32. Calculating PAE using the Equation Editor

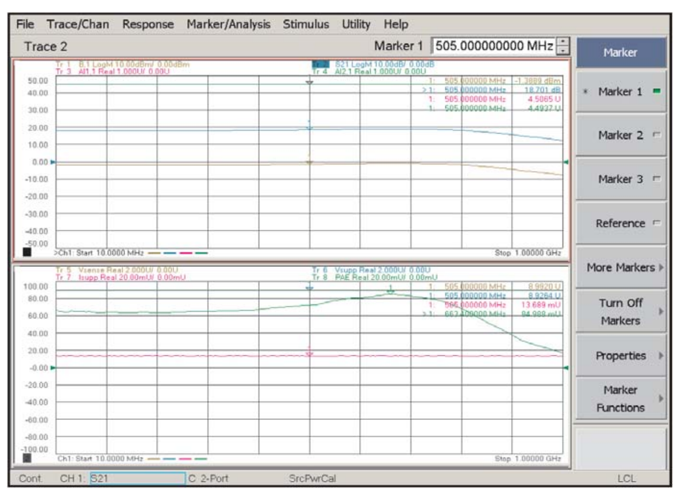


Figure 33. PAE measurement results

PNA-X flexibility

Expanding capabilities with an external vector signal source and analyzer

Comprehensive solutions for wireless communications amplifier measurements

For wireless communication amplifiers, S-parameter, compression, noise figure, and IMD measurements are necessary, but they are not always sufficient. Other measurements that require digitally-modulated RF signals are often needed, such as EVM and ACPR. A network analyzer cannot supply stimulus signals with digital modulation, and the network analyzer's receivers cannot provide the necessary digital demodulation. However, the flexible test set of the PNA-X can be used to add external vector signal sources and analyzers to extend the suite of RF measurements capable with a single connection to the DUT. In Figure 34, an Agilent MXG signal source and an MXA spectrum analyzer are shown connected to the rear panel of the PNA-X. They can be switched in to measure parameters requiring digital modulation and demodulation.

Using the mechanical switches supplied by the PNA-X network analyzer as shown in Figure 35, the user can easily switch between the internal capabilities of the PNA-X to measure S-parameters, gain compression, noise figure, and distortion, and then switch in the vector signal source and spectrum analyzer to measure EVM and ACPR. This approach gives a multi-instrument test system without an external switch matrix, thereby simplifying the test system and improving test throughput.

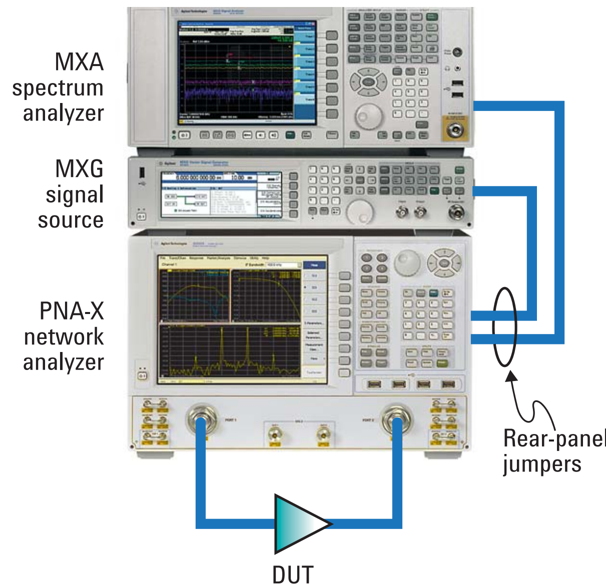


Figure 34. Extend the range of measurements made with a single connection to the DUT by adding vector signal generators and analyzers.

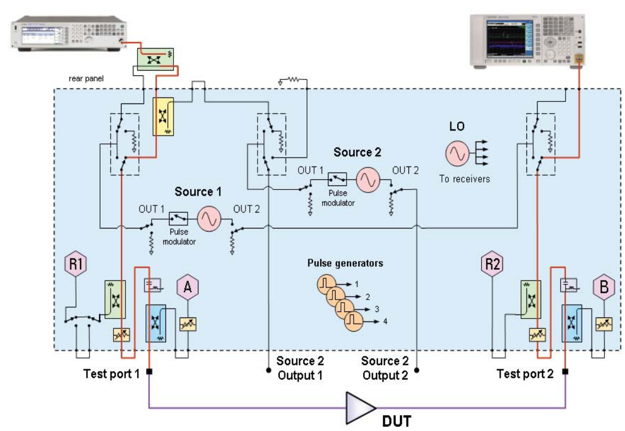


Figure 35. Block diagram showing connection of signal generator and spectrum analyzer to extend suite of RF measurements.

Nonlinear Vector Network Analyzer (NVNA)

Provides Breakthrough Analysis of Nonlinear Device Performance

Agilent's PNA-X-based 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. Agilent's NVNA provides three nonlinear options to help solve your toughest design problems:

- Component characterization
- X-parameters
- Pulse-envelope domain

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 vector-corrected waveforms of incident, reflected and transmitted waves to and from the DUT. Displayed data can be represented in the 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.

X-parameters extend the power of S-parameters to large-signal conditions, providing a behavioral, black-box nonlinear design framework. X-parameters are determinable from a simple set of physical measurements on the DUT, yielding 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 components driven well into compression. X-parameters in conjunction with Agilent's ADS design and simulation tools minimize design iterations, speed simulation and deterministically model the nonlinear behavior of your active components.

The pulse-envelope domain helps you gain key insights into understanding time-dependent memory effects in active nonlinear devices, such as those caused by self-heating or contributions from biasing circuits. NVNA pulse-envelope domain measures the vector-corrected amplitude and phase of the fundamental and harmonic pulse envelopes of your DUT versus time.

For more information, see the NVNA Brochure, literature number 5989-8575EN.

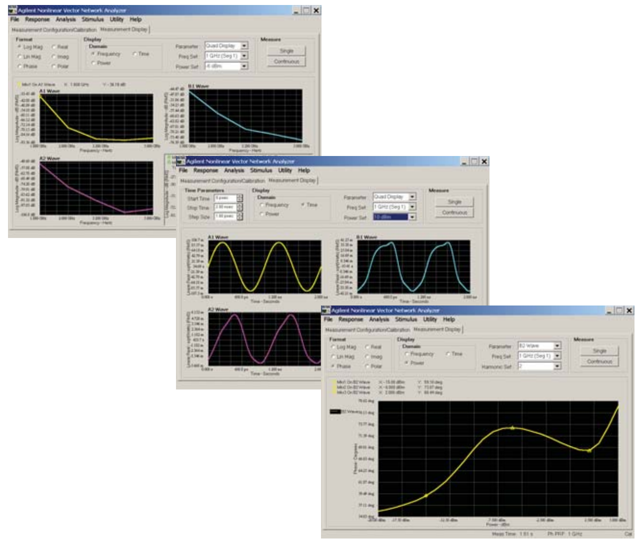


Figure 36. Easily move between domains

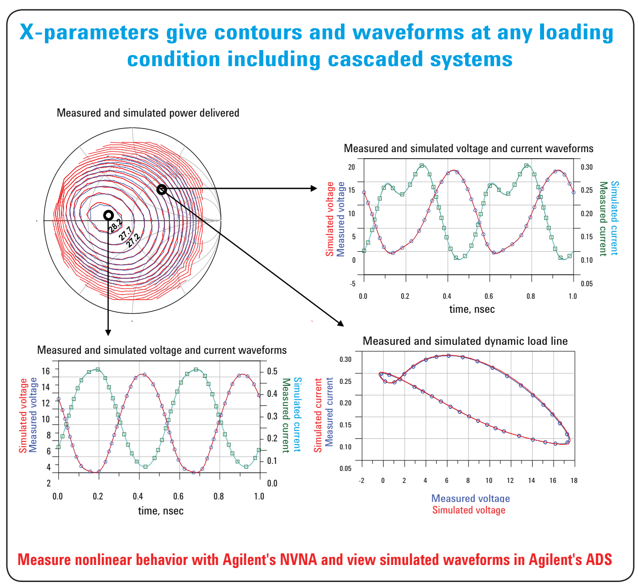


Figure 37. Comparisons of actual waveform measurements and ADS simulations using X-parameters show remarkable correlation.

Flexible Multiport Measurements

PNA-X multiport test features

- Customized multiport test sets increase the number of system test ports from 4 to as many as your DUT requires.
- Quick-SOLT dramatically reduces the number of calibration standards required for full system calibration, greatly speeding the calibration process
- N-port calibration provides the highest level of measurement accuracy
- Control of test sets is integrated into the PNA-X firmware for seamless operation
- 32 independent test channels for fast, flexible measurements

PNA-X Banded Millimeter-Wave Solutions

Up to 500 GHz

Two and four-port banded millimeter-wave systems configured with the PNA-X offer exceptional dynamic range all the way to 500 GHz without additional external synthesizers. Pulsed millimeter-wave measurements can easily be achieved by simply adding built-in pulse generators and modulators, with no extra external equipment required. Create the most cost-effective solution for your application by purchasing just the modules and frequency ranges you need. A wide selection of waveguide modules is available to meet your specific frequency needs from 50 to 500 GHz:

N5260AW15, 50 to 75 GHz

N5260AW12, 60 to 90 GHz

N5260AW10, 75 to 110 GHz

N5260AW08, 90 to 140 GHz

N5260AW06, 110 to 170 GHz

N5260AW05, 140 to 220 GHz

N5260AW03, 220 to 325 GHz

N5260AS02, 325 to 500 GHz

For two-port systems, the N5261A 2-port test set controller is needed. For four-port systems, the N5262A 4-port test set controller is needed.

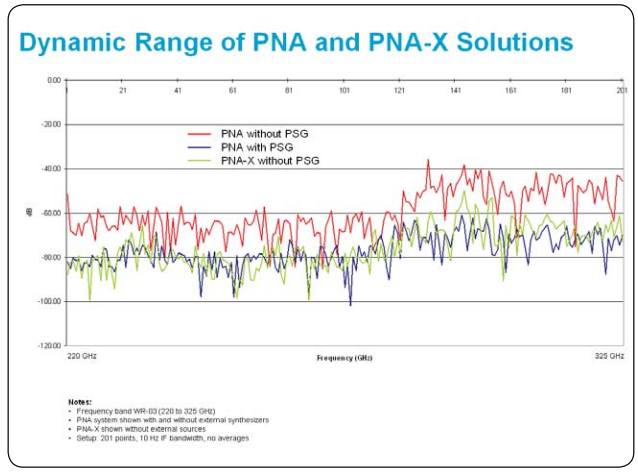
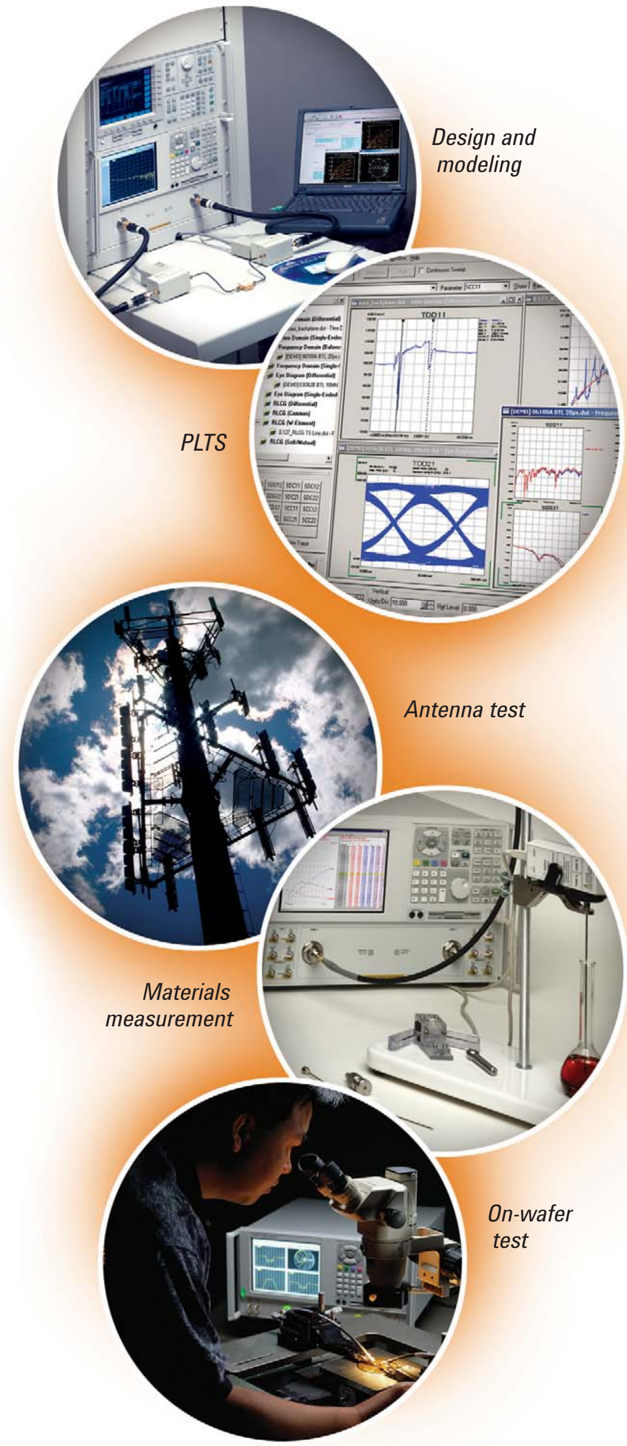


Figure 38. The PNA-X provides excellent dynamic range up to 325 GHz, without the need for external RF and LO sources

Figure 39. PNA-X-based 4-port millimeter-wave system

PNA-X Simplifies Measurements When the Requirements are Difficult



High-frequency design and modeling

- PNA-X drivers included in Agilent's Advanced Design System (ADS) for easy connectivity
- Simple downloading of S-parameters into ADS for simulation
- Modeling of devices using PNA-X and IC-CAP

Physical layer test systems (PLTS)

- TDR, TDT, frequency domain and eye-diagram analysis
- Complete characterization of single-ended, differential, common-mode and mode conversion performance
- N-port error-corrected measurements
- RLCG model extraction

Antenna test with new N5264A measurement receiver

- High-sensitivity receivers with -145 dBm noise floor
- Direct-IF access for use with external mixers
- Fast measurement speed of 400,000 points per second
- 500,000,000 point data buffer
- Forward and reverse sweeps for near-field scans
- Drop-in replacement for 8530A, including code emulation

Materials measurements

- Measurement of dielectric and magnetic properties
- Variety of data formats
- Variety of techniques available to meet your material test needs

On-wafer component test

- Variety of TRL calibration techniques for accurate measurements
- One-box, 4-port network analyzer for differential measurements
- Accurate power control and de-embedding techniques
- Compatible with other on-wafer calibration software for comprehensive probing solutions

PNA-X Measurement Receiver

Fast Antenna Measurements with the N5264A

The PNA-X Measurement Receiver sets a new industry standard for antenna test with a 30% faster data acquisition speed than any other antenna receiver on the market. The PNA-X antenna receiver is compatible with the MXG or PSG signal sources as well as existing distributed frequency-converter hardware such as the 85309A LO/IF distribution unit and 85320A/B mixers. The receiver with an MXG source can completely replace the 8530A and 8360 sources for existing antenna ranges and typically results in a system speed improvement that is 10 times faster. Additionally, the built-in 8510/8530A code emulation software provides a drop-in replacement for existing antenna ranges utilizing an 8530A.

This dedicated receiver is an ideal solution for antenna test engineers working on radar or satellite communications in the aerospace and wireless industries – where large volumes of data are required to fully characterize complex antenna arrays. It is supported by major antenna system integrators such as Orbit/FR-Satimo, Nearfield Systems Inc., and the System Planning Corporation.

Key Specifications

- Five IF inputs available for simultaneous measurements with external mixers
- 400,000 points per second data acquisition simultaneously on five receiver channels
- High sensitivity receivers with -145 dBm noise floor provide 20 dB better receiver dynamic range than existing antenna receivers (134 dB at 10 Hz IFBW)
- Fast-CW mode enables 500 million point data buffer (Option 118)
- Built-in 26.5 GHz LO source with +10 dBm output power (Option 108)
- 8510/8530A built-in code emulation for drop-in replacement functionality
- LAN and two GPIB interfaces, plus TTL I/O control port

For more information, see the Antenna Test Selection Guide, literature number 5968-6759E.

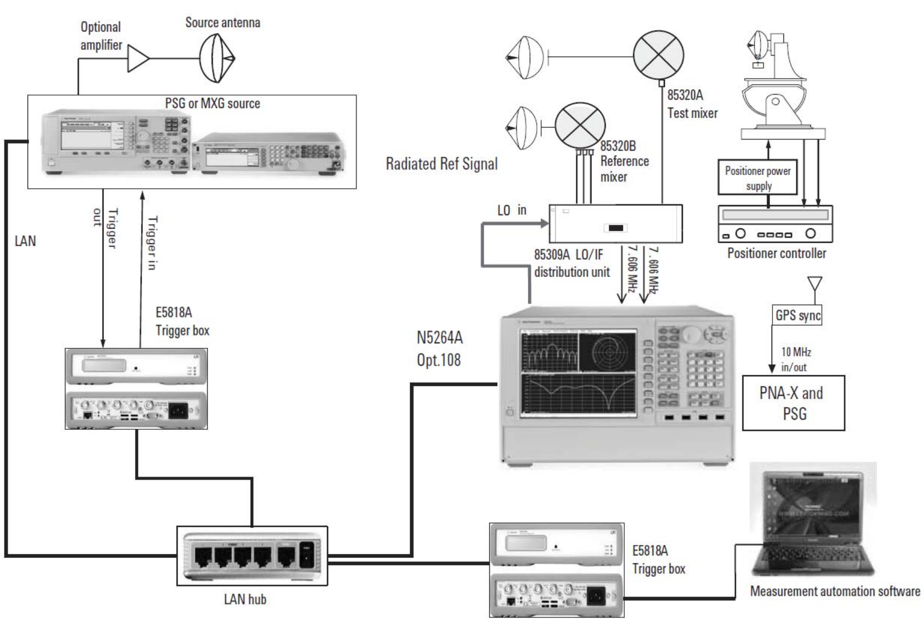
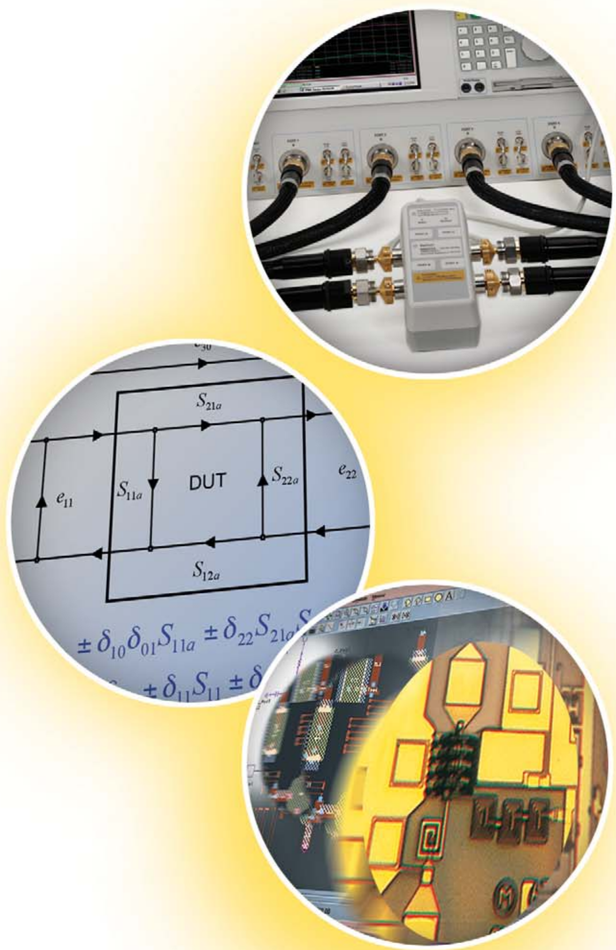


Figure 40. Typical far-field antenna measurement configuration using Agilent's PNA-X measurement receiver

State-of-the-Art Calibration Capabilities

Calibrating network analyzers is critical for high accuracy measurements and can be particularly challenging in non-coaxial environments such as fixtures, wafers or waveguides. Additionally, multiport devices are more prevalent than ever and require more sophisticated calibration techniques and procedures. The need has never been greater for calibration tools that are more accurate and easier to use. Agilent's series of calibration techniques and components help solve these challenges, enhance ease of use and improve accuracy.



Calibration techniques and features for PNA-X

High-performance ECal modules
- Frequency range: 300 kHz to 67 GHz
- 2-port and 4-port models
- 9 connector types for same or mixed-connector modules
- User-characterizations provide other connector combinations including waveguide

Non-insertable devices
- Unknown thru calibration
- Adapter removal calibration

Multiport calibration
- QSOLT (quick short, open, load, and through)
- N-port calibration (6-port, 8-port, 12-port, or more)

Data-based models and expanded math calibrations for highest accuracy

In-fixture measurements
- TRL or LRM calibration
- Automatic port extensions for loss/delay compensation
- Embedding/de-embedding

Advanced mixer calibrations
- Scalar mixer calibration – fully match-corrected power-meter-based calibration for conversion gain or loss
- Vector mixer calibration – fully match-corrected technique for absolute group delay measurements of frequency-converters

Advanced amplifier calibration technique
- Enhanced response calibration for high-power amplifier measurements
- De-embedding of attenuators
- Fast source-power calibration technique
- Unique noise figure calibration removes the errors caused by imperfect system source match

Unknown thru calibration

Unknown thru calibration procedures and requirements

As shown in Figure 41, open, short and load standards are applied to ports 1 and 2. Then, an unknown non-zero-length thru is connected to ports 1 and 2.

The unknown thru can be an adapter/connector or even the DUT. It needs to be reciprocal and the phase must be known to within a 1/4 wavelength with an insertion loss of less than 40 dB.

Unknown thru—application environments

Unknown thru calibration can be applied to the following situations to improve measurement accuracy and ease of use:

- When the DUT is non-insertable. Examples include when the DUT's connectors are the same gender, or when the ports have different connector types. In these cases, a zero-length thru cannot be used for calibration.
- When the measurements of physically large DUTs require long test port cables. The movement of these cables can cause errors as shown in Figure 42. Cable movement is minimized if the unknown thru is of similar length as the DUT.
- When the two ports of the DUT are not in-line, test port cable movement can cause errors. Cable movement is minimized if the unknown thru is similar in shape to the DUT.

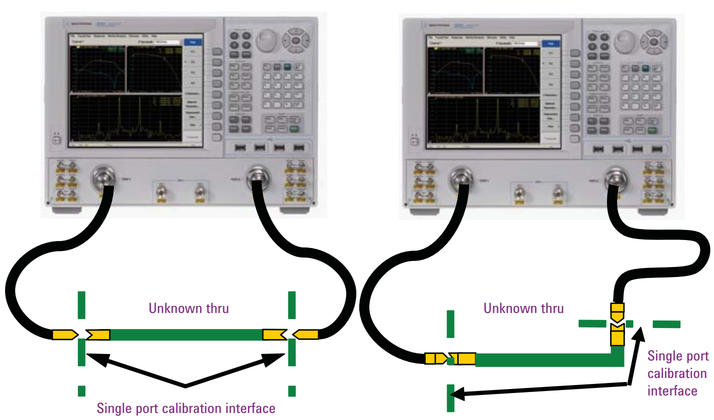


Figure 41. Unknown thru calibration

Unknown thru – response accuracy

For traditional calibration of non-insertable components, the adapter removal technique is often used. Figure 43 shows the comparison between the unknown thru and adapter removal calibration techniques. It is clear from this figure that the unknown thru calibration technique is more accurate.

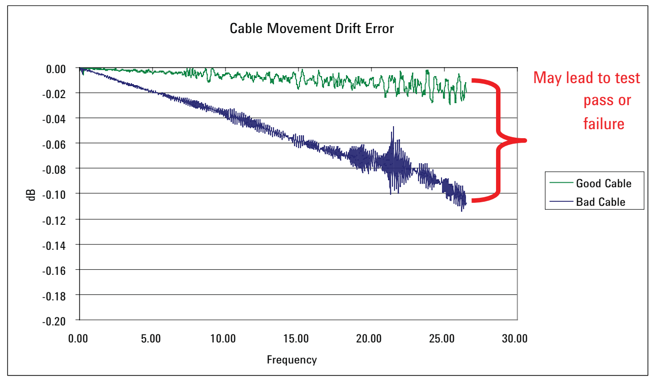


Figure 42. The effects of cable movement on measurement accuracy after calibration

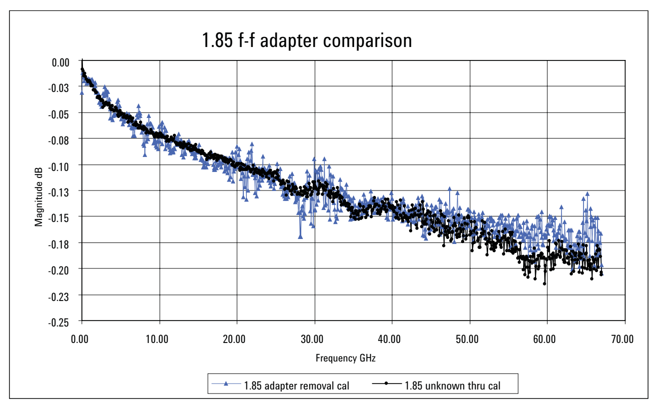


Figure 43. Accuracy comparison between unknown thru and adapter removal calibrations

QSOLT (quick short, open, load, and thru)

The traditional SOLT calibration technique for multiport calibration is a lengthy process. For example, a 4-port calibration requires 15 steps and an 8-port calibration needs 31 steps.

To reduce calibration time, Agilent introduced the Quick SOLT calibration method. With QSOLT, the user need only make open, short and load calibrations at one port, followed by thru connections between that port and the other ports. Using Agilent's calibration method, an 8-port calibration would involve only 10 steps, as shown in Figure 44.

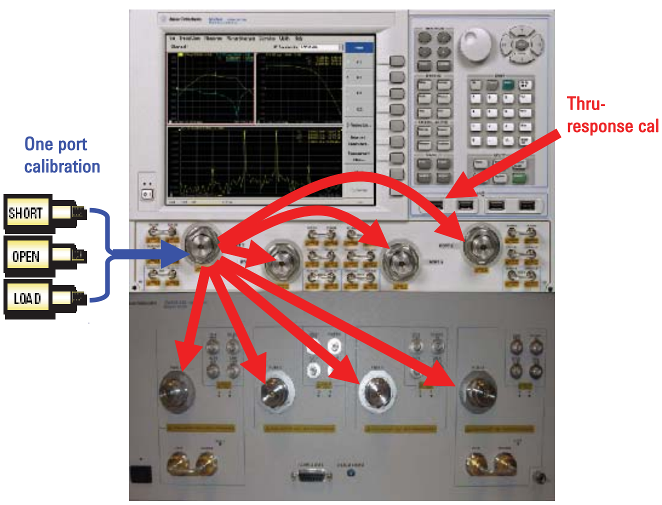


Figure 44. QSOLT calibration process

High-performance ECal modules

To simplify the calibration procedure and improve test efficiency, Agilent offers a wide variety of ECal modules as shown in Figure 45A. Models are available with frequency range from 300 kHz to 67 GHz, in 2- or 4-port versions. Mixed-connector-type ECals are available as shown in Figure 45B.

Customers can also store up to five user characterizations for non-standard connector arrangements. For example, Figure 45C shows a 1.85 mm (f-m) ECal module configured for waveguide calibrations.

Figure 45:

A. Variety of ECal modules
B. Mixed-connector-type ECal
C. Port connectors customized with user characterization

Enhanced Response Calibration

For some components, such as power amplifiers, a simple response calibration is traditionally used, but this approach is not accurate. The 2-port calibration, although more accurate, is not necessarily efficient. Agilent offers an enhanced response calibration technique that is both efficient and more accurate then a simple response calibration. As shown in Figure 46, this method eliminates five forward error terms. Compared to a simple response calibration, the enhanced response calibration improves the accuracy of both input match and forward gain or loss.

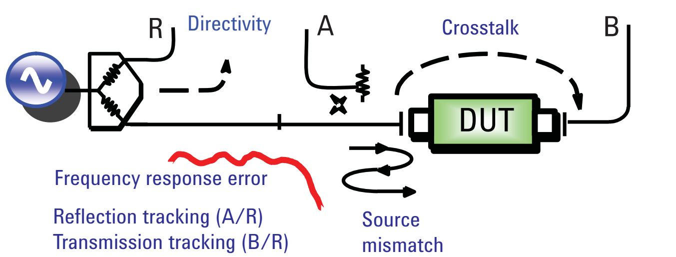


Figure 46. Enhanced-response calibration error model

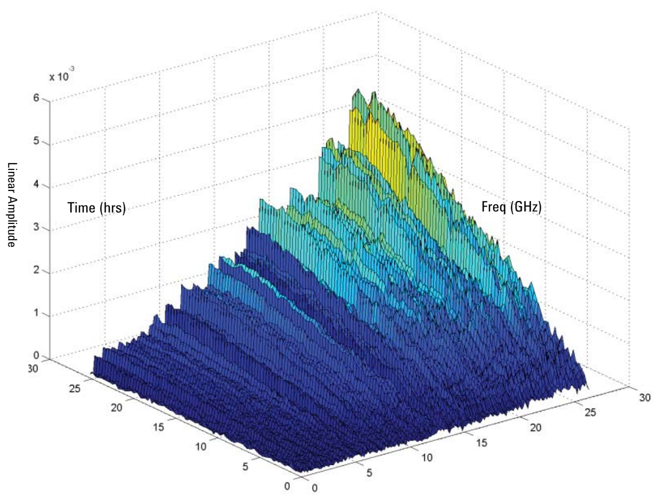


Figure 47. PNA-X after 24 hours: S_{11} amplitude drift versus time [1, 2]

1. Graphics created using PNA-X production test data. In a calibration lab environment, the PNA-X stability is expected to be better.
2. Stability is defined as the measure of the test port ratio.

PNA-X — Offering high levels of stability

PNA network analyzers are known for their extremely high levels of stability, which plays an important role in accurate measurement results. More stable hardware means that the calibration will remain extremely stable as a function of time and temperature, and it will not need to be updated as often. Test efficiency and accuracy will also be greatly increased.

Table 1. PNA-X frequency ranges, and typical amplitude and phase stability

	Amplitude stability (dB/°C)	Phase stability (degree/°C)
10 MHz – 50 MHz	0.01	0.29
50 MHz – 500 MHz	0.01	0.06
500 MHz – 3.2 GHz	0.01	0.07
3.2 GHz – 10 GHz	0.02	0.13
10 GHz – 16 GHz	0.02	0.13
16 GHz – 20 GHz	0.03	0.40
20 GHz – 24 GHz	0.03	0.54
24 GHz – 26.5 GHz	0.04	0.56

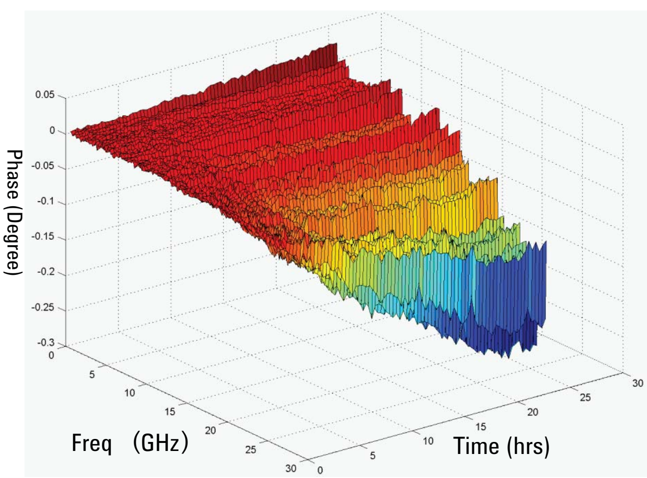
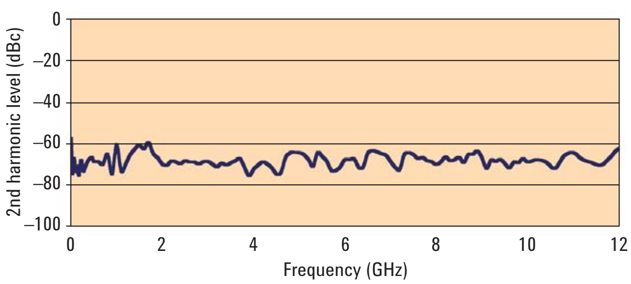


Figure 48. PNA-X after 24 hours: S_{11} phase drift versus time [1, 2]

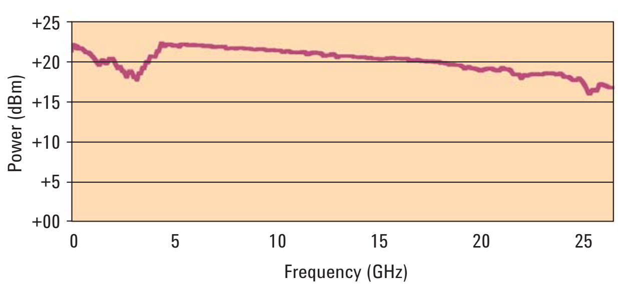
Outstanding Performance

Table 2: PNA-X specifications

Parameter	Configuration: PNA-X N5242A Option 200/400
Frequency range	10 MHz to 26.5 GHz
Number of ports	2 or 4
Dynamic range	127 dB
Noise floor	-114 dBm
Max output power	+13 dBm
Receiver 0.1 dB compression point	+12 dBm input
Trace noise	0.005 dB rms at 100 kHz IFBW -5 dBm
Power sweep range	38 dB
Max IF bandwidth	5 MHz
Measurement speed	4.5 us/pt
Display size	26.4 cm
Touch screen	Yes



Typical PNA-X source harmonics



Typical PNA-X ouput power

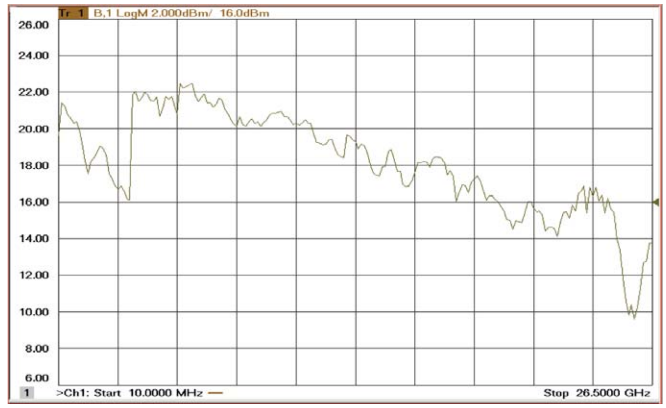


Figure 49. Typical output source power of fully-configured PNA-X

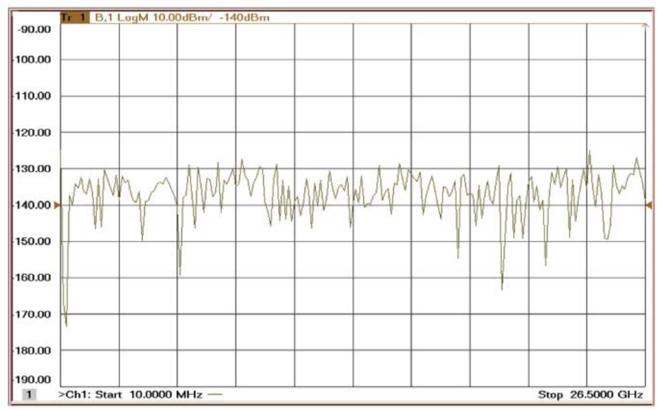


Figure 50. Typical PNA-X noise floor with direct connection to receiver

PNA-X—Completing the Solution

Protect confidential data

The best method for maintaining security is to remove the hard disk drive. The PNA-X provides a removable hard disk drive as a standard feature, enabling the user to remove it for safe storage. Also, the PNA-X can suppress frequency information from the screen and disable file saving.

Protect your software investment

Agilent protects investment in 8753, 8720 and 8510 software by providing full code emulation in the PNA-X.

Network analyzer forum

Visit the online network analyzer discussion forum at ***forums.tm.agilent.com*** to learn how your peers are solving some of their most challenging measurement problems.

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