

Keysight Technologies

Going Beyond S-parameters with an Advanced Architecture for Vector Network Analysis

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In both R&D and manufacturing, engineers face a number of significant challenges when testing radio frequency (RF) components. In R&D, solving design challenges faster and with fewer design iterations is paramount. Manufacturing demands ever-lower test times and test costs, while maintaining accuracy and maximizing yield.

One way to ease the pressure is with a flexible, highly integrated measurement solution such as the Keysight Technologies, Inc. N5242A PNA-X microwave network analyzer. With its advanced architecture, the PNA-X not only delivers excellent performance and accuracy, but it also can be configured for a variety of measurements beyond the traditional scattering parameters (S-parameters) associated with network analyzers. Built-in elements such as a second signal source and frequency combiner enable accurate, informative characterization of nonlinear behavior in RF and microwave devices, particularly amplifiers, mixers and frequency converters.

Ensuring accurate system simulation

Accurate magnitude and phase measurements are crucial to modern wireless and aerospace/defense systems. During the design phase, system simulations need highly accurate component characterizations to ensure that the system will meet its performance requirements. In manufacturing, accurate measurements verify that each component meets its published specifications.

S-parameters are the most widely used measurements of RF components – filters, amplifiers, mixers, antennas, isolators and transmission lines. These measurements characterize the complex-valued (magnitude and phase) reflection and transmission performance of RF devices in the forward and reverse directions. They also fully describe the linear behavior of RF components, which is necessary, but not sufficient, for full-system simulation. Deviations such as non-flat amplitude response versus frequency or non-constant-slope phase response versus frequency can cause serious system degradation. System impairments also result from the nonlinear performance of some RF components. For example, amplifiers exhibit gain compression, amplitude-modulation-to-phase-modulation (AM-to-PM) conversion and intermodulation distortion (IMD) if driven at power levels that exceed their linear range.

Outlining the core measurements

The most commonly used instrument to characterize RF components is the vector network analyzer (VNA). A traditional VNA contains a single RF signal generator that provides a stimulus for the device under test (DUT) and multiple measurement receivers to measure incident, reflected and transmitted signals in both the forward and reverse directions (Figure 1). The source sweeps in frequency at a fixed power level to measure S-parameters and sweeps its power level at a fixed frequency to measure amplifier-gain compression and AM-to-PM conversion. These measurements characterize linear and simple nonlinear device performance.

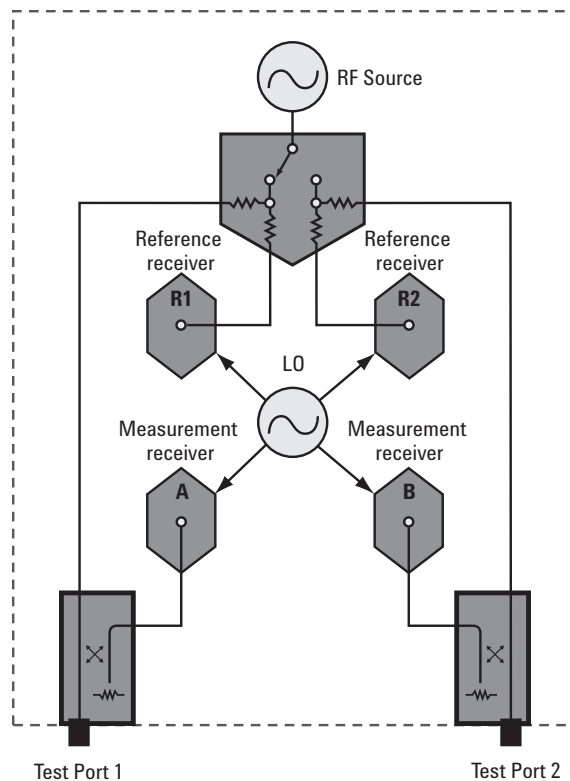


Figure 1. Block diagram of a traditional two-port VNA

For basic S-parameters and compression testing, the source and receivers are tuned to the same frequencies. By offsetting the source and receiver frequencies, however, amplifier harmonics can be measured by tuning the receivers to integer multiples of the stimulus frequency. The ability to offset the source and receiver frequencies also enables measurements of magnitude, phase and group-delay performance of frequency-translating devices such as mixers and frequency converters.

While these measurements are typically done with a continuous-wave (CW) stimulus, many devices require testing with a pulsed-RF stimulus, which means the test signal must be gated on and off with a specific pulse width and repetition rate.

Traditional VNAs have two test ports, which was sufficient when most RF devices had only one or two ports. With the rapid rise of wireless communication, three- and four-port devices have become commonplace, and as a result, two- and four-port network analyzers are equally prevalent.

Simplifying amplifier and mixer measurements

Available with two or four ports, the PNA-X features four major improvements to the traditional VNA architecture:

- **Two sources:** Frequency and power level settings for the second internal source are independent from those of the main source. The second source can be used for nonlinear amplifier tests such as intermodulation distortion (IMD) or as a fast, local oscillator (LO) signal for testing mixers and converters.
- **Signal combiner:** The internal signal combiner can sum the two sources prior to the associated test-port coupler of the instrument. This simplifies the setup of amplifier tests that require two signal sources.
- **Switching and access points:** Additional switches and RF access points enable flexible signal routing and the addition of external signal-conditioning hardware (e.g., a booster amplifier) or external test equipment (e.g., a digital signal generator or vector signal analyzer).
- **Pulse capabilities:** Internal pulse modulators and pulse generators provide a fully integrated pulsed S-parameter solution.

These improvements simplify test setups and improve test times when measuring amplifiers, mixers and converters. They also work together to expand the range of measurements that can be made with a single set of connections to the DUT. Figure 2 shows an example of simultaneous measurements of S-parameters, gain and phase compression and fixed-signal IMD on an amplifier.

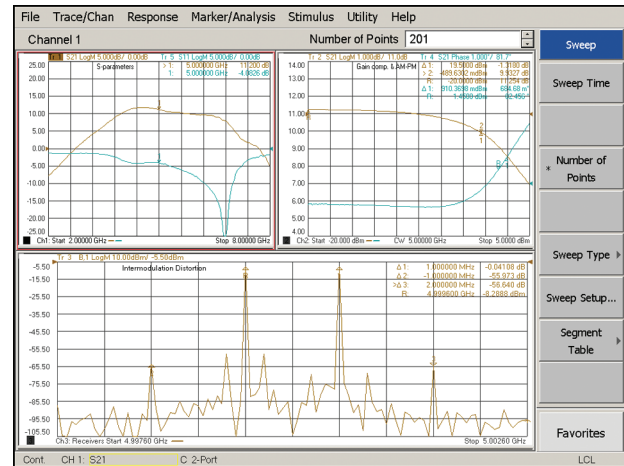


Figure 2. PNA-X example showing simultaneous measurements of amplifier S-parameters, compression and IMD

Enhancements in both sources also simplify amplifier and mixer measurements. For example, the maximum signal power available at the test ports is typically +13 to +20 dBm (depending on model and frequency). This is very useful for driving amplifiers into their nonlinear region and is often required when using a source as an LO signal for testing mixers. The sources also contain low harmonics (typically –60 dB or better), which improves harmonic and IMD measurement accuracy. Also, a power sweep range of typically 40 dB makes it easier to characterize an amplifier's transition from linear to nonlinear operation.

Addressing a variety of measurements

While a VNA needs just a single RF source to measure S-parameters, compression and harmonics of components, a second internal source enables complex nonlinear measurements such as IMD, especially when coupled with a signal combiner.

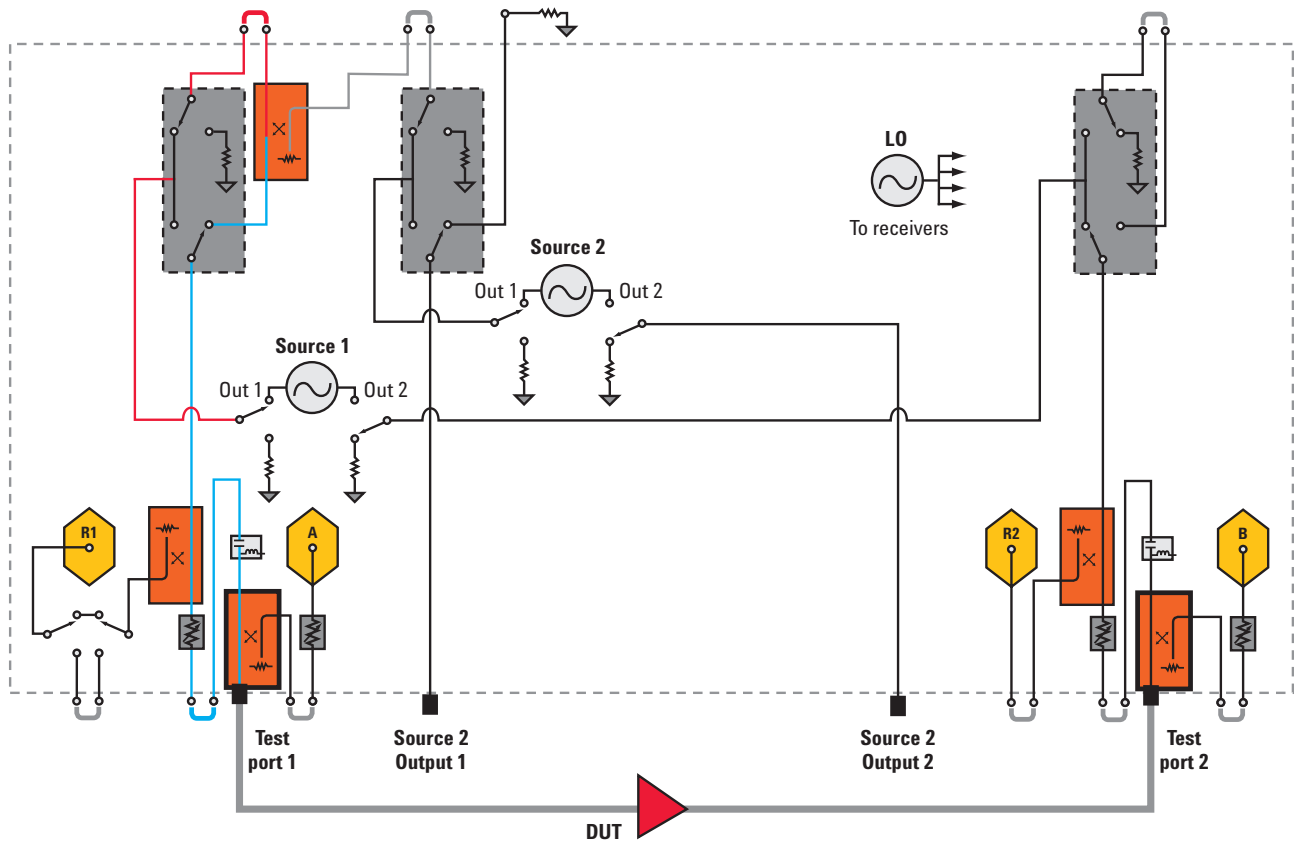


Figure 3. Block diagram of a two-port PNA-X configured for IMD measurements

For IMD measurements, two signals are summed using the signal combiner and then routed to the input of an amplifier under test (AUT). Figure 3 shows how the PNA-X accomplishes this with the internal sources and combiner.

AUT nonlinearities will cause intermodulation products to appear alongside the amplified input signals. In communications systems, these unwanted products fall within the operating band and cannot be removed by filtering. In practice, only the third-order products are measured because they are the most significant contributors to system impairment.

Figure 4 shows an example of a swept IMD measurement performed with the PNA-X. The two middle traces show the stimulus signals and the two lower traces show the IMD products. The upper trace takes advantage of the PNA-X's equation feature to calculate and display the third-order intercept point (IP3).

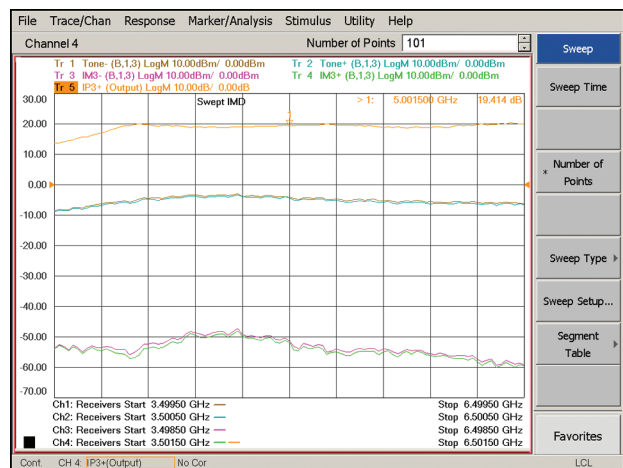


Figure 4. PNA-X example of a swept-frequency IMD measurement

A useful variation of swept IMD is to sweep power levels rather than frequencies. This helps R&D engineers develop nonlinear, behavior-based models of transistors and amplifiers. Figure 5 shows such a measurement: Both the amplitude and phase of the fundamental plus third-, fifth- and seventh-order intermodulation products are shown versus input power.

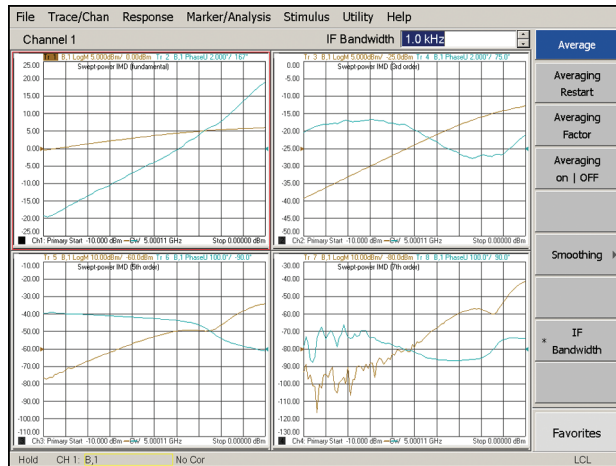


Figure 5. PNA-X example of a swept-power IMD measurement

Using a VNA for these measurements offers three advantages over other approaches. First, a single test instrument and a single set of connections can produce a full suite of measurements: S-parameters, gain compression, output harmonics, IMD and so on. Second, with the VNA's power-meter-based calibrations, measurement accuracy is higher than that obtained using a spectrum analyzer. Finally, this measurement would take several minutes using a spectrum analyzer and two standalone signal generators, but only takes about 0.6 second on the PNA-X.

Phase-versus-drive is another common two-source test easily accomplished with the PNA-X. This parametric test characterizes an amplifier's small signal performance in the presence of a large adjacent-channel or out-of-band signal. One large signal and one small signal, each at different frequencies, are summed and delivered to the AUT; the power of the large signal is varied (using a power sweep) while the S₂₁-phase of the smaller signal is measured.

Another two-signal technique used to develop nonlinear, behavior-based transistor and amplifier models is called “hot S-parameters.” This method characterizes the small signal S-parameters of an amplifier (or often, just S₂₂) at a given frequency in the presence of a large (hot) input signal that is offset from the S-parameter test signal and that drives the AUT output into compression. Care must be taken to ensure that the hot signal coming out of the AUT is not greater than the damage level of the VNA.

Measuring balanced components

Balanced circuitry reduces susceptibility to, and generation of, electromagnetic interference. Balanced components may be balanced-to-single-ended devices with three RF ports or balanced-to-balanced devices with four ports. Testing these components is easy with a four-port VNA, which can measure differential- and common-mode responses as well as mode-conversion terms.

These tests can be accomplished with either a single-ended or true-mode stimulus. The single-ended method tests one port of the DUT at a time (requiring just one RF source) and mathematically calculates the differential-, common- and cross-mode behaviors. This is the fastest and most accurate technique provided the applied power levels keep the AUT in a linear or mildly compressed region of operation.

Testing the balanced performance of an amplifier under high-drive-level conditions, in which nonlinearities cause significant errors in single-ended measurements, requires a true-mode stimulus. This method applies two signals of equal amplitude to the input terminal pair of an amplifier with a phase difference of either 180 degrees (the differential-mode signal) or zero degrees (the common-mode signal). Conceptually, this is easily done with a dual-source VNA, but two things are required for accurate measurements: high-resolution adjustment of phase difference between sources and the ability to adjust source phase and amplitude to offset input mismatch caused by the interaction of source output impedance and AUT input impedance. The PNA-X meets both of these requirements.

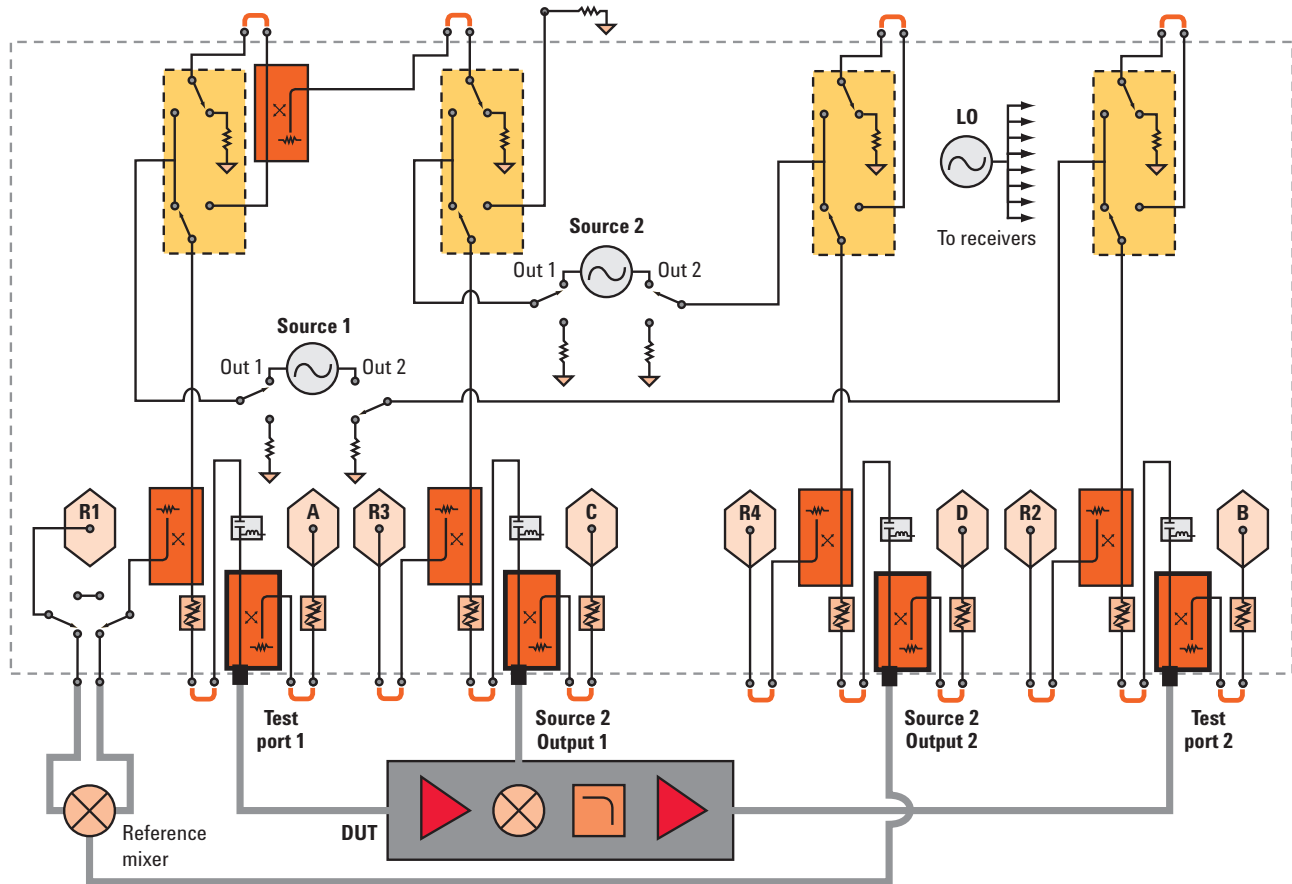


Figure 6. Block diagram of a four-port PNA-X configured for vector-mixer measurements

Testing mixers and converters

A second internal source is also useful for testing frequency-translating devices such as mixers or converters, which require an LO signal in addition to an input stimulus. The second source is especially useful for swept-LO testing, where the LO signal is swept in conjunction with the RF input signal but with a fixed offset. This approach is often used to measure the front-end components in broadband frequency converters. Using an LO signal derived from a VNA's internal source provides considerable speed improvements when compared to using an external signal generator (up to 35 times faster with the PNA-X).

The setup for mixer and converter measurements using the PNA-X is very simple. To test port match and conversion loss or gain, the input, output and LO ports of the DUT are connected to ports one, two and three, respectively, on the PNA-X. Adding a reference mixer enables testing of the phase or group-delay response of a mixer or converter. The dual-outputs of the second source can be used to drive both the reference mixer and the DUT mixer (Figure 6).

Conclusion

VNA-based test systems provide the engine for measuring RF and microwave components used in wireless communication and aerospace/defense systems. Compared to traditional VNAs, the advanced architecture of the Keysight PNA-X microwave network analyzer provides greater flexibility, enabling engineers to measure a broad range of high-performance, leading-edge components with a single set of connections. The key additions are the second signal generator and an internal signal combiner, which simplify measurements of amplifiers, mixers and converters. In addition to traditional single-source measurements of S-parameters, compression and harmonics, the two sources can be used in IMD, phase-versus-drive, hot S-parameter and true-mode stimulus testing. The attributes of high port power, low harmonics and wide power-sweep range are well-matched to the requirements of today's devices.

