WHITE PAPER

Power Amplifier Performance Verification Essentials

Modulation distortion analysis using the ENA-X network analyzer

KEYSIGHT

Challenges of Power Amplifier Characterization

5G implementation requires a revolutionary transformation in communication technology. As a result, the wireless communications industry's emphasis on system integration, power efficiency, and device reliability continues to grow. Critical requirements for 5G infrastructure necessitate faster development of highly integrated, reliable RF devices capable of faster, ultra-low latency data rates.

The power amplifier (PA) is essential to modern RF communication chains, shown in Figure 1. As such, the PA is a critical determining factor of transmission quality and battery life for 5G transmitters.

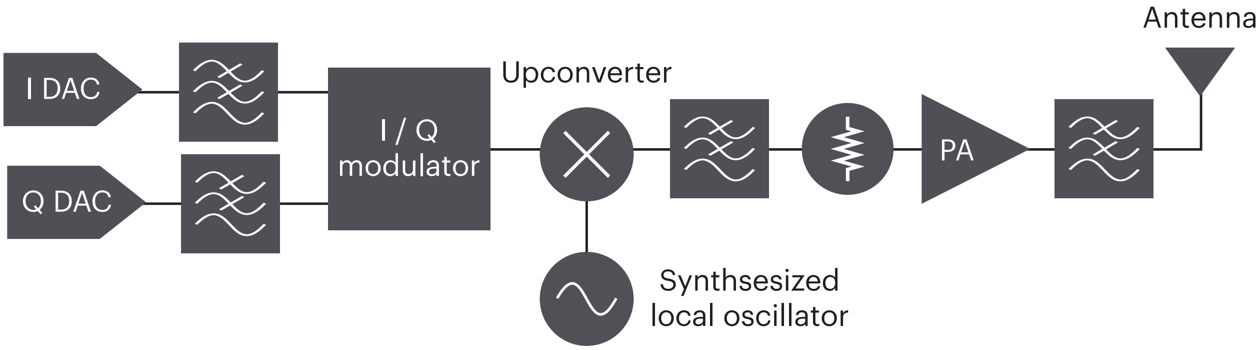


Figure 1. Diagram of a typical RF signal path, including a power amplifier

To satisfy 5G system requirements, developers need accurate and repeatable testing to verify transmitter component performance. The wide bandwidth and complex modulation schemes required to implement 5G impose stricter component error vector magnitude (EVM) qualifications than previous generations of telecommunication systems. Developers face increasing challenges in shortening system development cycles while certifying PA conformance with a traditional EVM measurement and vector signal analyzer (VSA) setup, shown in Figure 2.

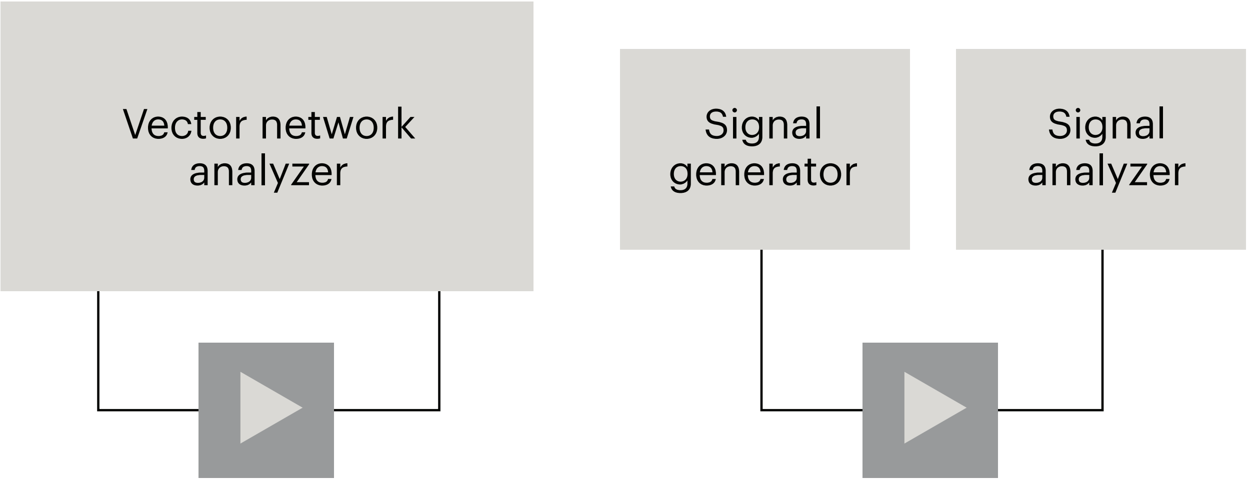


Figure 2. Traditional PA test requires a VNA for network analysis and VSA for ACPR, noise power ratio, and EVM

Typically, developers conduct nonlinear PA measurements in the time domain using a VSA and vector signal generator (VSG). Then, they follow up with network analysis; we refer to this process as the VSA method. However, Keysight's frequency domain characterization approach, the vector network analyzer (VNA) method, only needs a VSG and ENA-X VNA with modulation distortion software — a signal analyzer is not required. The VNA method improves access to and accuracy of figures of merit (FOM) and reduces test cycle time by up to 50% by simplifying the test setup.

You will learn the following in this white paper:

- Significance of nonlinear power amplifier characterization
- Differences between time-domain and frequency-domain characterization measurements
- Benefits of the E5081A ENA-X network analyzer that optimize high-power PA test

Importance of Nonlinear Power Amplifier Characterization

PA characterization plays a critical role in:

- Verification by developers that the PA meets subsystem performance specifications
- Determination by customers that the PA meets their 5G system requirements
- Assignment of market value to the device based on its performance

Why characterize the nonlinearity of power amplifiers?

While many test parameters exist for robust amplifier characterization, EVM and adjacent channel power ratio (ACPR) are the most critical for PA performance verification. EVM and ACPR quantify PA nonlinearity, data that developers require for two reasons: one, because nonlinear response directly affects signal demodulation and bit error rate (BER), and two, nonlinearities cause spectral regrowth, creating interference in frequency bands outside the channel of interest.

Nonlinearity causes in-band and out-of-band distortion products for PAs stimulated with wideband input signals. While engineers remove linear distortion through filtering, nonlinear effects are harder to address. Developers must quantify the PA's nonlinearity to ensure the device meets efficiency specifications and follows strict 5G EVM and ACPR standards. Essentially, strong linearity indicates that the PA will amplify the input signal without adding distortion.

What is EVM, and why is it important?

EVM is the industry-standard FOM for evaluating the in-band distortion of a communication system. The error vector is the vector difference between the ideal reference signal and the measured signal at a given time. Less than ideal conditions will distort the received and transmitted signals, so quantifying modulated signal quality requires EVM measurements. Modulation standards, such as 802.11ac and 5G New Radio (NR), set the minimum acceptable EVM level.

What is ACPR, and why is it important?

The terms ACPR, *adjacent channel power level, and adjacent channel leakage ratio* (ACLR) all refer to the same thing, namely, the ratio of transmitted power on the assigned channel to the power received in an adjacent radio channel after a receive filter. This FOM measures how much one channel may interfere with another. ACPR is the industry-standard FOM for quantifying out-of-band distortion characteristics. ACPR measurements hold particular importance for the UMTS and LTE standards.

Though EVM and ACPR were important in previous communication system generations, due to rapid increases in system complexity, 5G transmission systems require precise measurements to certify performance compliance to more stringent requirements. For example, the requirements are 3.5% EVM in 256 quadrature amplitude modulation (QAM) to 1% EVM for 1K QAM.

Time Domain Versus Frequency Domain Characterization Measurements

Time domain and frequency domain are two characterization approaches. While traditional time domain characterization was satisfactory for previous needs, 5G NR technologies require a more streamlined characterization method.

Time domain characterization

Time domain measurement refers to measurements taken with respect to time. An oscilloscope is a prime example of a time domain device, measuring voltage and current across a component (y-axis) as a function of time (x-axis). Traditionally, the characterization of PA nonlinearity required measurements taken in the time domain using a VSA and VSG. The VSG provided the input signal to the device under test (DUT), while the VSA captured the output signal and calculated metrics such as EVM and ACPR.

While this method of time domain characterization satisfied past communication requirements, successfully implementing 5G Frequency Range 2 (FR2) systems demands that developers measure performance metrics using extremely wide signal bandwidths in the millimeter-wave (mmWave) spectrum. This next-generation technology makes VSA PA characterization — especially EVM — increasingly challenging for several reasons, shown in Figure 3.

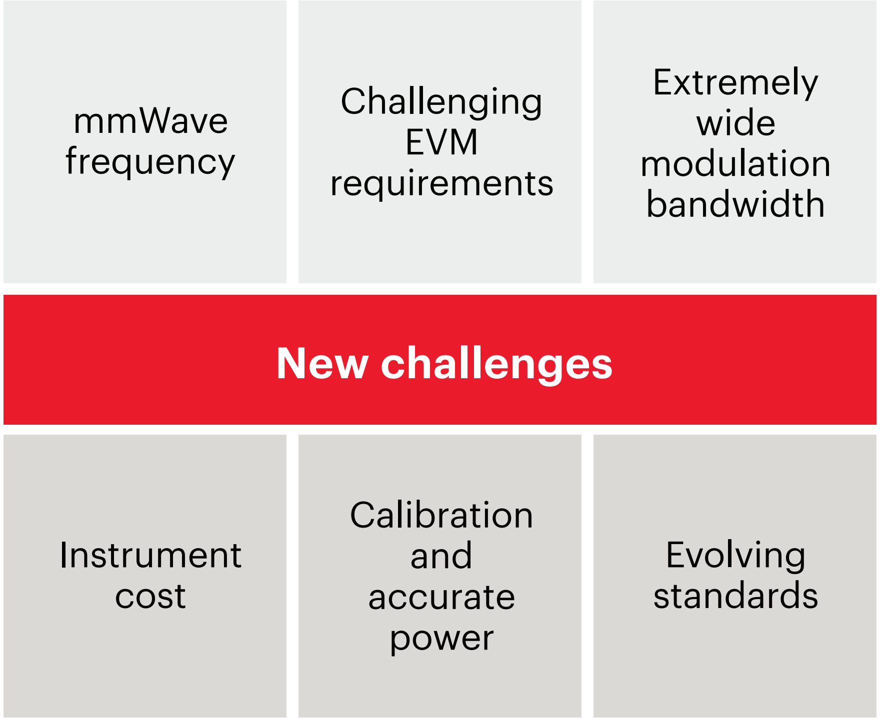


Figure 3. New technological challenges introduced by 5G NR

System and DUT EVM differentiation

Signal source integrity directly impacts EVM results. In the VSA method, the EVM of the test system, or residual EVM, is indistinguishable from the DUT EVM. The VSA assumes whatever error measured is attributable to the PA. Not only is this inaccurate but as EVM requirements grow stricter, it presents a significant barrier to qualifying a PA as 5G-compliant.

In addition, as signal bandwidth gets increasingly wider, the system's signal-to-noise (SNR) ratio degrades. The noise limits the minimum EVM resolvable by the measurement. Random noise at low power levels also results in less accurate and reliable EVM measurements. Nonidealities of the generated input signal and wideband noise at the receiver limit the minimum EVM attainable by the VSA.

Calibration challenges

Issues calibrating the VSA method include complexity, robustness, signal fidelity, and repeatability. While multiple ways to calibrate the test system exist, even the most advanced techniques may include errors — especially when the test signal has a wide bandwidth, and the DUT has a poor mismatch.

Digitizing the input signal using a signal analyzer that does not produce any nonlinear distortion mitigates EVM measurement errors. However, this solution presents significant implementation challenges across wide bandwidths. The solution also requires intimate knowledge of the VSA and drastically slows the entire measurement process. These calibration methods make implementation more complex and suffer from non-robust error mitigation. In many cases, you trade one error vulnerability for another. Signal fidelity presents another issue for the VSA method because of lossy cables and mismatch at higher frequencies, causing the actual signal applied to DUT to deviate from the ideal.

Required equipment

As mentioned earlier, the traditional time domain characterization measurement setup requires three primary pieces of equipment: a VSG, VSA, and VNA. In addition, time domain characterization requires unique cabling and calibration equipment for each instrument. Alternating between the VSA and VNA for DUT parameterization costs more in terms of test hardware, software, and peripherals. It also increases device testing time because of recalibration and serially switching setups. Avoid wasting valuable time manually reconfiguring setups or automating complex switch-based systems by using frequency domain characterization up to 44 GHz on the E5081A ENA-X VNA solution.

Frequency domain characterization

Frequency domain measurement refers to measurements taken with respect to frequency. A VNA is an example of a frequency domain device measuring signal power (y-axis) as a function of a given frequency range (x-axis). VNAs are the go-to component test and electrical network analysis instruments. Quintessential VNA component tests include S-parameters, gain compression, and IP3 measurements.

However, with modulation distortion (MOD) software, the ENA-X goes beyond standard network analysis, directly characterizing PA distortion parameters. The ENA-X includes an integrated upconverter to increase flexibility, so conducting complex wideband modulated measurements only requires a low-frequency vector signal generator (VSG). For example, generating a 44 GHz modulated stimulus requires only a 6 GHz vector signal generator like the Keysight N5281B MXG, shown in Figure 4.

Frequency domain characterization reduces measurement complexity by offering a fully integrated, single-connection, multiple-measurement characterization setup — including EVM and ACPR — on the ENA-X VNA. The ENA-X includes switching in the hardware path, enabling modulated signals to route through the VNA test ports and the reference receiver. By consolidating network analysis and distortion characterization in one setup, the ENA-X enables developers to complete S-parameters, EVM, and ACPR tests without reconnecting the DUT to minimize test cycle time. Additionally, frequency domain characterization using MOD software achieves low residual EVM and enables full vector correction for enhanced accuracy.

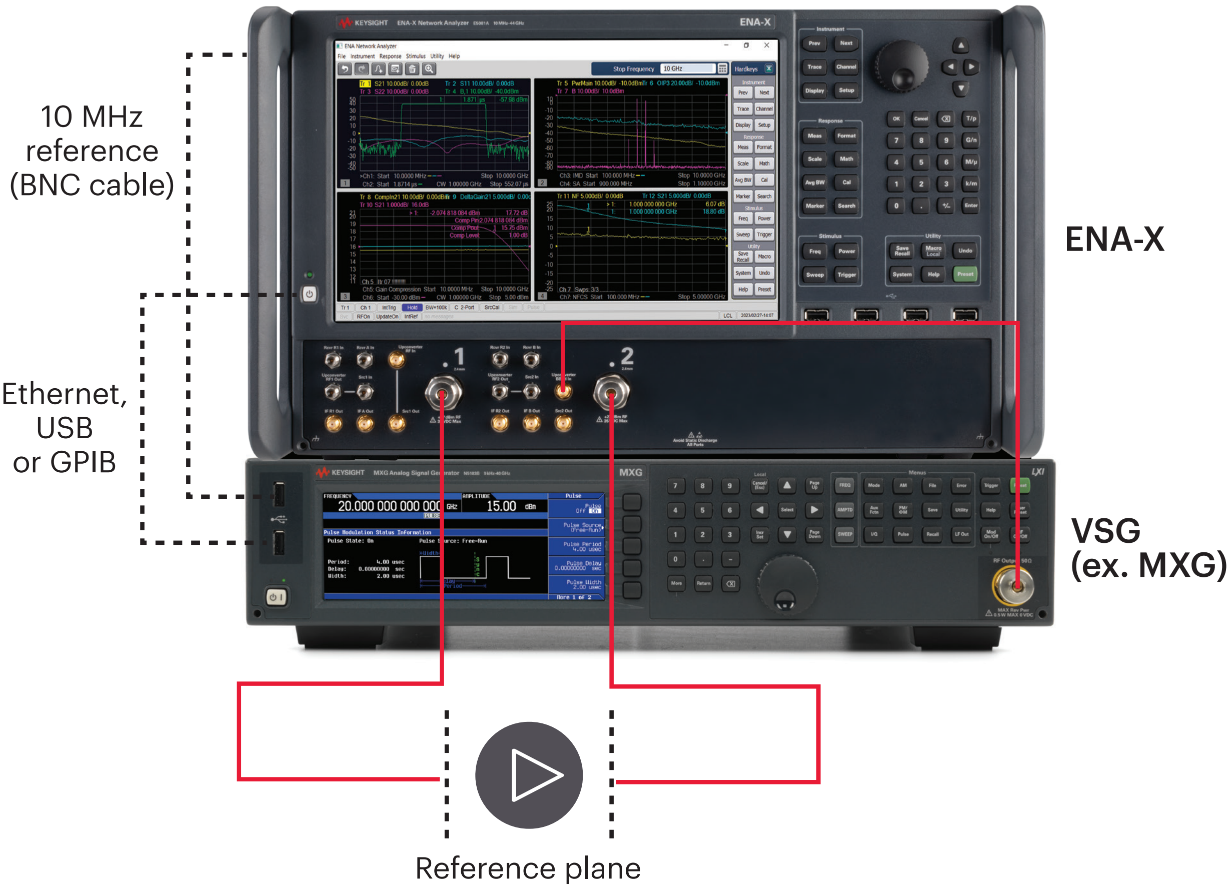
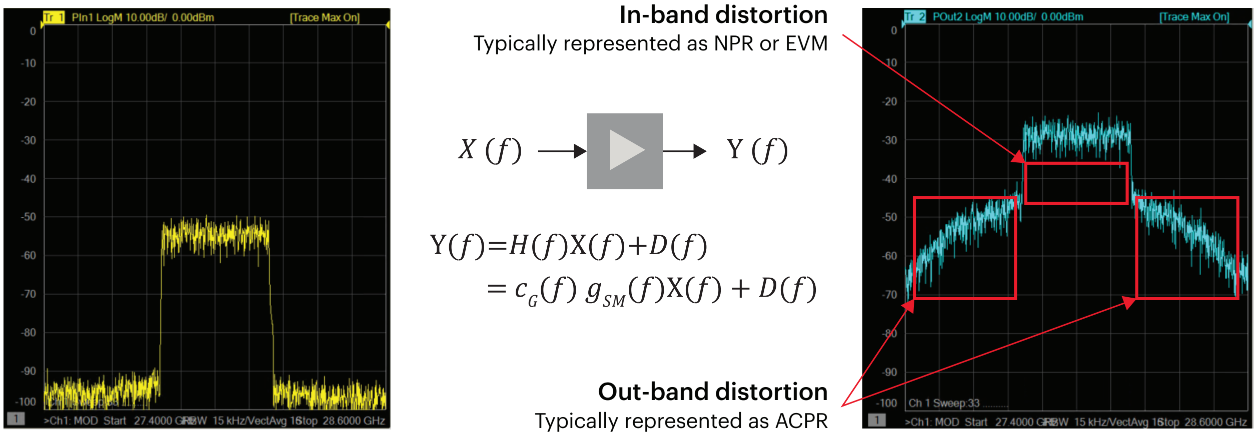


Figure 4. VNA method set-up using the ENA-X network analyzer’s upconverter path with the MXG

What is modulation distortion analysis, and what does it improve?

Increasingly as 5G development progresses, many PAs amplify modulated signal stimulus. Like with simpler signal stimulus, PA modulated signal performance achieves the greatest efficiency at power levels close to the amplifier's saturation point. However, wireless standards, such as 802.11ac, restrict the maximum spurious emissions allowed for a given RF component over a range of frequencies. Developers must characterize amplifiers under these complex modulation schemes to verify performance within these restrictions.

The modulation distortion software application reimagines amplifier distortion measurements using a vector-calibrated ENA-X to achieve accurate and repeatable EVM results, shown in Figure 5. The MXG's wideband input signal stimulates the DUT through our spectral correlation technique as the MOD application measures the input and output signal tone by tone in the frequency domain. Then, the ENA-X stitches the frequency together to achieve a wideband coherent measurement. The measured output signal decomposes into linearly and nonlinearly correlated components. At this point, the MOD distortion application calculates EVM and ACPR in the frequency domain.



$$Y(f)=H(f)X(f)+D(f)$$
$$= c_G(f)\, g_{SM}(f)X(f) + D(f)$$

Figure 5. EVM and ACPR measurements on the VNA showing the in-band distortion buried under the signal

The ENA-X uses state-of-the-art calibration techniques to remove any contributions of the test setup — input port mismatch, channel power, and source error contributions — from the measurement. The wider dynamic range and source power calibration also create more accurate and repeatable EVM measurements.

Simple setup and a single connection

The same setup used for measuring S-parameters, gain compression, and noise figure also captures EVM and ACPR. You can take both linear and nonlinear performance parameters with one setup, one connection, and one “cal-all” calibration.

Best accuracy and measurement repeatability

When using the ENA-X to measure nonlinear DUT behavior, calibration methods like fixture de-embedding move the calibration plane to the DUT plane. Input port mismatch and channel power are also correctable — as is the IQ data — yielding a flat input signal at the reference plane with suppressed signal ACPR. Given this measurement’s coherent nature, every trace comes out the same, enabling the ENA-X calibration techniques to deliver measurement reproducibility and input signal fidelity quickly.

Lowest residual EVM

The MOD application isolates the distortion contributions of the DUT due to a wider system dynamic range or lower noise floor. This means the frequency domain PA characterization differentiates system distortion and noise from the DUT’s EVM, purifying the PA characterization and revealing the true performance of the PA.

Key Benefits of the ENA-X VNA That Enhance High-Power Amplifier Test

While low-power conditions sufficiently capture linear S-parameters, gain compression and distortion tests require high-power input signals. Further, most PA designs will operate close to saturation to optimize power-added efficiency (PAE) while maintaining overall system-level performance targets. The SNR or noise figure dominates the EVM for low power levels, and at high power, the non-linear distortion dominates EVM.

In order to complete nonlinear PA characterization, you will need a booster amplifier for the high-power test setups. But including a booster amplifier in the setup and calibration adds complexity and error potential to the measurement. The ENA-X was designed with these high-power considerations in mind.

Notably, the E5081A network analyzer provides direct receiver access and receiver attenuators for high-power PA test.

Direct receiver access

The booster amplifier's extremely high reverse isolation, S21, makes accurate DUT S11 measurements challenging using the standard set up. The ENA-X network analyzer provides direct internal receiver access through a configurable test set architecture as a workaround, shown in Figure 6.

The configurable architecture enables developers to reroute the S11 DUT signals through a path alternate to the booster amplifier directly to the ENA-X receiver. This flexibility allows for accurate S11 amplifier measurements while using high-power signals.

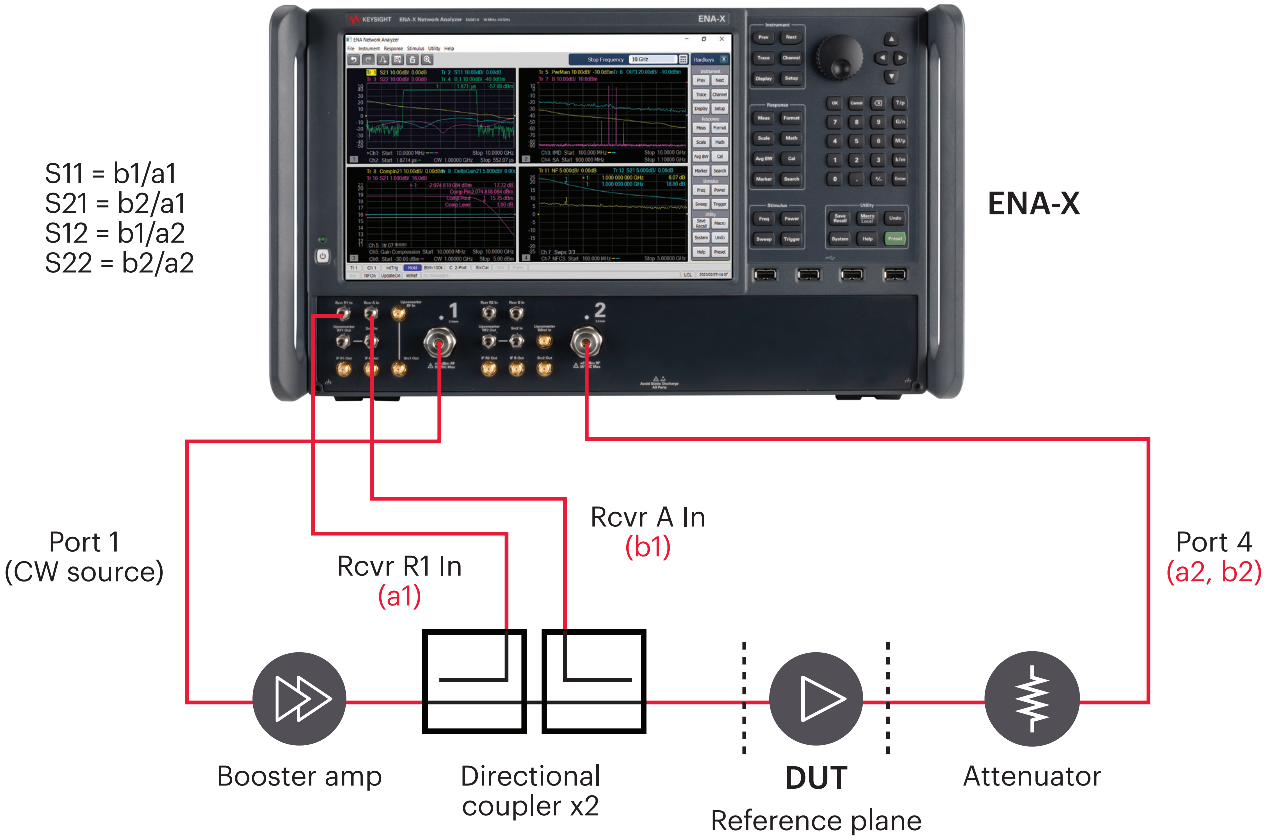


Figure 6. A typical configuration for high-power measurements with the 2-port E5081A is shown.

Receiver attenuators

The test instrument's internal component power-handling capability is a key consideration for high-power measurements. High power levels risk damaging the network analyzer, causing costly repairs. Typically, a high-power amplifier test requires an external attenuator to protect against potential receiver compression leading to inaccurate measures or test set damage. However, adding external fixtures to the test set adds error potential and calibration complexity. To minimize the risk of instrument damage and measurement error, the ENA-X network analyzer consolidates the setup through built-in receiver attenuators, eliminating the need for external attenuators.

Conclusion

Designing power amplifiers compatible with 5G infrastructure poses significant challenges because of wide bandwidth signals, complex modulation schemes, and increasingly strict EVM and ACPR requirements. The traditional VSA characterization method no longer satisfies design engineers' needs. The E5081A ENA VNA modulation distortion solution provides several PA characterization benefits that overcome wideband measurement challenges. Those benefits include:

- Wide dynamic range that enables low residual EVM due to the lower noise floor.
- Easy calibration for vector-corrected measurements that enhance signal fidelity at the DUT input, resulting in significantly improved measurement reproducibility.
- Sophisticated software that permits distortion analysis under modulated conditions.

For any PA characterization, a VNA is essential to characterize the linear and nonlinear performance. With the MOD application, the test system makes traditional VNA measurements, EVM, and ACPR. The unique architecture of the ENA-X network analyzer enables RF developers to perform multiple multiport measurements on a single simplified setup, improving measurement accuracy and reproducibility, reducing test cycle time, and generating the lowest residual EVM results on the market.

Related links

- **Article:** An Innovative Method for High-Accuracy EVM Measurements
- **Video:** ADS2021 Compact Test Signal and Distortion EVM
- **Data Sheet:** M983xA Series PXIe Vector Network Analyzer
- **Product Fact Sheet:** Use the Right Vector Network Analyzer for the Job
- **Configuration Guide:** E5081A ENA-X and E5080B ENA

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