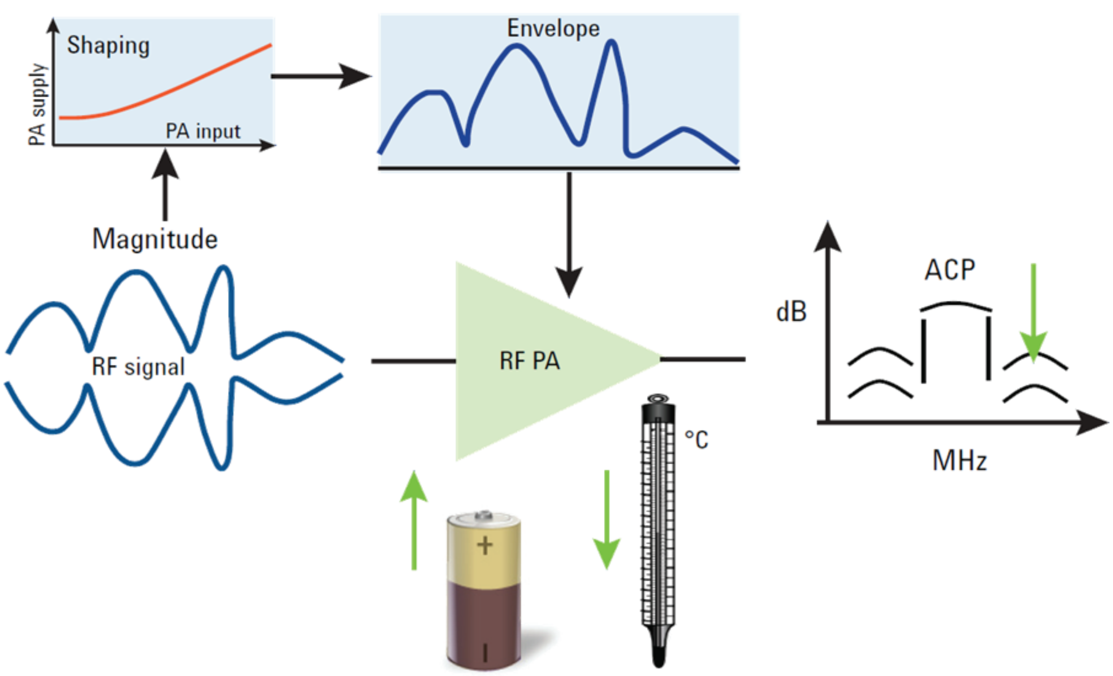
Keysight Technologies

Solutions for Implementing Envelope Tracking in Power Amplifiers

Application Note



Fast and Efficient Configuration and Test of Envelope Tracking Systems—From R&D to Design Verification and Into Production—Using a Range of Flexible and Accurate Hardware and Software Solutions

Overview

By their very nature, Power Amplifiers (PAs) are power hungry, nonlinear devices. They are also a critical component in modern mobile communication devices like smartphones and tablets, which hold increased battery capacity and power efficiency at a premium. PA techniques like Crest Factor Reduction (CFR), Digital Pre-Distortion (DPD) and Envelope Tracking (ET) were introduced as a way to overcome these issues, while at the same time reducing problems associated with distortion and nonlinearity. ET offers significant advantages in terms of improved battery life and RF PA performance, along with reduced heat dissipation. Also, it's an increasingly important capability for PAs that support high peak/average modulation schemes.

With smartphones and tablets increasingly employing wider bandwidths, Multi-Input Multi-Output (MIMO) technology, and higher order Orthogonal Frequency Division Multiplexing (OFDM) modulation formats to achieve higher data rates, the use of ET is projected to become even more critical.

Problem

While a PA operating in ET mode does exhibit greater power efficiency and better performance, these benefits come at the price of complexity. And it's this complexity that makes configuring and testing an ET system so challenging.

Consider a basic ET system block diagram as shown in Figure 1. Here, the envelope detector generates the envelope by taking the magnitude of the IQ waveform and then applying a shaping table to determine the actual voltage supplied to the PA. Next, a shaped envelope is supplied to the Envelope Tracking Power Supply (ETPS), which modulates the Vcc so that the bias voltage tracks changes to the RF input waveform. Finally, the PA outputs the amplified RF signal.

Unlike polar modulation, ET does not apply a level limiter or operate with a fixed amplitude PA input signal. Instead, it uses a mixture of open and closed loop feedback, with delays introduced to the IQ or RF path to match those in the supply modulation path. In an open loop system, the shaping curve is applied to the envelope signal to match the supply voltage versus RF gain in the PA. Pre-distortion may also be used.

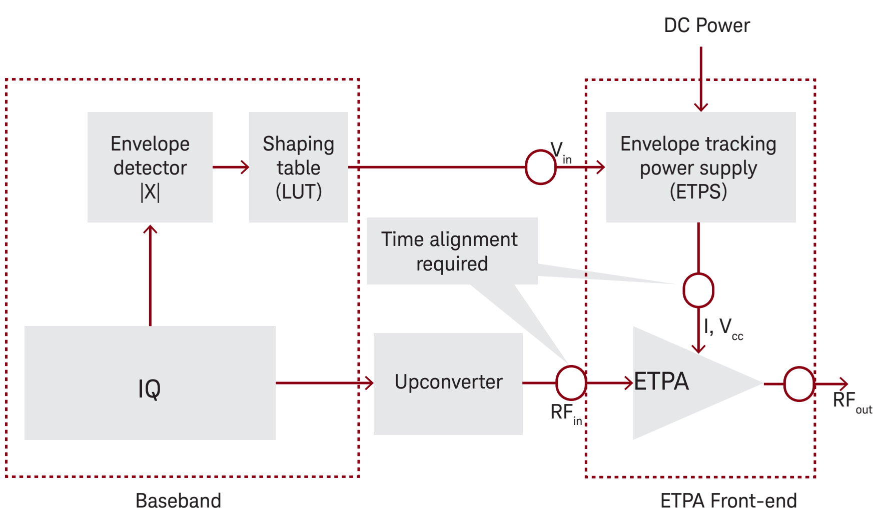


Figure 1. Shown here is a basic ET system block diagram.

What makes the use of ET mode so challenging is that the PA has to be treated as a 3-terminal active device, and that's just the beginning. A low noise, high bandwidth power supply is needed, which usually operates in a combination of switched and linear modes. Additionally, a shaping curve or table (which determines characteristics of the ET system) has to be designed and optimized—a process that requires multiple difficult steps and often takes a great deal of time and effort (Figure 2).

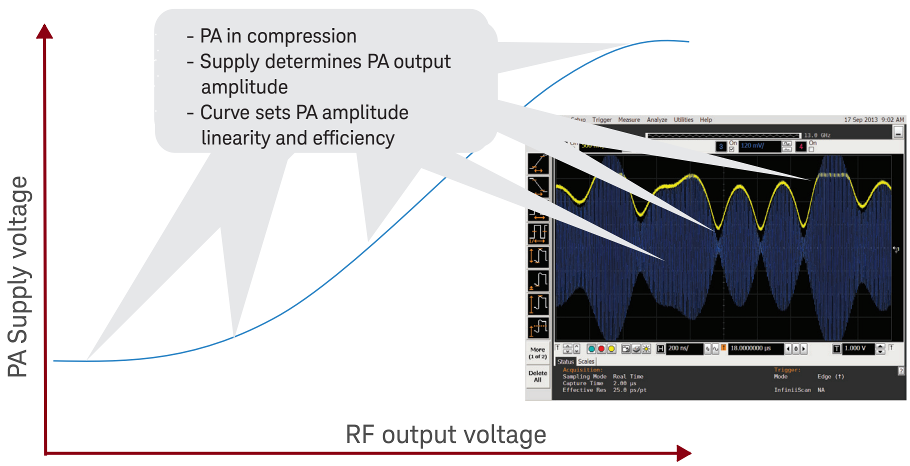


Figure 2. A number of different steps are required when designing an envelope curve to achieve different design goals (e.g., maximum efficiency or linearity).

Solution

To properly test or evaluate the shaping table and all other ET components (e.g., ETPS, RF PA and ET-based radio design) when implementing an ET system, a number of different factors must be considered. In addition to the actual design of the shaping table and the characterization of the PA, the designer will also likely need to check the interaction between the ET system operation and antenna mismatch. The envelope signal and RF signals need to be aligned to within 1 ns or better, to avoid an asymmetric Adjacent Channel Leakage Ratio (ACLR). Linearity measurements will also need to be made as they are a critical metric for assessing the performance of the ET system.

Other issues that must be considered include ripples in group delay through the ETPS that cause excess distortion in the RF PA output and the receiver band noise floor. In an ET system, all but the RF carrier decoupling capacitors are removed. Spurious signals and noise on the power supply line for the RF PA appear on the output. Any increase in the transmitter noise floor that appears at the receiver duplex frequency in a Frequency Division Duplexing (FDD) radio can be particularly troublesome as this noise gets coupled through the antenna duplexer, reducing the receiver's sensitivity.

Another factor for the designer to consider is how to measure the improvement in system performance that the use of ET enables. Measuring the performance of the RF PA by itself is a very difficult undertaking that requires measurement of current with sufficient bandwidth. The supply I, V and RF power measurements need to be time aligned with a very high degree of accuracy to provide an instantaneous PAE measurement. A much easier approach entails measuring the performance improvement as a combination of the ETPS and the ET PA using a bench supply to measure average current.

Complicating these issues is the sheer logistical challenge associated with making all of the necessary measurements (Figure 3). Dealing with this challenge requires two things: an ET design and test flow like that shown in Figure 4, and a highly flexible and accurate ET test system based on common tools to enable effective teamwork.

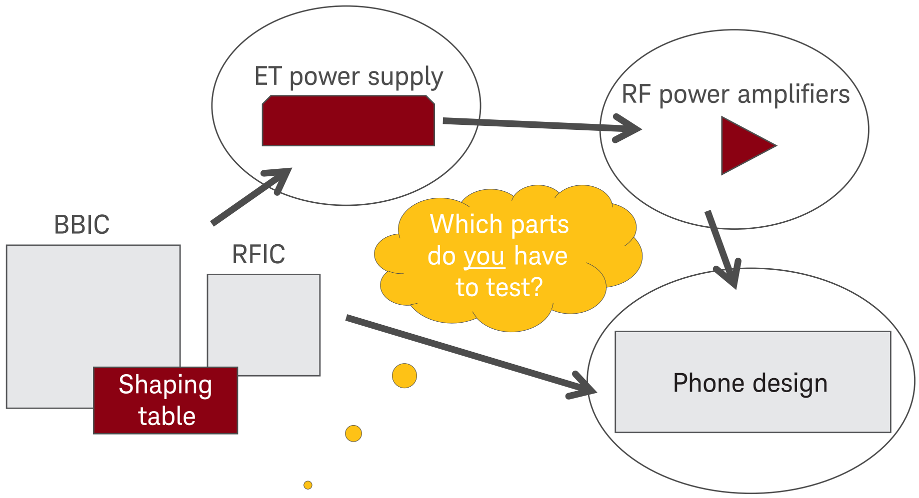


Figure 3. Testing or evaluating an ET systems presents many logistical challenges.

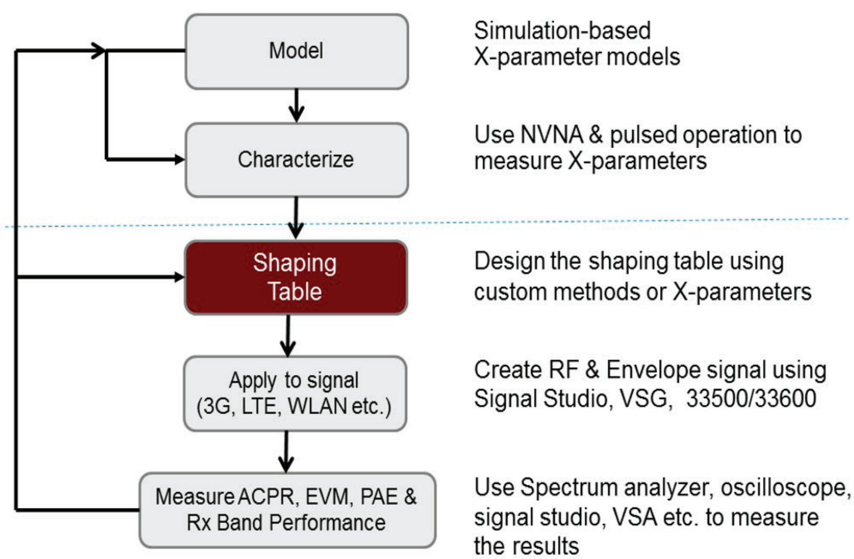


Figure 4. Shown here is a proposed ET design and test flow.

Fortunately, Keysight Technologies, Inc. offers multiple solutions for the flexibility, accuracy and continuity needed to effectively evaluate ET components and ET-based radio designs. They include simulation environments, signal generators and analyzers, signal generation and analysis software, LXI bench instruments, and PXI modular instruments, which can be used with the ET design and test flow shown in Figure 4 to provide today's designers a solution for ET system test—from R&D to design verification and into production.

For the modeling portion of the flow, SystemVue electronic-system level design software or Advanced Design System (ADS) software can be utilized. During characterization, the Nonlinear Vector Network Analyzer (NVNA) is used to measure the nonlinear behavior of the PA. That information can then be used to create X-parameter* models. ADS can also be used to simulate and generate X-parameter models. Swept frequency and pulse power measurements are performed using the PNA-X microwave network analyzer and N6705B DC power analyzer with N6781A Source/Measurement Unit (SMU).

Next, the shaping table is designed using custom methods or X-parameters. The RF and envelope signal is created (with the shaping table applied to the signal) using N7614B Signal Studio software for PA test, the vector signal generator MXG/EXG/ESG and 33522B/33622A Trueform arbitrary waveform generator. Finally, the signal's PAE, ACLR and receiver band performance is measured and the result analyzed using the X-Series signal analyzer, Infiniium 9000A oscilloscope, and N7614B Signal Studio or 89600 VSA software.

ET System Testing In Detail

As shown in the Figure 4, testing ET systems involves a number of tasks, including: modeling and simulation, waveform creation, synchronized RF and envelope signal generation, PA distortion testing, and measurement of instantaneous PAE. A typical test system for the bench that can be used to perform these tasks is shown in Figure 5.

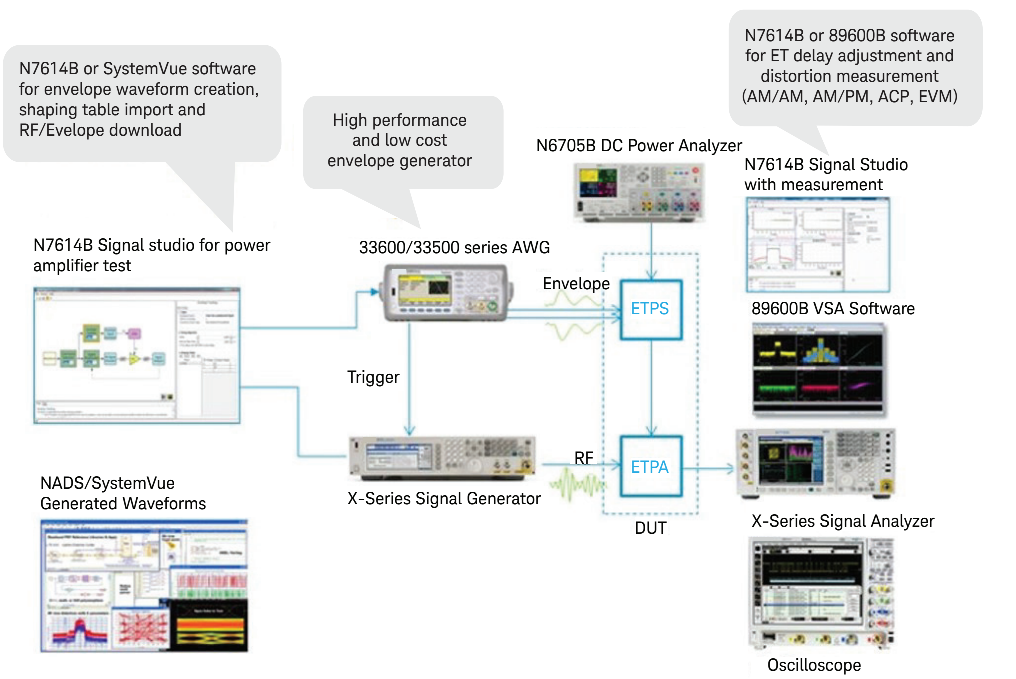


Figure 5. Shown here is a typical PA test solution configuration with support for ET. It includes waveform generation software, a signal generator for the RF signal, an arbitrary waveform generator for the envelope signal, a DC power supply, and a signal analyzer for spectrum and distortion measurement.

In this case, for system-level modeling and simulation, SystemVue is used to make performance trade-offs between the ET system's baseband and RF performance. Like SystemVue, ADS helps designers develop and share customized models prior to performing simulations to better understand performance and the impact of different devices. However, while SystemVue works at the system level, ADS targets device simulation and is extensively used in R&D. Both SystemVue and ADS include links to the measurement hardware compatible signal generation and signal analysis applications, Signal Studio software for signal generation, and 89600 VSA software for signal analysis.

Keysight's N7614B Signal Studio features an ET option that offers designers an easy way to generate both the RF and envelope signals required for evaluation and performance test of the ET system. An ET control window in Signal Studio provides access to the shaping table management and hardware control functions needed to create the envelope signals. Signal Studio can download the RF waveform directly to the Keysight vector signal generator, which can be the MXG, EXG or ESG. The N7614B can also download the envelope waveform directly to a 2-channel AWG—either the 33522B (up to 30 MHz, 250 MSa/s) or 33622A (up to 120 MHz, 1GSa/s)—with its differential (tracking) outputs, low broadband noise and precision triggering alignment with the vector signal generator, where the RF signal is generated.

Once waveforms are downloaded, Signal Studio's ET control function allows for both automatic and manual timing adjustment of RF and envelope signals giving 1-ps resolution, without the need to regenerate waveforms. This enables fine tuning of envelope timing by monitoring the adjacent channel power or error vector magnitude of the ETPA output.

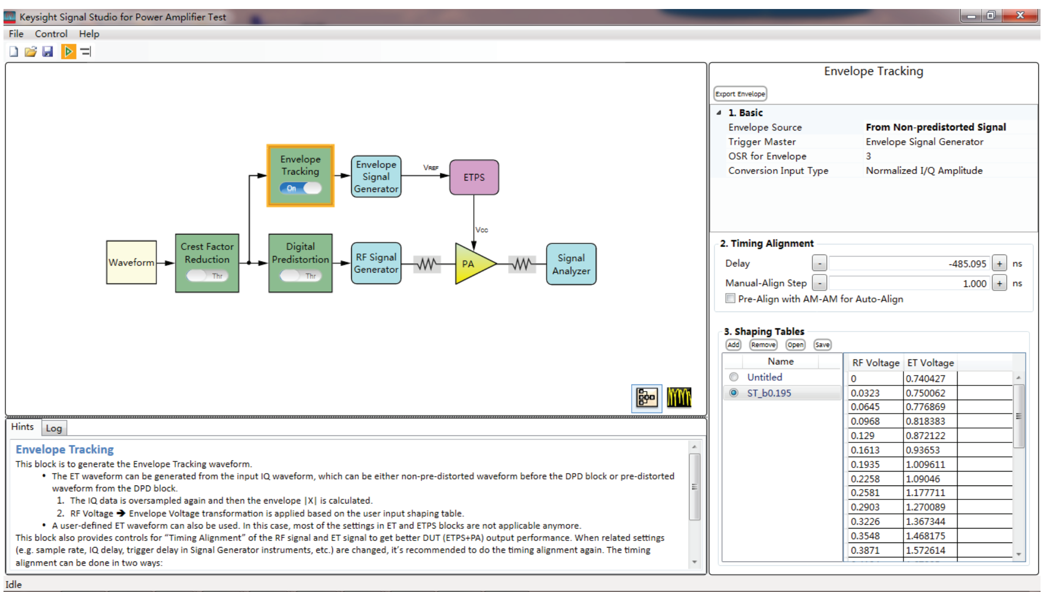


Figure 6. Shown here is the N7614B Signal Studio for PA envelope tracking block with shaping table management, timing alignment and envelope generation settings.

If the absolute time delay must be measured, the 9000A scope alone can be used. With up to 4 GHz bandwidth, 20 GSa/s, 12-bit+ resolution (with averaging), sub-nanosecond time synchronous RF capture, and differential input/high impedance probes, it provides the measurement speed, ease of use and performance needed for RF waveform, envelope waveform, envelope voltage, and current measurements.

The entire ET system (RF signal, envelope signal, ETPS, and RF PA performance) can then be evaluated using the X-Series signal analyzer, PXA/MXA/EXA, and N7614B Signal Studio software. Based on the original waveform (inside the N7614B) and data captured from the spectrum analyzer, the N7614B can make both distortion measurements (e.g., AM/AM, AM/PM) and spectrum measurements (e.g., channel power and ACP). It's even possible to make signal quality measurements like Delta EVM, Dynamic EVM and demodulation EVM, which requires the X-Series measurement application (Figure 6).

The N7614B software provides a flexible I/Q waveform interface, which supports free pre-loaded waveforms for WLAN and LTE, Signal Studio generated waveforms, and customer-defined waveforms. Engineers use these waveforms as input into the PA when making measurements during test. Based on the results, the PA can then be adjusted to improve its output signal quality using ET alone or in conjunction with other PA technologies like CFR and DPD (Figure 7). Keysight's general-purpose signal generator, signal analyzer and arbitrary waveform generator help to simply this process, as necessary, to ensure optimal PA performance.

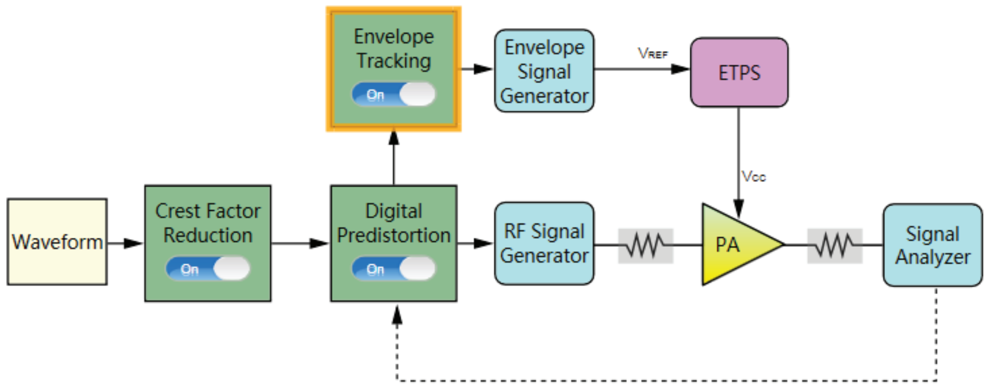


Figure 7. Shown here is the N7614B Signal Studio measurement view with both envelope tracking and digital pre-distortion technologies applied.

PA characterization involving both swept frequency and pulse power measurements, as well as nonlinear analysis, can be performed using the PNA-X microwave network analyzer with NVNA and N6705B DC power analyzer with N6781A SMU. The PNA-X enables high speed, high dynamic range measurement of both active and passive components. Pulsed PA characterization can be carried out using the dynamic capability of the N6705B DC Power Analyzer with N6781A SMU.

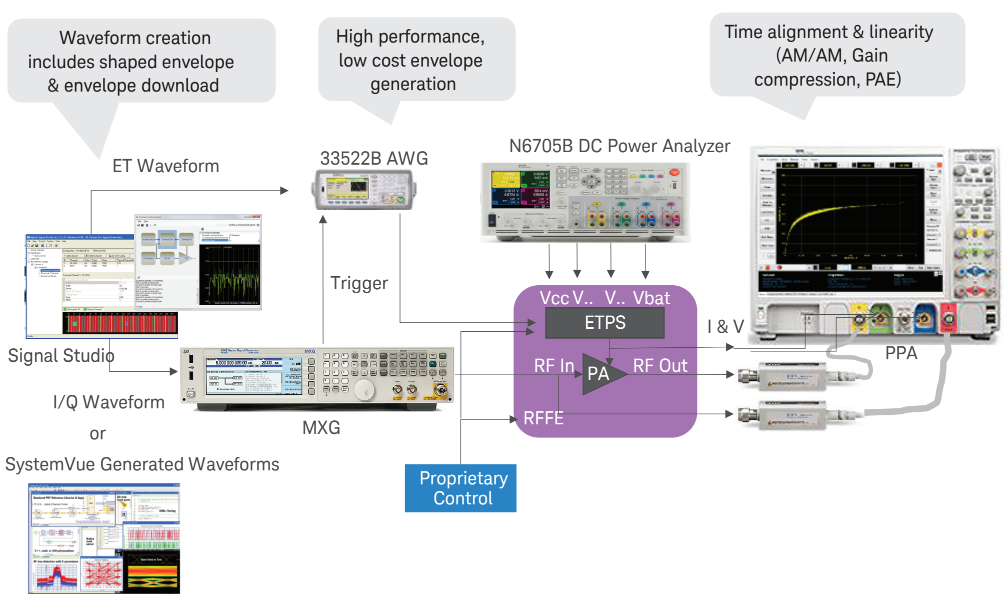


Figure 8. Envelope tacking power amplifier PAE measurement using the 8990B.

RF power modulation measurements, an essential part of PA performance and efficiency testing, can be performed using the U2021XA Series of USB RF power sensors. Analysis of the modulated power can then be performed using the 8990B peak power analyzer and N1912A wideband sensor (Figure 8). The 8990B combines a dual-input peak power RF analyzer and a 2-channel oscilloscope function, which allows accurate time-aligned measurement of RF power with voltage and current flow. The N1912A sensor features a 150-MHz video bandwidth for repetitive signals.

A test solution for production testing of PAs with ET includes waveform generation software, a PXI vector signal generator, an arbitrary waveform generator for the envelope signal, SMUs and Digital Inputs Outputs (DIOs) for DUT control and DC measurements, and a PXI vector signal analyzer with Keysight's 89600 VSA X-Series measurement application software.

Summary

While ET offers today's PA designers a number of performance advantages, those benefits come at the cost of increased complexity and a whole host of challenges that must be overcome when configuring and testing an ET system. Fortunately, an ET test system and ET design and test flow from Keysight offers designers a way to cut through the complexity and mitigate the challenges. The test system, comprised of both hardware and software solutions, offers the accuracy, flexibility and functionality to efficiently evaluate ET components and ET-based radio designs—from R&D to design verification and into production.

The Power to Accelerate Wireless Design and Test

Keysight is a leader in wireless test, focused on the highest-performance design and test of wireless devices and networks, with application-focused platforms optimized for existing and emerging standards. Adding to this optimal R&D and field support, Keysight allows engineers to better understand the intricacies of the continuously evolving wireless industry so you can accelerate your development of products.

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Related Applications

- Front-end module test
- 3G/LTE BTS and UE PA test
- WLAN AP and STA PA test
- Other general-purpose ET PA test

Related Keysight Products

Signal Generators

- MXG-B N5182B
- MXG-A N5182A
- EXG N5172B
- ESG E4438C
- PXI M9381A

Signal Analyzers

- PXA N9030A
- MXA N9020A
- EXA N9010A
- PXI M9391A and M9393A

Envelope Generators

- 33522B arbitrary waveform generator
- 33622A arbitrary waveform generator

Software

- ADS
- SystemVue
- N7614B Signal Studio for Power Amplifier Test
- 89600B VSA software

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