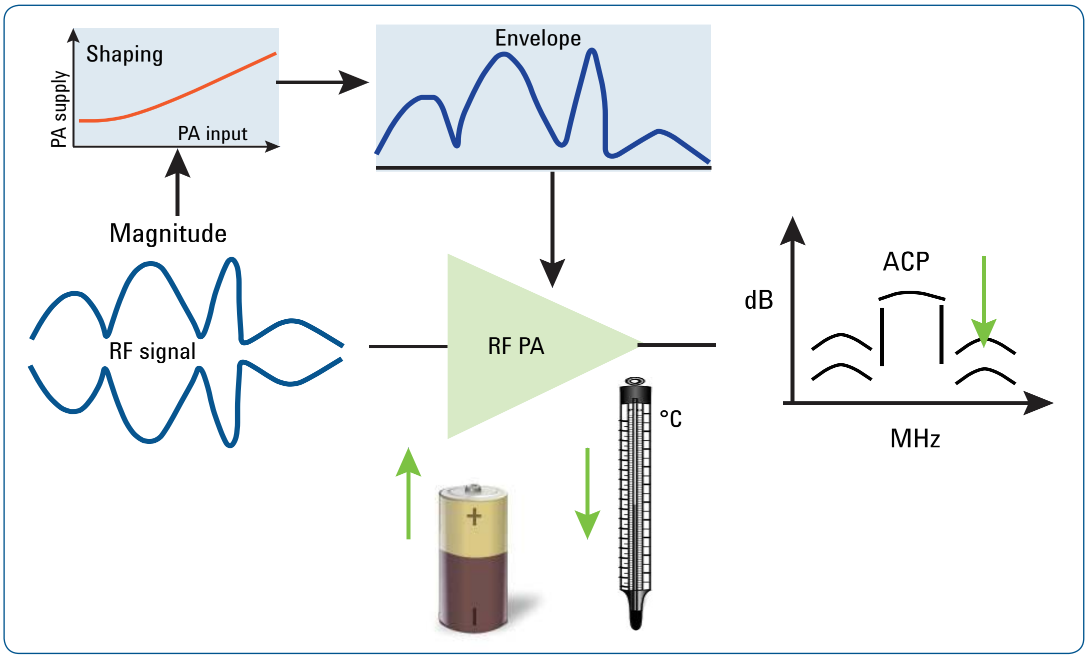
Solutions and Measurement Tools for Use in Average Power and Envelope Tracking Design

Application Note



A high level view of envelope tracking operation and the benefits

Introduction

With the advent of LTE, the transmission system in a cellular smartphone must process signals with both a very wide range of average power, to suit the user's location in the cell, and a high (8 dB) short term peak to average power ratio due to the nature of the LTE signal. Depending on the amplifier technology, the device may have to operate several dB below the level it would be capable of providing with a W-CDMA waveform. This comes at a time when battery capacity is already at a premium, heat dissipation within the handset is based on a budget and frequency coverage of multiple spectrum bands is required.

The RF power amplifiers account for a significant portion of both the energy consumed and heat generated by the RF front end. Individual amplifiers may be required for each band. Fortunately, combining a multi-phase switched mode power supply with a high frequency linear amplifier enables an "on demand" approach to the supply voltage that can be used to deliver a useful reduction in both energy used and heat generated.

With amplifier technologies having a soft AM/AM compression characteristic, supply modulation may also be used to significantly improve linearity. This reduces in-band and out-of-band intermodulation signals at higher powers. The use of boost mode in the SMPS to give transient increases in supply voltage enables further linearity improvements.

This document provides an outline of the techniques involved and the solutions Agilent provides for RF, baseband and system developers.

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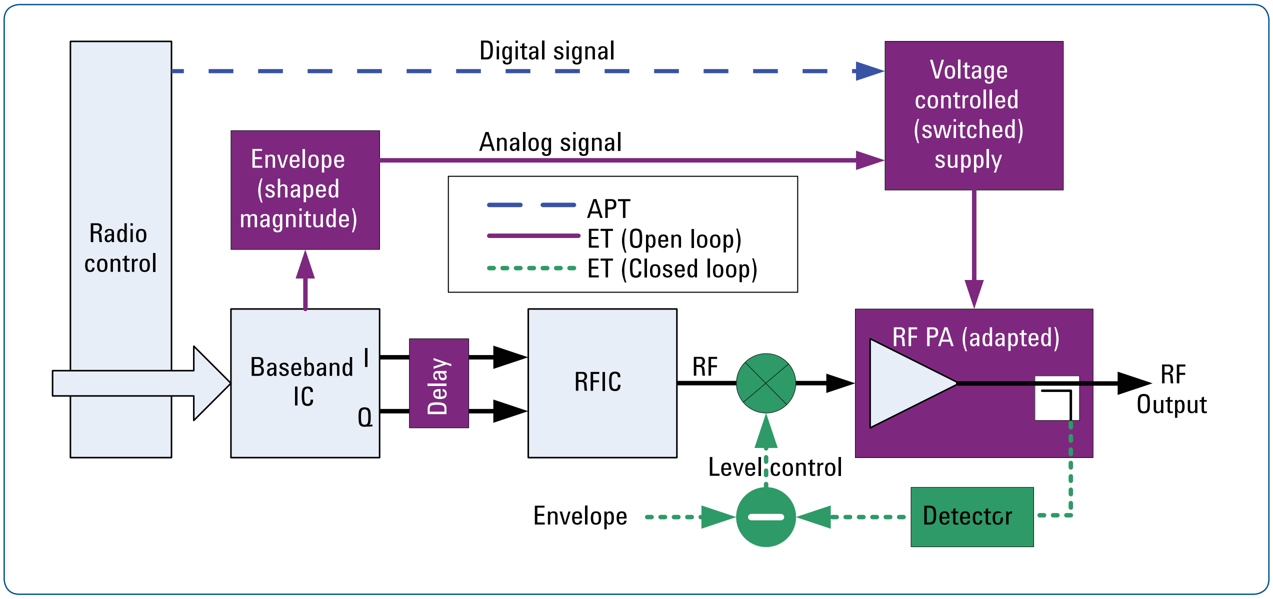


In a practical system, the envelope signal may be generated in the RFIC.

Average Power and Envelope Tracking Techniques

Control of the power amplifier supply voltage as a function of the signal amplitude is not new. For example, in 1988 Su and McFarland of HP Labs published a description of a single chip CMOS lineariser using closed loop envelope elimination and restoration, EER, for use with NADC signals. Today, a number of PAs and PA modules offer switched high and low power operation. Average power tracking, APT, and envelope tracking, ET, are mechanisms to get further improvements in PA performance and efficiency by matching the operating point of the transistors in the PA to the RF signal amplitude. Both use a control signal derived from the magnitude of the "live" signal required, but there are several ways this may be implemented.

As the name suggests, APT works on a slower timescale than ET. Using data from the radio's MAC layer, an APT system adjusts the bias conditions of the amplifier with a time resolution in the order of 1-10ms. This means many RF design techniques stay the same, although device characterisation and modeling has to be performed at multiple operating points.

Unlike EER or polar modulation, envelope tracking does not apply a level limiter or operate with a fixed amplitude PA input signal. It may use 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. ET can offer considerable benefits in terms of power efficiency and amplifier performance, but the PA has to be treated as a 3 terminal active device.

A low noise, high bandwidth power supply is also needed. Usually this will operate in a combination of switched and linear modes.

The envelope signal is derived from the baseband IQ signal, or the RF it produces. In an open loop system, a 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.

Increased efficiency is likely to mean the PA is operating in compression with a lower gain, resulting in principle in an increase in carrier frequency harmonics. In the frequency banded world of cellular transmitters, these are filtered out, having given suitable consideration to harmonic impedance matching and biasing within the PA circuitry.

As might be expected, the task of implementing ET systems involves a number of modelling and measurement techniques, many of which can be done using the equipment described below.

Task and Solution Summary

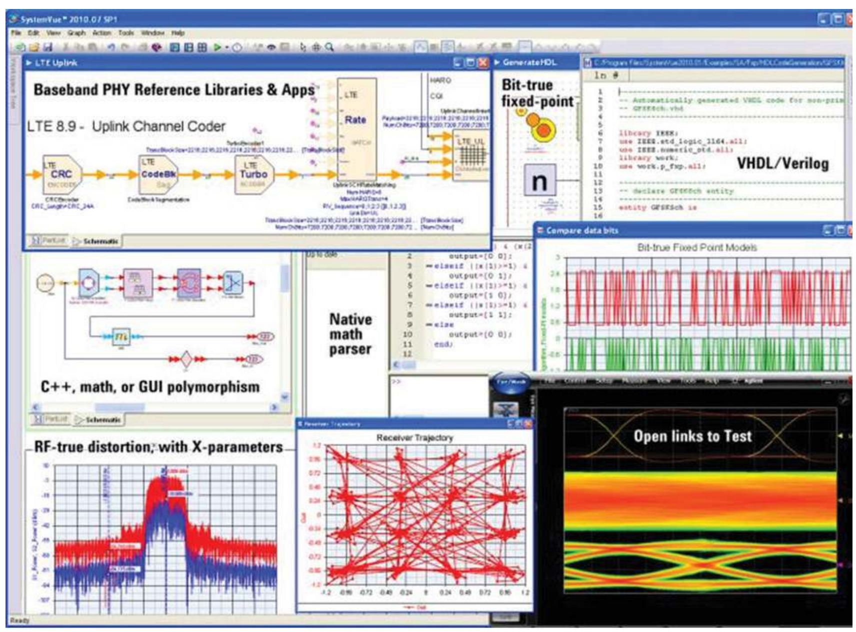
ET component and System simulation	ADS SystemVue	Design examples are available. Used widely and as the basis for the OpenET Alliance ET system simulation
PA characterisation	PNA-X N6705B + N6781B MXG with 3522B	X parameter measurement and extraction Pulsed power supply with network analyzer or triggered RF source / analyzer Synchronous RF and baseband arbitrary waveform generation
ETPS and RFPA performance	Signal Studio for LTE MXG-A with 33522B	Option K for envelope tracking generation & hardware control Synchronous envelope and RF generation
ET system evaluation	MXA or PXA with wide-band analysis 9000 Infiniium scope 89600 VSA v17	ACP, EVM. Noise floor extension in PXA for RX band noise Mixed RF and baseband measurement Multi-measurement, mixed based baseband and RF analysis
System debugging	N2795A N2793A	Low capacitance probing

System Simulation

Conventional amplifier design involves tight integration between device characterisation, modeling and system simulation. This process becomes more important when using multiple operating points. The removal of larger bypass capacitors and use of active devices for supply modulation introduces new noise paths which must be understood within the overall design. In an FDD radio, there will be an impact on coupled receive band noise.

Performance trade-offs need to be made between the baseband and RF performance. SystemVue Electronic System-Level Design Software is suited to this task. An example application is analysis of the impact of DAC quantisation noise and other baseband distortions on the control input of an ET power supply and resultant broadband RF noise.

Full ET system simulation is dependent on the availability of models with the appropriate supply voltage dependencies.



W1461 SystemVue communications architect core platform

Device Simulation

Like SystemVue, ADS plays an important role in letting designers develop and share customized models before performing simulations to understand performance and the impact of device spread.

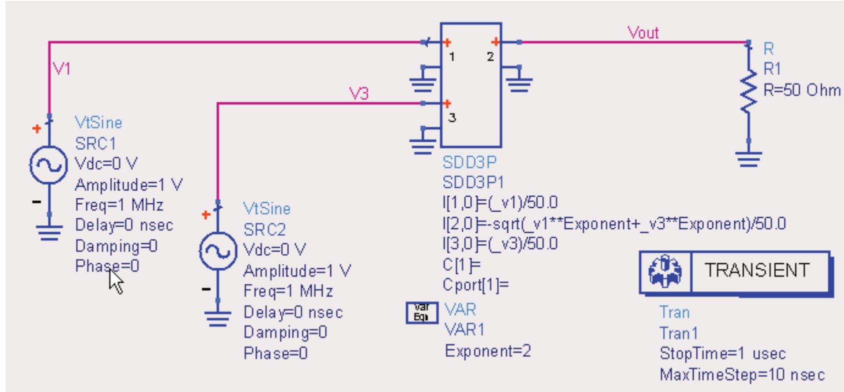
ADS includes a number of Design Guides that can be used as the starting point for power and envelope tracking simulations, to assess the variations in a broad range of parameters affected by supply and/or bias modulation. Both SystemVue and ADS include links to the measurement hardware compatible signal generation and signal analysis applications, Signal Studio and 89600 VSA.

Electro-thermal modeling is also possible using the W2349EP

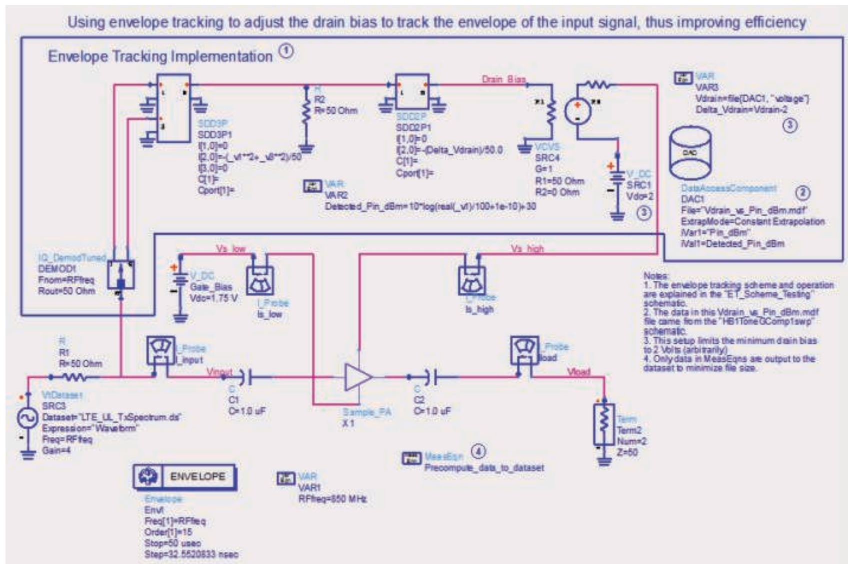
Power Amplifier RF Design

Swept frequency measurements are needed to evaluate inter-stage impedance matching at different operating points, while pulsed power measurements avoid thermal effects affecting device operation. Non-linear analysis is needed to model the amplifier as a function of supply and bias voltages.

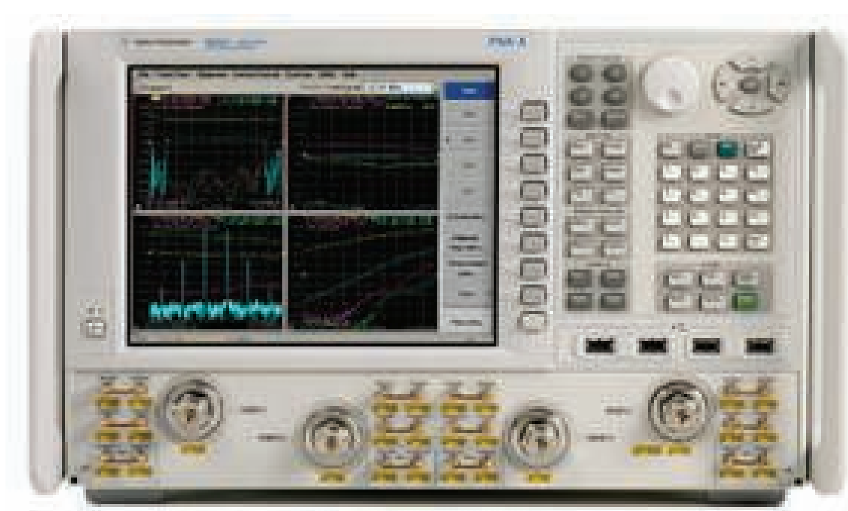
The PNA-X N5242A microwave network analyzer enables high speed, high dynamic range active and passive component measurement. X-parameter analysis coupled with ADS enables active device characterisation.



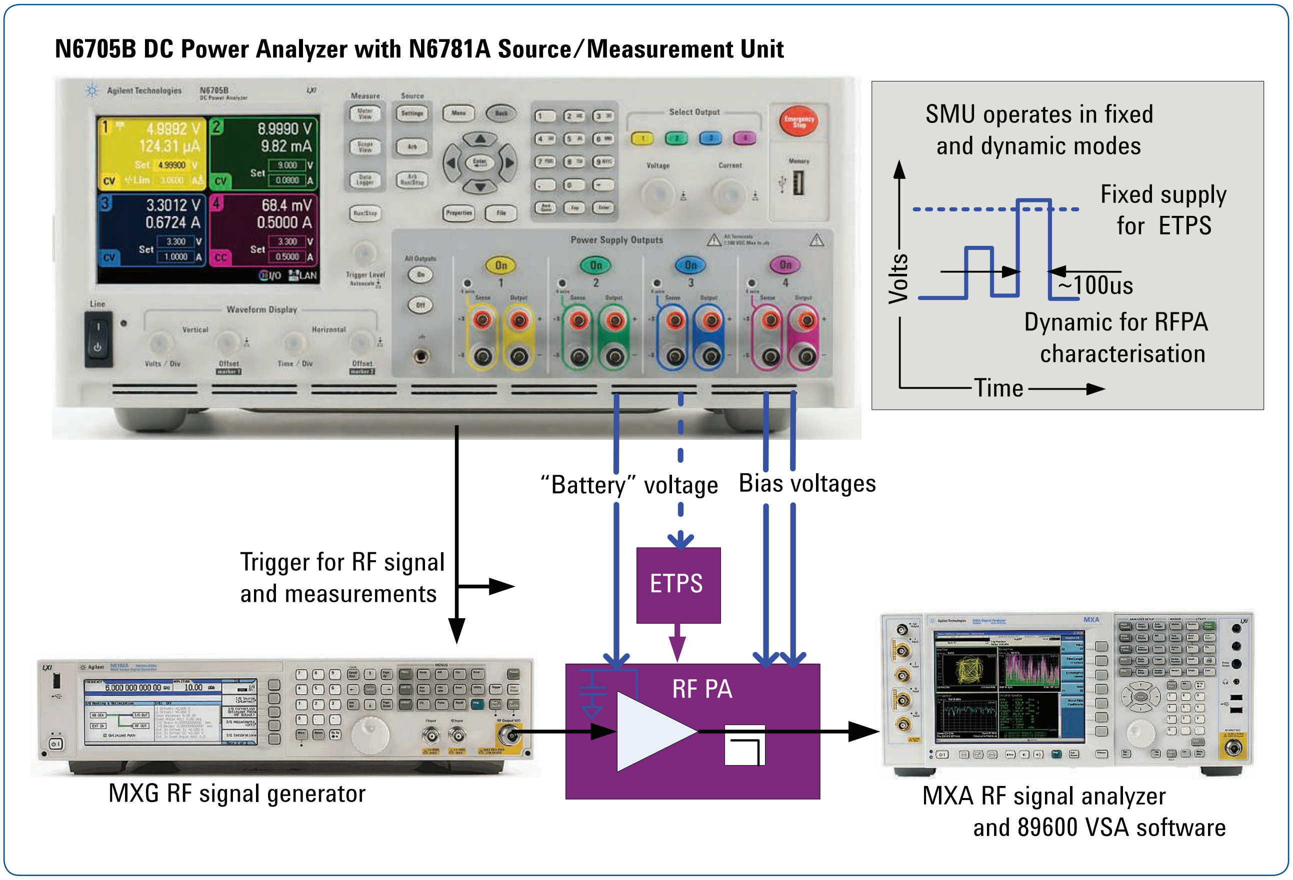
The diagram shows an example using a Symbolically Defined Device which allows you to very quickly and easily implement non-linear models without having to write code.



ADS Amplifier Design guide based envelope tracking example with 1 tone non-linear simulation



PNA-X N5242A microwave network analyzer



Use of the N6781A SMU in pulsed mode operation for PA characterisation

Smart Power Supplies

Bench supplies can be used in two ways, fixed or time-varying. In an operational ET system, the PA supply modulation can have more than 20 MHz bandwidth. It is typically 1-3x the RF bandwidth. This means most decoupling capacitors have to be removed. To maintain low power supply impedance, the supply has to be placed physically very close to the PA. In practise the ETPS is a separate component, using a mix of switched mode and linear operation. In this configuration a bench supply can be used to feed the ETPS itself, and provide the other supply voltages needed to bias the RF PA.

Pulsed PA characterization can be carried out using the dynamic capability of a suitable bench supply. Triggered current & voltage measurement allow PAE measurements to be made, and enable PA gain characterisation (using lower frequency test signals). For APT, where the bandwidths are inherently lower, a bench mounted supply or source measure-ment unit is also a natural choice. An SMU, such as the N6705B, integrates a low noise power supply with precision current and voltage control & measurement.

The N6705B DC power analyzer, with N6781A 2-quadrant SMU module and 14585A application software gives voltage & current control with logging. Measurement bandwidths are up to 10 or 60 kHz depending on the amount of capacitive loading. User defined triggering enables correlation of external measurements.

Wideband voltage and current sensing

Measuring the instantaneous current allows in-depth analysis of the PA operating point and the power added efficiency, PAE. A high-side, wideband current monitor may be integrated with the ET supply using a differential probe such as the 200 MHz 1153A. A low noise amplifier allows the use of a low value current sense resistor. Alternatively, with a suitable PCB layout, it may be possible to use a current sensor.

The 1153A differential oscilloscope probe

The N2783B current sensor has 100 MHz bandwidth, and 100mV/A sensitivity

Low capacitance probing

Line impedances in an active system often use high impedances to minimize the associated current drain. Active probes generally present the lowest capacitive loading when probing. The N2795A (single ended) and N2793A (differential) are examples with an input capacitance of 1pF or less.

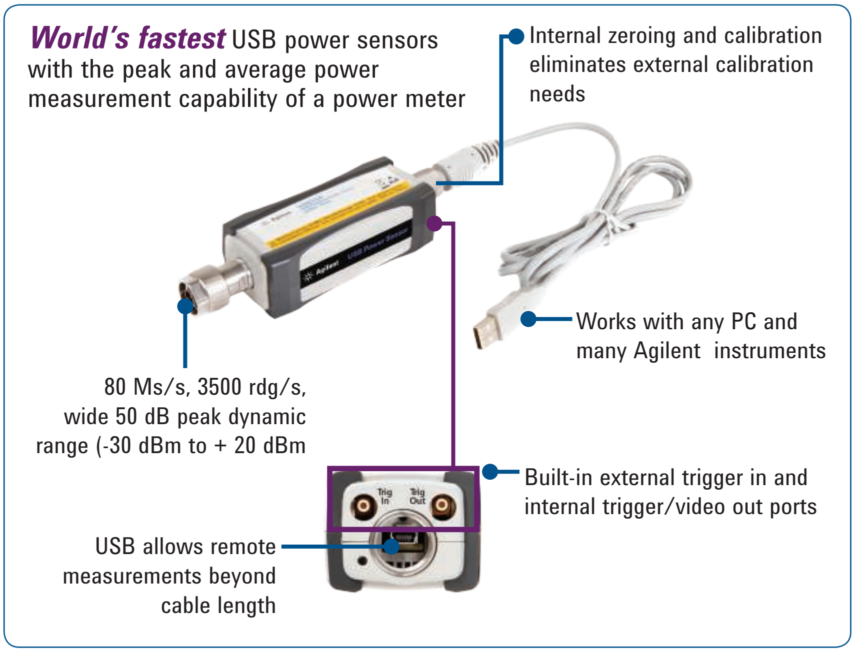
RF power measurement

Accurate absolute power measurements are an essential part of amplifier performance and efficiency testing. The RF performance and high speed USB 2.0 interface of the U2000 series fit the needs for device characterisation. The new U2020A X-series of sensors allow power modulation measurements.

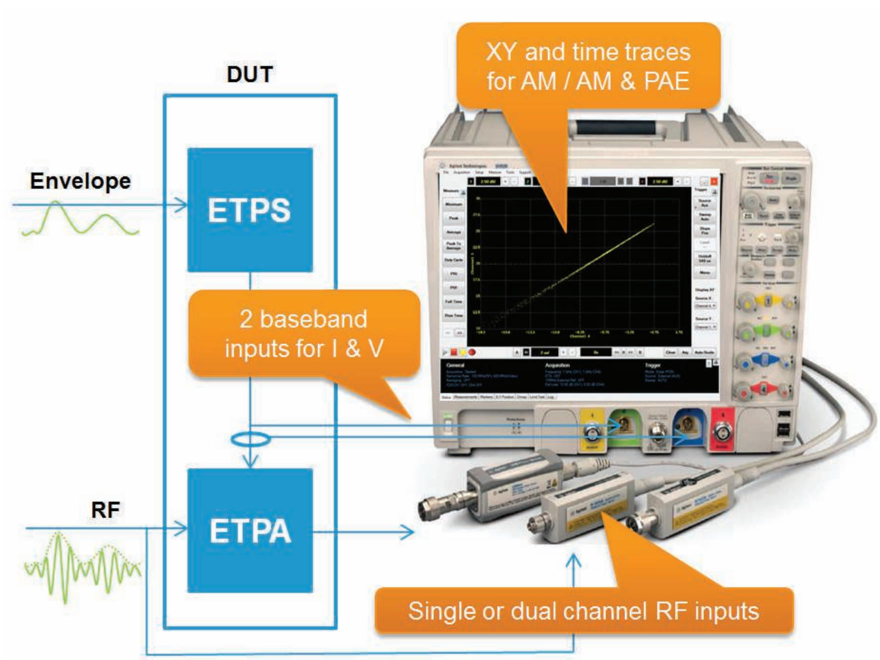
Modulated power analysis

Comparison of swept RF power at the input and output of the PA allows fast assessment of compression. Applying user math to RF and supply based waveforms gives simultaneous displays of power and power added efficiency, PAE.

The 8990B Peak Power Analyzer combines a dual input peak power RF analyzer and a 2 channel oscilloscope function. This allows accurate time aligned measurement of RF power with voltage and current flow. The N1923/N1924A wideband sensors have a 150 MHz video bandwidth for repetitive signals.



The 2020 series of USB power sensors gives flexibility in the combinations of instruments used for ET evaluation



8990B peak power analyzer with combined power sensor and oscilloscope functions

Synchronous baseband and envelope measurement

Oscilloscopes provide the measurement speed, ease of use, and performance needed for both envelope voltage and current measurements. USB provides a high speed data transfer path for post processing.

Combined with 89600 VSA software, the Infiniium family of oscilloscopes are the most integrated RF and baseband analysis tool available.

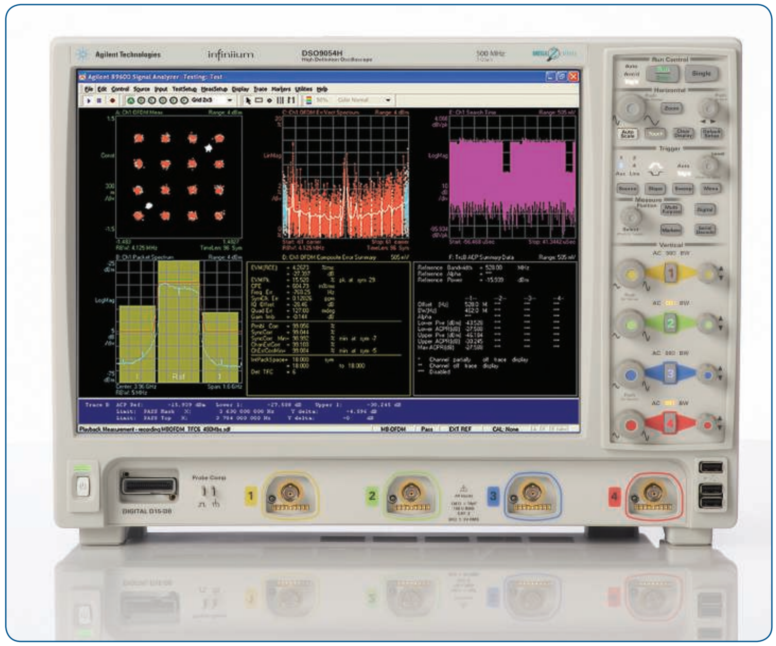
Adjacent channel power and wideband spurious signal measurements

Adjacent channel power is one of the most sensitive measurements for testing timing and amplitude misalignment when applying envelope tracking. An imbalance between the ACP components either side of the wanted signal is evidence of a timing error.

The EVM of the modulated RF signal also needs to be evaluated before and after the PA, or RF up-converter, as an IQ signal. The PXA incorporates these measurements.

Wideband swept analysis is needed to measure the impact on receive band noise from the ET power supply itself, or the signal used as the envelope tracking input. The noise floor extension function in the PXA maximises dynamic range without using external filtering.

The PXA N9030A with baseband inputs gives up to 80 MHz IQ measurement bandwidth, with 2 independent 40 MHz channels. The differential inputs are compatible with Agilent oscilloscope probes.



The 9000 series of oscilloscopes can be used standalone or in conjunction with the 89600 VSA for mixed RF and envelope measurements.

16 bit resolution baseband and high performance RF inputs make the N9030A PXA signal analyzer an ideal tool for all RF PA evaluation tests.

Combined RF, baseband and envelope analysis

Time aligned envelope and RF modulation measurements provide the deepest understanding of system operation. A shared external trigger allows measurements from different instruments to be combined. Where needed, an RF pulse or modulated signal can be used for cross domain time calibration.

The multi-measurement function in the 89600 VSA software allows overall performance testing of key parameters such as ACP and EVM.

Measurements from multiple inputs can be viewed together, making it straightforward to see any impairments occurring dynamically.

The combination of the 89600 VSA with ADS or SystemVue and measurement hardware, such as an X-Series analyzer or an Infiniium oscilloscope, is a uniquely integrated way to compare modeled and real device results with a single user interface.

89600 VSA software enables multi-instrument, mixed domain measurements. This example shows envelope, spectrum and demodulation using an MXA and DSO.

New built-in time alignment algorithms and trace functions allow XY plotting of both RF-RF and RF-BB signals.

Distortion measurements can be made without regard to a specific technology. A differential, or additive, EVM readout gives a quantified measurement of the amplifier performance.

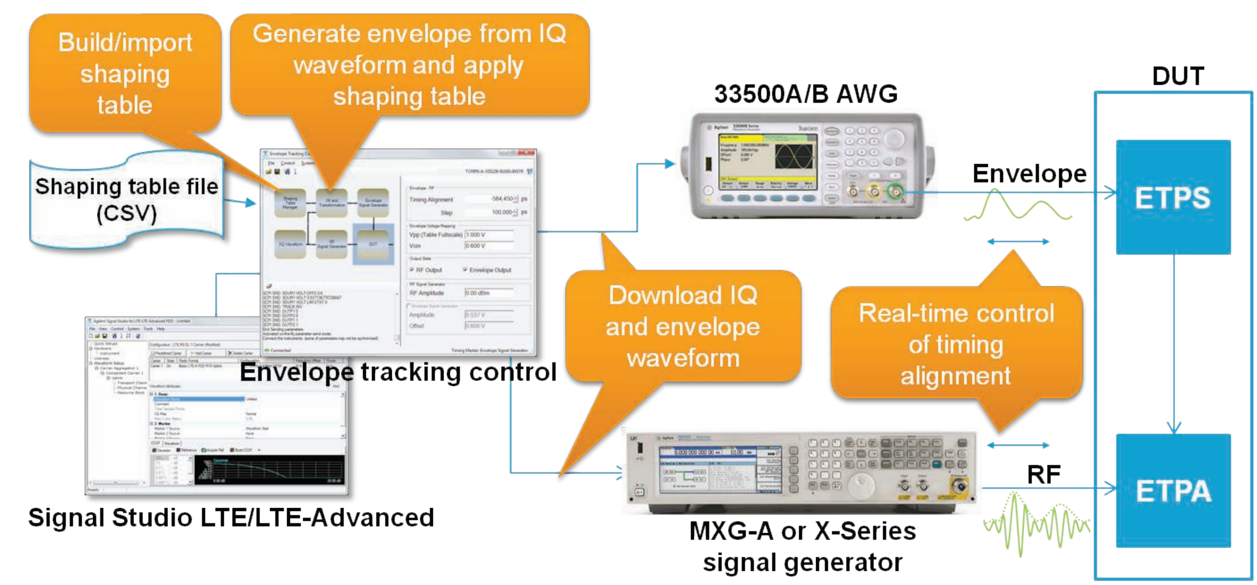
In the figure below, the 89600 VSA software screen shows how the software may be used to analyze the ETPS, the RF PA in ET mode, or the ET system as a whole.

Top left of 89600 VSA screen: The envelope spectrum, showing how the signal bandwidth extends considerably beyond that of the RF signal.

Middle left of 89600 VSA screen: RF spectrum with ACPI.

Bottom right of 89600 VSA screen: XY plot showing the shaping applied to the IQ magnitude signal before being used to drive the ET power. Measurement readouts include sub nanosecond timing between RF and baseband signals.

Analyze both RF and envelope signals using the 89600 VSA software



Synchronous envelope and RF signal generation

Synchronous RF and envelope waveform generation

When using envelope tracking, timing misalignment of the envelope and RF signals of more than 1 ns can have an adverse impact on the quality of a 20 MHz bandwidth transmitted signal. Both ACP and EVM are affected.

Timing alignment to this level can be achieved either using a pair of RF signal sources with shared baseband clock, or with a combination of one RF and one baseband source. The 10 MHz reference is shared between the two sources, along with a trigger signal. The key to alignment is to ensure the sources are in a consistent trigger state when the waveform play-out begins.

The Envelope Tracking option for Signal Studio for LTE/LTE-Advanced (N7624B/25B-KFP) provides an easy way to generate the IQ (RF) and envelope signals required for evaluation and performance test of the ET system. The addition of the envelope tracking control window gives access to shaping table management and hardware control functions for both RF and envelope signals.

Signal Studio downloads the RF waveform directly to the 1st generation MXG (N5182A) and the X-Series signal generators, and it can download the envelope waveform to the 33500A/B Series waveform generators, while 2ch 33522A/B models are capable of differential output operation. Note that for optimum timing repeatability, use of 1st generation MXG and 33500A/B series is recommended.

Once waveforms are downloaded, Signal Studio's Envelope Tracking Control function allows for dynamic timing alignment of RF and envelope signals giving 1ps resolution, without the need to regenerate waveforms. This enables fine tuning of envelope timing by monitoring ACP or EVM measurement of the ETPA output.

Envelope waveforms can be downloaded to the 33522B or N8241A using other software applications including SystemVue, ADS, Benchlink Pro and Matlab.

	RF	Base band	Func. Gen	Baseband bandwidth	Memory depth (sa)
MXG				To 80 MHz	Up to 1 G
33522B				30* MHz	Up to 16 M
N8241A				500 MHz	Up to 16 M

Useable to 50 MHz

Summary

Average power tracking techniques are becoming more widely adopted, while envelope tracking is attracting increasingly visible industry interest as it progresses through development. The Agilent equipment shown in this guide will give the combination of measurement performance and flexibility of application to ensure you have the tools you need to design and implement these systems successfully.

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