Keysight Technologies

Envelope Tracking and Digital Pre-Distortion Power Amplifier Testing for LTE User Terminal Components

Application Note

Introduction

With the introduction of 4G LTE, mobile communications were able to achieve higher data throughput than ever before. However that achievement is accompanied by unprecedented battery requirements for mobile terminals. LTE employs the SC-FDMA modulation format in the uplink and it has a higher Peak-to-Average Ratio (PAR) than W-CDMA. One of the most power-hungry components of a mobile terminal is the power amplifier (PA). As shown in Figure 1, the power level of the LTE uplink signal stays relatively low most of the time and goes to peak power only occasionally, but the PA is designed to deliver the highest efficiency only at peak power. Since the high power supplied to the PA won't be used most of the time, it is mostly dissipated as heat and causes battery drain, impacting the thermal design power (TDP) of the mobile terminals. Envelope tracking (ET) has come to the forefront as a possible solution for this issue in mobile RF front end design. ET dynamically adjusts DC supply voltage based on the "envelope" of the PA input signal and delivers higher voltages only when needed, improving battery consumption and heat dissipation in the PA.

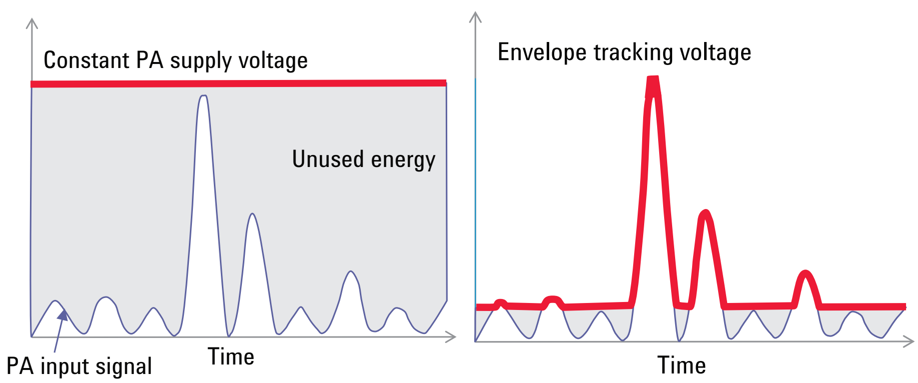

Figure 1. Time domain view of the input signal and bias voltage.

Another issue facing power amplifiers with high PAR signals, such as LTE, is non-linearity. When a high power signal is applied to the PA input, the PA can't linearly amplify the signal, resulting in a situation leading to gain saturation and distortion, ultimately leading to signal quality degradation, such as higher ACLR and EVM. Techniques such as crest factor reduction (CFR) and/or digital pre-distortion (DPD) are used to compensate for the non-linear behavior of the PA. DPD applies "inverse" distortion to the PA input signal to cancel the distortion generated by the PA. There are several types of DPD methods but a simple look-up-table (LUT)-based DPD that doesn't take memory effect into account is commonly used in mobile devices. This application note discusses measurement solutions for PA testing using ET and LUT-based DPD.

Envelope Tracking Overview

When testing ET devices, you will need an IQ signal for PA input and the associated envelope signal for modulating the PA power supply. The envelope is generated from the IQ sample's absolute magnitude, typically with 3x to 6x oversampling applied in order to create a smoother waveform. The base sample rate of a 20 MHz LTE signal is 30.72 MHz and the envelope's sample rate will be 92.16 MHz for 3x oversampling and 184.32 MHz for 6x oversampling. A high sample rate waveform generator is required to support these high sample rates. Raw envelope data generated from the IQ signal then goes through the shaping table before being applied to the ET power supply (ETPS). Typically, the shaping table has a so-called "de-troughing" function to avoid having the envelope voltage drop down to 0 V. Shaping tables are also used to maximize PA efficiency or to ensure constant gain over a wider input power level. This is called "iso-gain". It is not an exaggeration to say that ET system performance is defined by the shaping table.

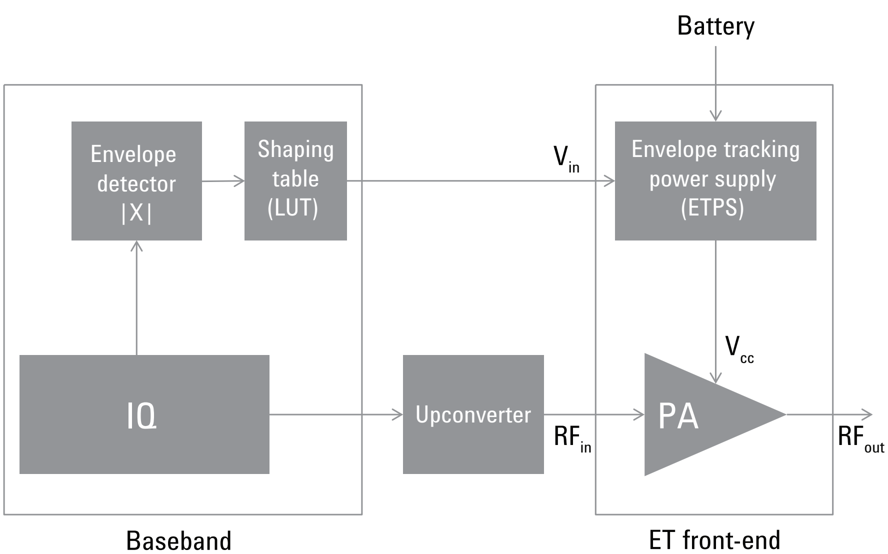

Figure 2. Envelope tracking system simplified block diagram.

ETPS dynamically adjusts the power supply voltage to the PA. As defined in the MIPI™ Alliance's eTrak standard, most ETPS have differential inputs and therefore, the envelope waveform generator must have differential output. ETPS output is applied to the PA's supply line. This voltage has to be applied to the PA with precise timing relative to the input RF signal. For a 100 RB LTE signal, typically the timing alignment between RF and envelope has to be less than 1 ns. Wider bandwidth LTE signals, such as carrier aggregation, require even more severe timing control. Rough timing adjustments between RF and envelope can be achieved with an oscilloscope before connecting to the ETPA and ETPS. However, due to internal delays in the ETPS and the RF PA, the final tuning has to be done with the ETPA output using parameters such as EVM or ACLR. Precise timing adjustments, down to a fraction of a nanosecond, may be required to optimize ET system performance.

Keysight's ET test solution

Keysight Technologies, Inc. offers two envelope tracking signal generation and analysis test solution configurations, which are shown in Figures 3a and 3b. The one in Figure 3a is made up of benchtop test instruments, while the one in Figure 3b is based on PXI test equipment.

Keysight's N7624/25B Signal Studio for LTE/LTE-Advanced software's envelope tracking option enables generation of the envelope waveform from LTE and LTE-Advanced IQ waveforms. An arbitrary oversampling ratio of up to 32x can be specified for envelope generation (The sample rate is also limited by envelope generator). The software's built-in shaping table manager allows for creating, importing and selecting multiple shaping tables quickly and easily. Generated IQ and envelope waveforms are then downloaded to the RF signal generator and arbitrary waveform generator (AWG) directly. The 33600/33500 series AWG can be used as an envelope waveform generator. After downloading waveforms, it is possible to adjust RF and envelope timing with 1 ps resolution in real-time, without re-generating the waveforms. This simplifies timing optimization. The 33600/33500 series AWG with its 2 ch output configuration supports differential output operation and has low wideband noise, making it an ideal function generator that can be connected to the ETPS input directly without filtering. Generated IQ and envelope waveforms can be saved and used in the other platforms, such as PXI, for higher throughput production testing.

It is also possible to use ET (and DPD) with non-LTE waveforms, such as W-CDMA or MATLAB, using the library waveform capability in the N7624B/25B Signal Studio software.

On the analysis side, Keysight's 89600 VSA software can be used with X-Series signal analyzers or a PXI VSA, as shown in Figure 3. The 89600 VSA software's multi-measurement and powerful graph function enables easy measurement of AM-AM, AM-PM and gain compression, by comparing PA input and output signals measured alternately a signal analyzer's single input.

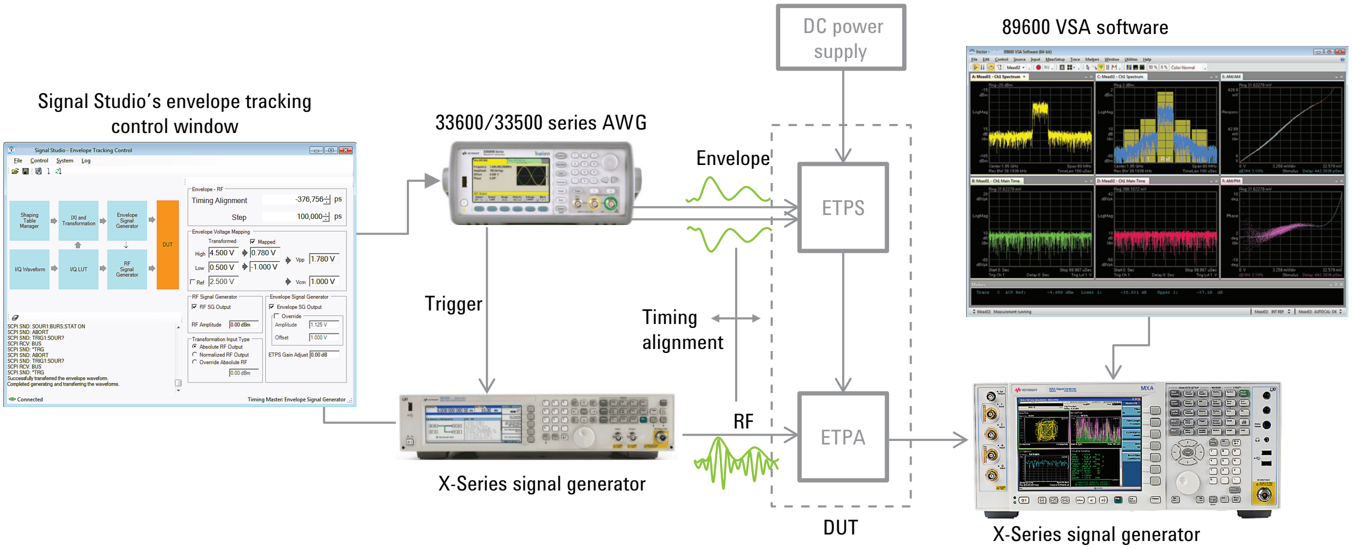

Figure 3a. ET signal generation and analysis test system with bench-top test instruments.

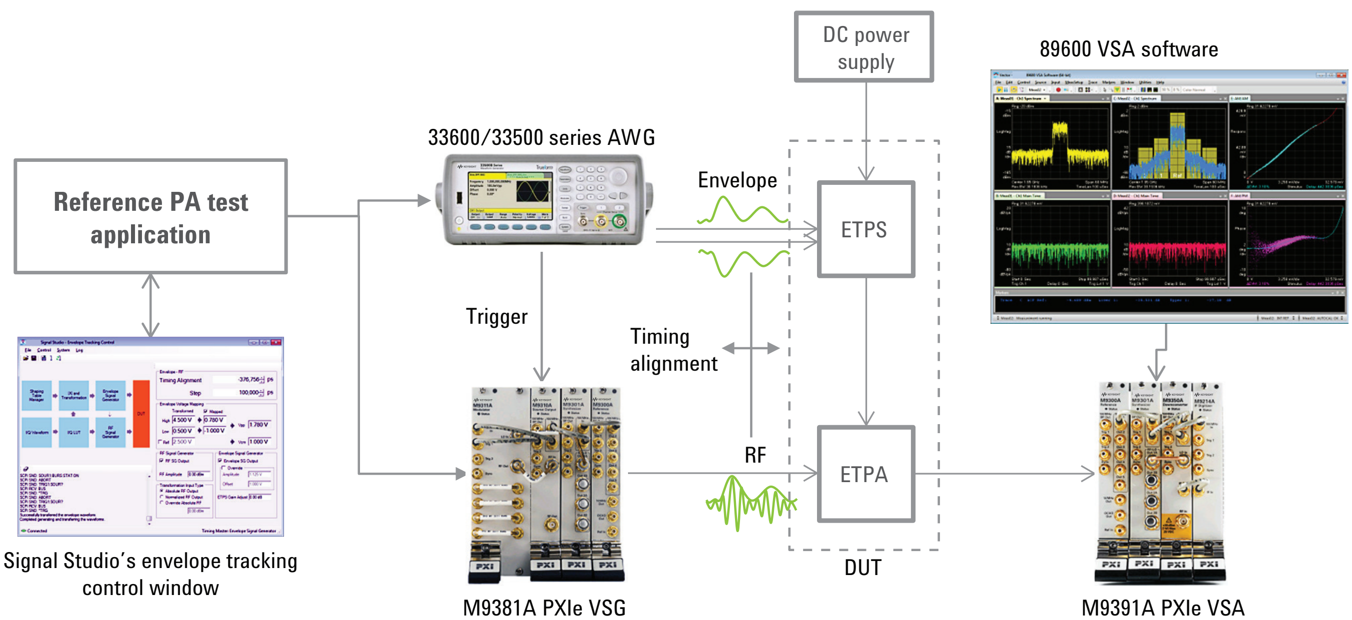

Figure 3b. ET signal generation and analysis test system with PXI test instruments.

Digital Pre-Distortion Overview

The LTE uplink signal could have as high as +7 dB PAR which is 2 to 3 dB higher than WCDMA/HSPA signals. As discussed earlier, the PA is required to have higher linearity to amplify high PAR signals. However, due to the limitations of cost, power consumption, and physical space, it is not easy to find higher linearity components that meet all of a particular system's requirements. Classic measures of PA linearity are AM-AM and AM-PM, comparing the input signal and the PA output signal. Figure 4's AM-AM curve shows reasonably linear characteristics with some minor deviation. On the other hand, AM-PM shows a relatively large phase shift over the range of the input power. If you take curve-fitting data and calculate the inverse characteristics to create a linear AM-AM curve and a flat AM-PM curve, the result is exactly what is needed for the DPD lookup table data. Figure 5 shows the DPD LUT calculation. During evaluation, you can typically repeat this measurement and the DPD LUT calculation several times to get optimum performance. This process is called DPD closed-loop iteration.

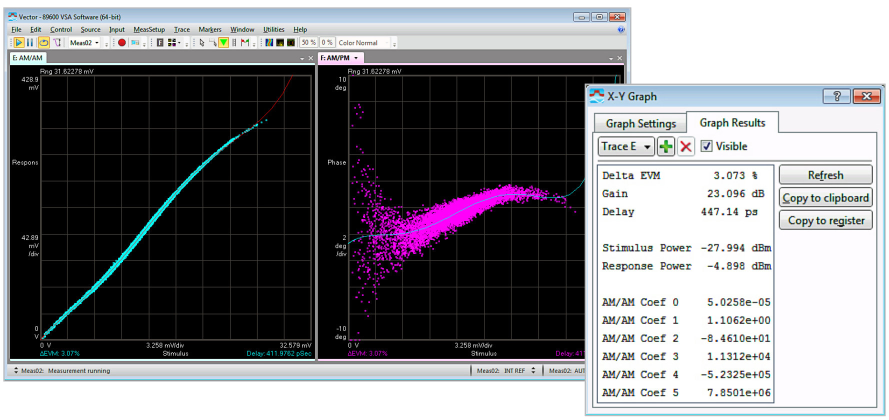

Figure 4. 89600 VSA software showing AM-AM and AM-PM curves.

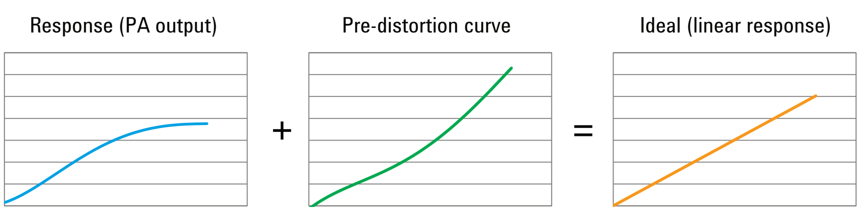

Figure 5. DPD LUT calculation.

Keysight's DPD solution overview

To apply digital pre-distortion, it is necessary to change amplitude and phase, based on an IQ sample's magnitude. Signal Studio for LTE supports LUT-based pre-distortion applied to IQ samples. As with the ET shaping table, multiple look-up-tables can be edited, imported, and switched with just a few clicks needed to apply DPD. You can also observe how DPD affects IQ samples by looking at a CCDF curve or spectrum before and after applying DPD, as shown in Figure 6.

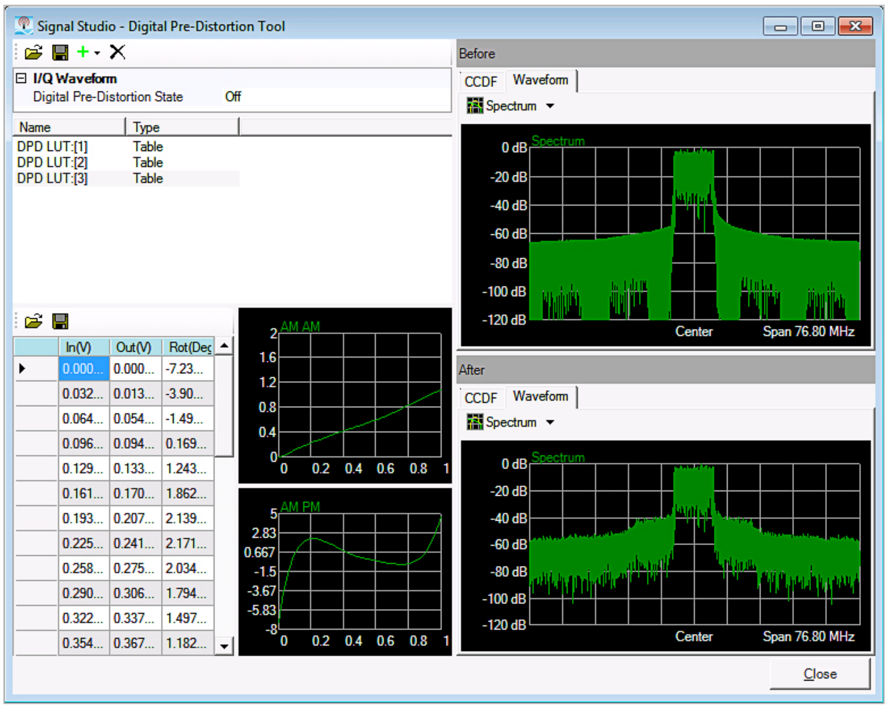

Figure 6. Signal Studio's digital pre-distortion tool panel.

To calculate the DPD LUT, compare the non-pre-distorted linear signal and the distorted PA output signal, plot the AM-AM and AM-PM curves, and generate curve fitting polynomial coefficients. The 89600 VSA software graph capability displays AM-AM, AM-PM, and gain compression traces as well as curve-fitting polynomials with a user-definable polynomial order up to 12. By taking these coefficients and calculating the inverse characteristics, it is possible to generate a DPD LUT that can be used in Signal Studio, with spreadsheet tools such as Excel.

The required measurement bandwidth for acquiring signals will be determined by the bandwidth to be optimized. For example, to cover the channel adjacent to a 20 MHz LTE signal, 60 MHz bandwidth must be available for capture. To cover an alternate channel, an additional 40 MHz BW would be required, which means 100 MHz BW would be needed overall. In case contiguous carrier aggregation is used with a 2x 20 MHz LTE carrier, 120 MHz bandwidth would be needed to cover adjacent and alternate channels. PXA and MXA X-Series signal analyzers and the M9391A PXIe VSA all support a maximum 160 MHz bandwidth, which provides adequate bandwidth for analyzing DPD-applied waveforms.

Combined use of DPD and ET

When applying DPD, in order to linearize AM-PM characteristics, the envelope is typically generated based on pre-distorted IQ waveforms. This means that at each DPD closed-loop iteration, both the pre-distorted IQ and the envelope waveforms need to be re-generated based on the updated LUT. Typically, ET will be applied and optimized before DPD, so that the DPD closed-loop iteration can be performed to compensate for amplitude and phase non-linearity, in order to understand if performance improvements are due to ET or DPD. Signal Studio for LTE and LTE-Advanced has integrated GUI support for both ET and DPD, allowing generation of ET-enabled DPD waveforms.

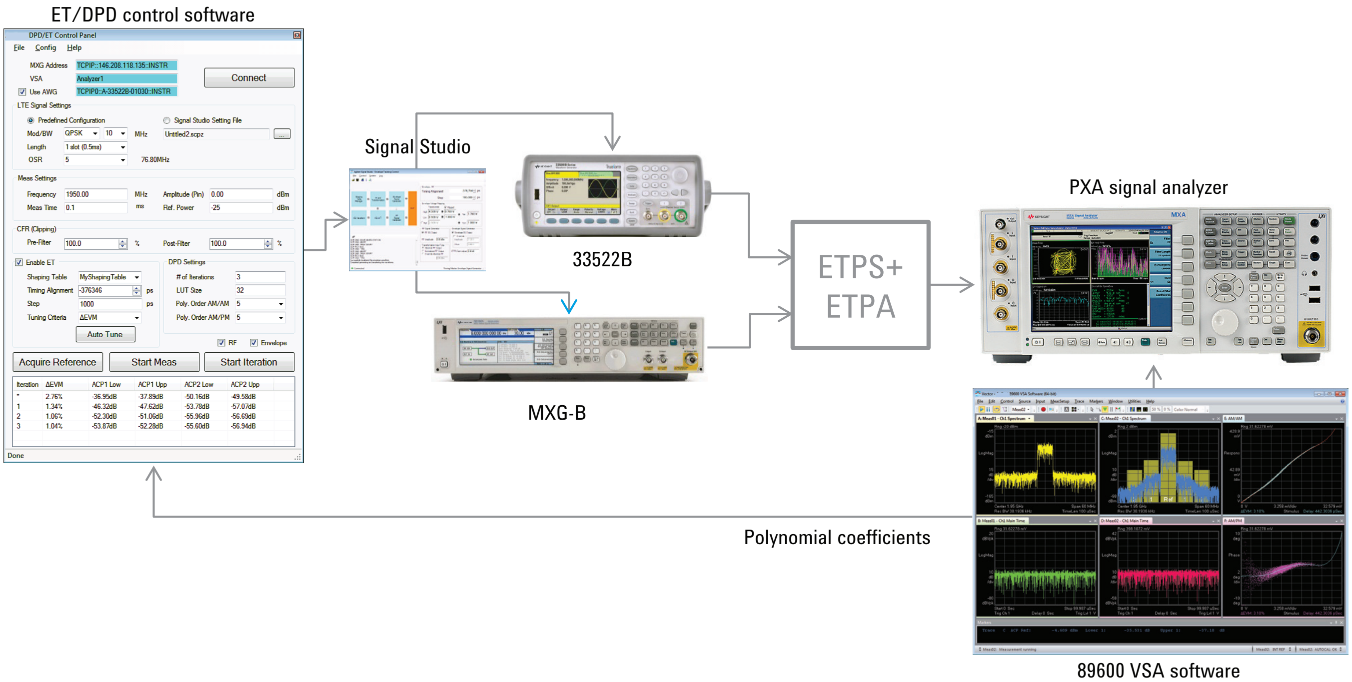

Figure 7. Sample software program performing a DPD closed-loop iteration on an ETPA.

This sample program, ET/DPD control software, shown in Figure 7, controls both Signal Studio and 89600 VSA software to extract curve-fitting coefficients of the AM-AM and AM-PM graphs, calculates the LUT, and applies digital pre-distortion. The process is then repeated for a specified number of iterations. Figure 8 and 9 show example results with 10 MHz LTE uplink with QPSK modulation applied, 5x oversampling for IQ, and 3x oversampling for envelope. The polynomial order is set to 5 for both AM-AM and AM-PM. After applying DPD, both AM-AM and AM-PM curves are linearized. Figure 9 shows the spectrum of the ET PA output with and without DPD. Without DPD, it has approximately –36 dBc ACLR dynamic range. Applying DPD improves ACLR down to –52 dBc.

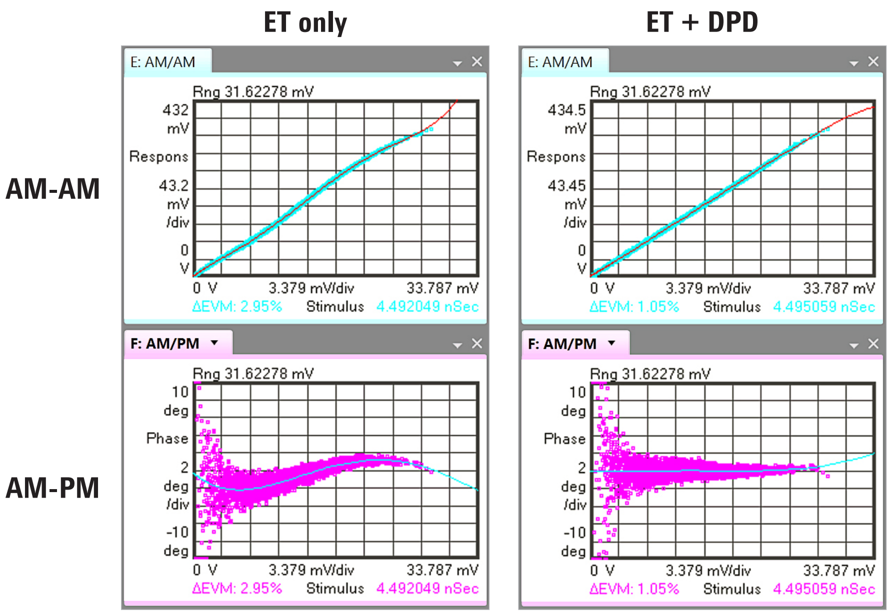

Figure 8. Effect of DPD linearization on an ETPA.

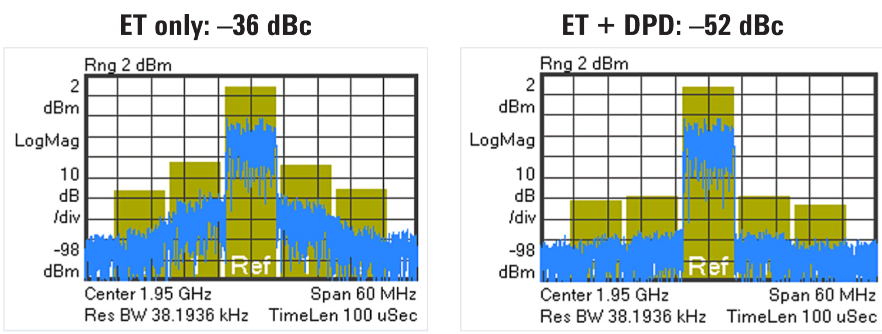

Figure 9. ACLR improvement shown with and without DPD.

Summary

The measurement solutions described in this application note offer methods for evaluating envelope tracking power amplifier to reduce power consumption in mobile RF power amplifier front end design. Using these solutions with the digital pre-distortion functionality in the Signal Studio and 89600 VSA software offers the advantage of performing evaluation of an RF front end before having a fully baseband-integrated system.

Ordering Information

Product	Option	Description
Software		
N7624B Signal Studio LTE/LTE-Advanced FDD[1]	3FP	MXG/EXG connectivity
	HFP	Basic LTE FDD R9
	JFP	Basic LTE-Advanced FDD R10
	KFP	Envelope Tracking
N7625B Signal Studio LTE/LTE-Advanced TDD[1]	3FP	MXG/EXG connectivity
	EFP	Basic LTE TDD R9
	JFP	Basic LTE-Advanced TDD R10
	KFP	Envelope Tracking
89600 VSA Software	200	Basic VSA
	300	Hardware connectivity
LXI Instruments		
N5182B MXG-B signal generator/N5172B EXG-B signal generator	50x	Frequency option
	1EA	High output power
	656/653	ARB baseband generator (for MXG-B/EXG-B)
	657	160 MHz RF bandwidth (for MXG-B)
	655	120 MHz RF bandwidth (for EXG-B)
33622A/33522B Waveform generator	MEM	Add memory
	OCX	Add high stability OCXO timebase
N9030A PXA Signal Analyzer/N9020A MXA signal analyzer	5xx	Frequency option
	B1X	Analysis bandwidth, 160 MHz
	B1A	Analysis Bandwidth, 125 MHz
PXI Instruments		
M9018A 18 slot PXIe chassis		
M9036A PXIe embedded controller	M08	Memory, 8 GB
M9381A PXIe vector signal generator	F0x	Frequency option
	300	Frequency reference module
	B16	160 MHz modulation bandwidth
	M05	Memory, 512 MSa
	UNZ	Fast switching
	1EA	High output power
M9391A PXIe vector signal analyzer	F0x	Frequency option
	300	Frequency reference module
	B16	160 MHz modulation bandwidth
	M01	Memory, 128 MSa
	UNZ	Fast switching

1. For existing Signal Studio users, Option MEU is required to use DPD and for short waveform generation.

Related Literature

Simulation and Measurement-based X-parameter Models for Power Amplifiers with Envelope Tracking, Literature number 5991-2733EN

Simulating Envelope Tracking with Advanced Design System - Application Note, Literature number 5991-1463EN

Signal Studio for LTE/LTE-Advanced FDD and TDD - Technical Overview, Literature number 5990-6086EN

Web

Envelope Tracking:
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