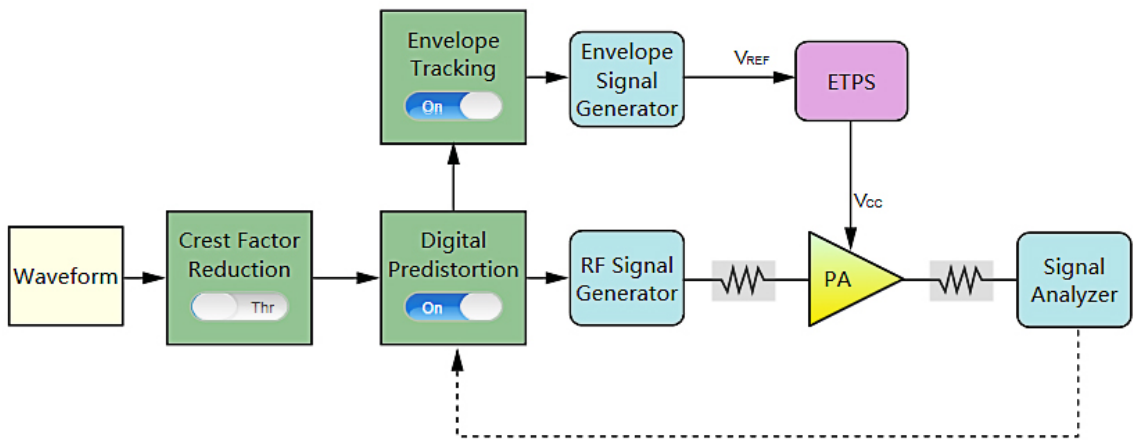


Keysight Technologies

N7614B Signal Studio for Power Amplifier Test

Technical Overview



- All-in-one test tool for performing power amplifier (PA) test flow with crest factor reduction (CFR), envelope tracking (ET), and digital pre-distortion (DPD)
- User-friendly interface for parameter settings, test flow control and instrument control
- Import user-defined I/Q waveforms, signal studio waveforms or free-of-charge pre-loaded waveforms
- PA measurement displays include CCDF, AM-AM, AM-PM, ACP and Dynamic EVM
- DPD supports both the open-loop model with Look-Up-Table (LUT) and the close-loop model with extract and apply
- ET can be combined with DPD and the envelope calculation can be performed using a non-pre-distorted signal, a pre-distorted DPD signal, or an user-specified envelope waveform
- Time alignment between the ET signal and the RF signal can be calibrated manually or automatically
- Test flow runs automatically inside Signal Studio

Simplify Signal Creation for PA Test

Keysight Signal Studio software is a flexible test suite of signal-creation and measurement tools that will reduce the time you spend on signal simulation. With the N7614B power amplifier test software, Signal Studio's performance-optimized test flow—validated by Keysight—enhances the characterization and verification of your devices. Through its application-specific user-interface you'll create a test flow with CFR, and/or ET, and/or DPD technologies for power amplifier test.

Modern mobile communications, such as LTE and 802.11ac demand higher data throughput, up to Gb/s, and use wider bandwidth, multi-input multi-output (MIMO) space-time coding, and higher order orthogonal frequency division multiplexing (OFDM) modulation formats. These requirements place new demands on linearity, bandwidth and power consumption in wireless components and place unprecedented battery requirements on mobile terminals or base stations. One of the most power-hungry and non-linear components is the PA. The design of the power amplifier must allow it to:

- Increase spectral efficiency
- Increase power added efficiency (PAE)
- Reduce distortion and non-linearity

Crest factor reduction, envelope tracking and digital pre-distortion, the three main PA test methods that have been introduced, are undergoing research aimed at achieving these goals. All of these methods are supported by the N7614B Signal Studio for power amplifier test software.

Crest Factor Reduction Technology

CFR is a technique used to reduce the PAPR of the transmitted signals so that the power amplifier can operate more efficiently. There are two CFR algorithms supported by N7614B.

- Clipping and filtering
- Peak windowing (Kaiser window)

Digital Pre-Distortion Technology

Power amplifiers with high PAR signals can create non-linearity problems. 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 worse ACP and EVM. DPD technology can be 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, including memoryless and memory, which convey the memory effect on a PA. N7614B supports the following three methods:

- Look-up table (extract or user-defined)
- Volterra series
- Memory polynomial

Typical measurements

Distortion measurement

- AM-AM
- AM-PM
- CCDF

Spectrum measurement

- Channel power
- ACP

Modulation quality

- Delta EVM
- Dynamic EVM
(X-Series measurement applications required)
- Demodulation EVM
(X-Series measurement applications required)

Envelope Tracking Technology

Modern modulated signals have high PAPR. Power amplifiers that must amplify these high PAPR signals, if using a fixed bias, must be operated at a relatively high output power back-off, to avoid greatly distorting the signal when its envelope excursion is near its peak. However, the greater the amount of back-off, the lower the efficiency of the power amplifier will be. Envelope tracking has come to the forefront as a possible solution for this issue in mobile RF front end design. ET dynamically adjusts the 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. N7614B supports envelope tracking technology, which can be applied on its own, or combined with DPD. When combined with DPD, ET can be applied and optimized before or after DPD is applied. Precise timing adjustment, down to a nanosecond or a fraction of a nanosecond, is required to optimize ET system performance. N7614B software supports:

- Automatic time delay adjustments (based on ACP measurement results)
- Manual time delay adjustments (based on ACP or EVM measurement results or an external oscilloscope)

Apply your signals in real-world testing

To use N7614B Signal Studio for Power Amplifier Test software, you must have a properly configured PC and several properly configured instruments, as described in the following. Signal Studio software complements these platforms by providing a cost-effective way to tailor them to your test needs in design, development and production test.

Digital pre-distortion test

- Signal generators
 - MXG X-Series
 - EXG X-Series
 - ESG
- Signal analyzers
 - PXA
 - MXA
 - EXA

Envelope tracking test

- Signal generators
 - MXG X-Series
 - EXG X-Series
 - ESG
- Signal analyzers
 - PXA
 - MXA
 - EXA
- Envelope signal generator
 - 33522B waveform generator
 - 33622A waveform generator

Crest Factor Reduction Test

CFR is a technique used to reduce the PAPR of the transmitted signals so that the power amplifier can operate more efficiently.

N7614B Signal Studio supports two kinds of CFR algorithms:

Clipping and filtering

- Clipping and filtering, the conventional method, includes both hard clipping and low-pass filtering
- Clipping can cause sharp corners in a clipped signal, which leads to an unwanted out-of-band emission (increased ACP)
- To reduce the unwanted out-of-band emissions, the clipped signal will then go through a low-pass filter to reduce the high frequency signals which correspond to the sharp corners in the clipped signal
- Clipping and filtering methods utilize two main parameters; target PAPR and Max iteration

Peak windowing

- Peak windowing aims to smooth the sharp corners which result from hard clipping
- In the peak windowing algorithm, clipping is implemented by multiplying the original signal in the region of the peak with a windowing function such as Kaiser, Gaussian and Hamming
- The peak window method's main parameters are target PAPR, max iteration, max window length, and beta as the Kaiser window adjustment parameter

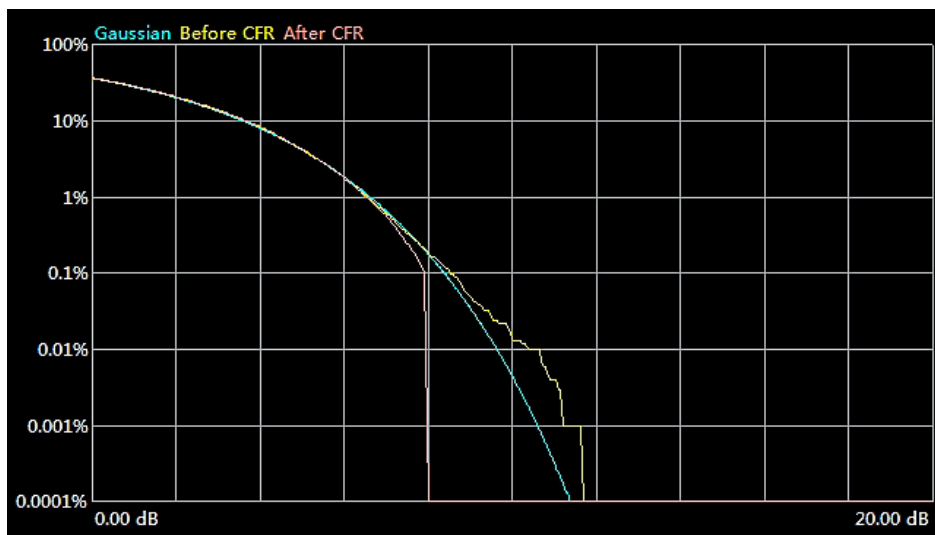


Figure 1. CCDF results traces with CCDF before CFR, CCDF after CFR, and Gaussian as reference

Before CFR ▼	
10%	3.65 dB
1%	6.55 dB
0.1%	8.50 dB
0.01%	10.65 dB
0.001%	11.65 dB
0.0001%	11.65 dB
Peak	11.65 dB
ΔEVM	--- %

Figure 2. CCDF results before CFR

After CFR ▼	
10%	3.65 dB
1%	6.50 dB
0.1%	7.90 dB
0.01%	7.95 dB
0.001%	7.95 dB
0.0001%	7.95 dB
Peak	8.00 dB
ΔEVM	2.20 %

Figure 3. CCDF results after CFR with a delta EVM result, using peak windowing

You can see that the original 802.11ac waveform with 40 MHz BW and MCS9 has a peak PAPR of about 11.65 dB. With the peak windowing CFR technology, the PAPR is successfully reduced to 8.00 dB. However, the delta EVM is deteriorated about 2.20%. CFR technology can be used independently or it can be combined with DPD technology to reduce the PAPR and compensate for the non-linear behavior of the PA.

Digital Pre-Distortion Test

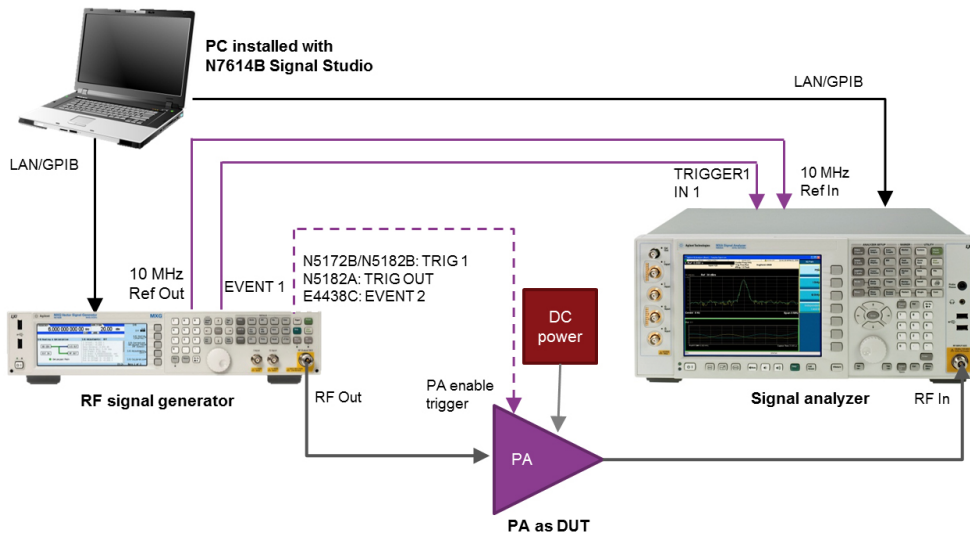


Figure 4. Typical power amplifier DPD test configuration using N7614B Signal Studio with an MXG X-Series signal generator and an X-Series signal analyzer.

As discussed earlier, the PA is required to have higher linearity to amplify high PAPR 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. DPD is one of the most cost-effective linearization techniques. DPD adds an expanding nonlinearity in the baseband that complements the compressing characteristic of the RF power amplifier (see Figure 5). Ideally, the cascade of the pre-distorter and the power amplifier becomes linear and the original input is amplified by a constant gain. With the pre-distorter, the power amplifier can be utilized up to its saturation point while still maintaining good linearity, thereby significantly increasing its efficiency (see Figure 6).

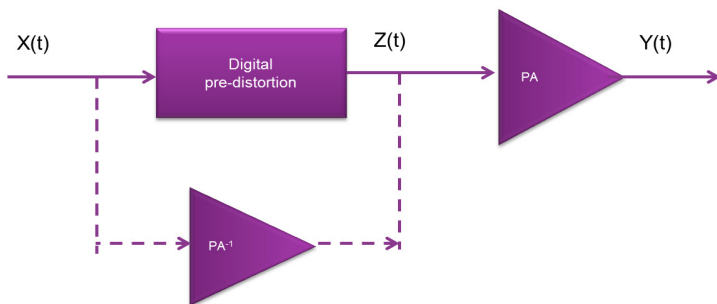


Figure 5. DPD for a PA cascade

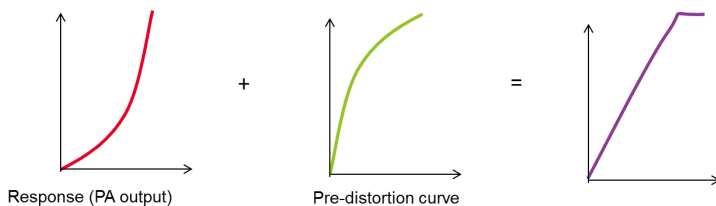


Figure 6. PA response with DPD

As shown in Figure 6, the DPD can be seen as an “inverse” of the PA. The DPD algorithm needs to model the PA behavior accurately and efficiently for successful DPD deployment.

N7614B Signal Studio software supports two kinds of DPD modes:

Exact and apply

- Three PA model types are supported: Memory polynomial, Volterra series and look-up table
- Users can specify the number of iterations
- For memory polynomial and Volterra series memory model types, users can specify the memory order and non-linear order
- The DPD model can be exported for further verification

User-defined IQ LUT

- User provides the AM In (V) – AM Out (V) shaping and AM (V) - PM Out (deg) shaping table
- Support the LUT table edition directly with GUI
- Support the LUT table open and save

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 or 20 MHz 802.11n/ac signal, 60 MHz bandwidth must be available for capture. PXA and MXA X-Series signal analyzers support a maximum 160 MHz bandwidth, which provides bandwidth for analyzing DPD-applied waveforms up to 40 MHz LTE or WLAN signals.

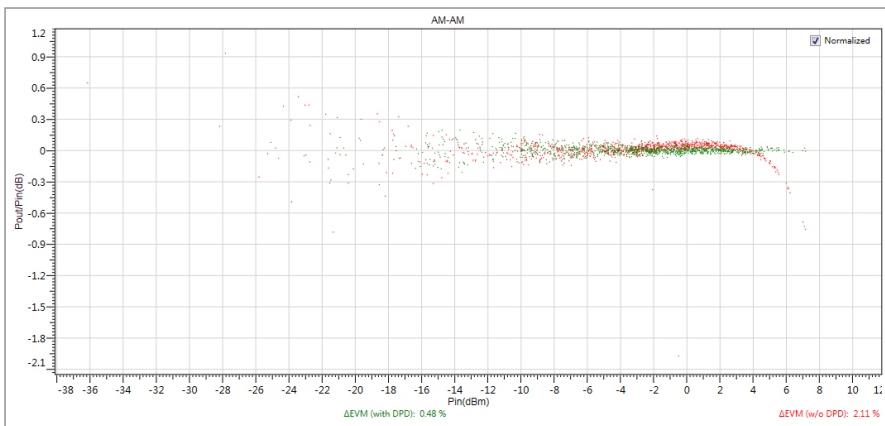


Figure 7. PA AM-AM result for 802.11n 20 MHz MCS7 using DPD memory polynomial

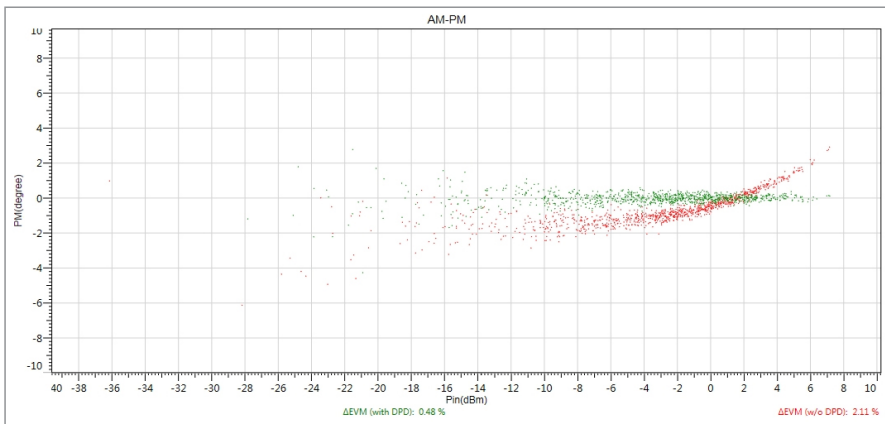


Figure 8. PA AM-PM result for 802.11n 20 MHz MCS7 using DPD memory polynomial

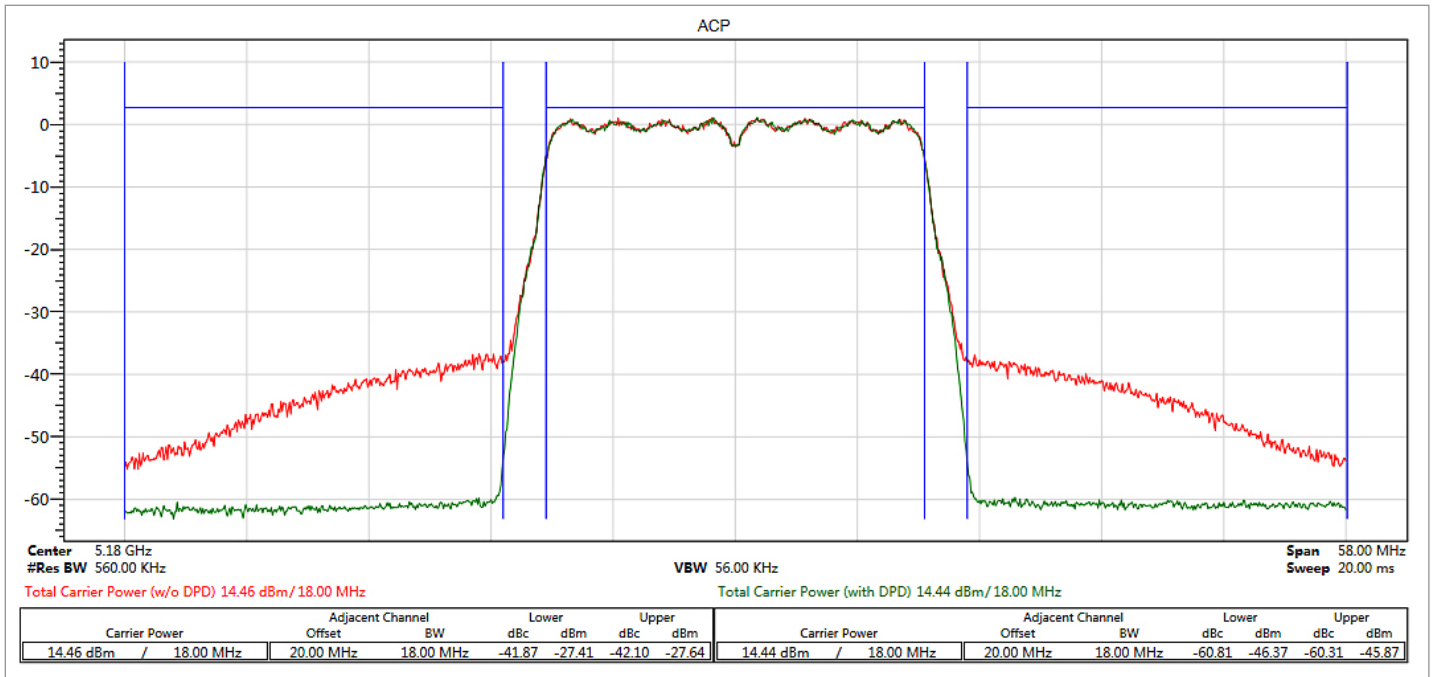


Figure 9. PA ACP result for 802.11n 20 MHz MCS7 using DPD memory polynomial

Envelope Tracking Test

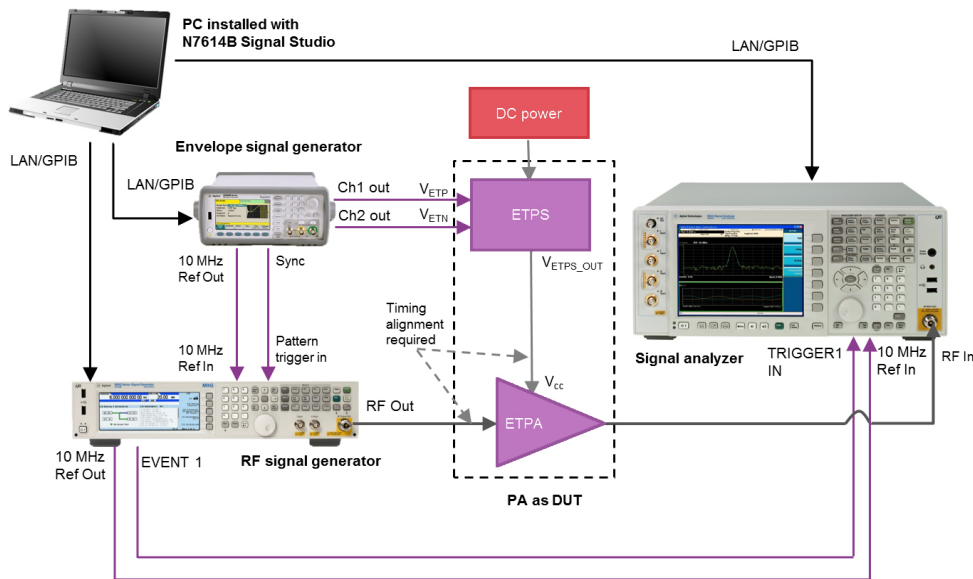


Figure 10. Typical PA ET/ET+DPD test configuration using N7614B Signal Studio with an MXG X-Series signal generator and an X-Series signal analyzer

Envelope tracking is an adaptive power control scheme for RF power amplifiers in which the RF PA power supply (V_{CC_PA}) is dynamically adjusted to match the envelope of the transmit signal.

Envelope tracking provides two key system benefits:

- Maximum RF PA efficiency for longer battery life and usage time
- Maximum RF PA heat reduction

Oversampling

The envelope is generated from the IQ sample's absolute magnitude, typically with 3x to 6x oversampling applied in order to create a wider bandwidth waveform. The basic 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.

Shaping table

Raw envelope data generated from the IQ signal will go 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 usually based on maximum efficiency operation. Another commonly used table is called Iso-Gain, in which the instantaneous supply voltage is chosen to achieve a particular constant PA gain.

Timing alignment

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. Typically the timing alignment between RF and envelope has to be less than 1 ns. 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.

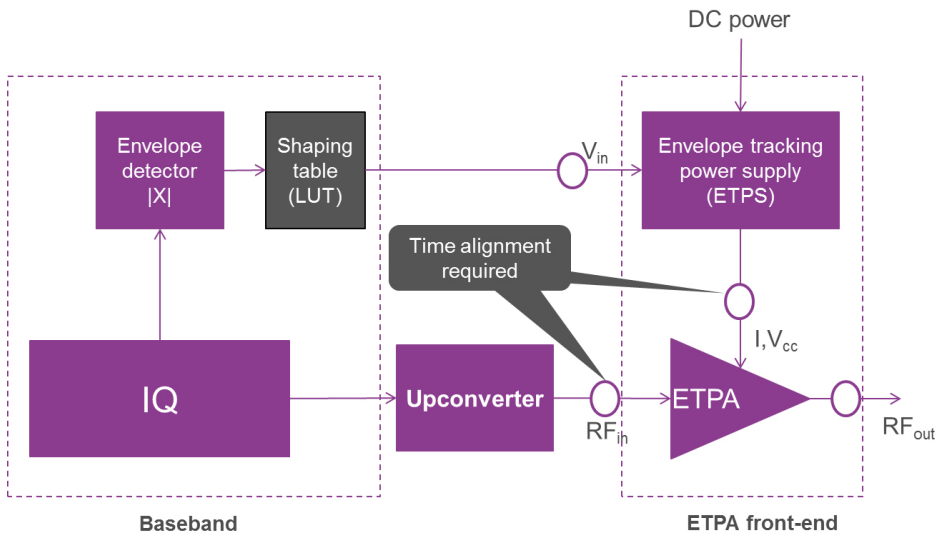


Figure 11. Envelope tracking system simplified block diagram

N7614B Signal Studio Envelope Tracking for Power Amplifier test provides:

Envelope tracking key features

- Envelope calculation can be from non-predistorted I/Q signal or pre-distorted I/Q signal
- Envelope waveform can be imported from user-defined waveform
- Oversampling ratio for envelope can be user-defined
- Shaping input can be normalized I/Q amplitude or absolute RF output voltage
- Envelope waveform can be exported
- ETPS characteristic parameters can be user-defined

Shaping table (LUT)

- Users provide the RF voltage to envelope voltage shaping table
- Supports the ET shaping table edition directly in the GUI
- Supports the ET shaping table open and save function

Timing alignment

- Supports automatic alignment based on ACP measurement results
- Delay step can be settable as low as 1 ps
- Supports manual alignment based on ACP, EVM or time domain

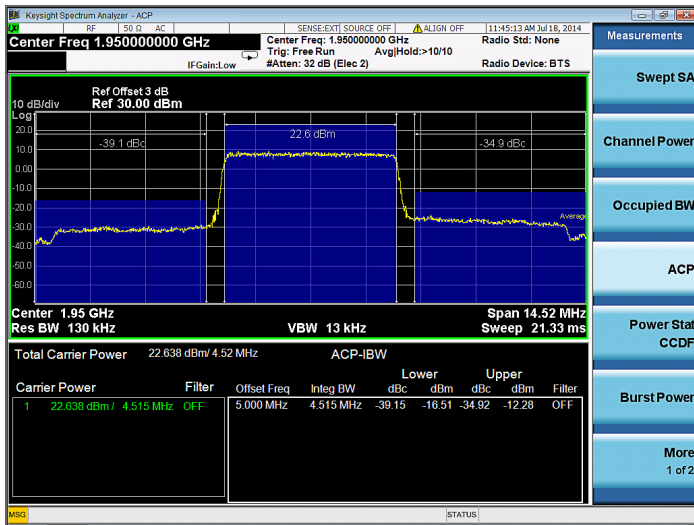


Figure 12. ET ACP measurement when time delay is not adequately adjusted

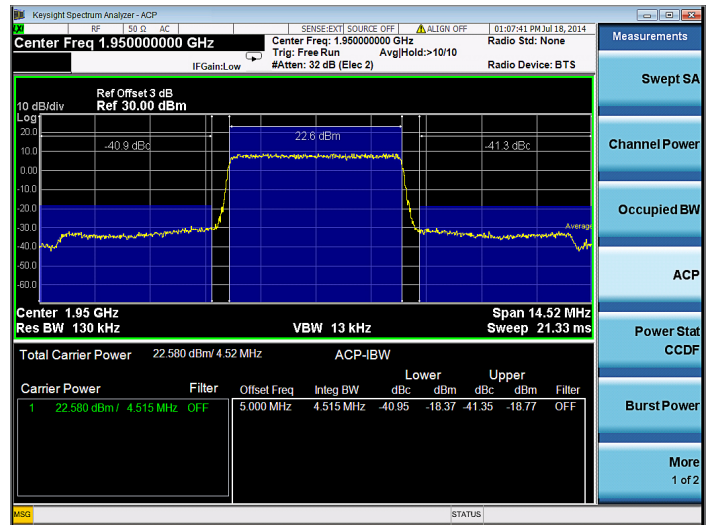


Figure 13. ET ACP measurement after automatic alignment

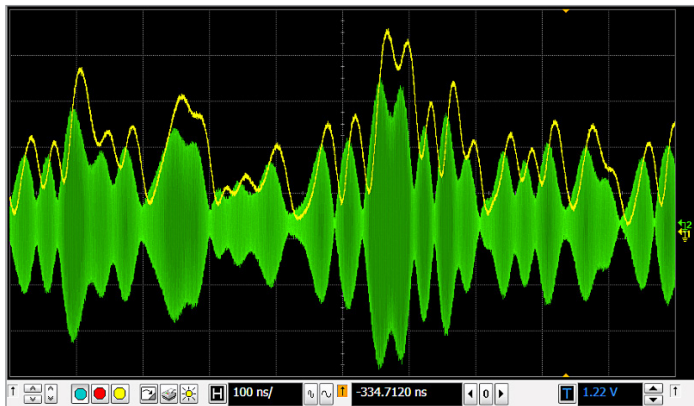


Figure 14. ET measurement in time domain when time delay is not adequately adjusted

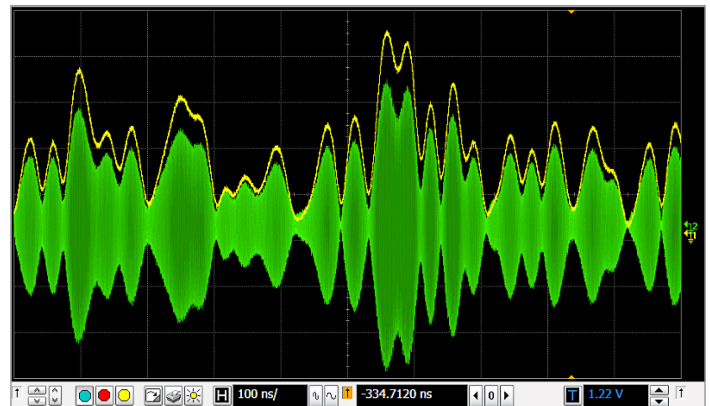


Figure 15. ET measurement in time domain after time alignment

You can see here that when the time delay between the PA RF input and the Vcc input is not adjusted adequately, the ACP measurement results will show worse, unbalanced results for the lower and upper channels. In time domain, the results may indicate that the two signals are not aligned. Automatic alignment is based on an ACP measurement which is fast and convenient, but you can perform manual alignment if needed based on ACP, EVM, or time domain measurements.

Combined Use of ET and DPD

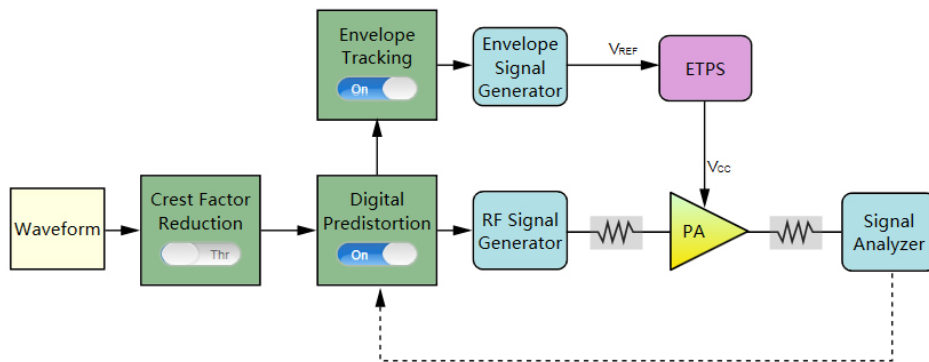


Figure 16. ET can be chosen from a Non-predistorted waveform or Pre-distorted waveform

When applying DPD together with ET, in order to linearize AM-PM characteristics, the envelope is typically generated based on pre-distorted I/Q waveforms. This means that for each DPD closed-loop iteration, both the pre-distorted I/Q waveform and the envelope waveforms need to be re-generated based on the updated DPD model. In order to understand if performance improvements are due to ET or DPD, ET can be applied and optimized before DPD, and then a DPD closed-loop iteration can be performed to compensate for amplitude and phase non-linearity.

N7614B Signal Studio software has integrated GUI support for both ET and DPD. It can generate an envelope from a pre-distorted waveform or a non-predistorted waveform. If the envelope source is chosen from a non-predistorted signal, the envelope will be calculated before DPD is applied. If the envelope source is chosen from a pre-distorted signal, DPD will be exact and applied first, after which the envelope is calculated based on a pre-distorted waveform. The process will be repeated for a specified number of iterations.

Measurement

Figure 17 shows an example of 5 MHz LTE uplink with QPSK modulation. The original waveform has an ACP result of -36 dBc and the AM-AM trace shows that the PA 1 dB compression point happens at +1 dBm PA input. After ET technology is applied, you can see that the AM-AM and AM-PM traces are linearized and ACP is improved from -36 dBc to -41 dBc. When DPD technology is applied, together with ET, the AM-AM and AM-PM curves are further linearized and ACP results will be further improved from -41 dBc to -64 dBc.

ET only

ET and DPD

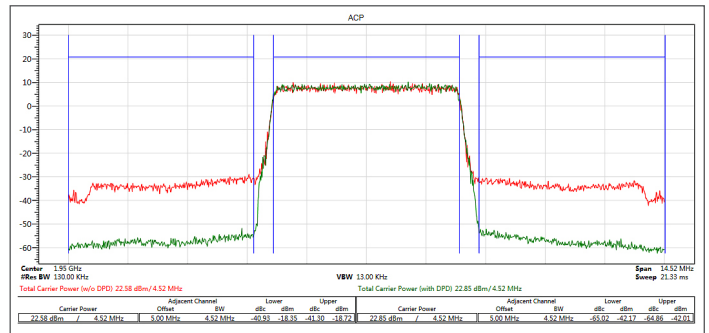
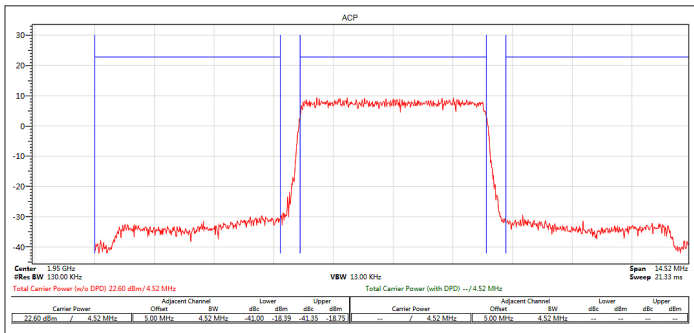
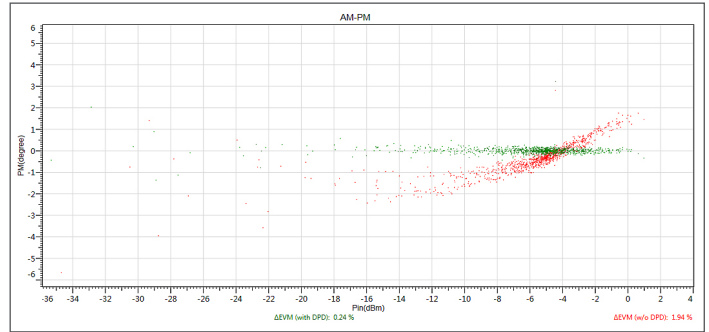
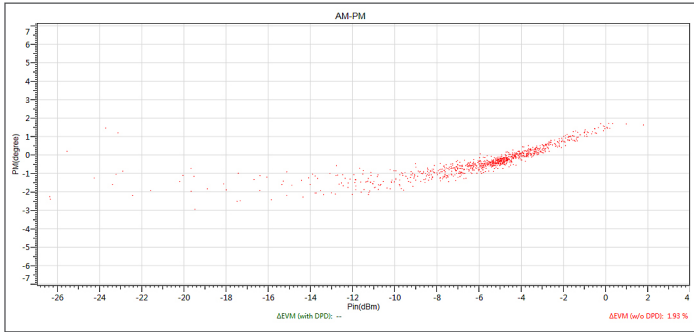
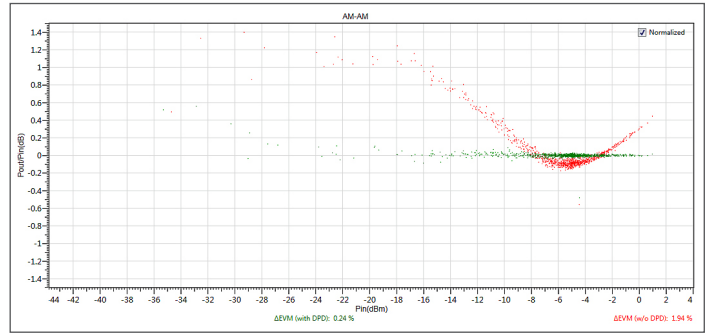
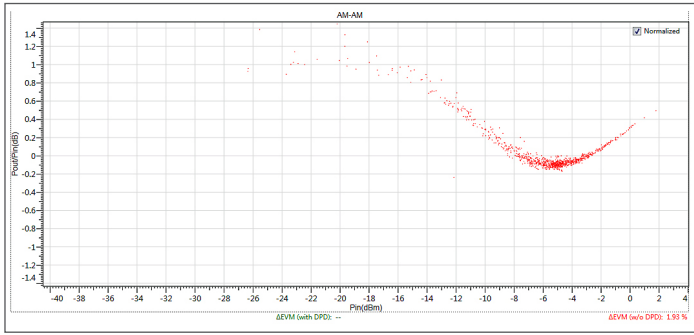


Figure 17. These graphs show the effect of ET only and ET with DPD with AM-AM, AM-PM and ACP results

Feature Summary

Power Amplifier Test		
Signal Studio	Parameter settings	Outputs or measurements
General	<ul style="list-style-type: none"> - Hint for each module - Instrument connection by LAN or GPIB - Instrument key parameter settings on N7614B GUI 	<ul style="list-style-type: none"> - Hint for each measurement - Log information for the running results
Waveform	<ul style="list-style-type: none"> - Preloaded, Signal Studio or user-defined - User defined types: <ul style="list-style-type: none"> - a) CSV or text files - b) Big Endian 16 bits - c) MATLAB - Set the OSR (oversampling rate for waveform) - Burst formation mask setting for WLAN - Marker source selection <ul style="list-style-type: none"> - a) None - b) Waveform start - c) From the input WFM file - d) PA enable mask - e) User defined bits 	
Power amplifier	<ul style="list-style-type: none"> - Set PA related parameters like loss In, loss Out, PA gain - Choose the power control <ul style="list-style-type: none"> - a) PA input - b) PA output - Power sweep setting for dynamic EVM 	
Crest factor reduction	<ul style="list-style-type: none"> - Support two CFR algorithms <ul style="list-style-type: none"> - a) Peak windowing - b) Clipping and filtering 	<ul style="list-style-type: none"> - CCDF table (Before CFR) - CCDF table (After CFR) - Delta EVM - CCDF trace (before CFR, after CFR and Gaussian as reference)
Digital pre-distortion	<ul style="list-style-type: none"> - Support two method: <ul style="list-style-type: none"> - a) Exact and apply - b) Apply I/Q LUT - Exact and Apply support three kinds of PA modeling types: <ul style="list-style-type: none"> - a) Memory polynomial - b) Volterra series - c) Look-up table (memoryless model) - Look-up table <ul style="list-style-type: none"> - a) LUT open/save - b) LUT add/remove - c) LUT edition on GUI 	<ul style="list-style-type: none"> - Export DPD model to CSV file - AM-AM trace - AM-PM trace - Delta EVM results (with or without DPD) - ACP trace and result metrics - Dynamic EVM trace (for WLAN only) <ul style="list-style-type: none"> - Choose WLAN radio standard - Choose guard interval
Envelope tracking	<ul style="list-style-type: none"> - Envelope calculation support three kinds of input: <ul style="list-style-type: none"> - a) From non-predistorted signal - b) From pre-distorted signal - c) User defined - OSR (oversampling rate) for envelope can be set with default 3x OSR - Shaping input support: <ul style="list-style-type: none"> - a) Normalized I/Q amplitude - b) Absolute RF output voltage - Shaping table <ul style="list-style-type: none"> - a) Open/save - b) Add/remove - c) Edition on GUI - Timing alignment: <ul style="list-style-type: none"> - a) Automatically - b) Manually 	<ul style="list-style-type: none"> - AM-AM trace - AM-PM trace - Delta EVM results - ACP trace and result metrics

Ordering Information

Software licensing and configuration

Signal Studio offers flexible licensing options, including:

- **Fixed license:** Allows you to create unlimited I/Q waveforms with a specific Signal Studio product and use them with a single, specific platform.
- **Transportable/floating license:** Allows you to create unlimited I/Q waveforms with a specific Signal Studio product and use them with a single platform (or PC in some cases) at a time. You may transfer the license from one product to another.

The table below lists fixed, perpetual licenses only; additional license types may be available. For detailed licensing information and configuration assistance, please refer to the Licensing Options web page at www.keysight.com/find/SignalStudio_licensing

N7614B signal studio for power amplifier test

Model-Option	Description
Connectivity	
N7614B-1FP	Connect to E4438C ESG signal generator
N7614B-3FP	Connect to N5182B/72B MXG/EXG signal generator
Capability	
N7614B-EFP	Envelope Tracking
N7614B-FFP	Digital Pre-Distortion

Try Before You Buy!

Free 30-day trials of Signal Studio software provide unrestricted use of the features and functions, including signal generation, with your compatible platform. Redeem a trial license online at

www.keysight.com/find/SignalStudio_trial

Hardware configurations

To learn more about compatible hardware and required configurations, please visit: www.keysight.com/find/SignalStudio_platforms

PC requirements

A PC is required to run Signal Studio. www.keysight.com/find/SignalStudio_pc

Additional Information

Websites

Access the comprehensive online documentation, which includes the complete software HELP, download the software, and request a trial license.

www.keysight.com/find/n7614b

www.keysight.com/find/SignalStudio

Keysight's ET and DPD test solutions

www.keysight.com/find/ET

www.keysight.com/find/DPD

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Singapore	1 800 375 8100
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