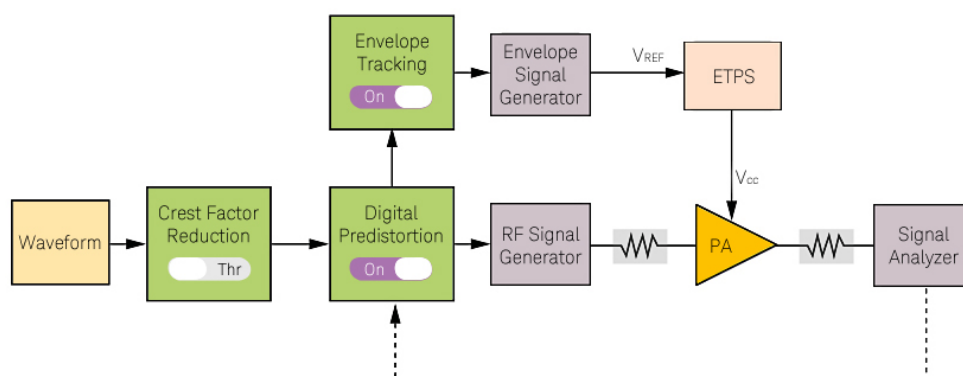# N7614C Signal Studio
for Power Amplifier CFR, DPD and ET Test

2021

- 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). Supports narrow-band, wide-band, and dual-band DPD and ET.
- 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 , EVM vs. Power and Power Added Efficiency (PAE)
- DPD supports the open-loop model with Look-Up-Table (LUT), the close-loop model (Volterra and Memory Polynomial), and customer defined DPD algorithms
- Time alignment between the ET signal and the RF signal can be calibrated manually or automatically
- Speed improvement to apply LUT-based DPD and shaping table for ET in real-time

Simplify Signal Creation for PA Test

Keysight Technologies, Inc. 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 N7614C 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 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

Techniques such as crest factor reduction, envelope tracking and digital pre-distortion, can be implemented to increase PA efficiency. All of these methods are supported by the N7614C Signal Studio for power amplifier test software.

Typical measurements

Distortion measurement
– AM-AM
– AM-PM
– CCDF

Spectrum measurement
– Channel power
– ACP

Modulation quality
– Raw EVM
– Demod EVM
– Dynamic EVM
– EVM vs. Power
  (X-Series measurement applications required)

Power measurement
– PAE

Crest Factor Reduction Technology

CFR is a technique used to reduce the peak-to-average power ratio (PAPR) of the transmitted signals so that the power amplifier can operate more efficiently. There are two CFR algorithms supported by N7614C.

– Clipping and filtering
– Peak windowing (Kaiser window)
– Peak cancellation

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, possibly resulting gain saturation and distortion, and 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. N7614C supports the following four methods:

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

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 the envelope excursion is near its peak. However, as the amount of back-off increases, the power amplifier becomes less efficient. Envelope tracking (ET) is the leading 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. N7614C supports ET 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. N7614C 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 N7614C Signal Studio for Power Amplifier Test software, you must have a properly configured PC and several properly configured instruments, as described here. 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	Envelope tracking test
Signal generators	**Signal generators**
– X-Series signal generator (MXG, EXG)	– X-Series signal generator (MXG, EXG)
– E8267D PSG	– M8190A AWG + E8267D PSG
– M8190A AWG + E8267D PSG	– PXIe VXT M9420A/M9421A
– M8190A 12-bit AWG (with SW DUC)	– PXIe VSG M9381A
– M8195A AWG (with SW DUC)	
– PXIe VXT M9420A/M9421A	**Envelope signal generator**
– PXIe VXT M9410A/M9411A	– X-Series signal generator (MXG, EXG)
– PXIe VXT M9415A	– 33522/33622 waveform generator
– PXIe VSG M9381A	– M8190A AWG
– PXIe Microwave SG M9383A	– M320xA PXIe AWG
– VXG M9384B	
	Signal analyzers
Signal analyzers	– X-Series signal analyzer (UXA, PXA, MXA, EXA)
– X-Series signal analyzer (UXA, PXA, MXA, EXA)	– PXIe VSA M9391A/M9393A
– PXIe VSA M9391A/M9393A	– PXIe VXT M9420A/M9421A
– PXIe VXT M9420A/M9421A	
– PXIe VXT M9410A/M9411A	
– 89600 VSA with oscilloscopes	

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.

N7614C Signal Studio supports three 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

Peak cancellation

– Peak cancellation method reduces the PAPR of a signal by subtracting spectrally shaped pulses from signal peaks that exceed a specified threshold
– The peak cancellation method's main parameters are target PAPR, max iteration, and crest factor
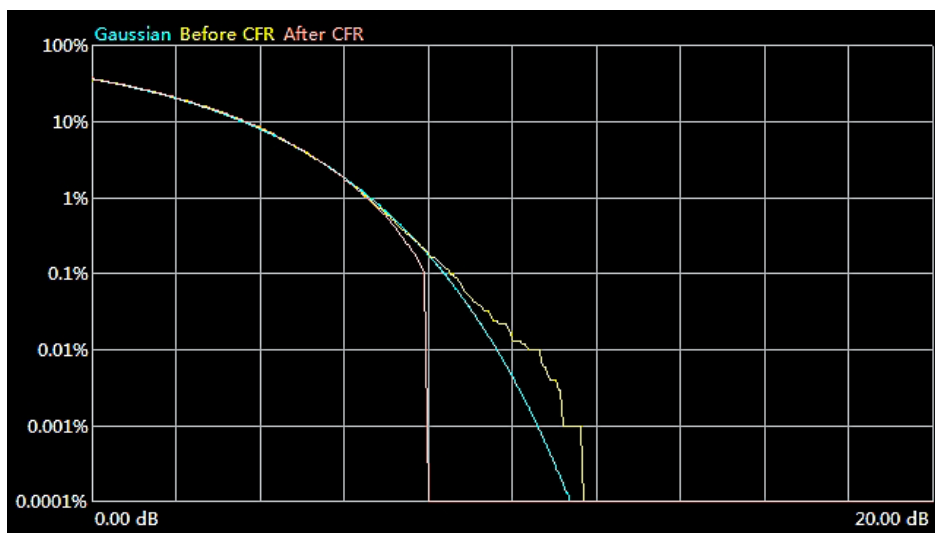

Figure 1. CCDF results traces with CCDF before CFR, CCDF after CFR, and Gaussian as reference

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 (Figure 2) has a peak PAPR of about 11.65 dB. With the peak windowing CFR technology (Figure 3), the PAPR is successfully reduced to 8.00 dB. However, the delta EVM deteriorated by 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.
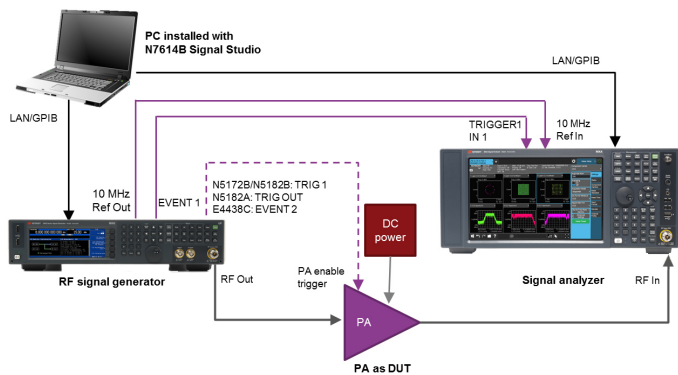
Digital Pre-Distortion Test

Figure 4a. Typical power amplifier DPD test configuration using N7614C Signal Studio with an MXG X-Series signal generator and an X-Series signal analyzer.
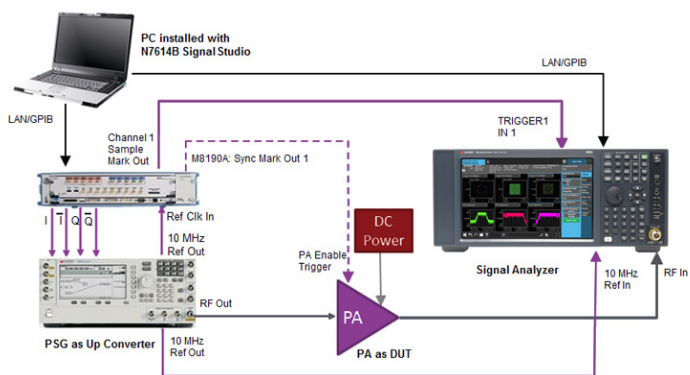
Figure 4b. Typical wideband PA test configuration using N7614C with M8190A AWG and PSG as signal generator and X-Series signal analyzer.

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, one of the most cost-effective linearization techniques, adds an expanding nonlinearity in the baseband that complements the compressing characteristic of the RF power amplifier (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 (Figure 6).
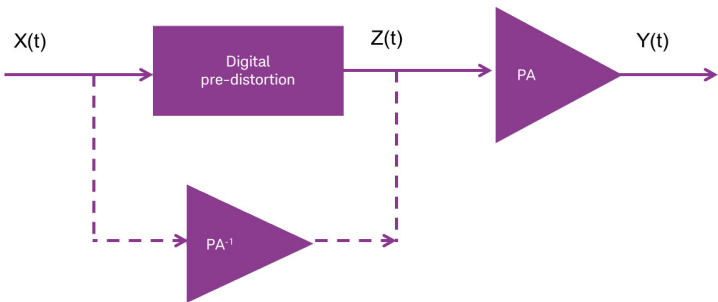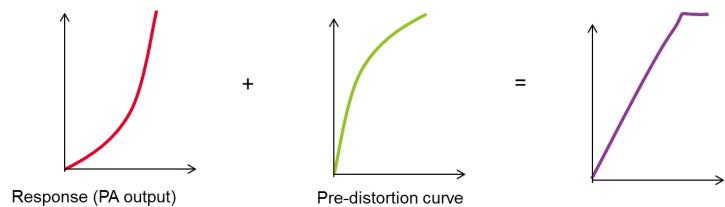

Figure 5. DPD for a PA cascade

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.

N7614C Signal Studio software supports two kinds of DPD modes:

Extract 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
– Customer's proprietary DPD algorithm written in MATLAB

Apply only

– For Look-Up-Table:
  – 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
– For Memory polynomial and Volterra, supports coefficient file import

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. The PXIe VSAs, 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.

Wideband DPD
For LTE 3CC/5CC or WLAN 80/160 MHz signals, the DPD algorithm requires more signal generator and signal analyzer bandwidth. We recommend a combination of the Keysight M8190A AWG, E8267D PSG and N9040B UXA as an ideal solution for wideband DPD measurement. Through the 89600 VSA software, the oscilloscope can be connected at the receiver side and wider bandwidth can be supported. Please note that for wideband systems up to the mmWave frequency band, calibration is usually needed. A tool for automatic calibration is provided in Signal Studio.

Dual-band DPD
For LTE non-contiguous carrier aggregation (CA) and WLAN non-contiguous 80 MHz + 80 MHz signal creation where the two band signals are separated up to several hundred MHz, the two signals cannot be created by one signal generator. Additionally, there may be cross modulation of two signals. In this case a dual-band DPD algorithm should be applied, which will measure each band separately and build the DPD model of each band considering the cross modulation.

Customer provided IP DPD
N7614C also supports the customer's DPD algorithm code written in MATLAB for both single-band and dual-band DPD tests. The customer can modify their code in the MATLAB environment and run it directly in N7614C software. All instrument connection and data processing will be done automatically in N7614C software.
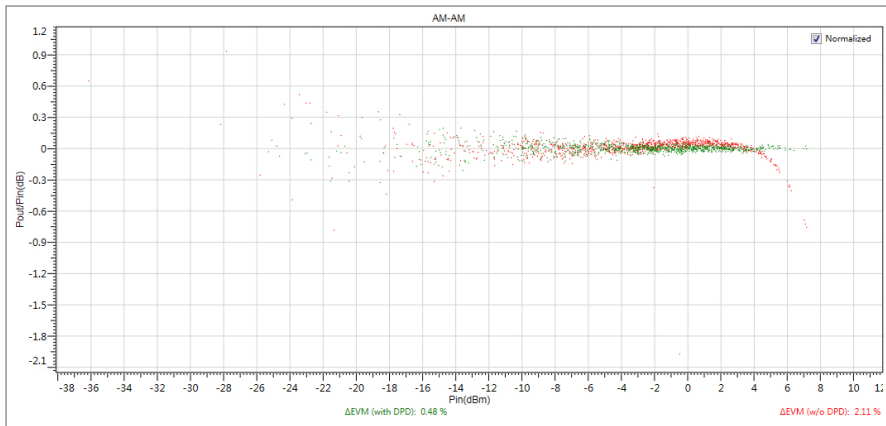
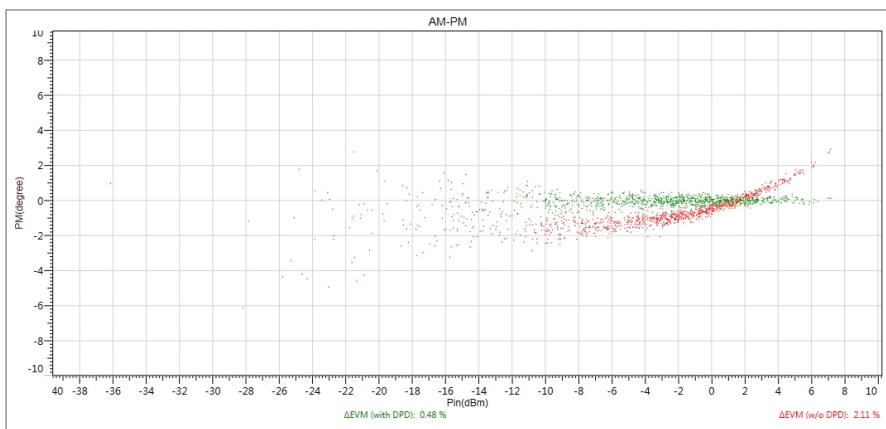Figure 7. PA AM-AM result for 802.11n 20 MHz MCS7 using DPD memory polynomial

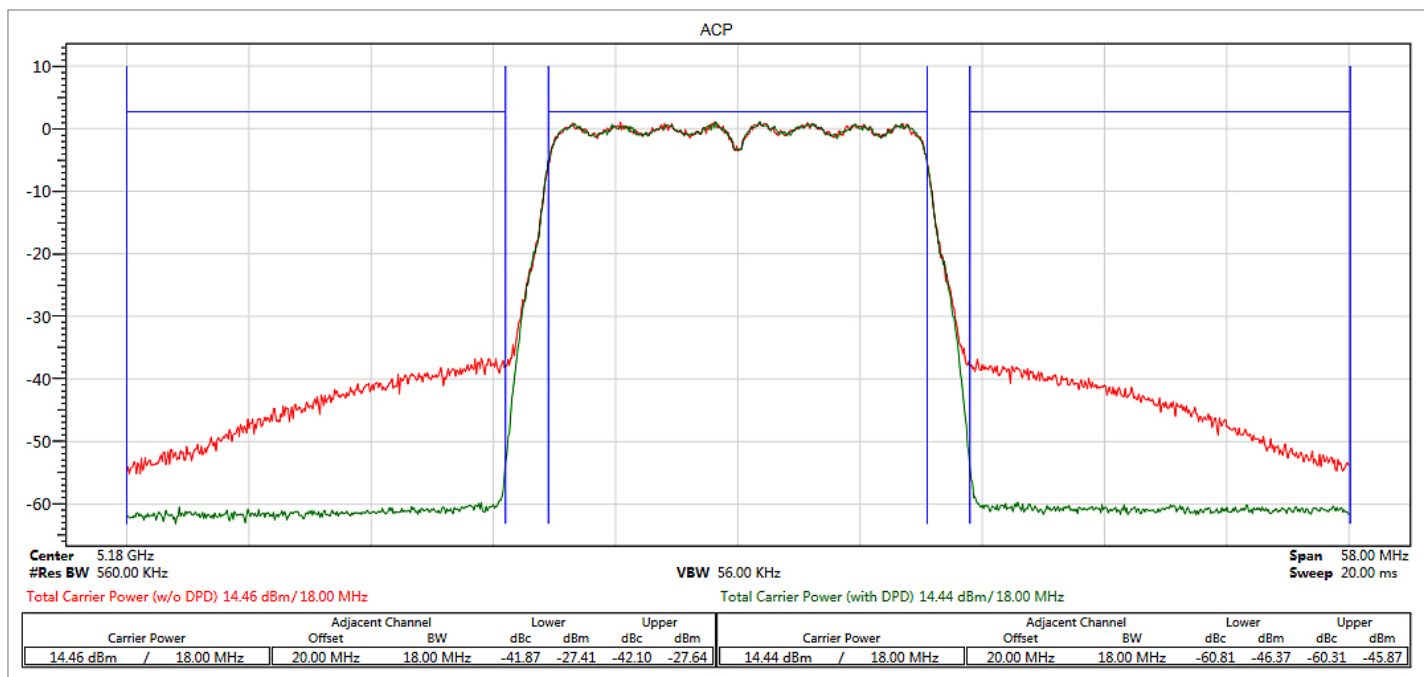Figure 8. PA AM-PM result for 802.11n 20 MHz MCS7 using DPD memory polynomial

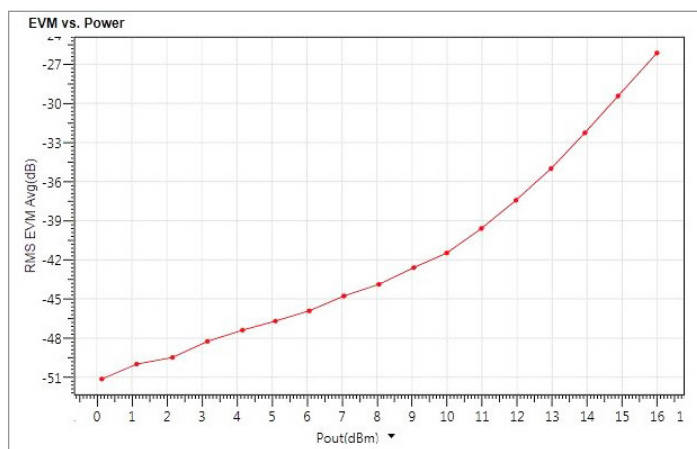Figure 9. PA ACP result for 802.11n 20 MHz MCS7 using DPD memory polynomial

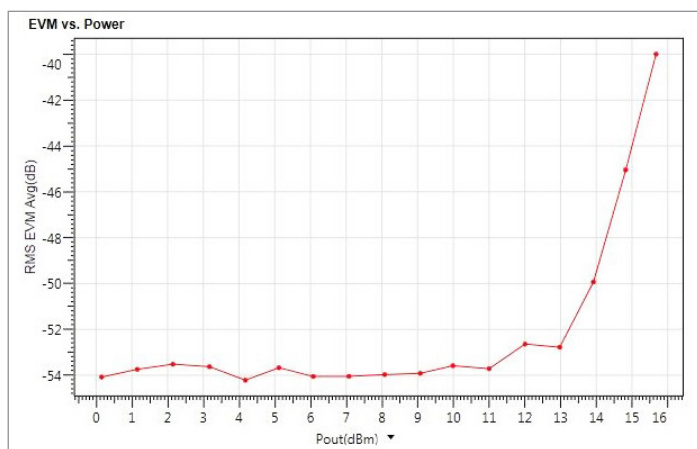Figure 10a. WLAN 802.11n 20 MHz EVM versus Power without DPD

Figure 10b. WLAN 802.11n 20 MHz EVM versus Power with DPD
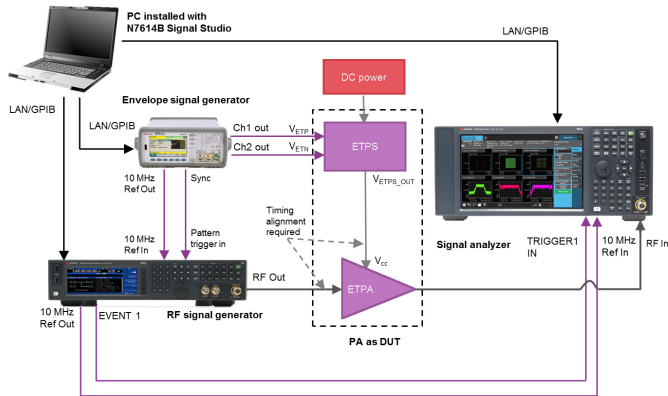
Envelope Tracking Test

Figure 11a. Typical PA ET/ET+DPD test configuration using N7614C Signal Studio with an MXG X-Series signal generator and an X-Series signal analyzer
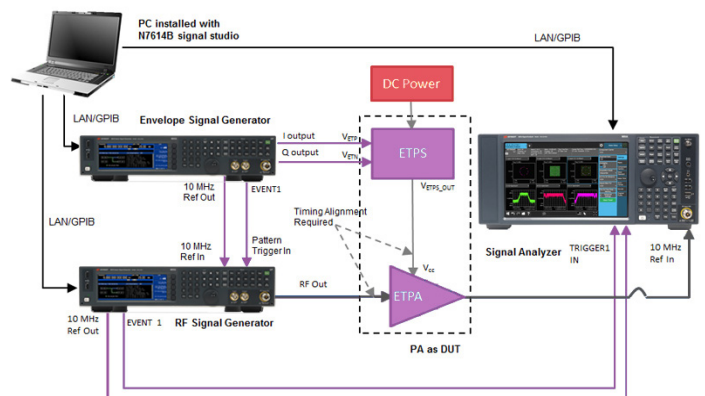
Figure 11b: PA ET/DPD test configuration using N7614C with dual MXG X-Series signal generator and X-Series signal analyzer

Envelope tracking is an adaptive power control scheme for RF power amplifiers in which the RF PA power supply (VCC_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.
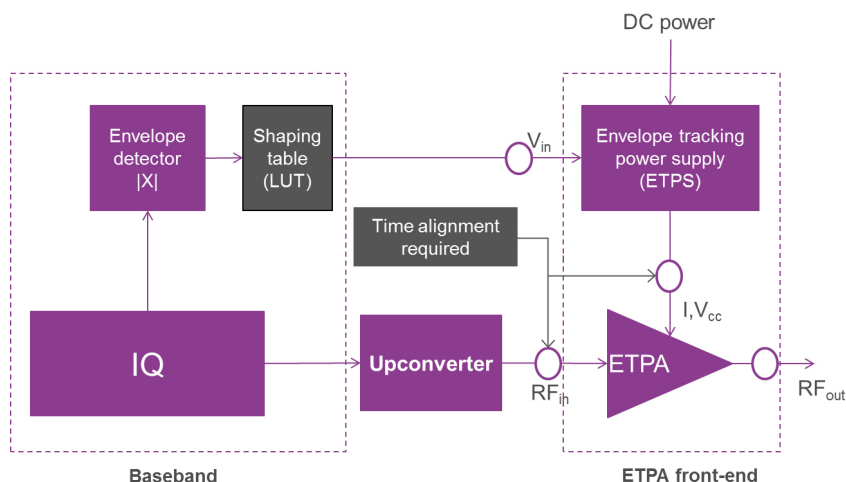

Figure 12. Envelope tracking system simplified block diagram

N7614C Signal Studio Envelope Tracking for Power Amplifier test provides:

Envelope tracking key features
- Envelope generator can use 33522B/33622A AWG, a second MXG or EXG, or M320xA PXIe AWG
- 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
- Envelope waveform can be exported as I/Q 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
- 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
- Supports shaping table in real-time with MXG-B or EXG as envelope generator

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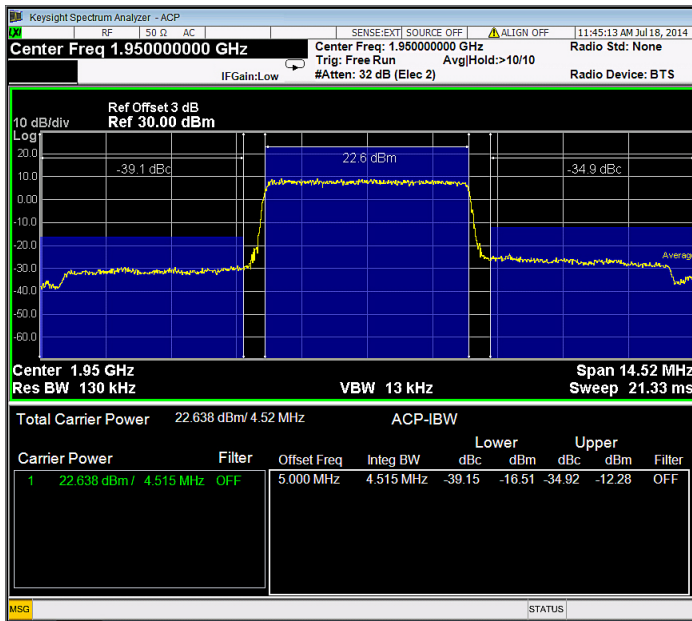- Supports manual alignment based on ACP, EVM or time domain

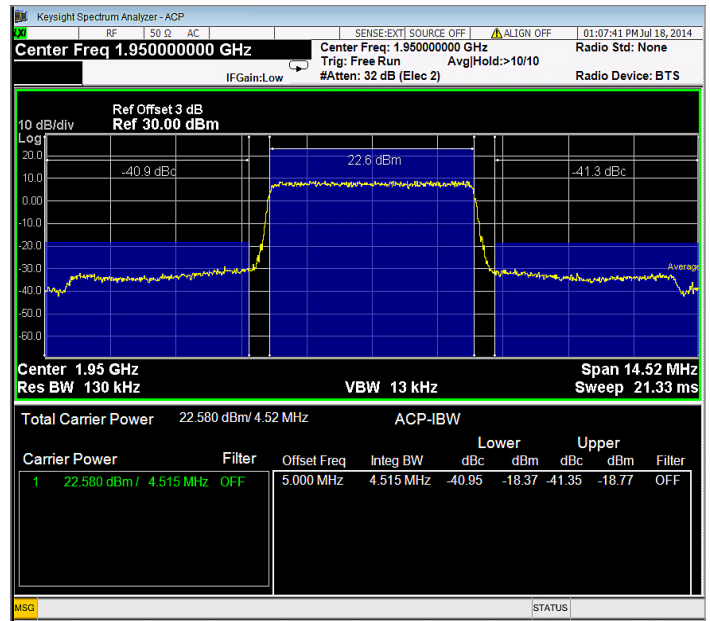Figure 13. ET measurement when time delay is not adequately adjusted

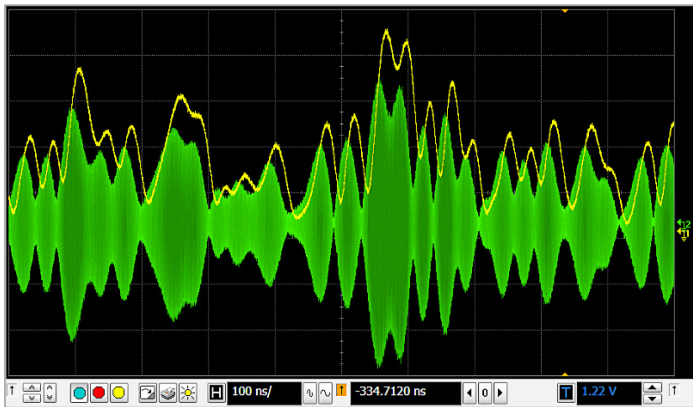Figure 14. ET ACP measurement after automatic alignment

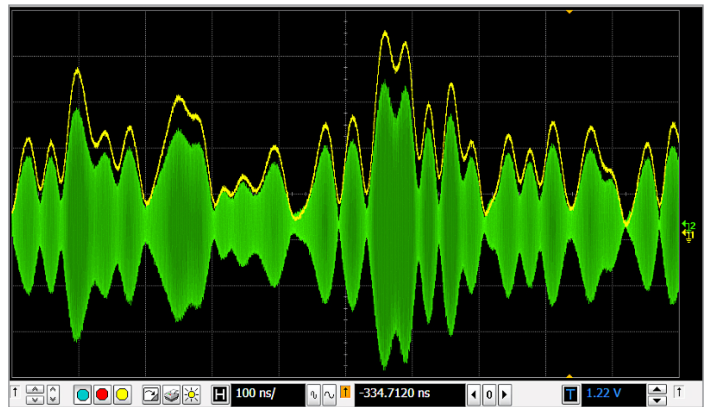Figure 15. ET measurement in time domain when time delay is not adequately adjusted

Figure 16. ET measurement in time domain after time alignment

Figures 13 and 15 illustrate what happens 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 (Figures 14 and 16) 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.

Dual-band ET

Only one signal generator is used and the ET signal is derived from the dual-band signal according to the different possible algorithms including user defined ET signal generation algorithms in MATLAB script. In addition to a pre-generated shaping table, user-defined MATLAB shaping functions also can be used.

PAE

PAE is an important performance parameter for power amplifiers. The equation for determining PAE is shown in below figure.

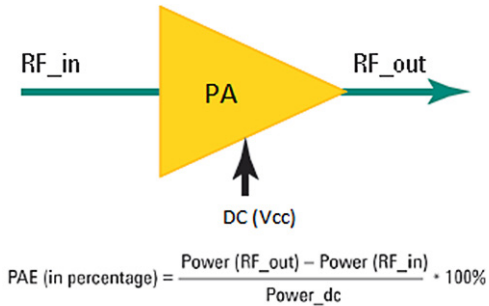$$PAE \text{ (in percentage)} = \frac{Power\,(RF\_out) - Power\,(RF\_in)}{Power\_dc} * 100\%$$

Figure 17. N7614C supports PAE measurement using a Keysight X-Series spectrum analyzer with Option BBA.
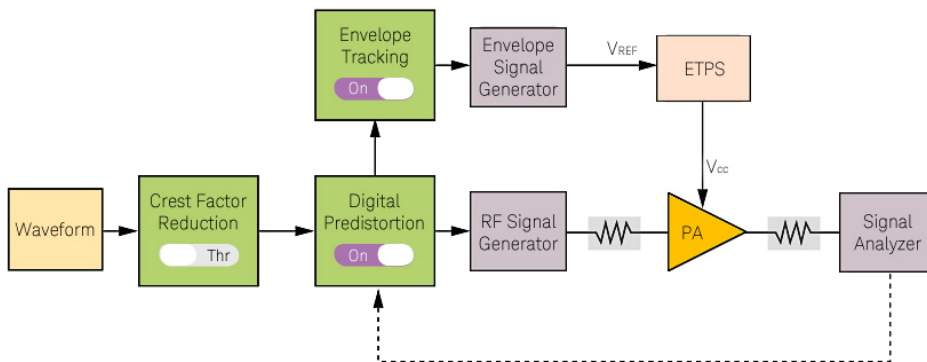
Combined Use of ET and DPD

Figure 18. 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.

N7614C 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 extracted 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 18 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.
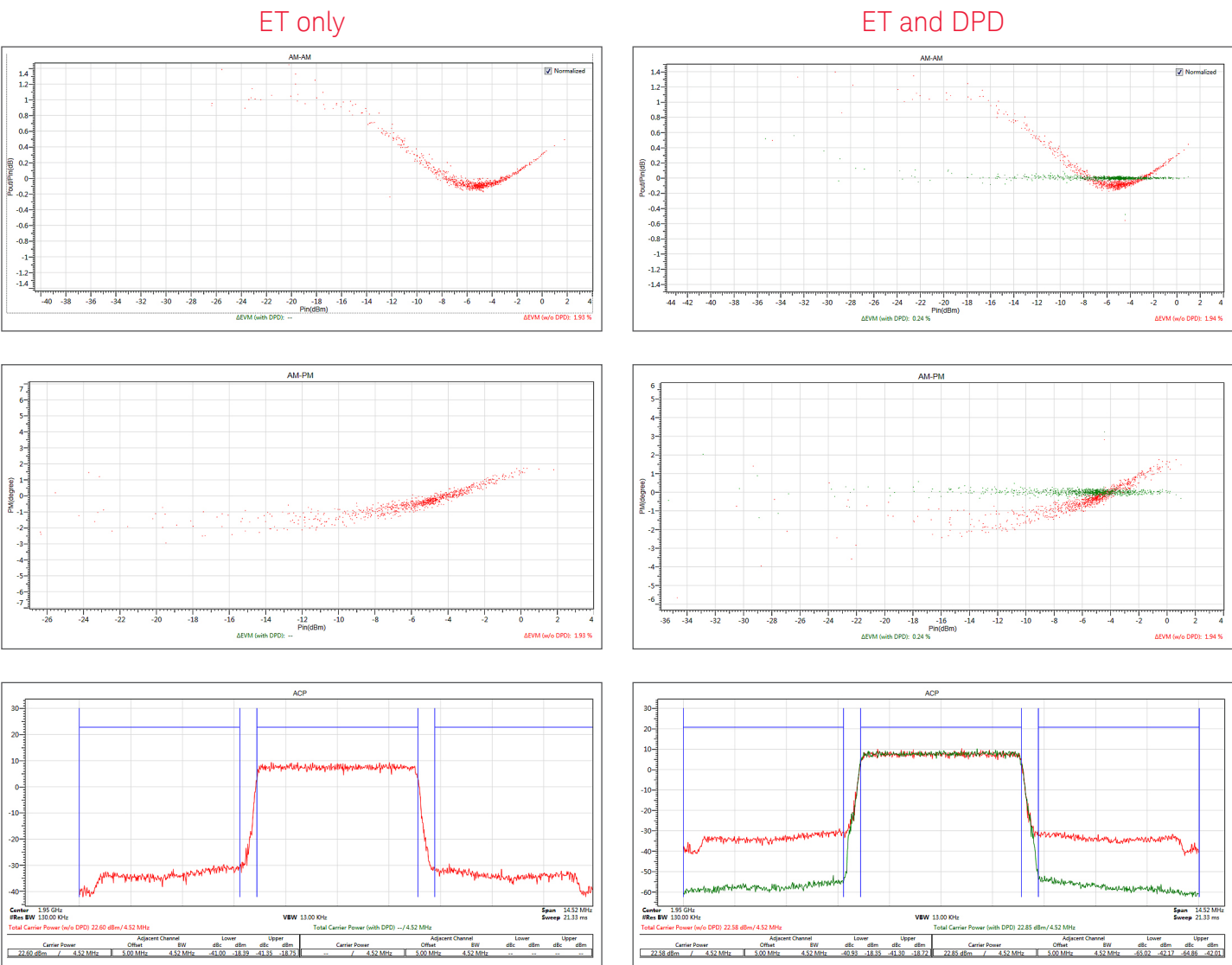
<div align="center">ET only   ET and DPD</div>

Figure 19. 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	– Hint for each module – Instrument connection by LAN or GPIB – Instrument key parameter settings on N7614C GUI	– Hint for each measurement – Log information for the running results

Waveform	– Preloaded, Signal Studio or user-defined
	– User defined types:
	  – CSV or text files
	  – Big Endian 16 bits
	  – MATLAB
	– Set the OSR (oversampling rate for waveform)
	– Burst formation mask setting for WLAN
	– Marker source selection
	  – None
	  – Waveform start
	  – From the input WFM file
	  – PA enable mask
	  – User defined bits	

Power amplifier	– Set PA related parameters like loss In, loss Out, PA gain
	– Choose the power control
	  – PA input
	  – PA output
	– Power sweep setting for dynamic EVM	

Crest factor reduction	– Support two CFR algorithms
	  – Peak windowing
	  – Clipping and filtering
	  – Peak cancellation
		– CCDF table (Before CFR)
		– CCDF table (After CFR)
		– Delta EVM
		– CCDF trace (before CFR, after CFR and Gaussian as reference)

Digital pre-distortion	– Support two method:
	  – Extract and apply
	  – Apply I/Q LUT
	– Extract and apply support four kinds of PA modeling types:
	  – Memory polynomial
	  – Volterra series
	  – Look-up table (memoryless model)
	  – User-defined MATLAB script
	– Apply user-defined DPD models
	– Wideband DPD support using M8190A AWG as baseband generator and E8267D as up-converter or M8190A DUC mode
	– Dual-band DPD with user-defined algorithms in MATLAB
		– Export pre-distorted waveform
		– Export DPD model to CSV file
		– AM-AM trace
		– AM-PM trace
		– Delta EVM results (with or without DPD)
		– ACP trace and result metrics[1]
		– EVM vs. Power (Raw EVM, Dynamic EVM, WLAN EVM or LTE EVM)

Envelope tracking	– Envelope calculation support three kinds of input:
	  – From non-predistorted signal
	  – From pre-distorted signal
	  – User defined
	– Envelope waveform can be exported as I/Q waveform
	– OSR (oversampling rate) for envelope can be set with default 3x OSR
	– Shaping input support:
	  – Normalized I/Q amplitude
	  – Absolute RF output voltage
	– Shaping table
	  – Open/save
	  – Add/remove
	  – Edition on GUI
	– Timing alignment:
	  – Automatically
	  – Manually
	– Shaping table can be applied in real-time if using the MXG-B N5182B or EXG N5172B as envelope generator
	– Dual-band ET with user-defined algorithms in MATLAB
		– AM-AM trace
		– AM-PM trace
		– Delta EVM results
		– ACP trace and result metrics[1]
		– EVM vs. Power (Raw EVM, Dynamic EVM, WLAN EVM or LTE EVM)
		– PAE

1. ACP measurements supports IQ analyzer mode when sweep mode is not available with PXIe VXT.

Ordering Information

Software licensing and configuration

Signal Studio offers flexible licensing options, including:

- **Node-locked:** Allows you to use the license on one specified instrument/computer.
- **Transportable:** Allows you to use the license on one instrument/computer at a time. This license may be transferred to another instrument/computer using Keysight's online tool.
- **Floating:** Allows you to access the license on networked instruments/computers from a server, one at a time. For concurrent access, multiple licenses may be purchased.
- **Time-based:** License is time limited to a defined period, such as 12-months.

N7614C Signal Studio for Power Amplifier Test

Waveform playback licenses (N7614EMBC)

Software License Type	Software License	Support Subscription (12-month) [2,3]
Node-locked perpetual license	R-Y5B-001-A[2]	R-Y6B-001-L
Node-locked 12-month license	R-Y4B-001-L[1]	Included
Transportable perpetual license	R-Y5B-004-D[2]	R-Y6B-004-L
Transportable 12-month license	R-Y4B-004-L[1]	Included

One-month software support subscription extension [3]

Support Contract	Description
R-Y6B-501	1-month of support subscription for node-locked perpetual licenses
R-Y6B-504	1-month of support subscription for transportable perpetual licenses

1. All time-based software licenses include a 12-month support contract.
2. Support contracts must be purchased for all perpetual licenses in the first year. All software upgrades and KeysightCare support are provided for software licenses with valid support contracts.
3. After the first year, support contracts for all perpetual licenses may be extended with annual and monthly support extensions.

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

Model numbers & options

To learn more about Signal Studio licensing, model numbers and options, please visit: www.keysight.com/find/signalstudio_model

Websites

www.keysight.com/find/SignalStudio

Comprehensive Online Documentation
www.keysight.com/find/signalstudio_support

Signal Studio for Power Amplifier Test
www.keysight.com/find/N7614C

Keysight's ET and DPD test solutions
www.keysight.com/find/ET
www.keysight.com/find/DPD

Keysight's RF PA/FEM characterization and test reference solution
with ET and DPD
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