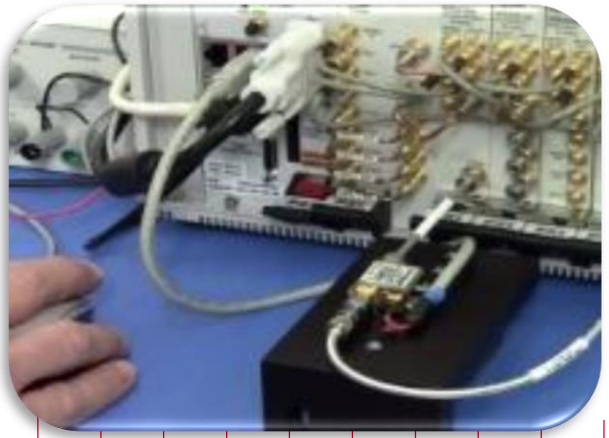
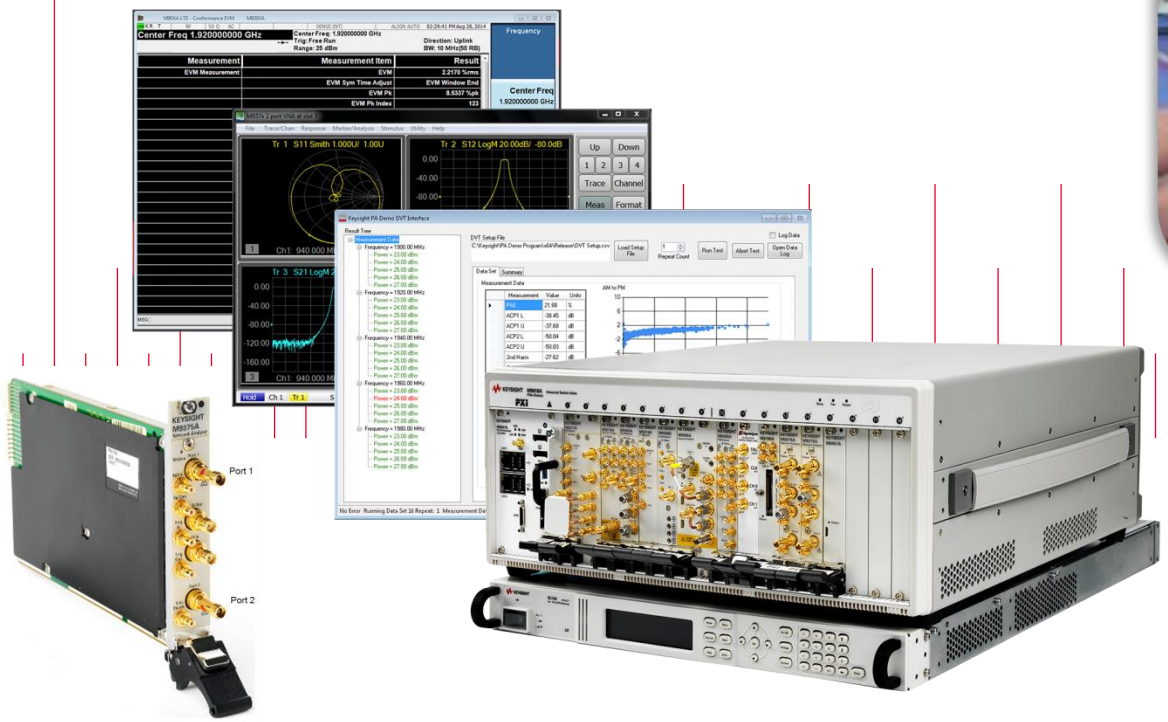
Power Amplifier Envelope Tracking and Digital Pre-distortion/Crest Factor Reduction Technologies and PXIe Solution





Robert Hood
Solutions Business Development

KEYSIGHT TECHNOLOGIES

March 2016

Agenda

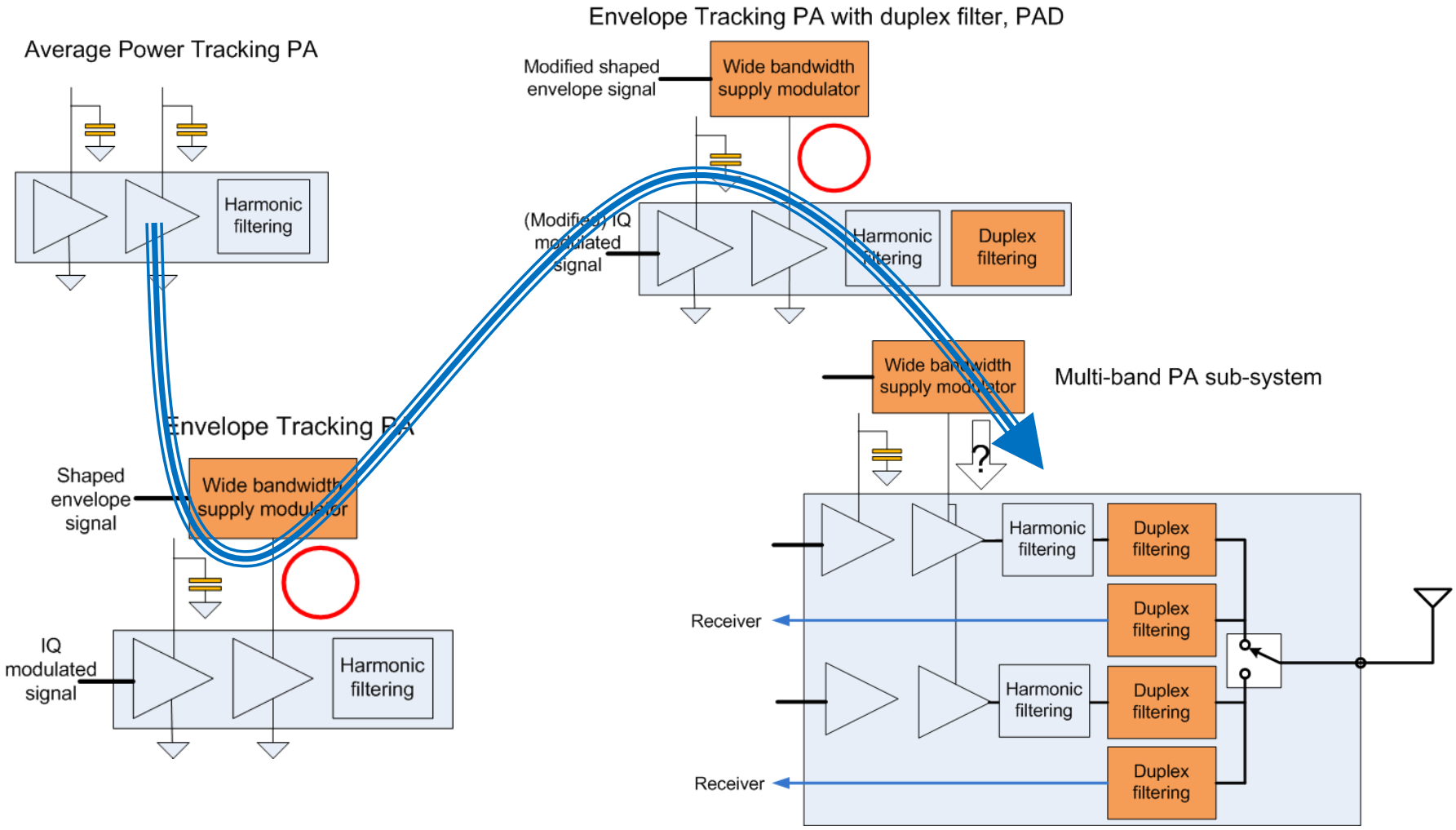
PA ET/DPD/CFR Test Technologies

- What are the key challenges for PA design?
- What are the CFR, DPD and ET technologies for PA?

Keysight PA Test Reference Solution

- PXIe Solution for PA Test
- PXIe Solution Architecture

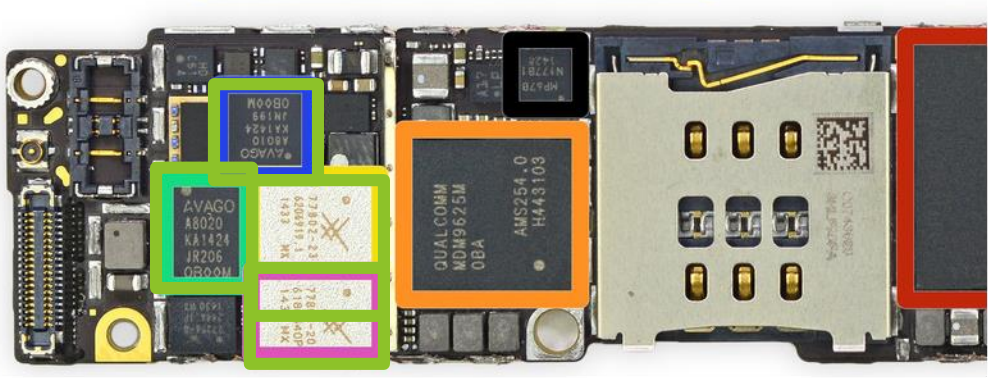
The Evolution of a Handset PA

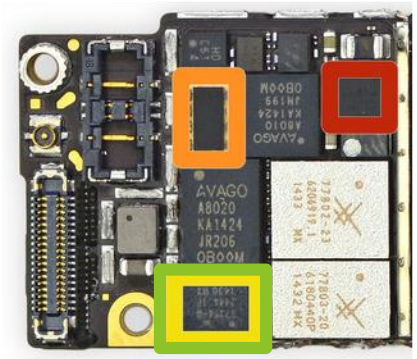


ET and PADs inside The iPhone 6

Orange: Qualcomm MDM 9625M LTE Modem
Yellow: Skyworks 77802-23 Low band LTE PAD
Green: Avago A8020 High band PAD
Blue: Avago A8010 Ultra high band PAD + FBARs
Purple: Skyworks 77803-20 Mid band LTE PAD
Black IvenSense MP67B 6 axis gyro / accelerometer

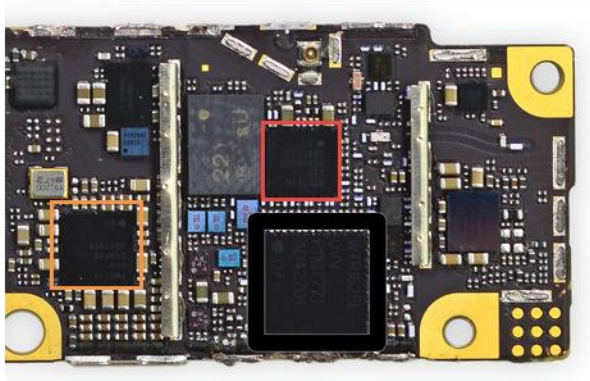
iPhone 6 teardown iFixit Sept 2014





Red: Qualcomm QFE1000 ETPS
Orange RFMD RF5159 Antenna switch
Yellow Skyworks 77356-8 Mid Band PAD

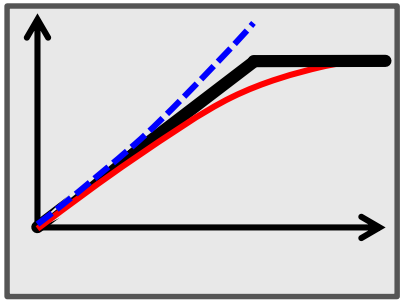
other side of PCA



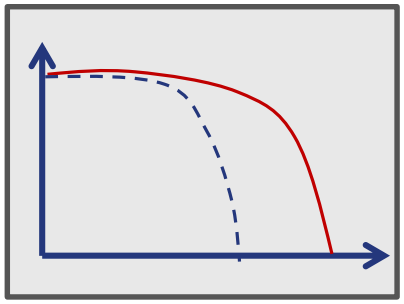
Black: Qualcomm WTR1625L RF transceiver
Red: Qualcomm WFR1620 Rx only companion, for carrier aggregation
Orange: Qualcomm PM8109 Power management IC

Three Methods to increase PA efficiency and linearity

ET: Envelope Tracking

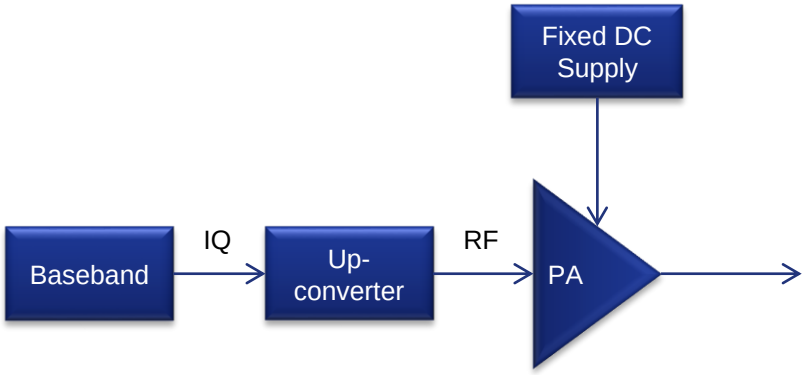


DPD: Digital Pre-Distortion

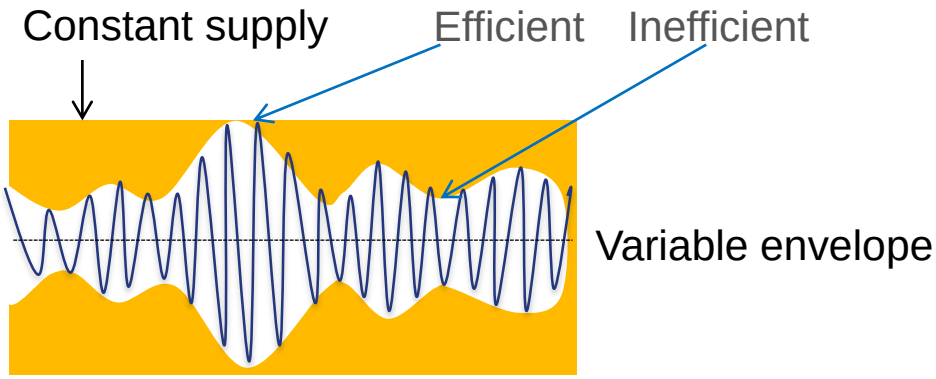


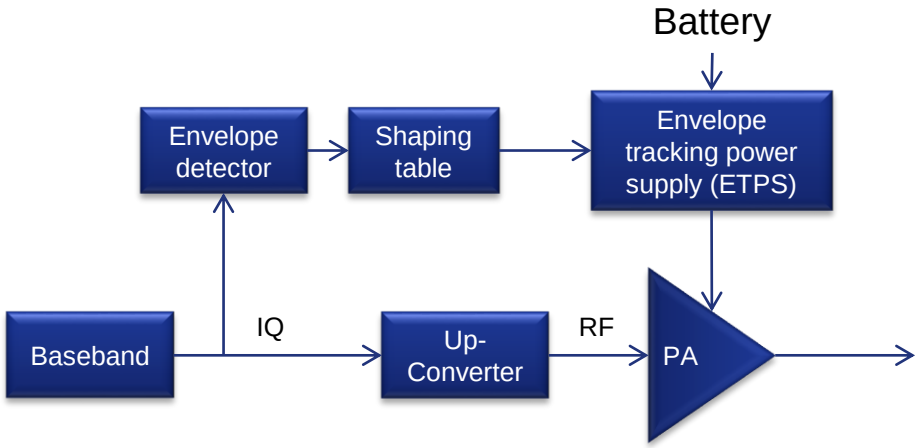
CFR: Crest Factor Reduction

Envelope Tracking vs. Fixed Supply - Concept

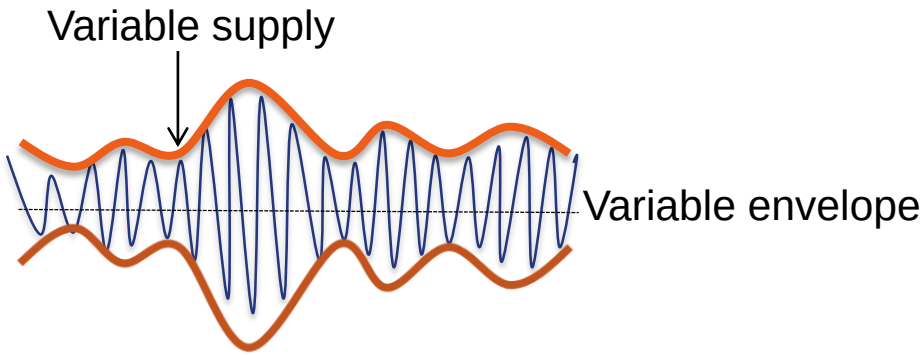


Conventional RF Amplifier

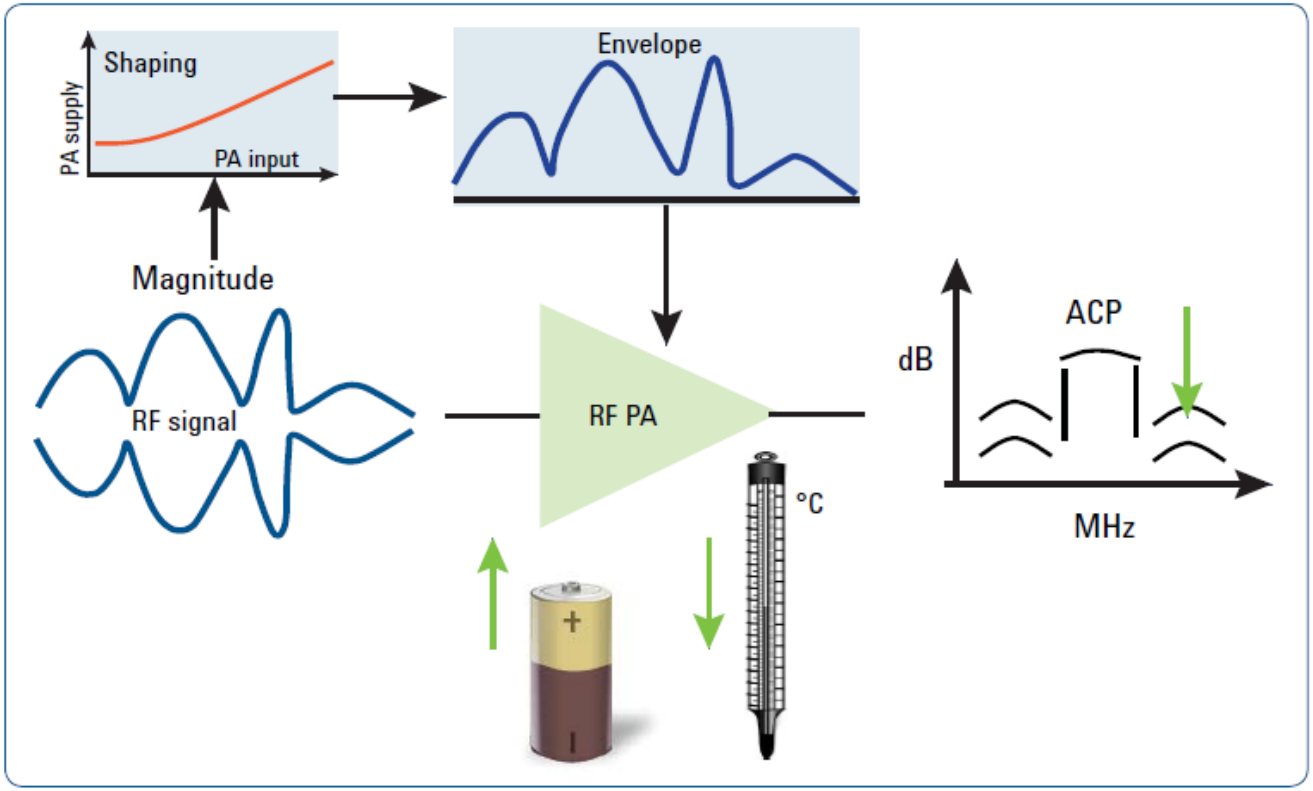




RF Amplifier with Envelope Tracking



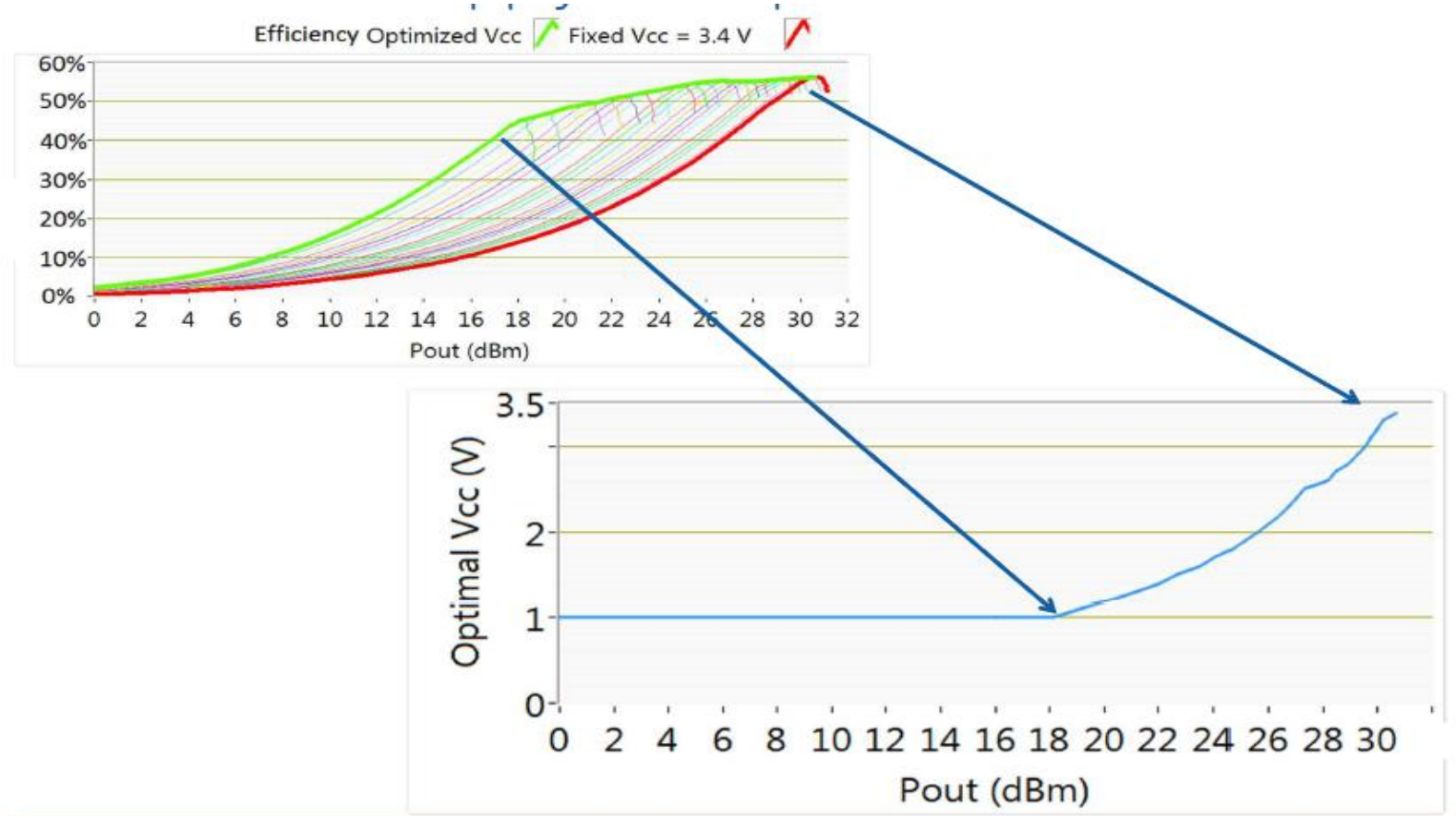
Envelope Tracking - The How & Why



Continuously adjust the supply voltage to change the PA's operating point

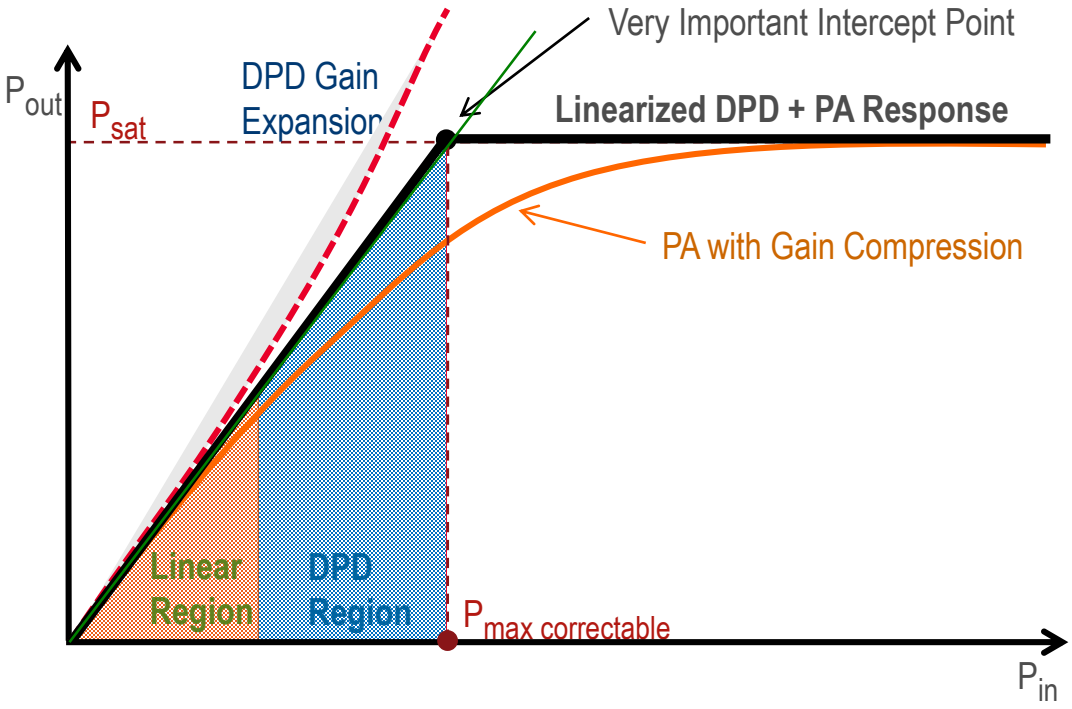
- Improve battery life
- Increase RF amplifier performance over broad frequencies
- Lower distortion
- Reduce heat dissipation

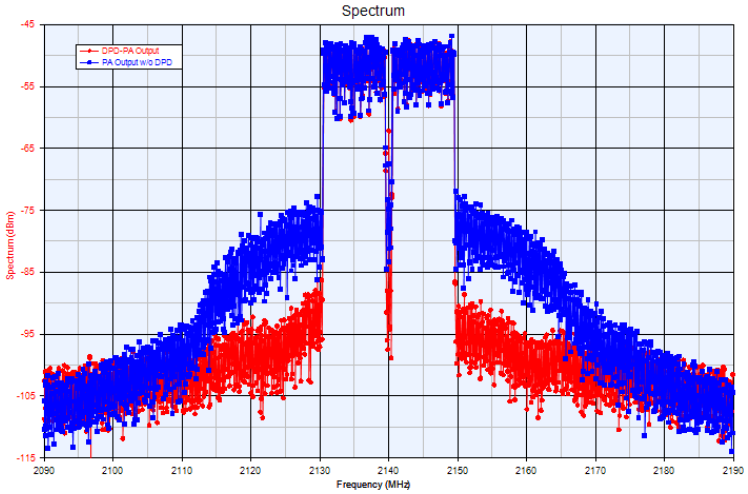
Envelop Tracking - Shaping Table Design



- A linear relationship between the IQ magnitude & modulated supply is not optimum
- A shaping table is used to optimize the PA's performance for efficiency or linearity

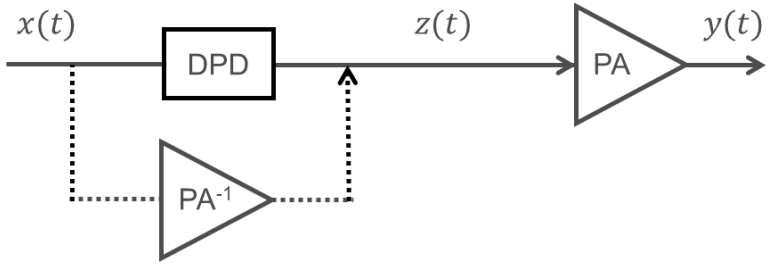
Digital Pre-Distortion (DPD) - Concept

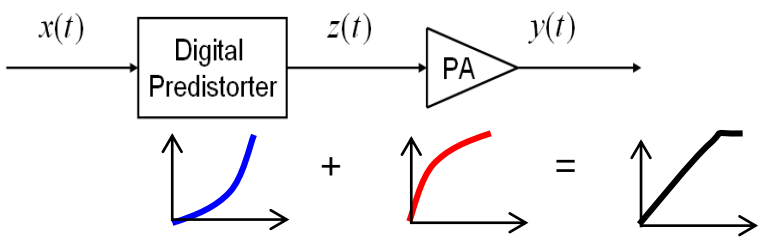




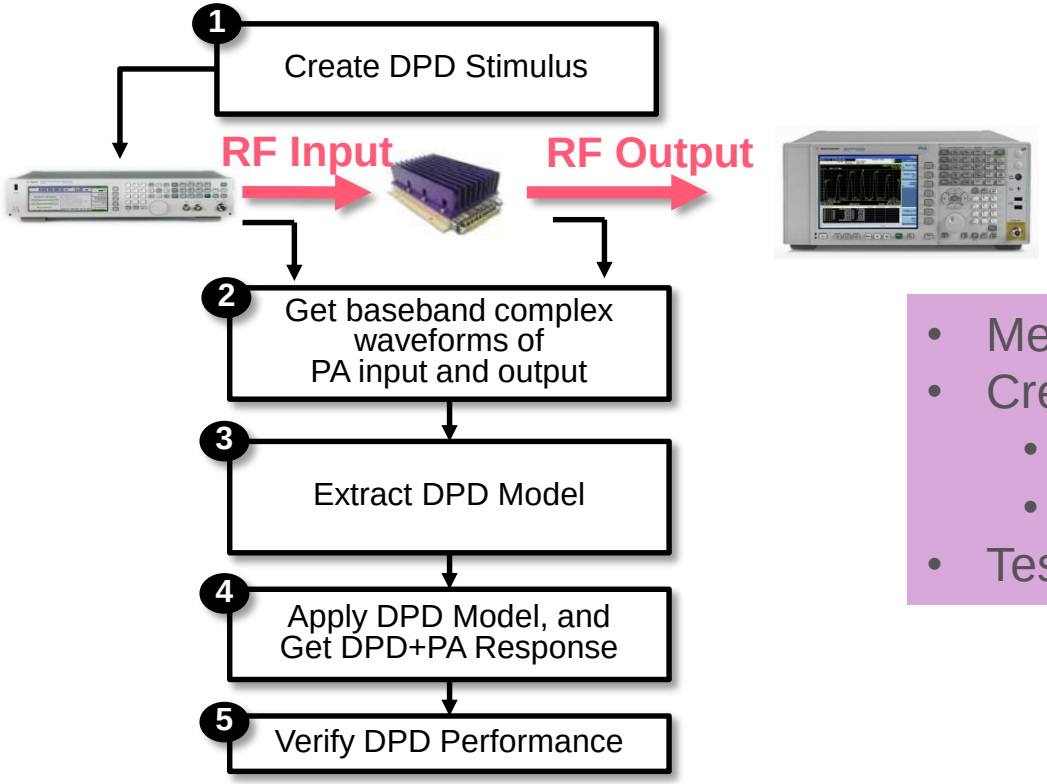
Raw PA output (no DPD)
PA+DPD, after 1 iteration to extract DPD coefficients

DPD corrects PA nonlinearities resulting in higher performing power amplifiers



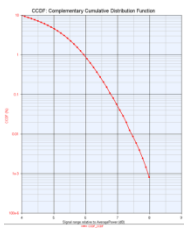


What is the DPD test procedure?

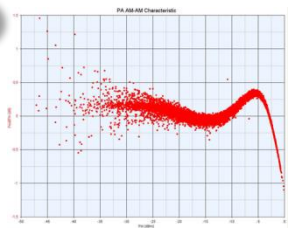


- Measure the distortion
- Create distortion table
  - Memoryless: Look-up-table
  - Memory: Volterra, Polynomial
- Test to see that the correction worked

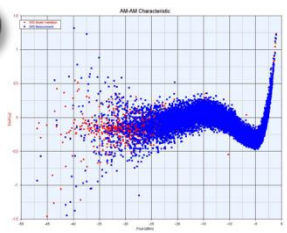
1 CCDF



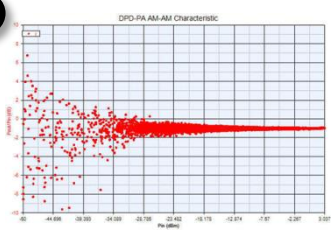
2 PA: AM-AM



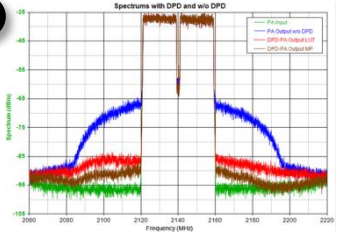
3 DPD: AM-AM



4 PA w/DPD: AM-AM

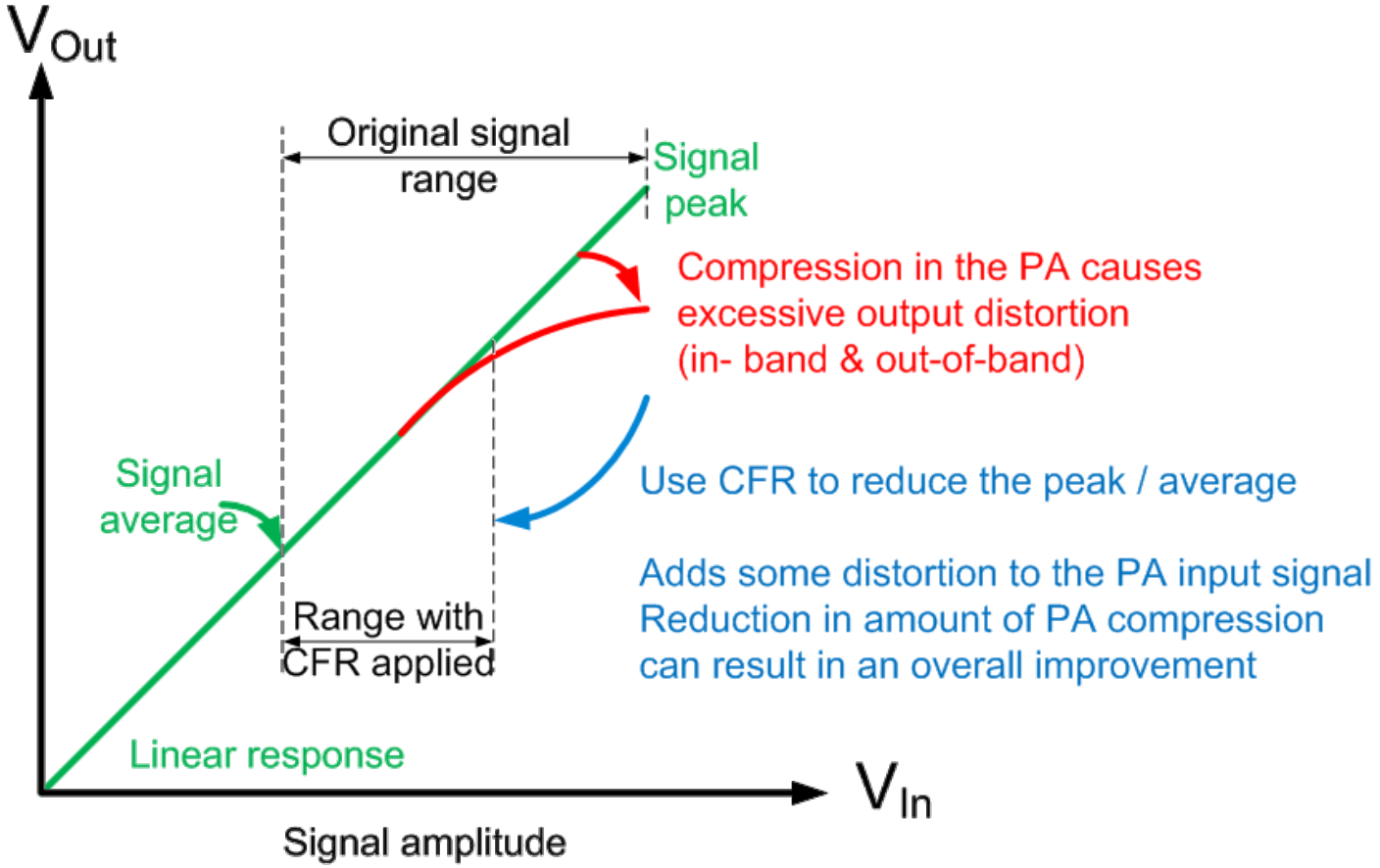


5 PA w/ DPD : ACP



Crest Factor Reduction - The How & Why

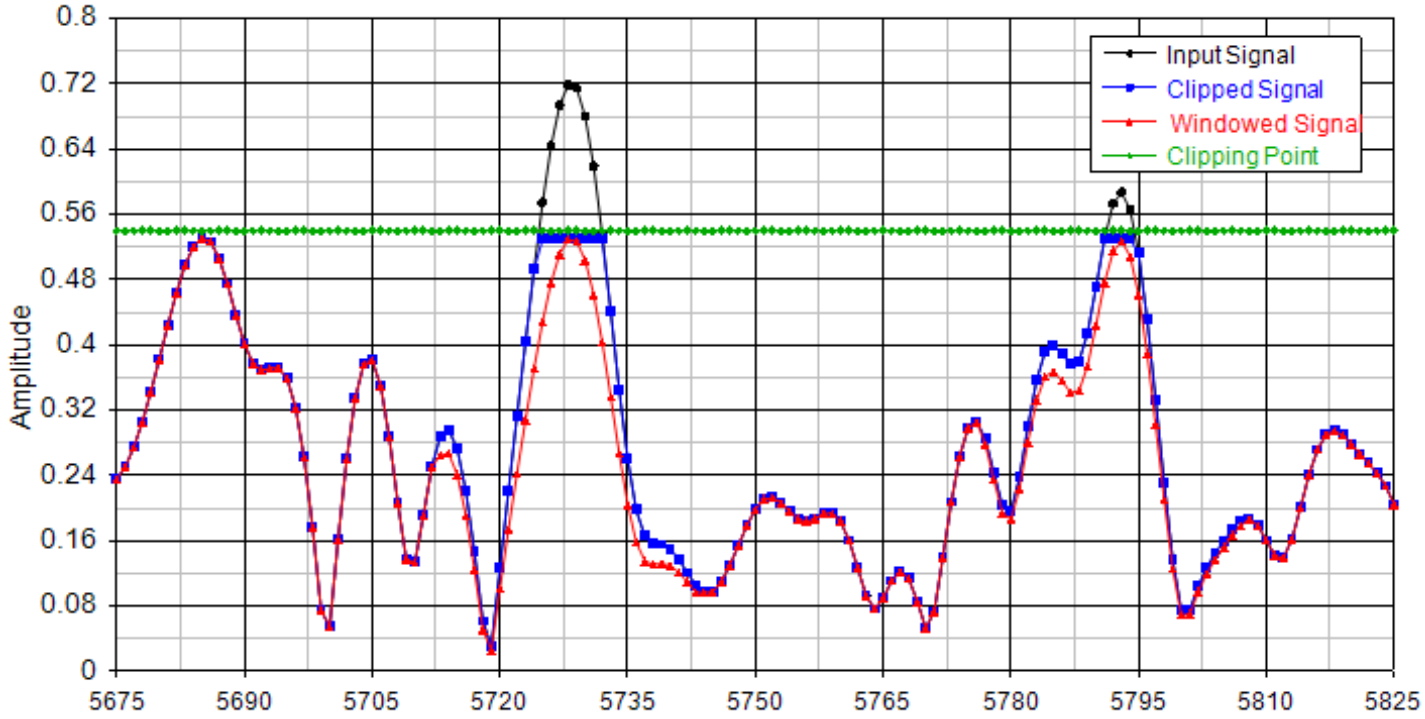
Reduce the PAPR to limit distortion produced in the PA



- CFR is not a linearization technique
- Two methods widely used: 1) Clipping and Filtering 2) Peak Windowing

CFR – Peak Windowing

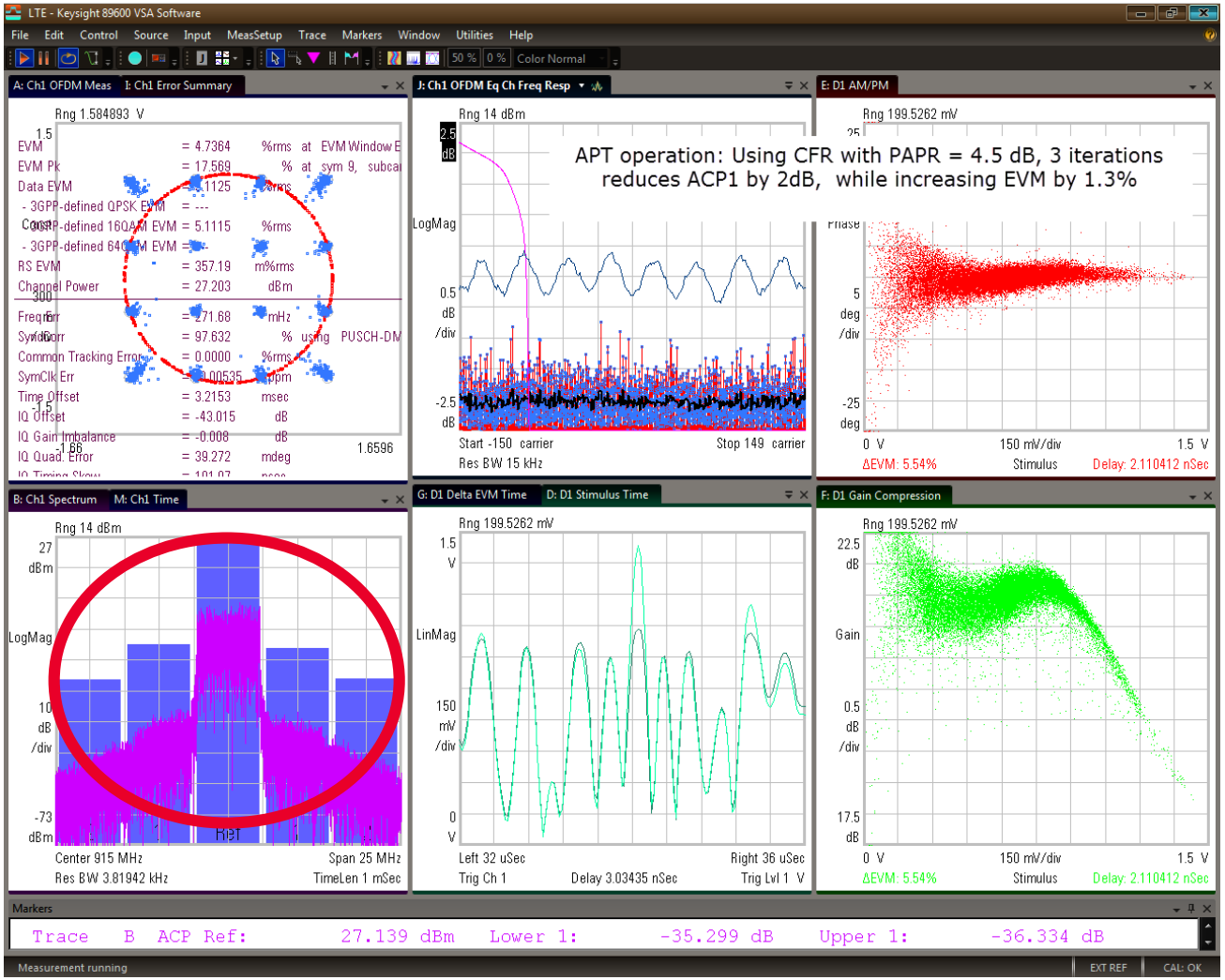
- Peak windowing aims to smooth the sharp corners which result from hard clipping
- In the peak windowing algorithm, clipping is implemented by multiplying the original signal in the region of the peak with a windowing function such as Kaiser, Gaussian and Hamming.



ACP-EVM Performance Trade-off Using CFR

Example: CFR using clipping & filtering

If ACPR fails the 3GPP spec., applying CFR can give a few dB improvement, enough to pass or provide some margin but EVM will increase.



Where do ET, DPD and CFR apply?

	ET	DPD	CFR
WLAN	Exploring/Verification On/Off … HS (Mainly in R&D)	Access Point (AP) and Station (STA)	Access Point (AP) and Station (STA)
Cellular	UE	BTS (normally complicated with real-time feedback) UE (normally pen-loop)	BTS
Benefit	Save Power Improve linearity	Improve Linearity	Improve linearity (PAPR)

Techniques to Mitigate PAPR Related Issues

Know your alphabet

Amplifier sizing

Back-off

Crest Factor Reduction

- Distort RF PA input signal to reduce distortion produced by PA compression
- Choose the method and compression level to match the PA characteristics

Digital pre-distortion

- Distort the RF PA input to cancel distortion produced by the PA
- Choose the method to suit the baseband capability and the PA characteristics

Envelope tracking

- Drive the RF PA with a fully modulated RF signal and synchronously modulate the PA supply voltage
- Adjust the RF PA operating point by controlling the RF / Envelope magnitude ratio, called the shaping table, or de-troughing function

Agenda

PA ET/DPD/CFR Test Technologies

- What are the key challenges for PA design?
- What are the CFR, DPD and ET technologies for PA?

Keysight PA Test Reference Solution

- PXIe Solution for PA Test
- PXIe Solution Architecture

What do we need to test in a PA?

- Basic Performance
  - $P_{out\ MAX}$, P_{3dB}
    - With ramped power signal
  - Gain, ACPR, PAE
    - With power servo technique
- Good Neighbor
  - Harmonic generation, intermod, spectral regrowth, in-band Rx noise
- Compatibility
  - Return loss, AM/AM, AM/PM, EVM, mismatch tolerance
    - Passive components of PAD – filters, duplexers
- Measurements as a function of frequency and output power level
- *Performance under ET and DPD?*

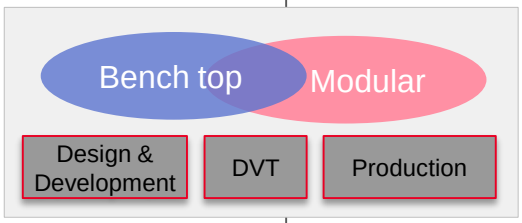
Keysight Power Amplifier Solutions Positioning

Bench-top
Ideal for R&D / Interactive DVT

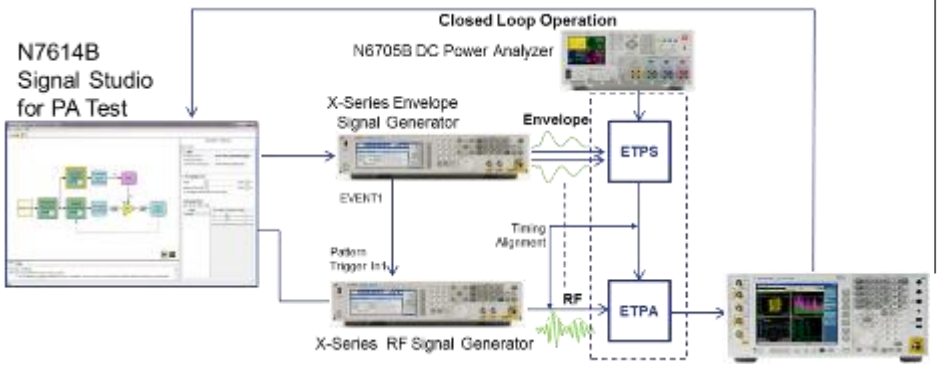
- Tiered RF Performance in X series
- Front panel maximizes measurement insight
- Asset Portability
- Wideband DPD
- Dual-band DPD
- Custom IP for DPD

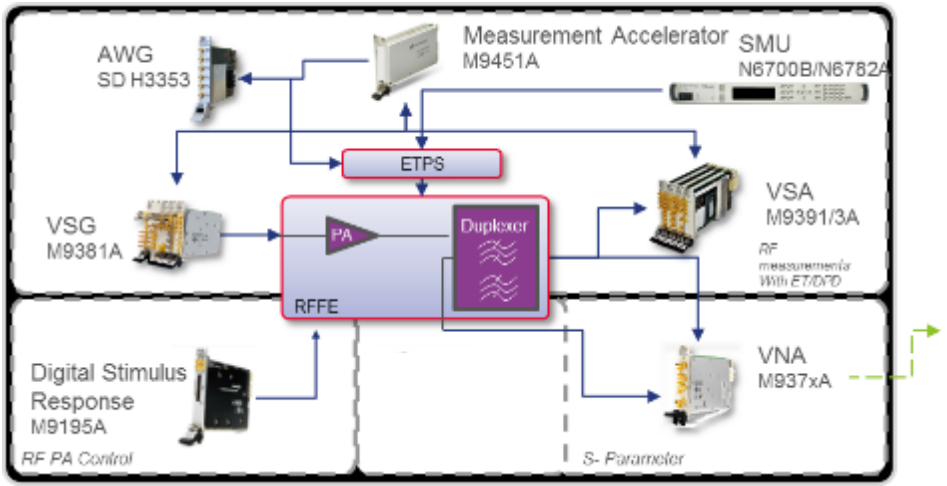
Modular
Ideal for Automated DVT / Production

- Optimized for automated test throughput
- Market leading ET/DPD measurement performance
- Smaller footprint
- FPGA for acceleration
- Reference Solution Software



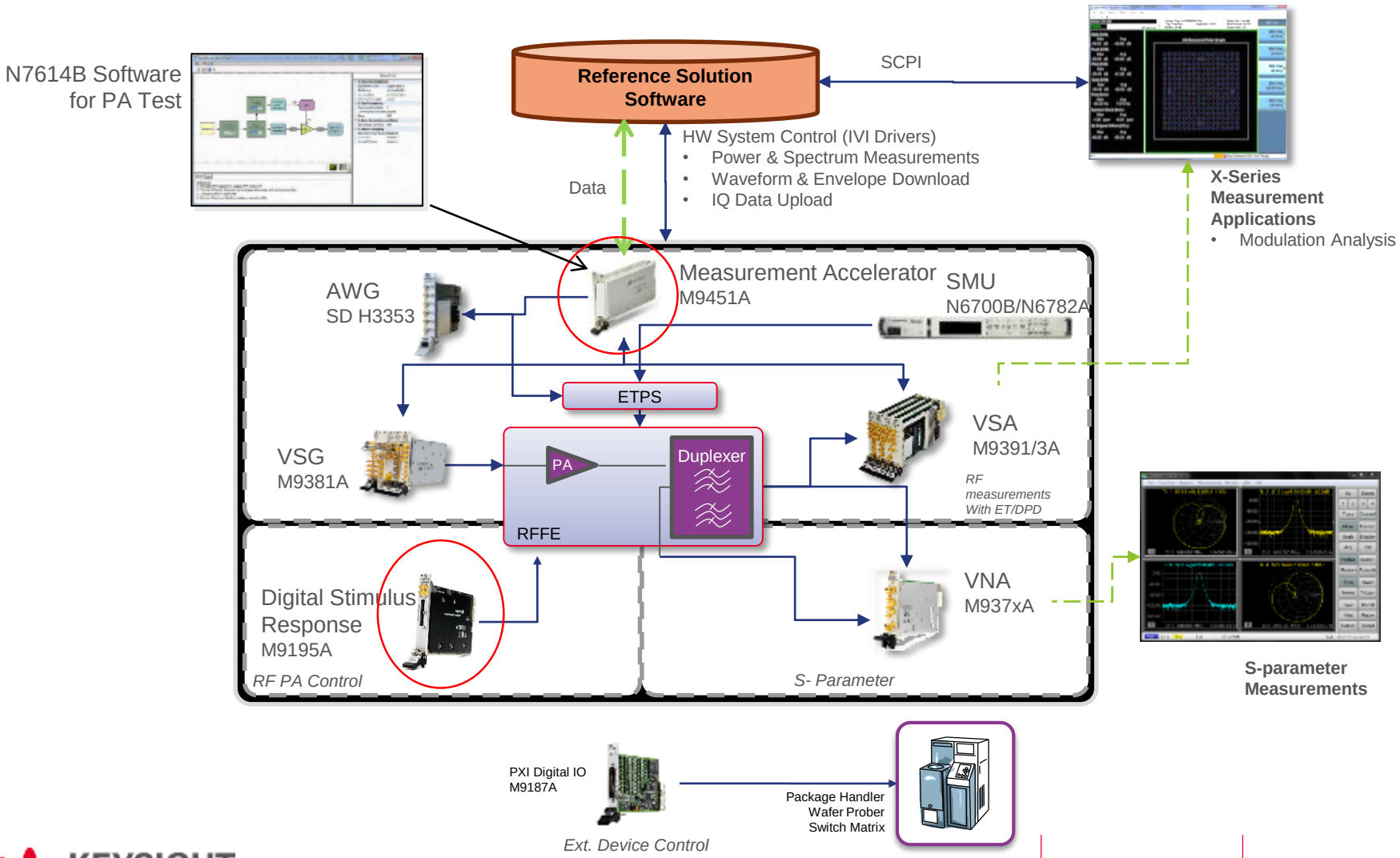
Common Measurement Science





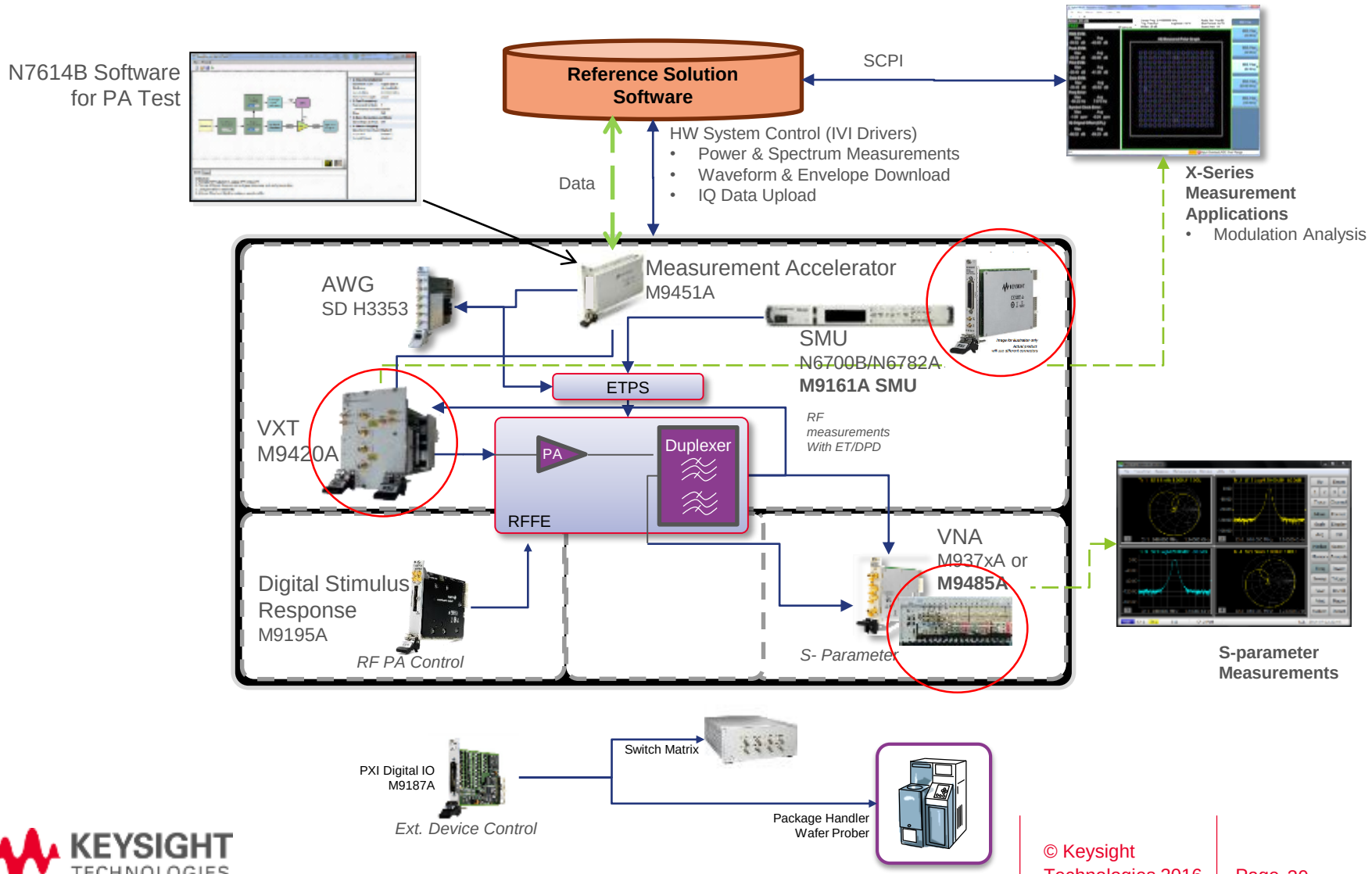
Keysight Reference Solution

Typical Block Diagram (Release3.0: VSG/VSA)



Keysight Reference Solution

Typ. Block Diagram (Releases3.1: VXT)



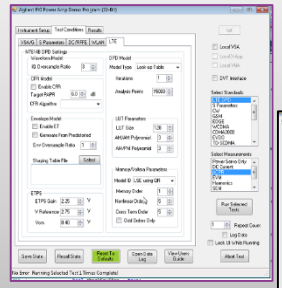
Power Amplifier Reference Solution

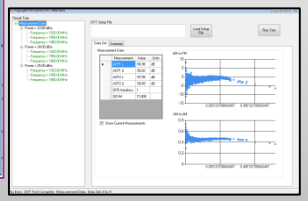
Minimize Customer Investment to Evaluate & Deploy

- Keysight Provided “Recipe” for Power Amplifier Tests using Keysight PXI Modules with LXI and Third Party Products, as needed
- Provides Demonstration of Capabilities, Measurement Ranges and Test Times
- Configurable to Test Customer Devices without Code Changes for First Level Evaluation
- Source Code to Minimize Porting Instruments into Customer’s Test Environment for Detailed Evaluation and Deployment
- Focus on PA design/validation/test and production test including support for ET and DPD
- **The bottom line…**
  - *Evaluate quicker, leverage Keysight’s measurement knowledge, deploy with lower risk*

Evaluation Software Environment

Software





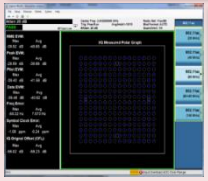
RF PA Test Evaluation GUI

Customer Test Executive

Test Program:
Test_WCDMA Test_LTE5MHz Test_LTE_10MHz
Test_GSM Test_EVDO Test_WLAN

Power Amp Test Library:

Init_Instruments	setupVsgVsa	measPout
Close_Instruments	setupVsgVsaFixedPin	measStdAcpr
Load Waveforms	servoInputPower	measLteAcpr
		measSpecHarms



X-Series Measurement Applications

M938xA VSG IVI-COM Driver

M9391A/93A VSA IVI-COM Driver

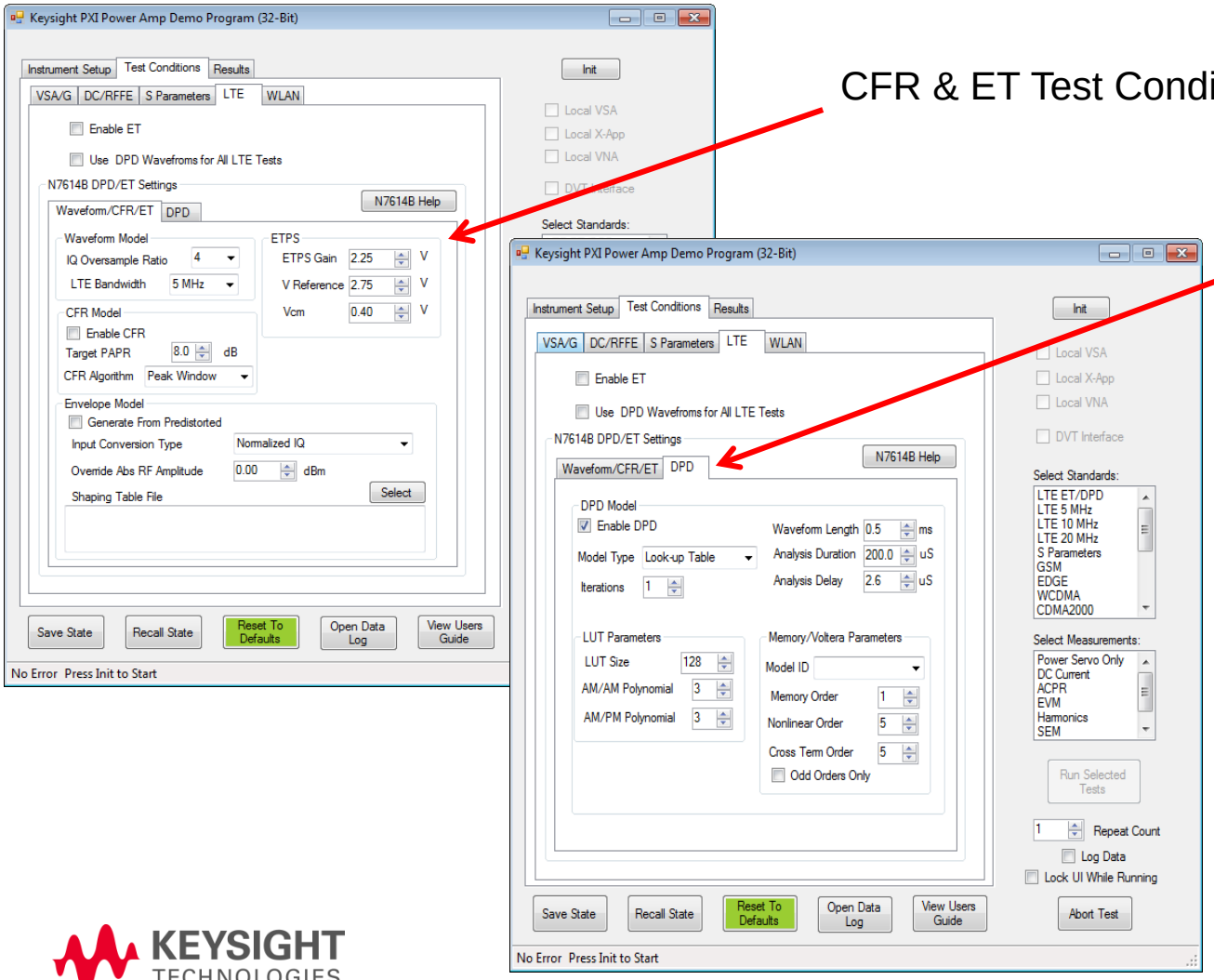
M937xAVNA IVI-COM Driver

Signadyne AWG IVI-COM Driver

PXI Modules

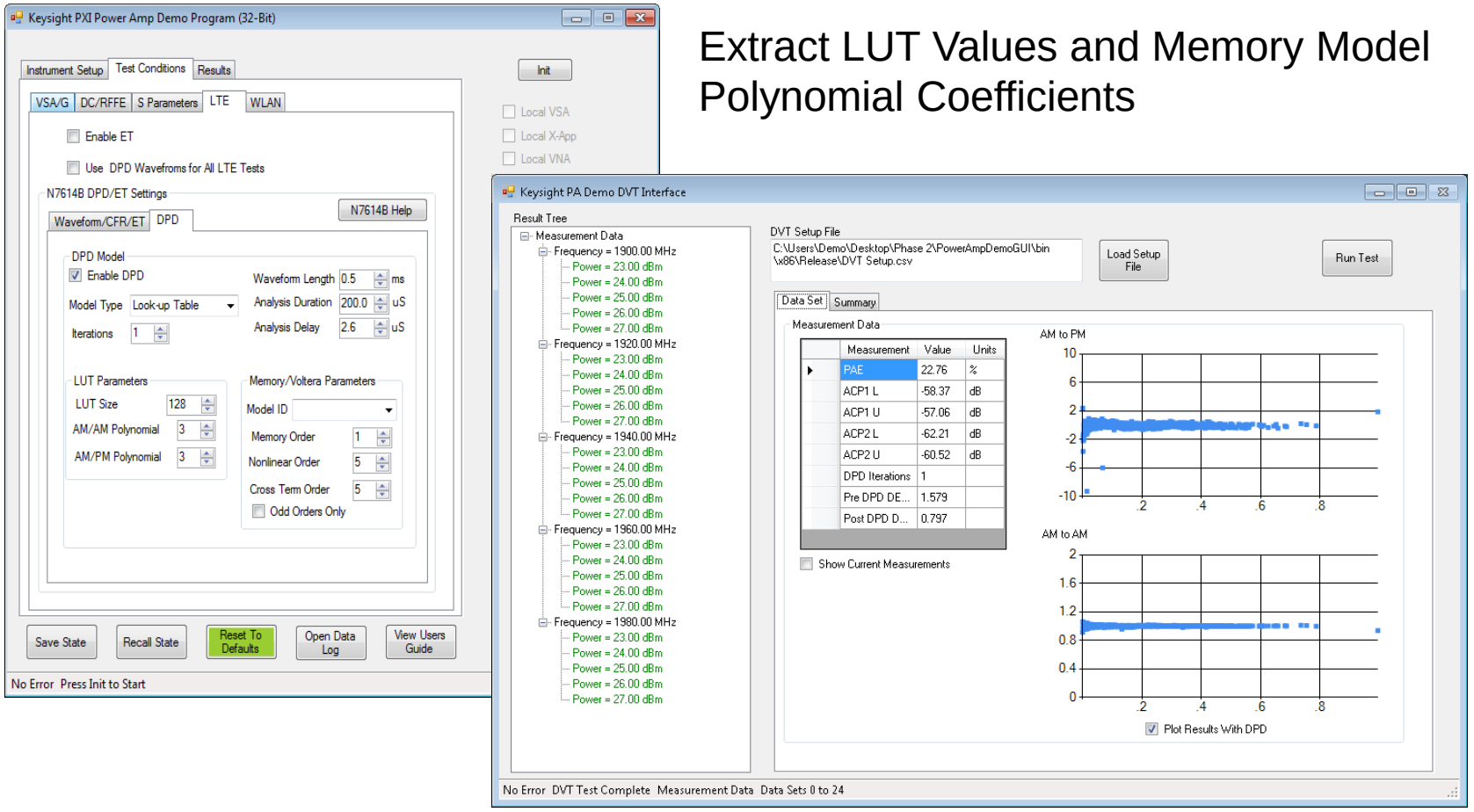
RF PA/FEM Characterization & Test Reference Solution

ET/ DPD Evaluation Software Environment



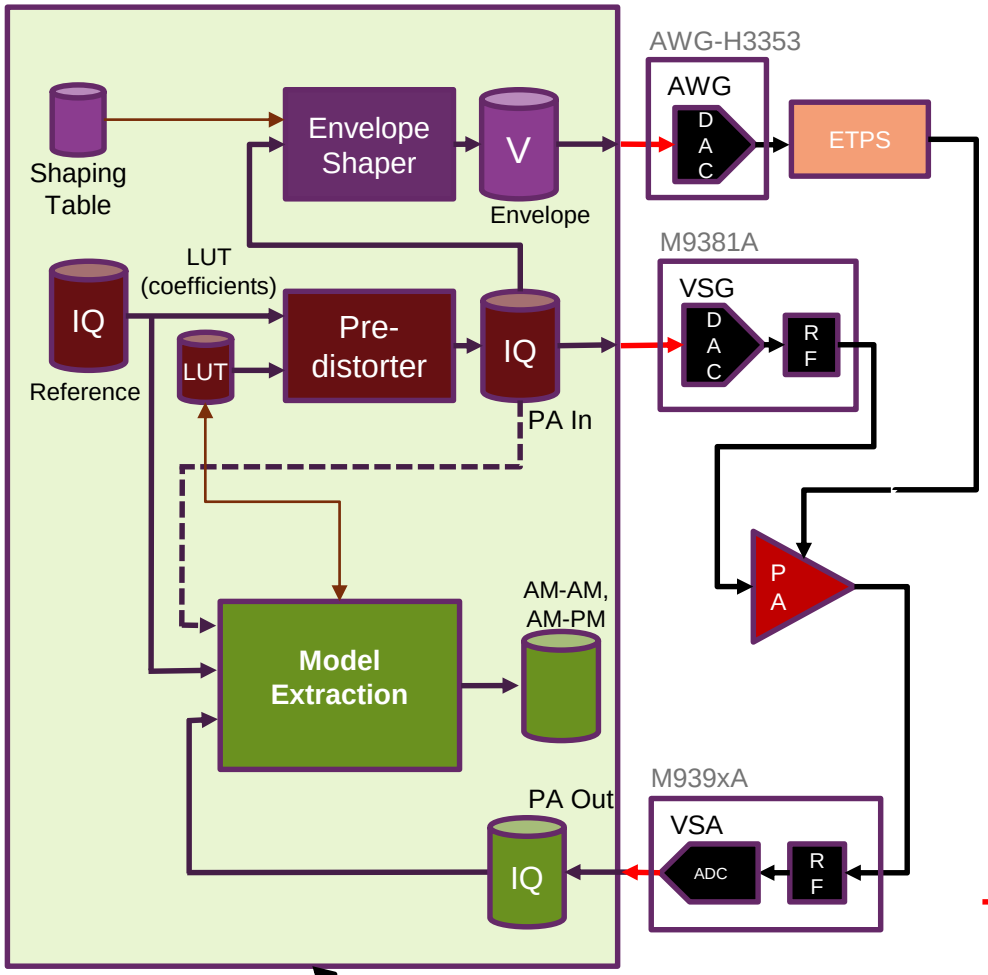
RF PA/FEM Characterization & Test Reference Solution

Optimized for insight – Code Example



Extract LUT Values and Memory Model Polynomial Coefficients

FPGA Speed Enhancement Architecture



M9451A Measurement Accelerator module

Some measurement speed improvements *

For ET/DPD capable UE 4G Power Amp

	Host PC Based			M9451A FPGA-based		
Waveform	**Model Extract**	**Model Apply**	**Total Test Time**	**Model Extract**	**Model Apply**	**Total Test Time**
5 MHz LTE	447.48 msec	45.78 ms	564.44 ms	4.04 ms	16.0 ms	69.52 ms
20 MHz LTE	1752.28 ms	169.92.5 ms	2101.14 ms	6.0 ms	63.0 ms	142.74 ms

- M9037A embedded controller, M9381A VSG, M9393A VSA, H3353 AWG, M9451A FPGA
- 500 msec LTE waveform using ET and DPD
- Measurements made using power servo technique: Gain, PAE, ACPR, Delta EVM, 2nd through 6th harmonics
- All times averaged over 50 measurements

Summary of Key Points

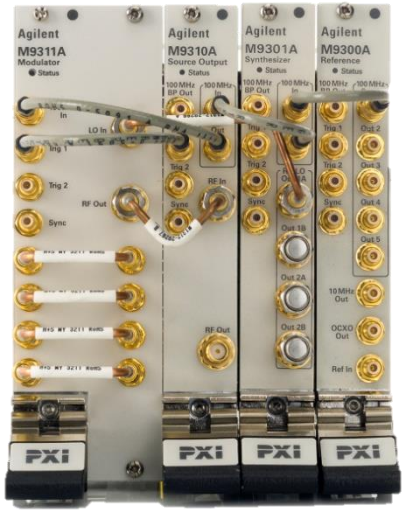
Keysight's PXI Reference Solution for Power Amplifier Testing

1. Proven solution in DVT and manufacturing by top tier PA vendors.
2. Enables software reuse for your solution that reduces deployment effort, time and cost.
3. Provides support for emerging UE technologies including ET, DPD and uplink CA.
   - *Market leading measurement precision and performance*

Questions/Discussion

M9381A VSG

- Performance characteristics
- Frequency coverage from 1 MHz to 3 GHz or 6 GHz
- 10 µs switching speed with fast-tune, an exclusive baseband tuning technology innovation
- RF modulation bandwidth up to 160 MHz (± 0.3 to 0.5 dB flatness)
- ± 0.15 to 1.0 dB absolute amplitude accuracy



- Software Enhancements in 1.2 release:
- Shared Frequency Reference
- PXI backplane triggers
- New PLL Mode (Best Wide Offset) for WLAN EVM and GSM/EDGE ORFS optimization
- Improved sync out trigger for Envelope Tracking

- Software Enhancements in 1.3 release:
- Add Time Synchronous MIMO capability, channel-to-channel deviation <20 ns

Meet the M9393A PXIe Performance VSA

The world's fastest, most accurate µW PXI VSA

Leverages proven designs

- Downconverter derived from PXA
- FieldFox calibrator for excellent accuracy
- M9391A PXI VSA digitizer & reference modules

Deploys cutting-edge technology

- Novel solid-state switches for speed & reliability
- Unique Keysight Labs production process to lower size & cost

Frequency range	9 kHz to 8.4/ 14/ 18/ 27 GHz
Analysis BW	40/100/160 MHz
Amplitude accy	+/-.15 dB
Tuning speed	150 us
Size	5 slots (4 + ref)

Keysight M9420A VXT Vector Transceiver

Compress Time, Compress Test

4 Up in one chassis

And/or

Create custom PXI solution

Description	Performance
Frequency range	60MHz to 3.8GHz or 6GHz
Analysis bandwidth	40MHz, 80MHz or 160MHz
Output Power	Standard: +10 dBm Optional: +18 dBm
Memory depth	256 MSa or 512 Msa
Slot Width	4-slots width (+ reference module)
4 RF Ports	Tx, Rx, Full Duplex, Half Duplex

HW Accelerated speed with high density & accuracy

- Combined VSG and VSA in single, 4-slot PXIe module
- **FPGA-Accelerated speed** with high **density** & **accuracy**
- Trusted X-Series software: industry tested algorithms, with code compatibility & bench top usability
- Ease evaluation and programming with ready-to-use IVI drivers, SCPI commands and **integration with the Keysight PA Reference Solution**

Create a flexible modular solution with one PXIe mainframe

KEYSIGHT TECHNOLOGIES

Ready to Run for Single Antenna Test

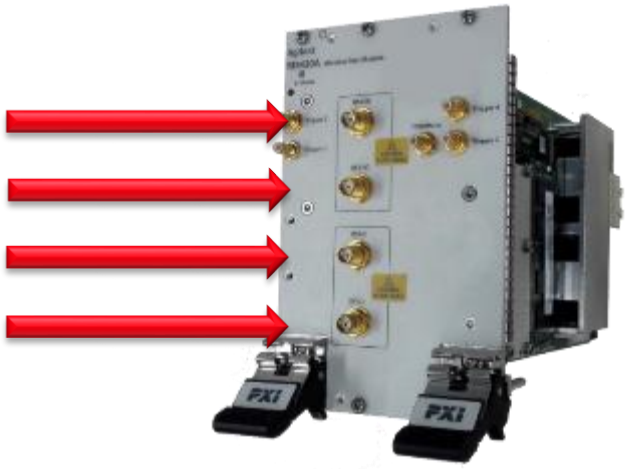
Optional Full & Half Duplex Ports

RF output port: Pure source output port provides highest output power level

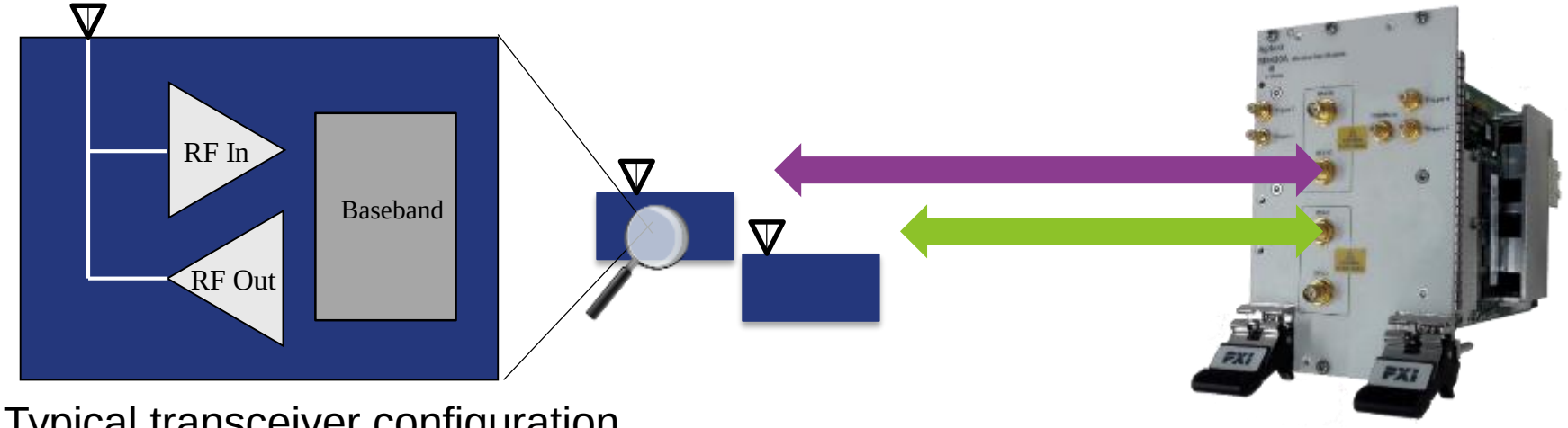
RF Half Duplex port: Internally switched RF input or output port

RF Full Duplex port: Bi-directional communication

RF input port: Pure receiver input port provide best DANL performance.

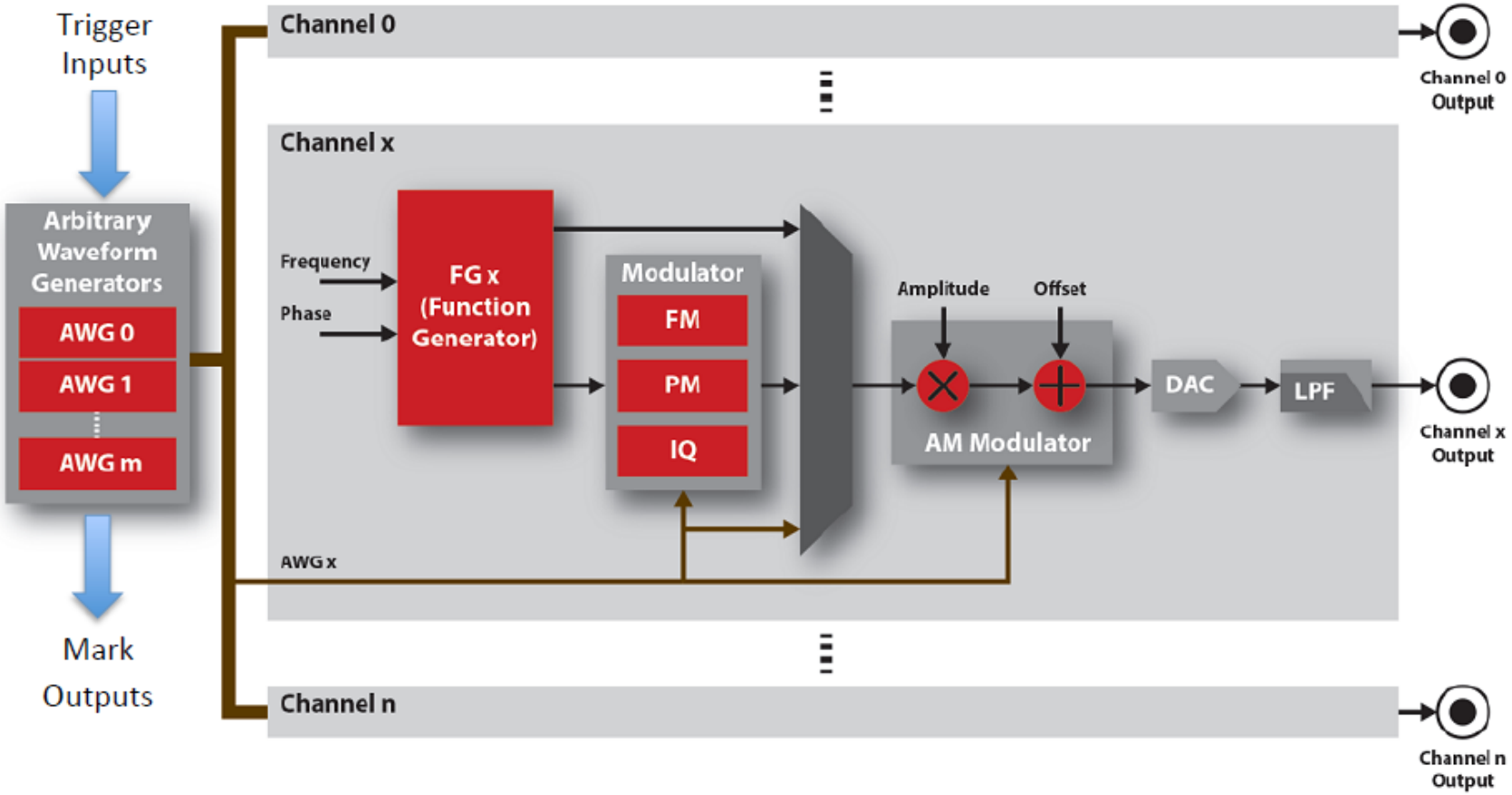


Bi-directional & switched communication over single port connection.



Typical transceiver configuration

AOU-H3300/H3400 Series – Block Diagram



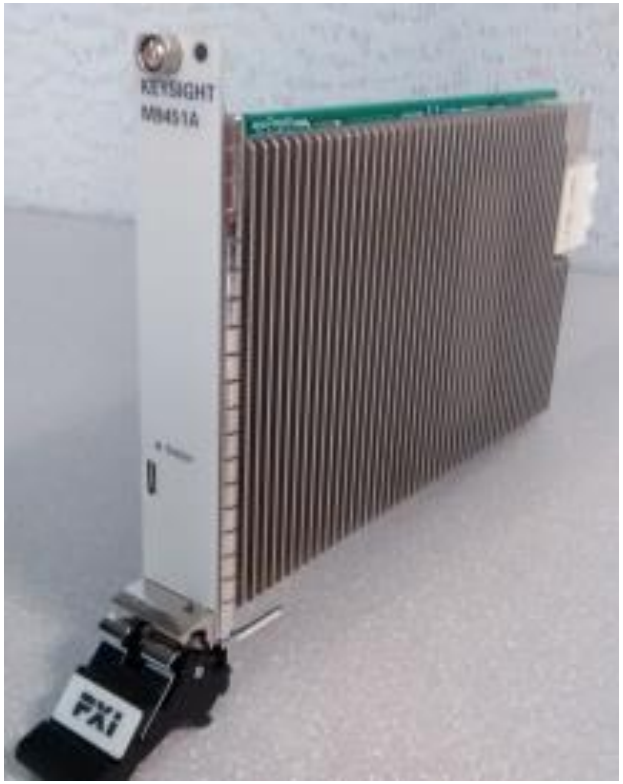
- F-Models (AOU-H3300F/H3400F) allow hardware implementation of custom FPGA algorithms
  - Output equalization / Digital pre-distortion
  - Custom filtering
  - Real-time waveform calculation/generation

RF PA/FEM
Reference Solution

M9451A Measurement Acceleration Module

- Dedicated FPGA module
- Initial release of gateware supports ET/DPD measurement acceleration only
- Module can be added to Keysight VSA/G PXI system for PA test
- APIs provided for integration into the customer test environment
- Uses same Keysight DPD methods utilized in *SystemVue* and N7614B PA test software

- Gateware Release 1.1 (Aug 2015)
  - Minor update; add Memory Polynomial method support
- Gateware Release 1.2 (end 2015)
  - Enable customized DPD methods
- Release 2.0 open programming (2016)
  - Ability for users to develop and embed own IP into the FPGA



PXIe Vector Network Analyzer, M937XA

Driving down the size of test

- Full two-port network analyzer in just one slot
- Widest available frequency range: 300 kHz to 4, 6.5, 9, 14, 20, 26.5 GHz
- Best PXI VNA performance in four key areas:
  - Speed: 18 msec across 401 points
  - Dynamic range: 114 dB (9 GHz), 110 dB (20 GHz)
  - Trace noise: < 0.003 dB specified, < 0.001 dB typical
  - Stability: ±0.005 dB/°C at 4 GHz, ±0.020 dB/°C at 26.5 GHz

M9195A Digital Stimulus Response (DSR)

Product Overview – Key Features for DUT RFFE Control

Digital I/O

- 16 bidirectional channels
  - ✓ Programmable logic levels: -1.5V to +6.5V (±75mA)
  - ✓ 125M vectors/ch memory
  - ✓ Up to 250 MHz pattern rate (with RZ support)
  - ✓ I/O channels are also capable of PPMU and static digital
- 4 high voltage IO channels for flash memory programming
- 4 open drain ports for fixture control

Vector Timing

- Independent channels: per channel & per clock cycle IO control, per vector timing, per period timing, on-the-fly modification
- 1 nsec edge placement resolution for per period vector control
- Per channel programmable stimulus/response compensation delay: up to 250ns with 50ps resolution
- STIL programming support

KEYSIGHT TECHNOLOGIES

ET Standards & Industry Groups

MIPI eTrak mipi alliance

- Specification for an analog interface between BBIC/RF IC and envelope tracking power supply (ETPS)
- Keysight (Agilent) is MIPI member, and a contributor to the group

OpenET Alliance openET alliance

- Advocates the benefits of ET
- Standardize interface and system specifications