RF 파워 앰프 테스트를 위한 Envelope Tracking 및 DPD 기술

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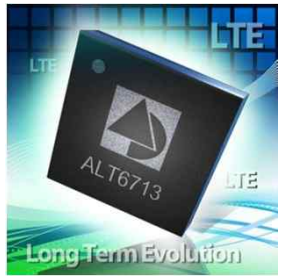
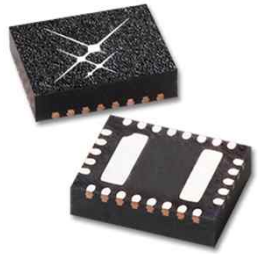
NATIONAL INSTRUMENTS

Welcome to the World of RFICs

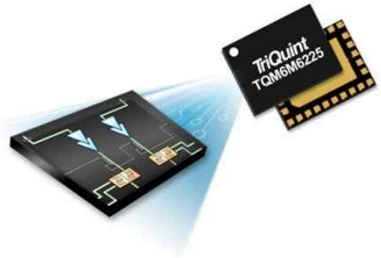


Power Amplifiers

Low Noise Amplifiers



RF Switches



Duplexer and Filters

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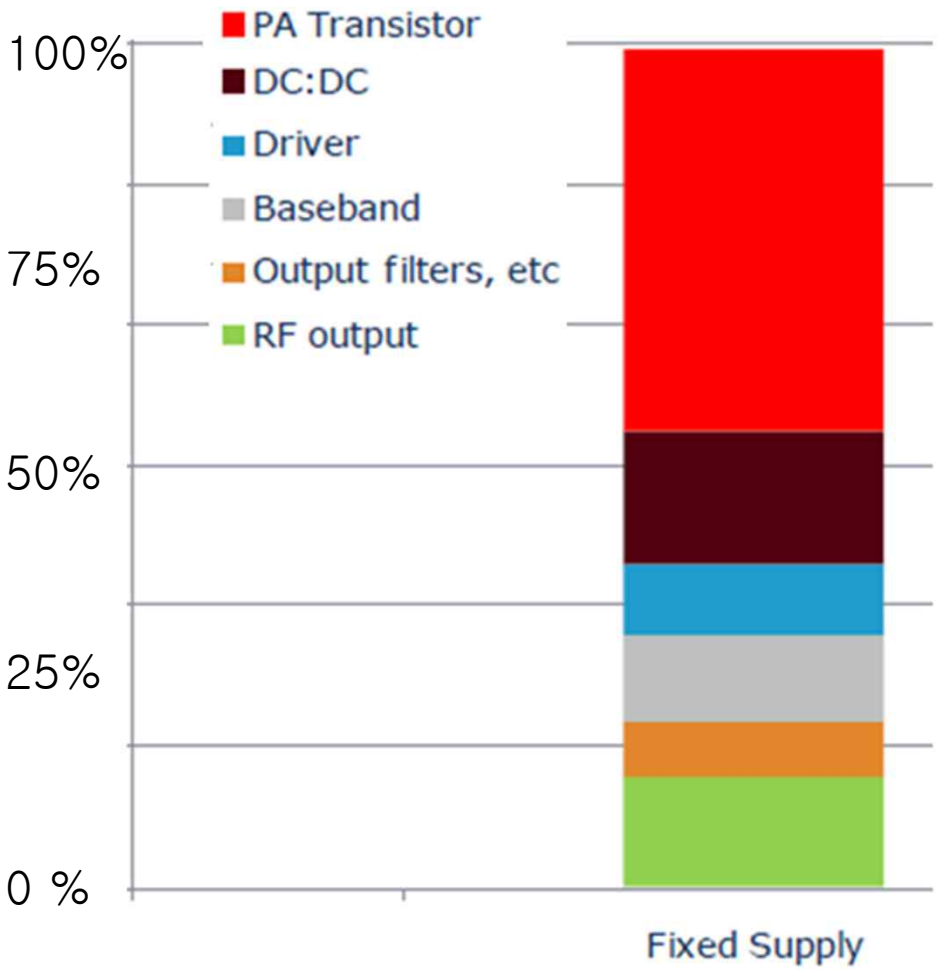
Transmitter Power Consumption



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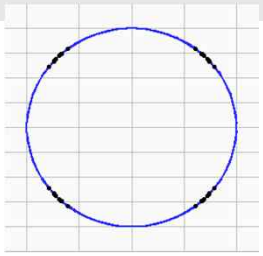
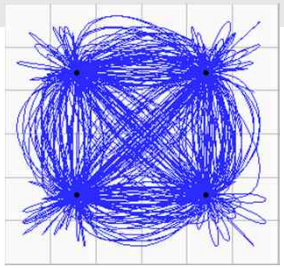
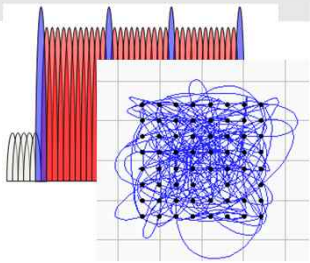
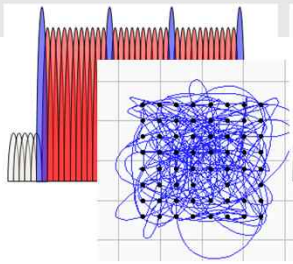
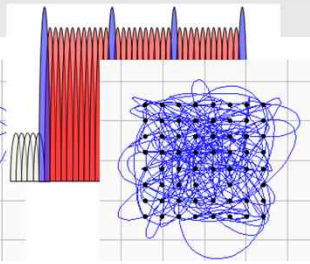
Comparing Wireless Standards

	GSM / EDGE	WCDMA	LTE	LTE-A	802.11ac
Generation	2G – 2.75G	3G	3.9G	4G	n/a
Max Data Rate	GSM:14 kbps EDGE:59.2 kbps	384 kbps to 5.76 Mbps	100 Mbps	3 Gbps	6.77 Gbps
Max Bandwidth	200 kHz	5 MHz	20MHz	100Mhz	160Mhz
Typical PAPR	0-2dB	3.5dB	8dB	12dB	12dB
Modulation Scheme	GMSK, 8PSK	QPSK	OFDM, MIMO Up to 64-QAM	OFDM, MIMO Up to 64-QAM	OFDM, MIMO Up to 256-QAM
Constellation Plot					

전력 효율성 향상을 위한 Envelope Tracking 기술

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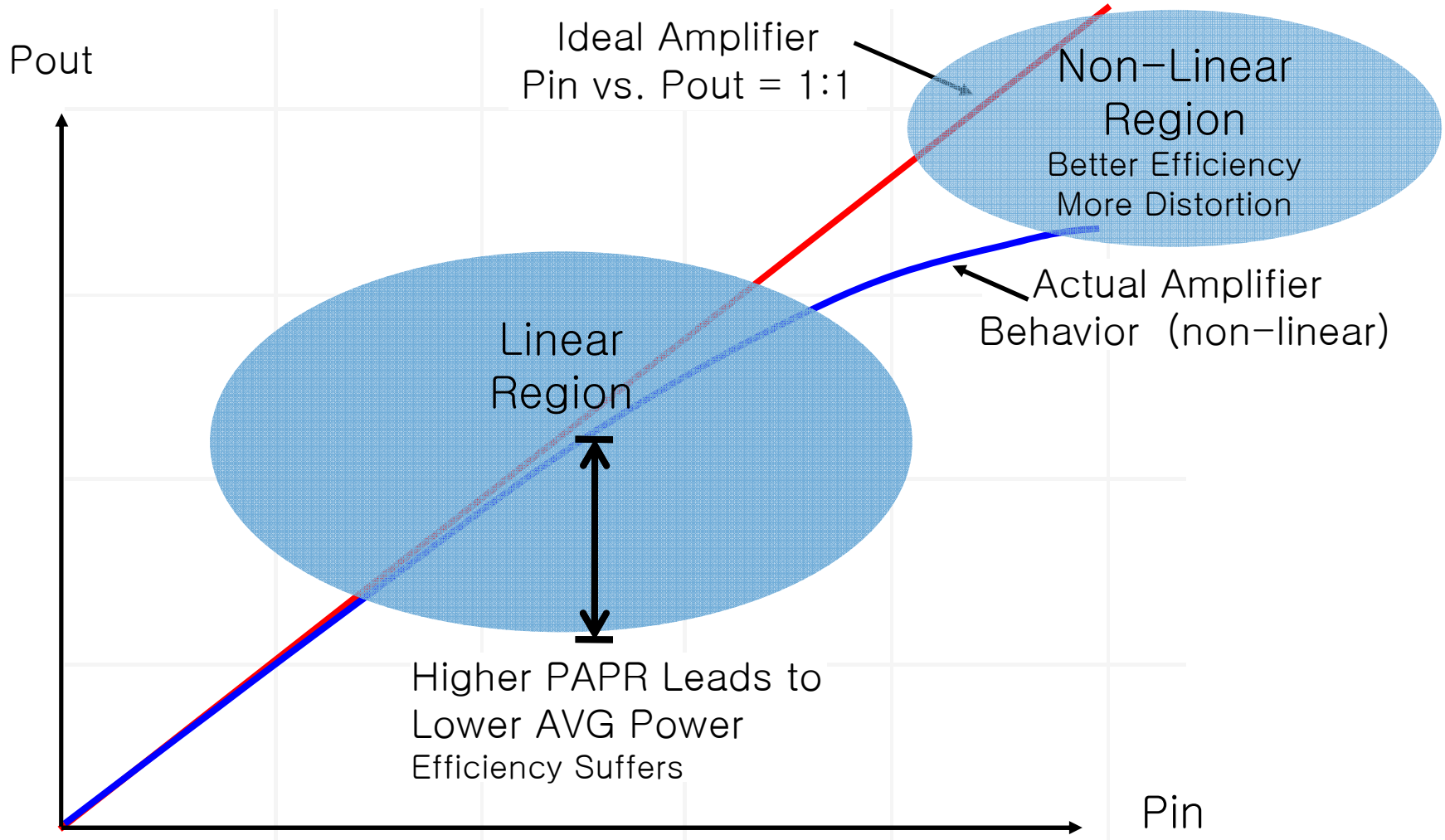
Common Issue with Transmitters



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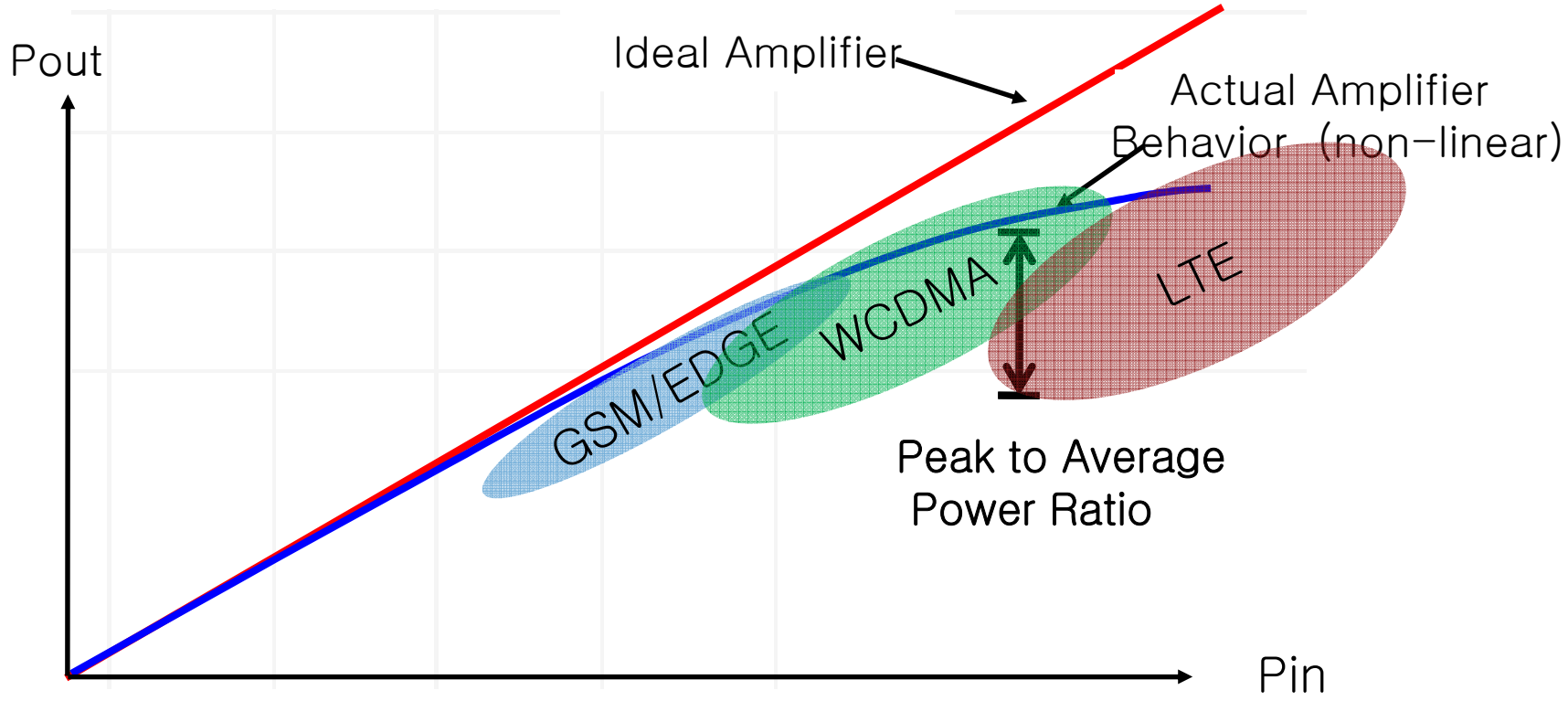
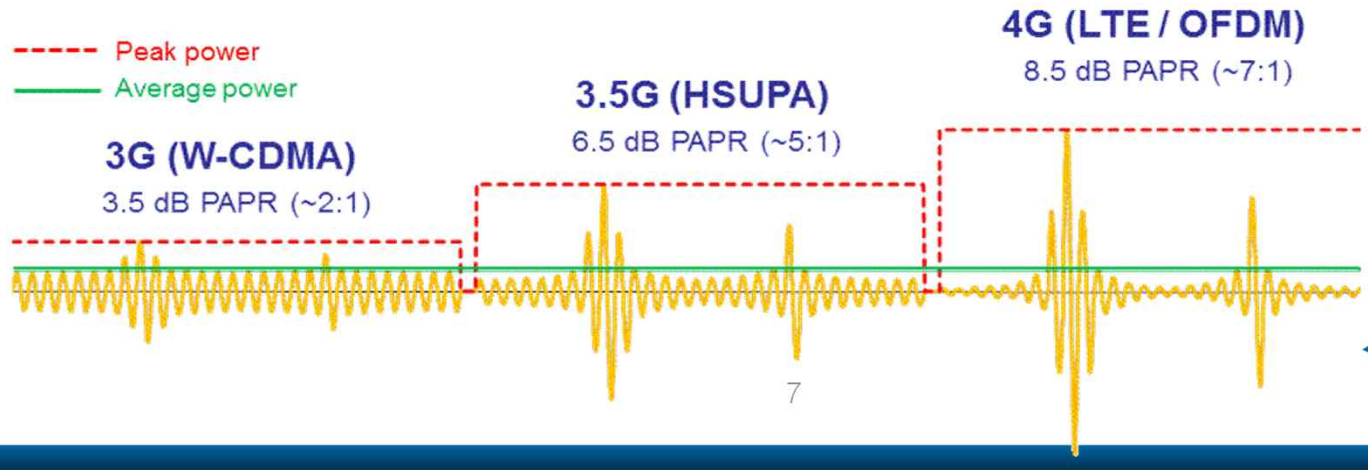
Behavior of PA for Various RF Standards





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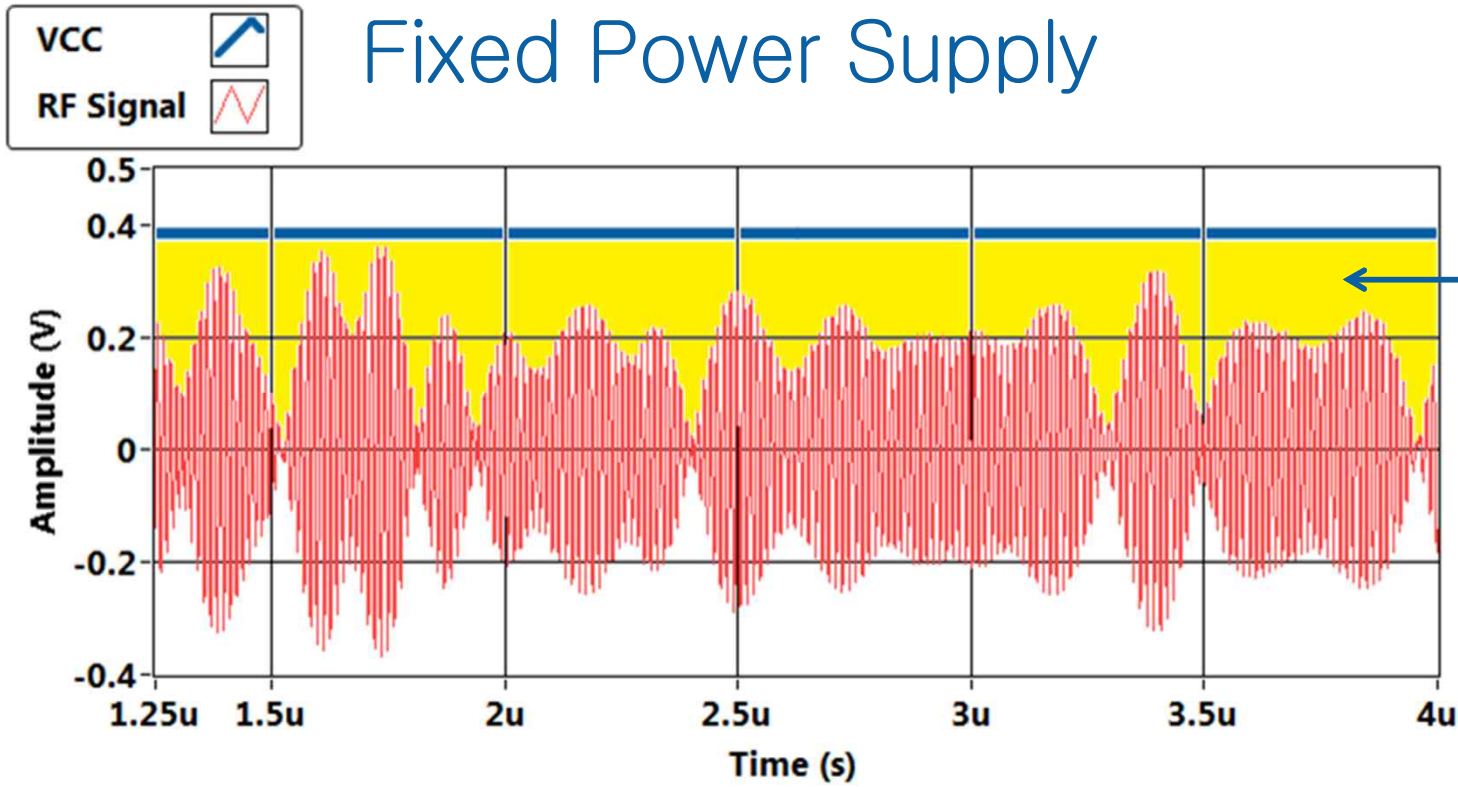
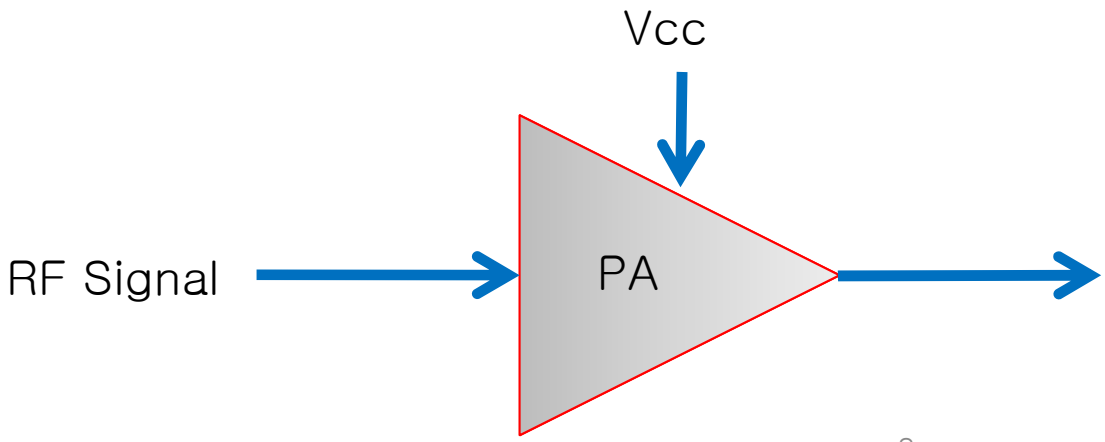
Fixed Power Supply



Area Dissipated as heat



- Simple But Poor Efficiency
- Efficiency a function of PA PR

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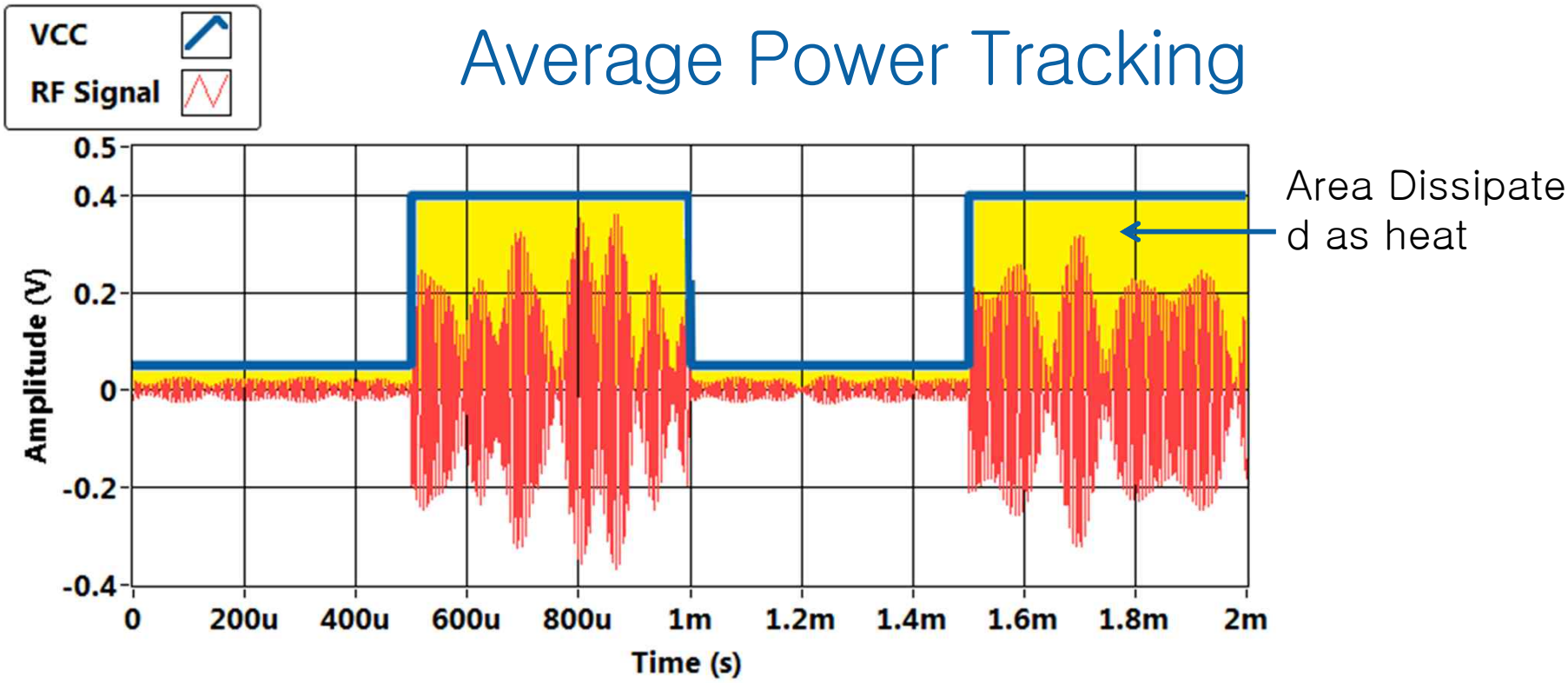
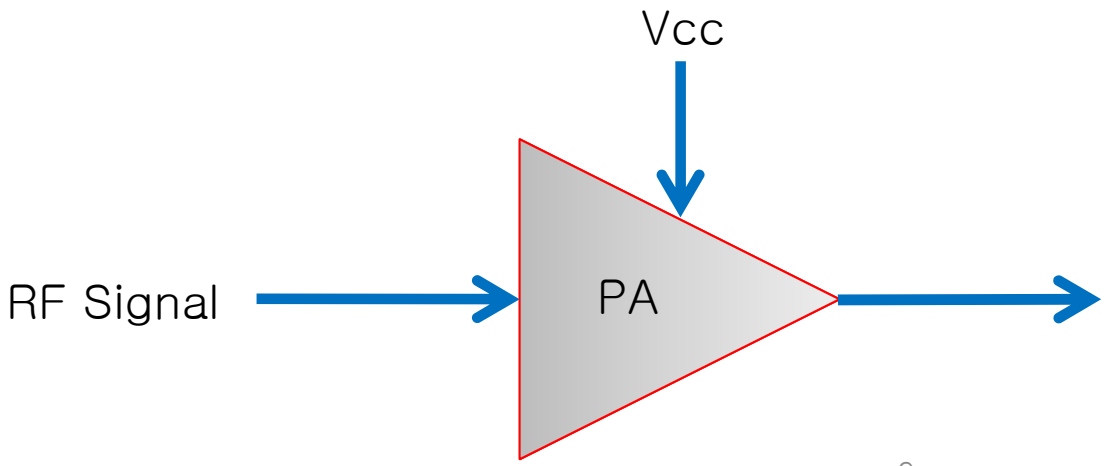
Average Power Tracking

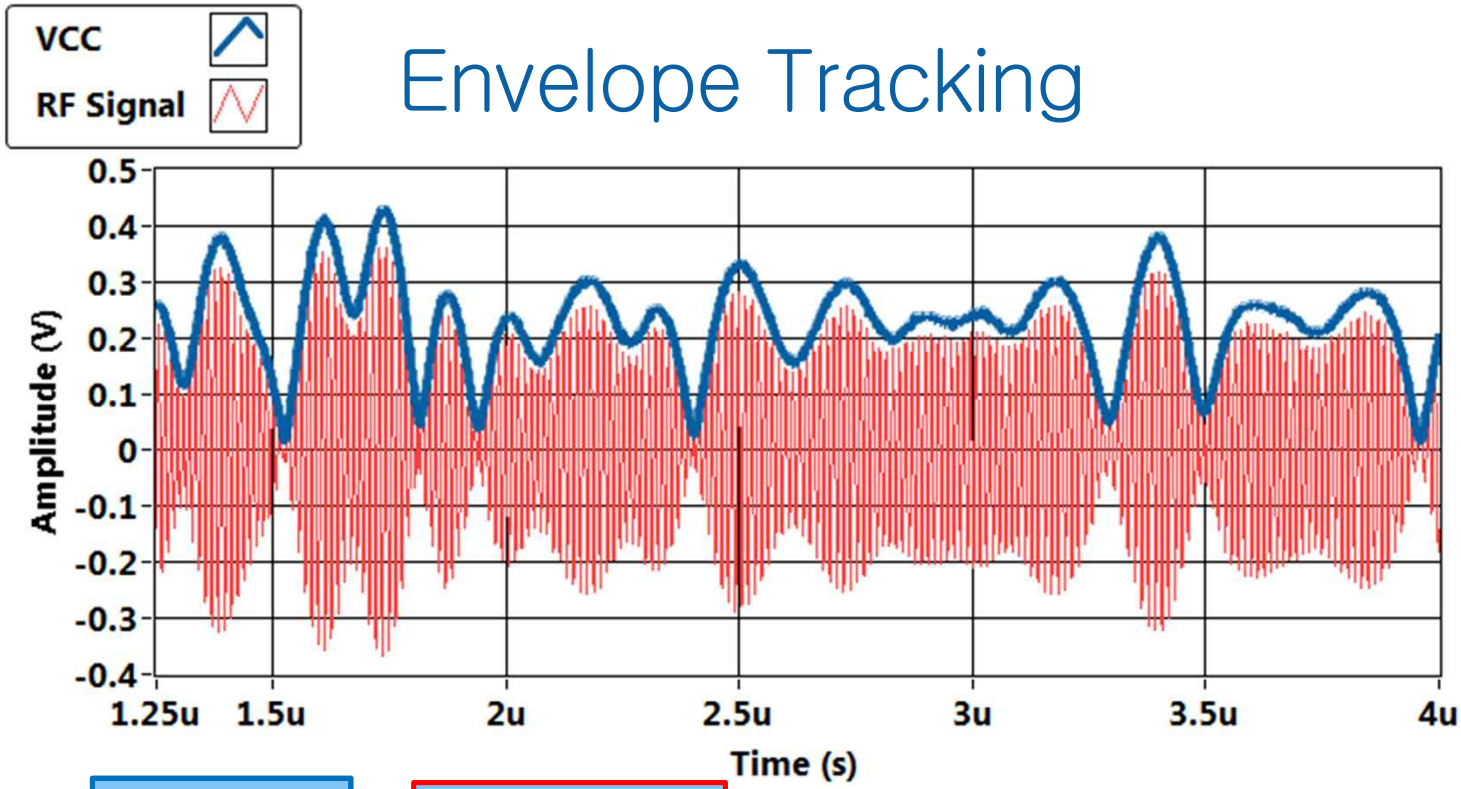


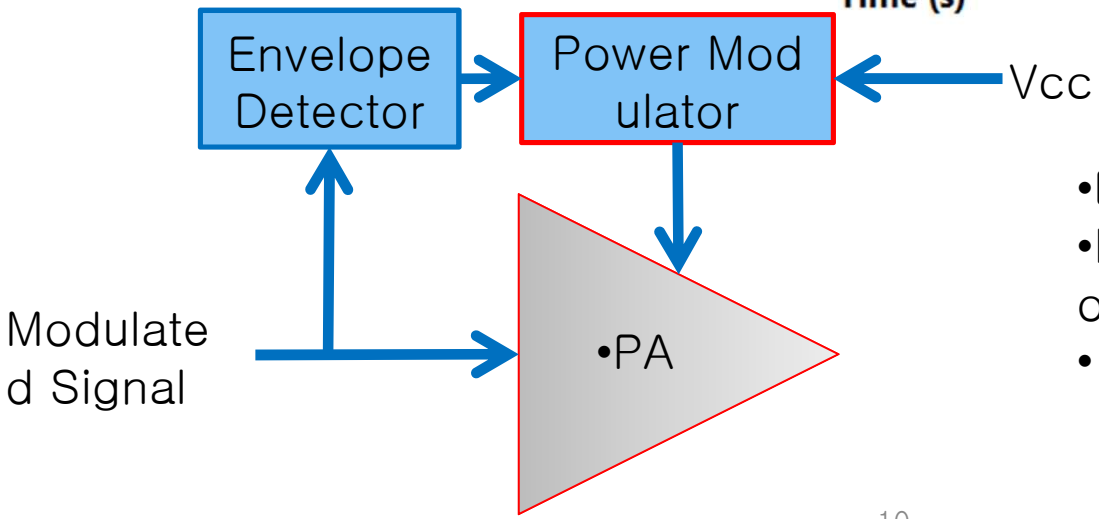
Area Dissipated as heat



- TDMA Per Slot Basis
- Improves Efficiency at Low Power
- No Impact on High Power
- Same Waveform Dependence

Envelope Tracking





- Dynamic High Bandwidth Supply
- Improves Efficiency in top 90% of Power Range
- Waveform Independent

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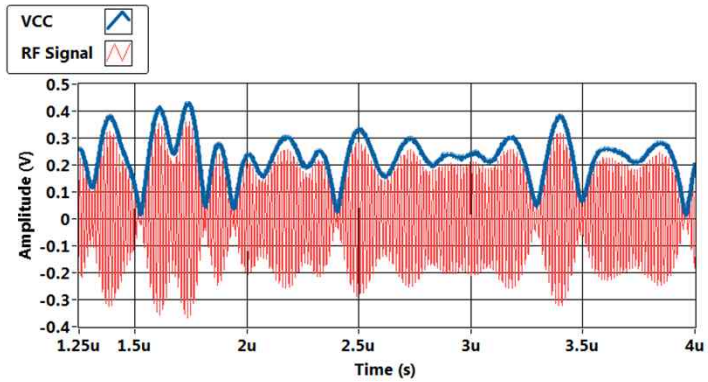
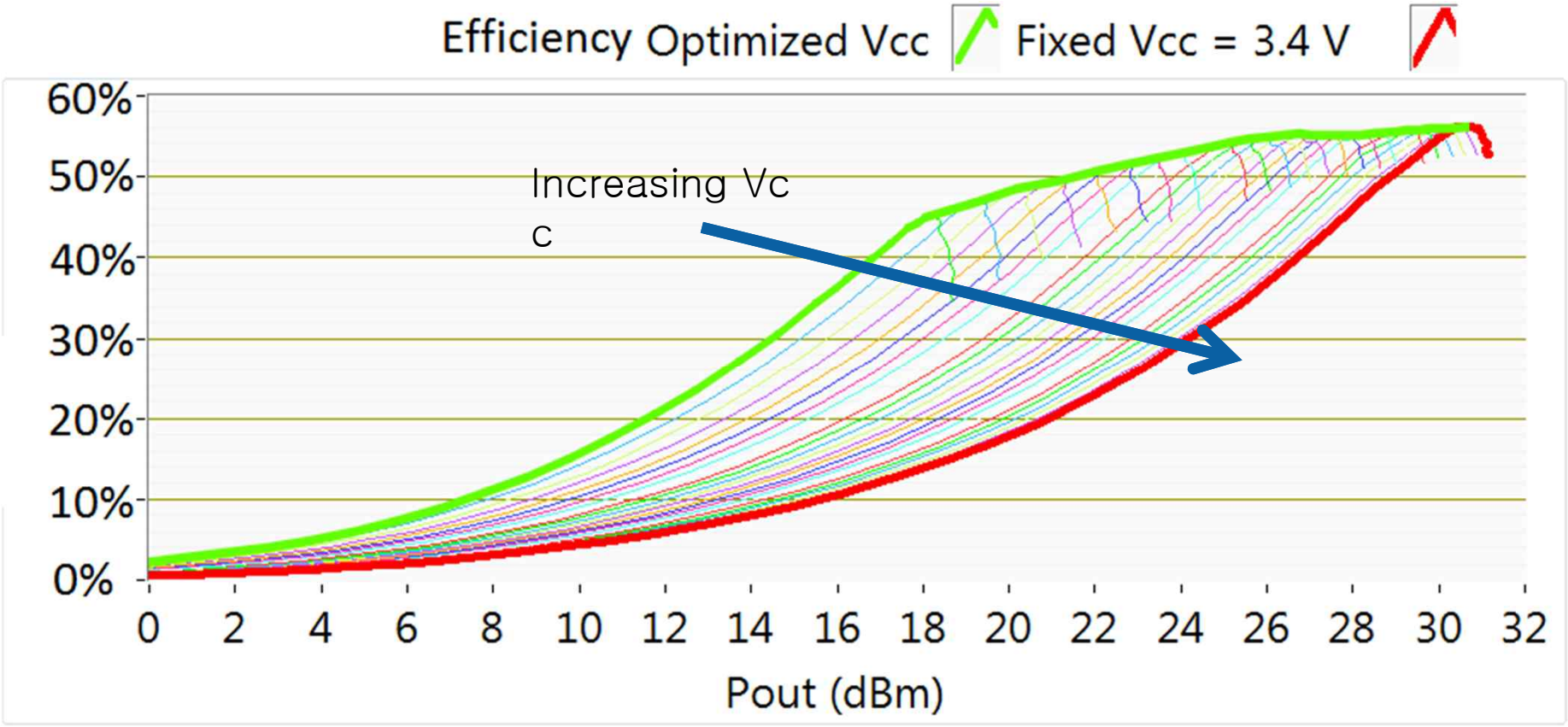
Envelope Tracking Fundamental Technique



$$\text{Power Added Efficiency (PAE)} = \frac{Pout - Pin}{P_{DC}}$$



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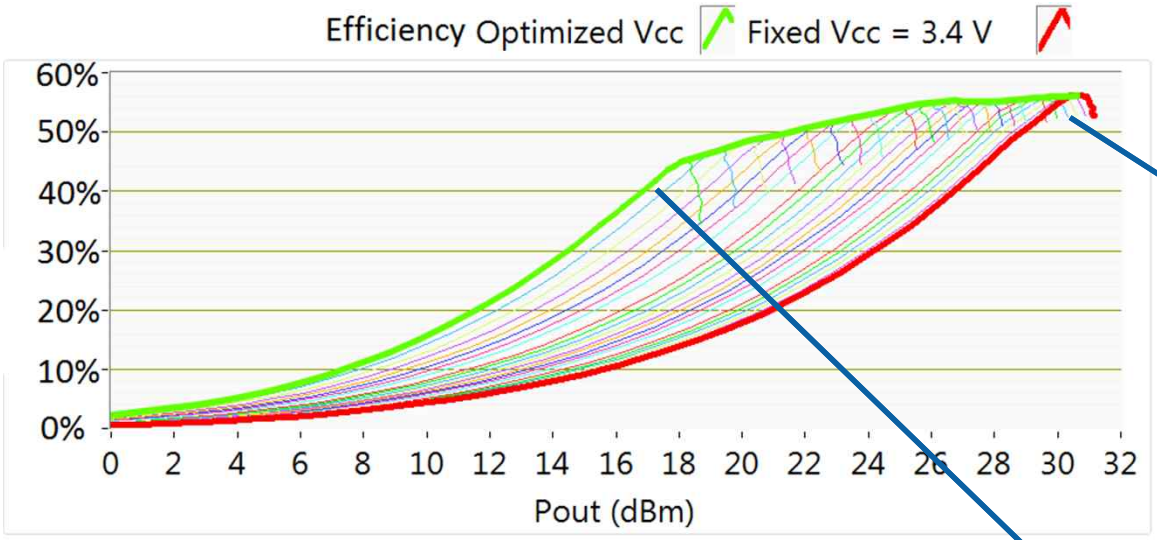
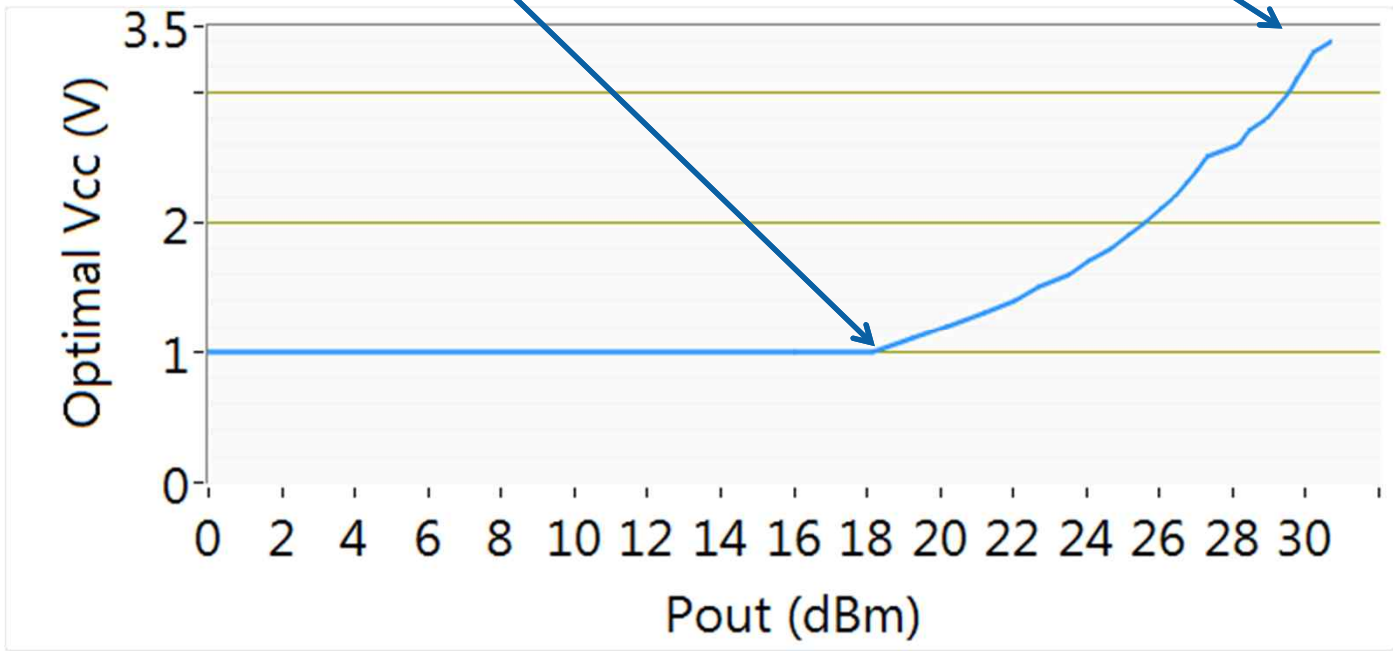
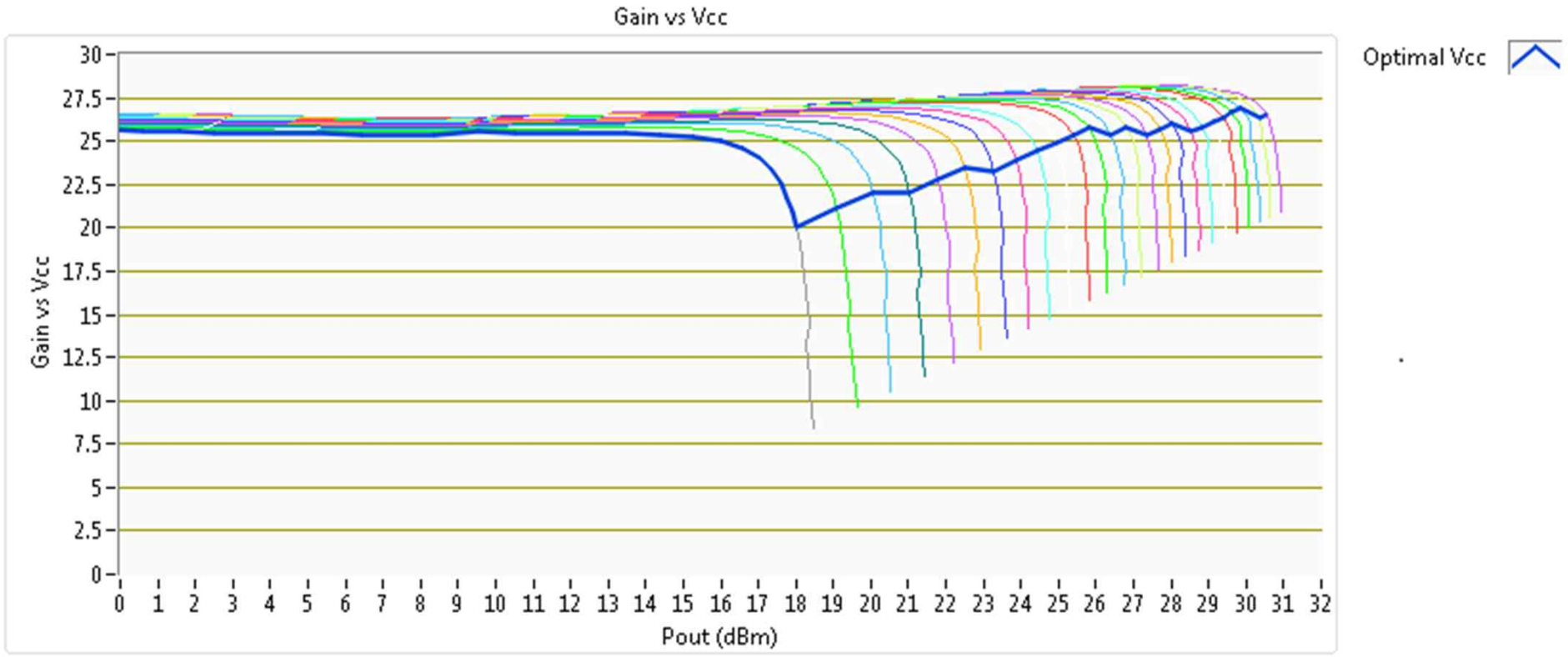
PA Power Supply Lookup Table





Pout vs Gain at Optimal Efficiency



DPD for AMAM, AMPM distortions

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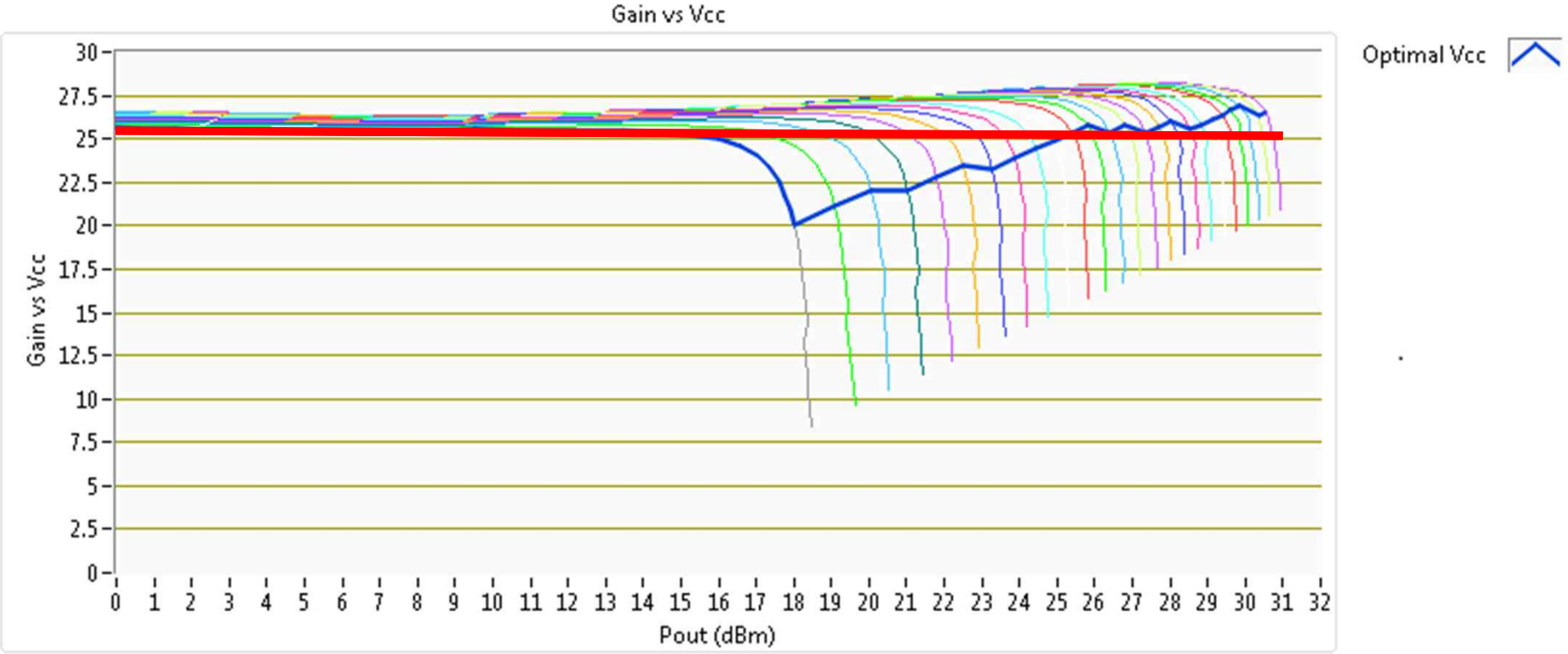
Pout vs Gain at Constant Gain (Isogain)



NO DPD Required

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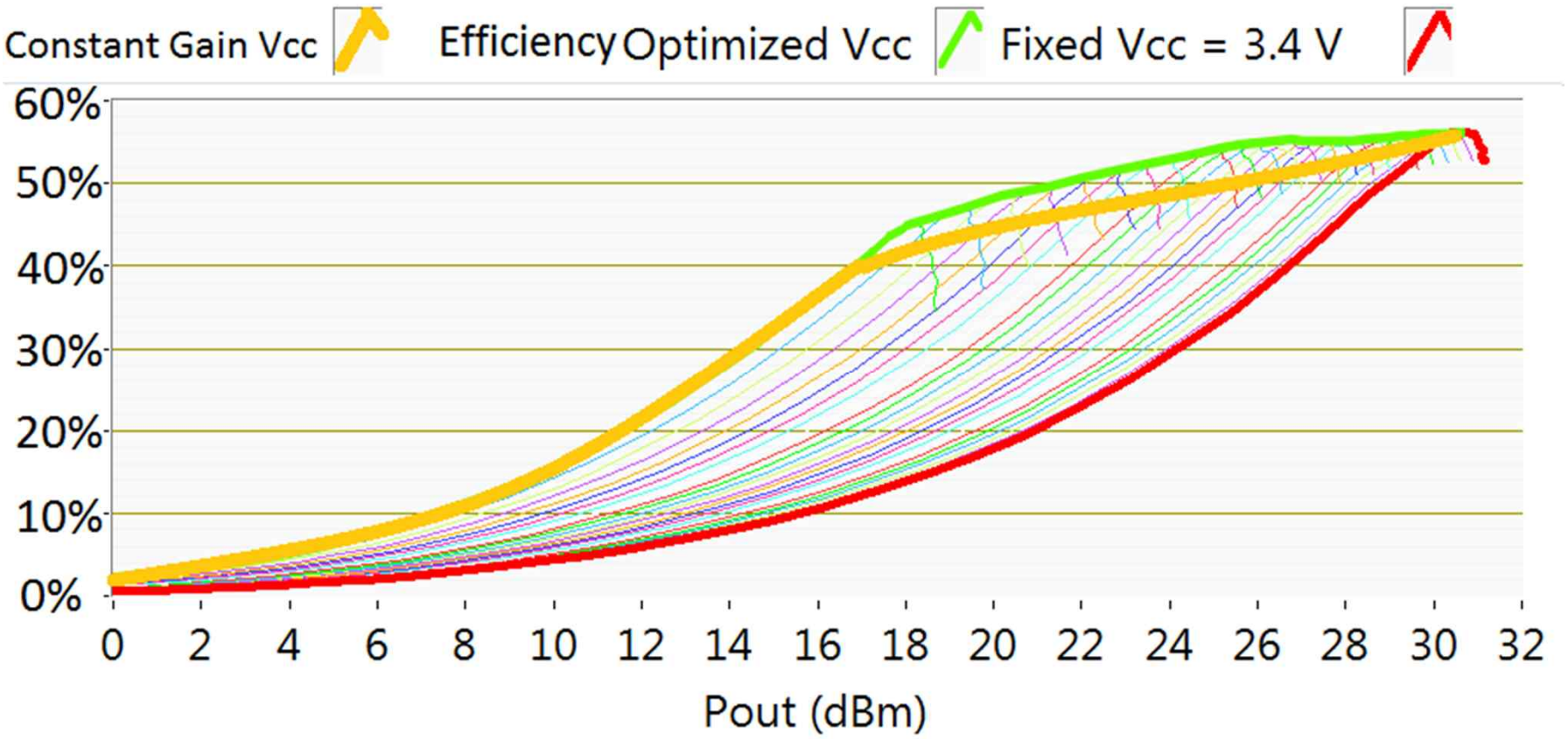
PA Efficiency vs Pin at Multiple Supply Voltages



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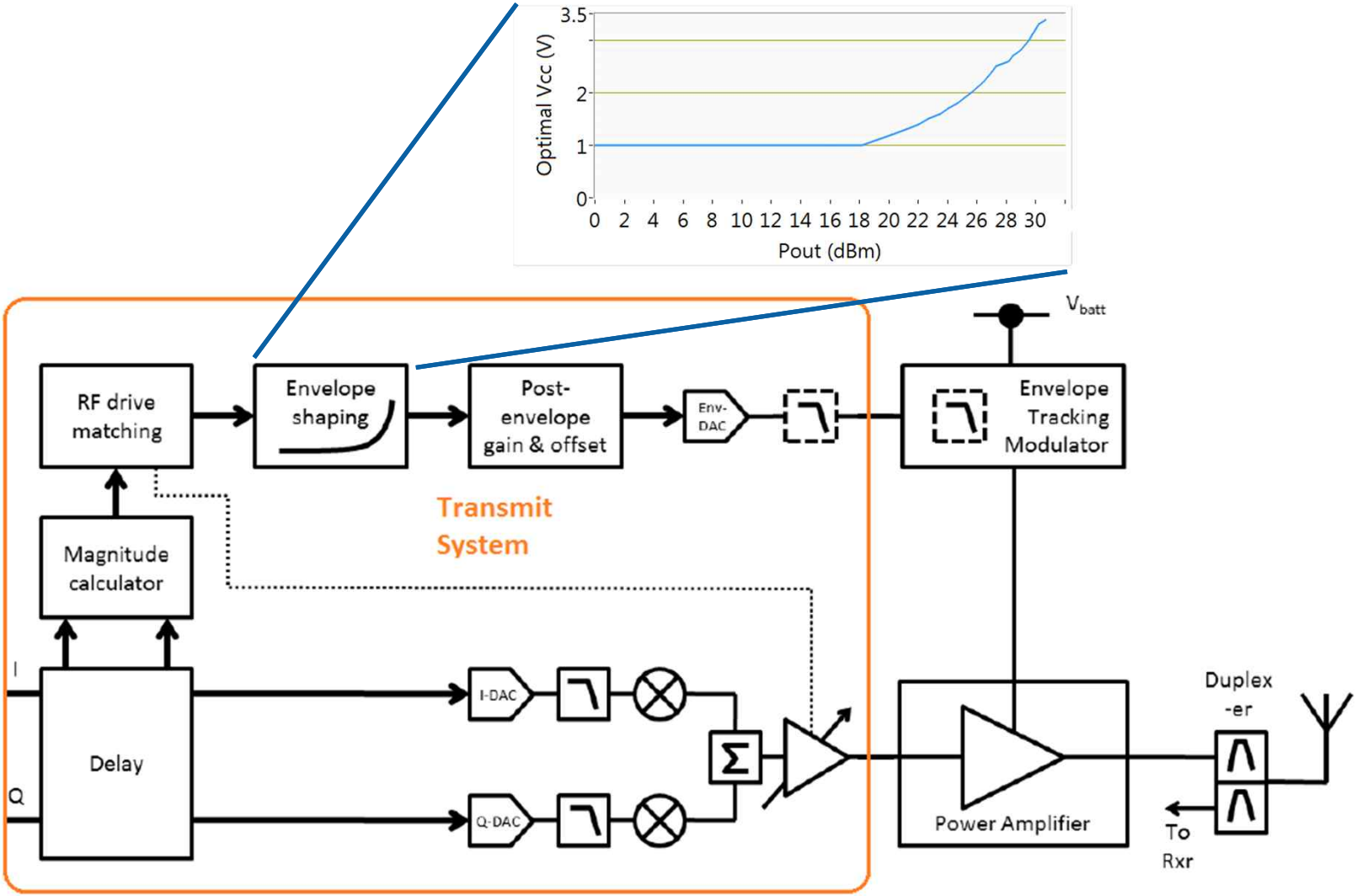
Envelope Tracking Transmitter



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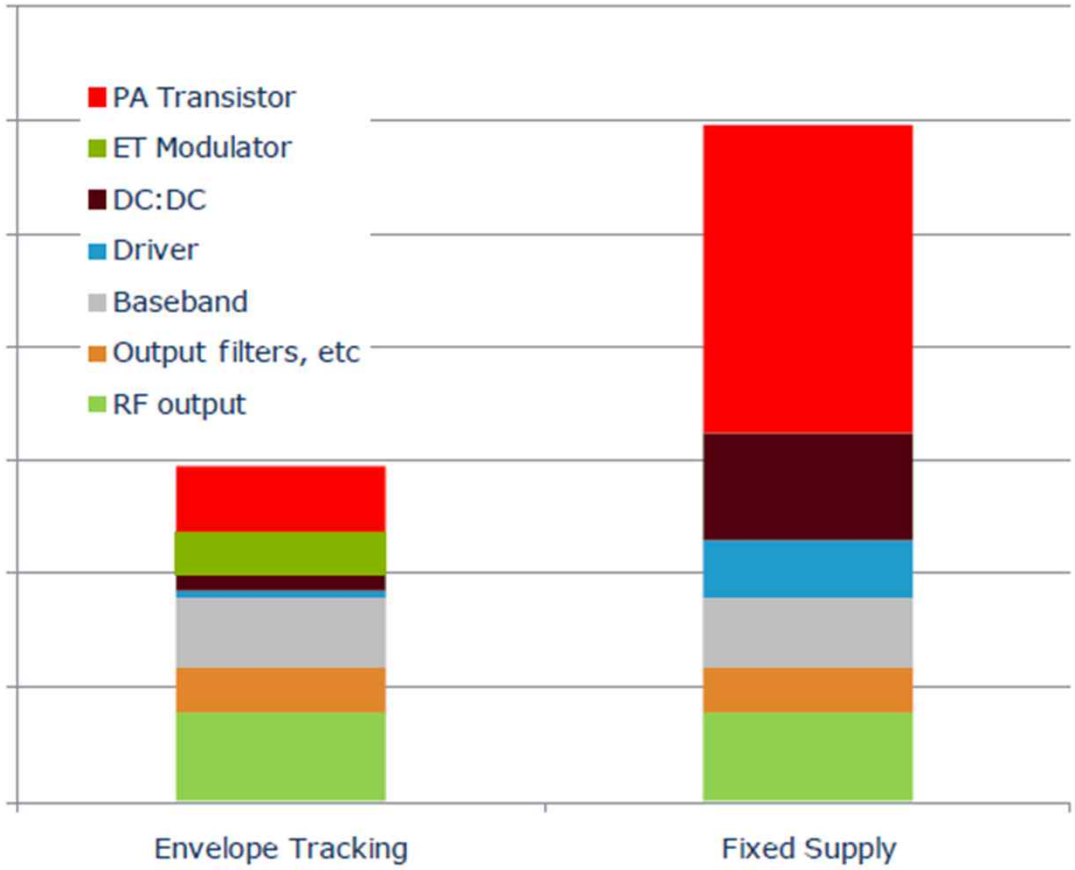
Transmitter Power Consumption



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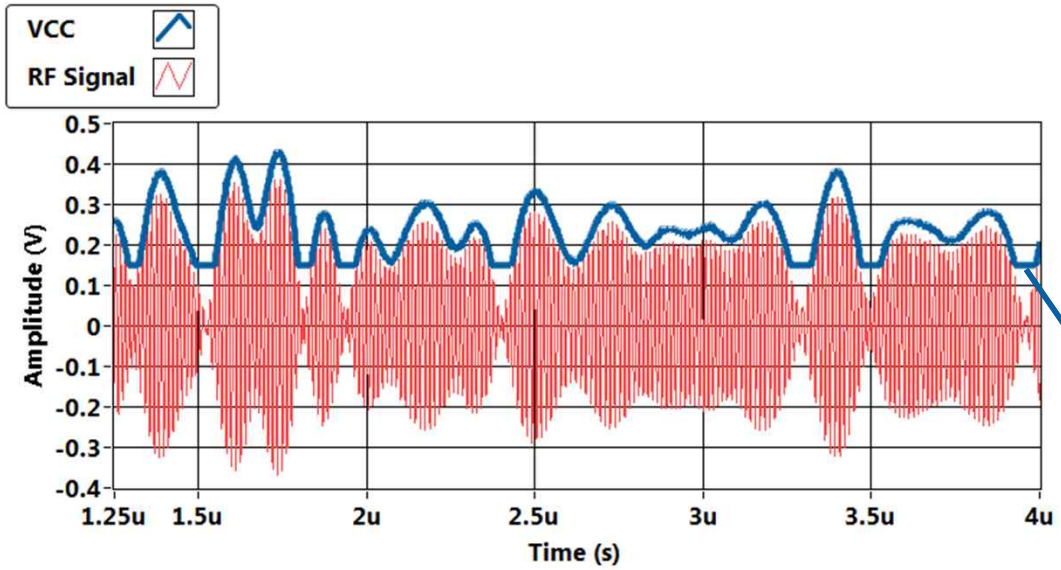
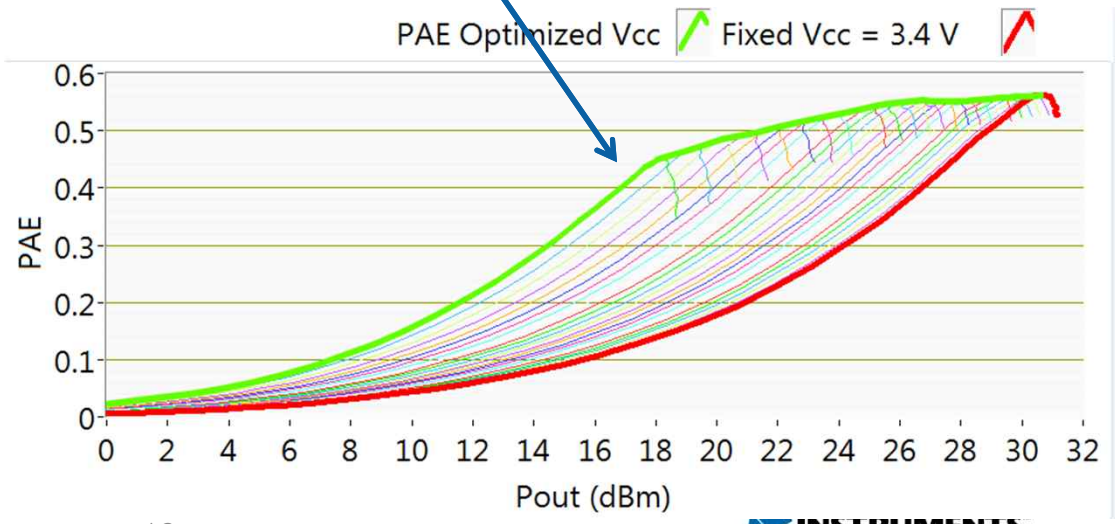
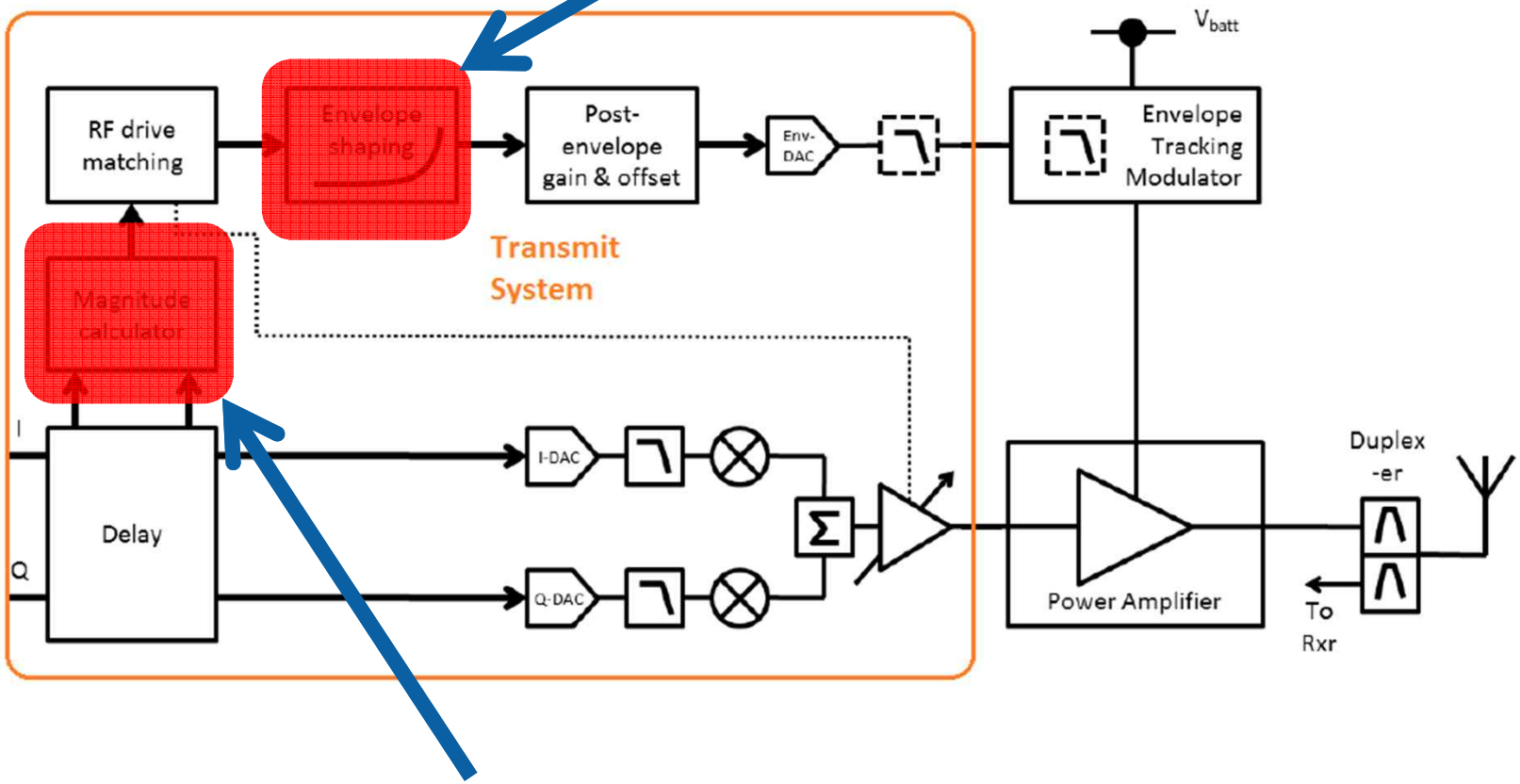
Envelope Power Supply Voltage Limits





Envelope Tracking Transmitter

Voltage Limits → Increased Bandwidth



Results in a Squared Term → Increased Bandwidth

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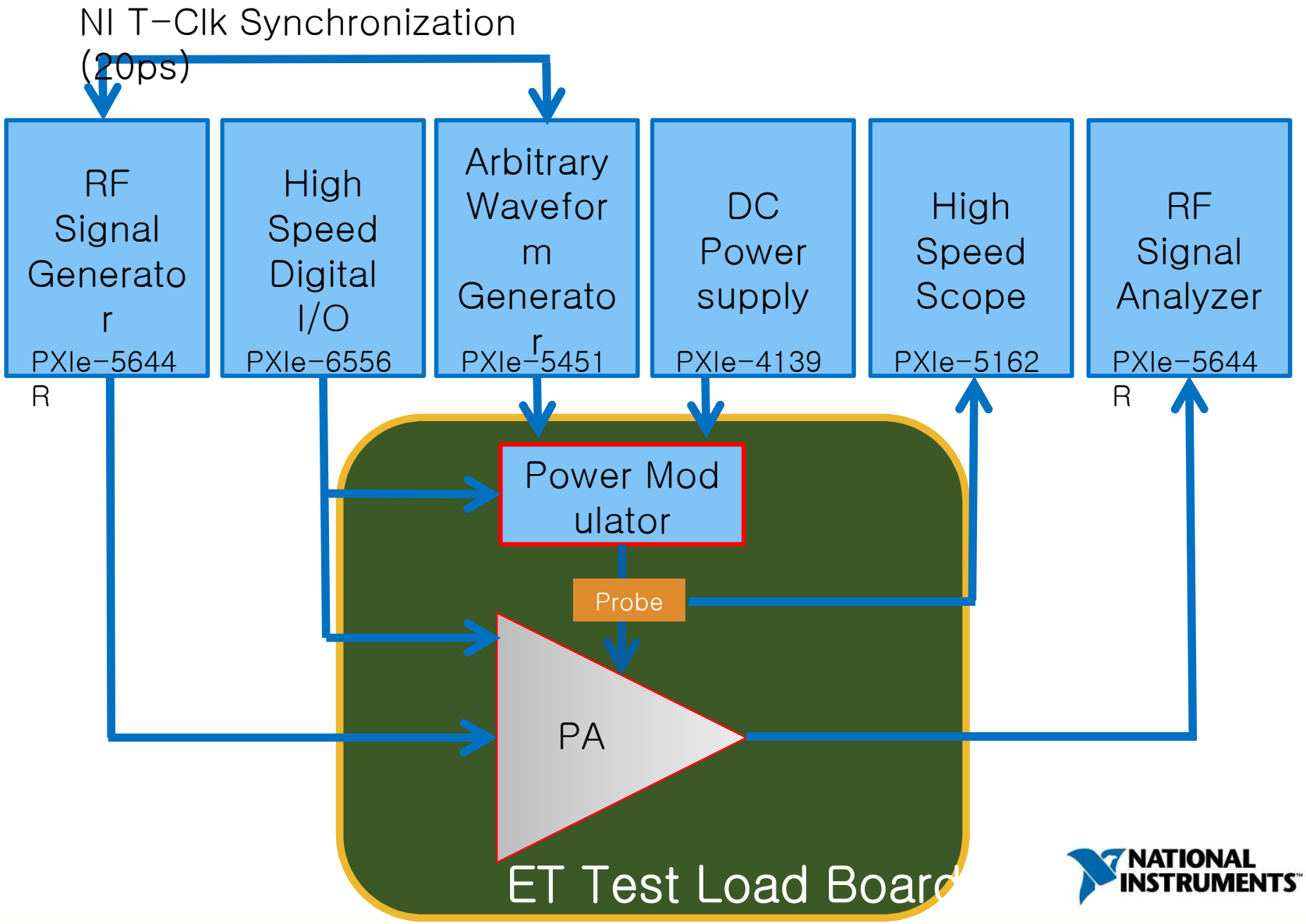
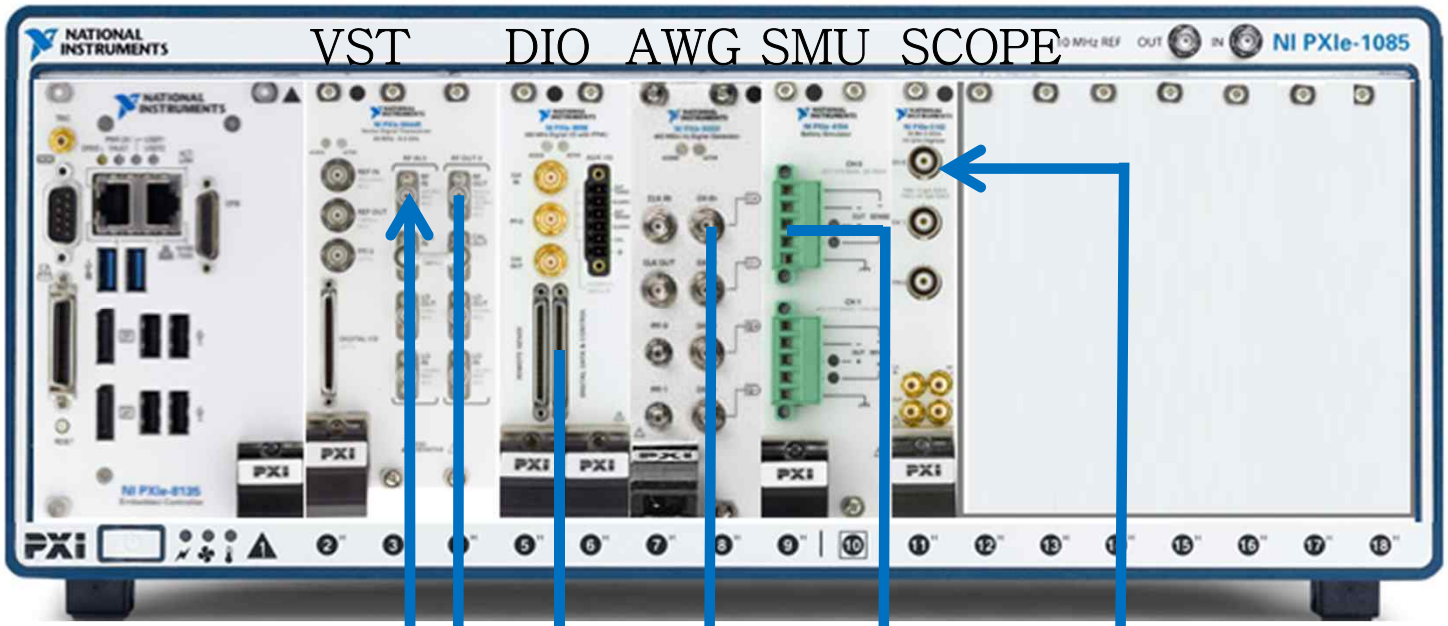
ET Challenges

- Envelope Signal needs >3x RF bandwidth. So for 20MHz LTE, a power modulator that runs at 60MHz is required.
- Very tight synchronization (~1ns) between VSG and power modulator. What happens if there's misalignment between the RF and the envelope?
- With DPD Bandwidths need to be more than 5X.
- Many customers are asking for IQ rates of 245.76MS/s (8x oversampled 20MHz LTE)

NI PXI기반의 Envelope Tracking Test System





Power Mod
ulator

Probe

ET Test Load Boar

PA

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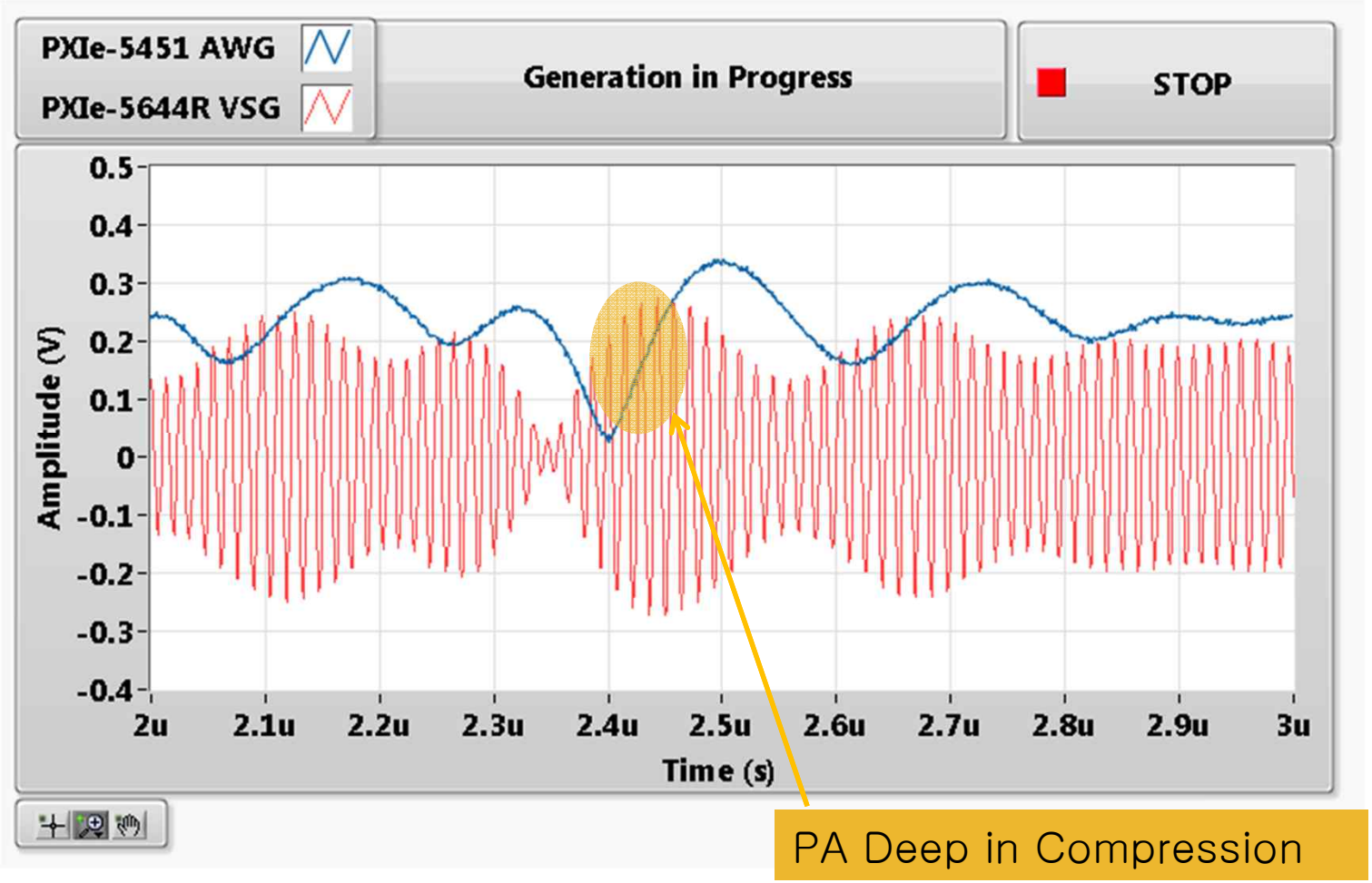
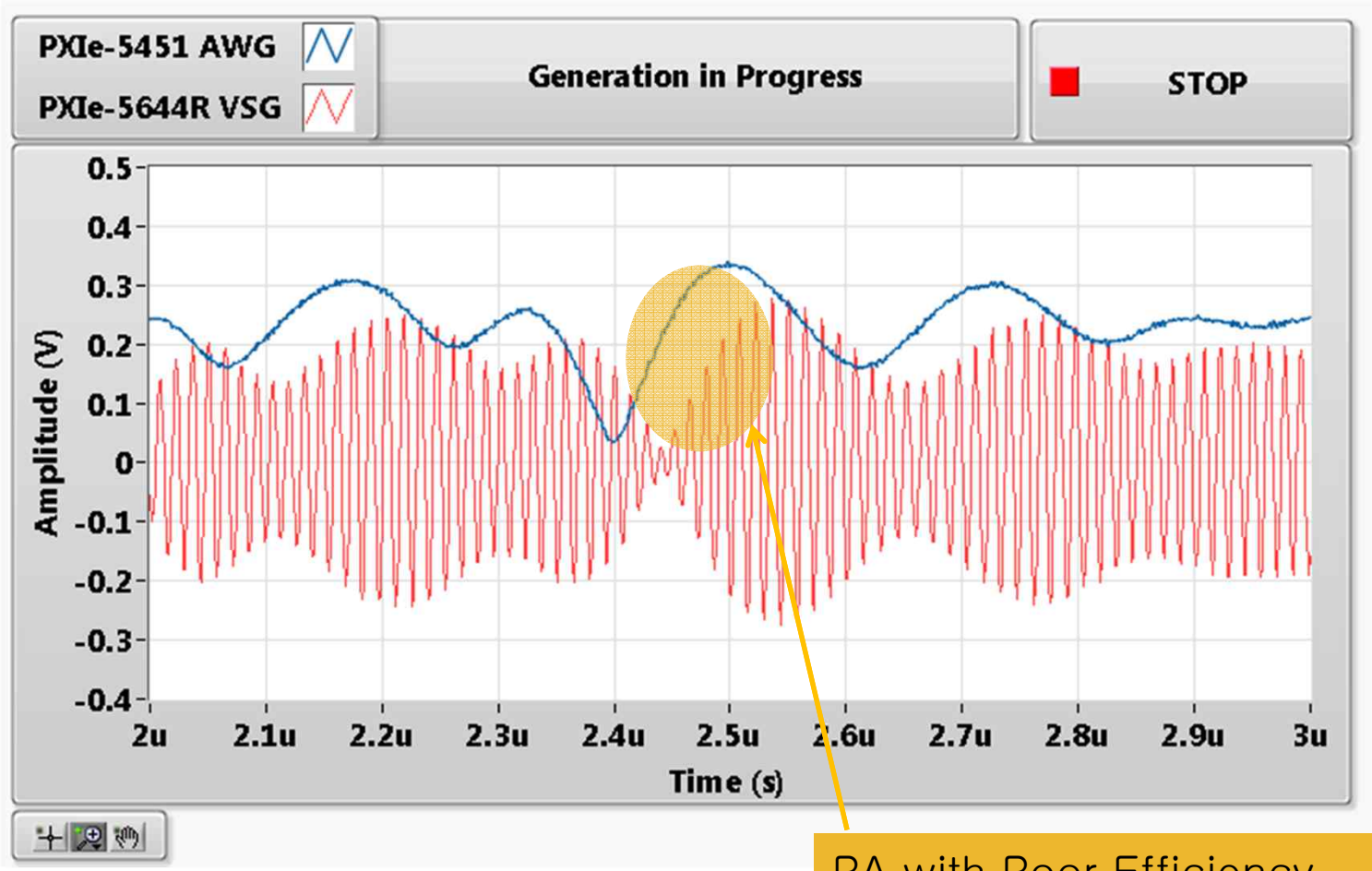
RF Leads Envelope



RF Leads Envelope



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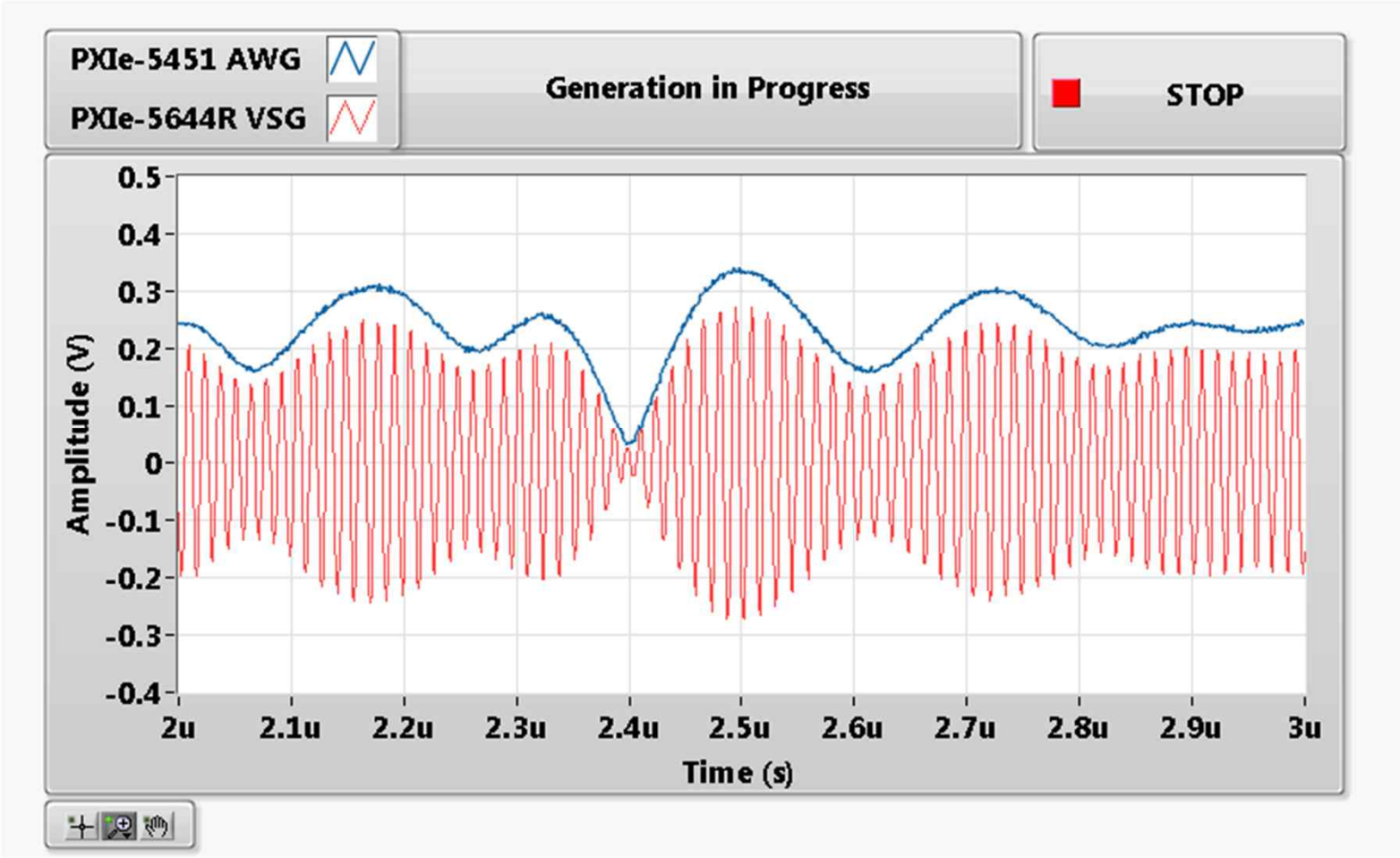
RF Synchronized with Envelope



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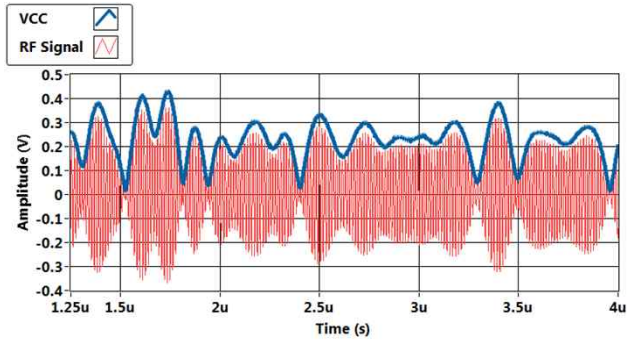
NI Envelope Tracking 테스트 장점

- 손쉽고 빠르게 Shaping Table 생성
  - Optimum Efficiency
  - Isogain (Constant Gain)
- NI-Tclk을 통한 RF와 Envelope간 정밀 동기: 20ps
- RF와 Envelope간 실시간 Delay 제어
  - Point-by-point EVM, ACP 분석



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선형성 향상을 위한 Digital Predistortion 기술

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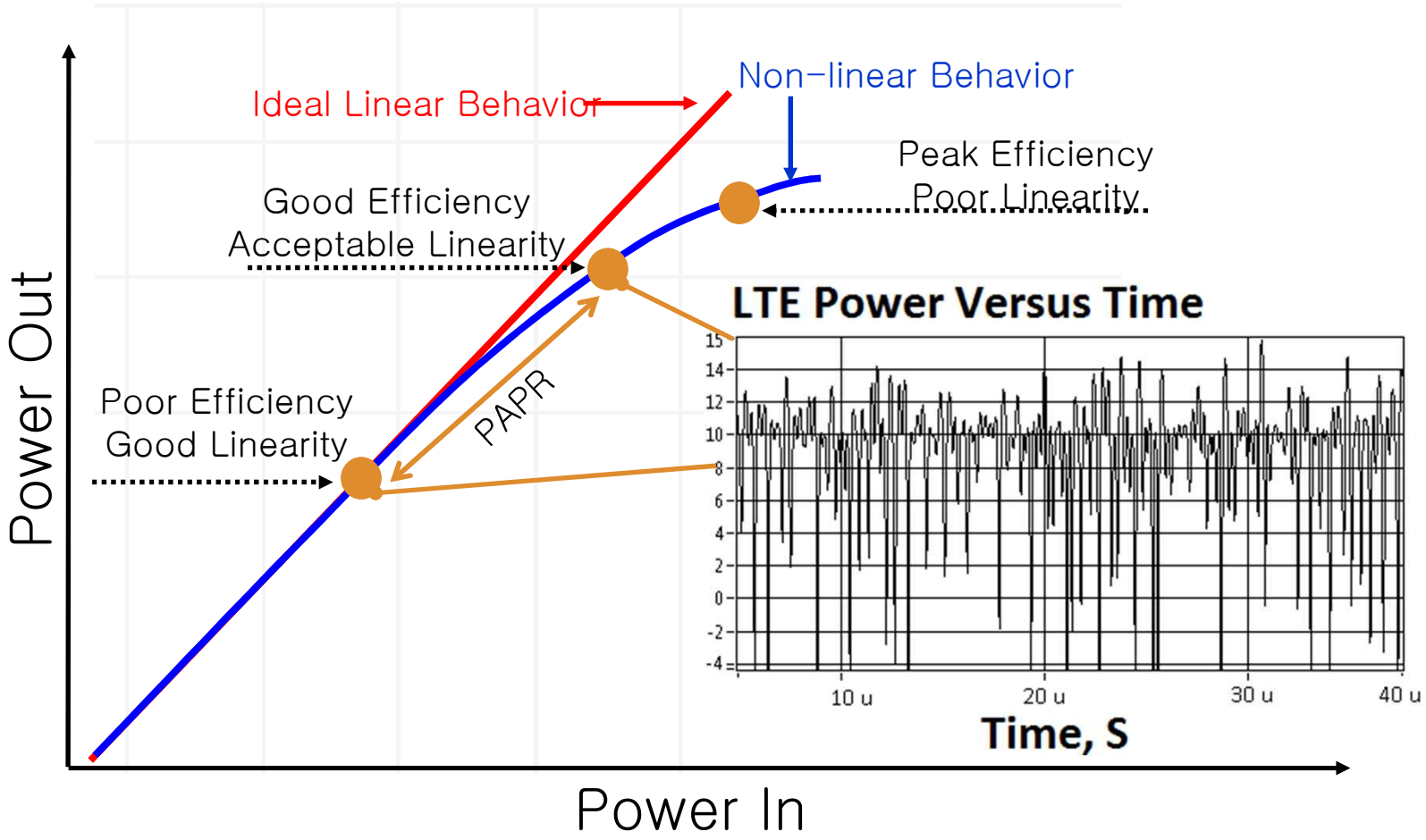
Amplifier AM-AM Efficiency & Linearity



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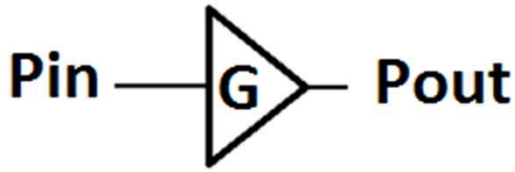
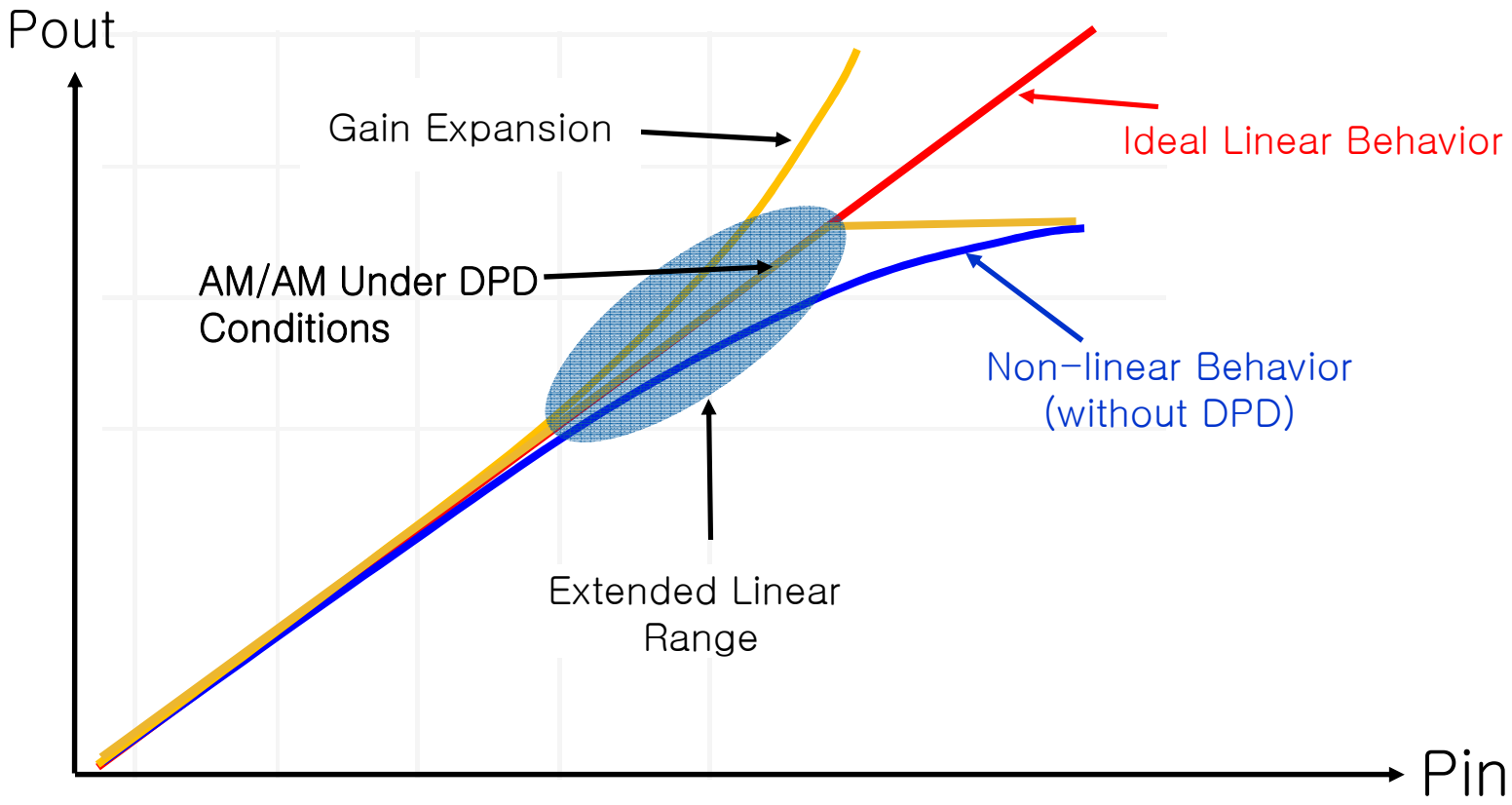
Fundamental Concept of DPD (AM–AM View)





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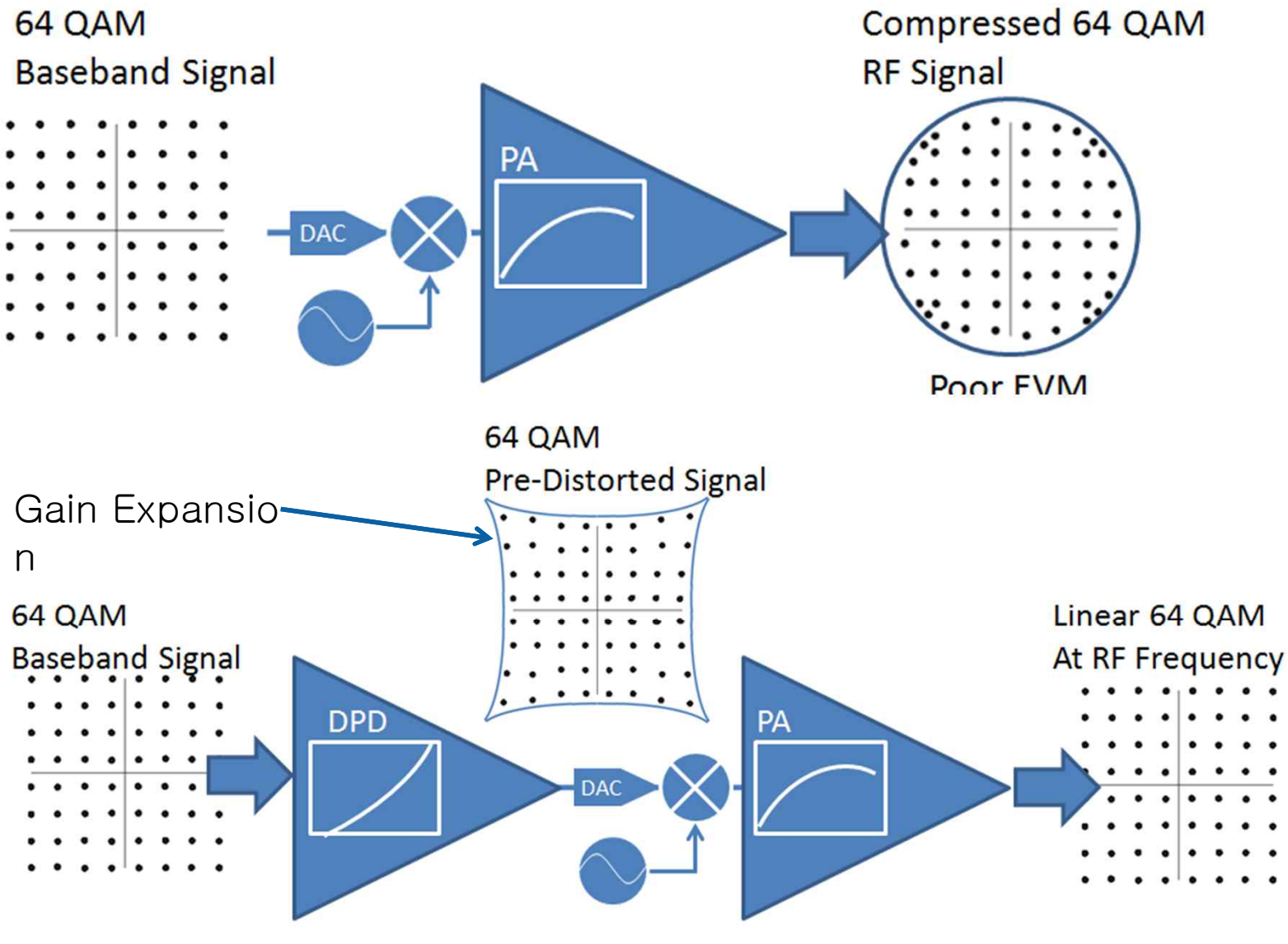
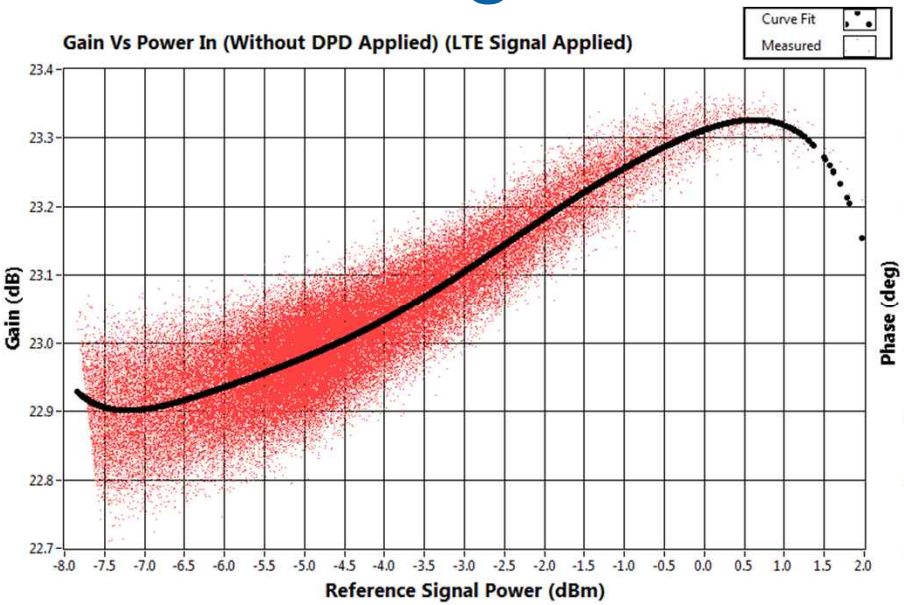
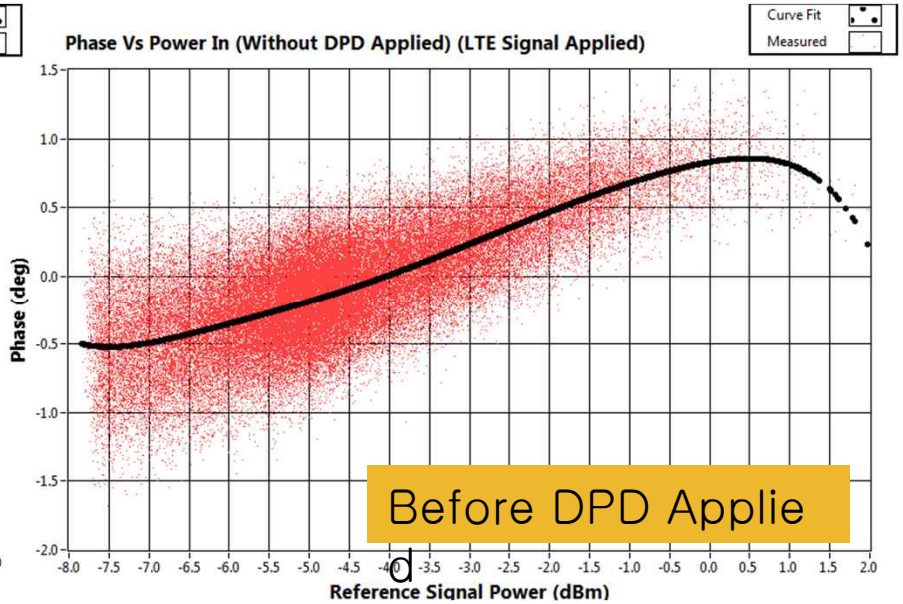
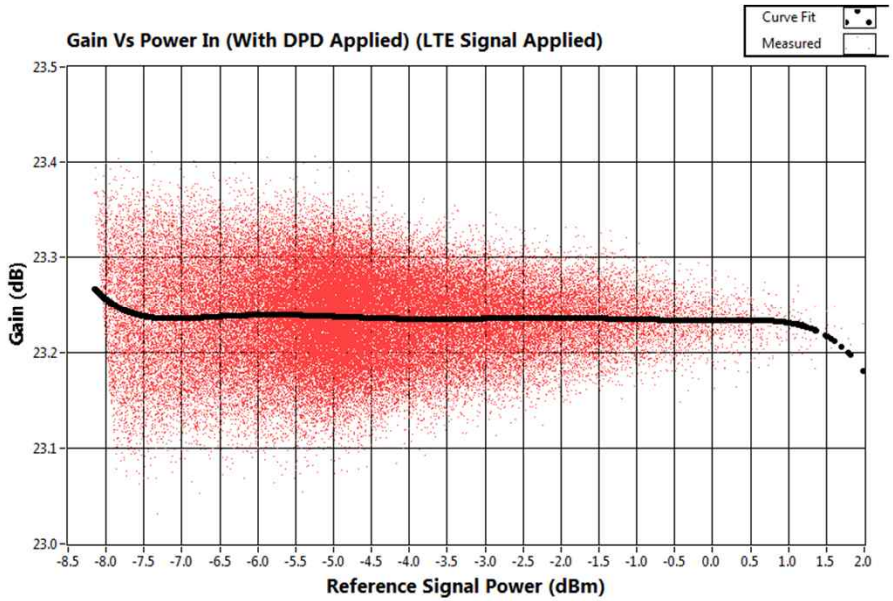
DPD as applied to Digital Modulation

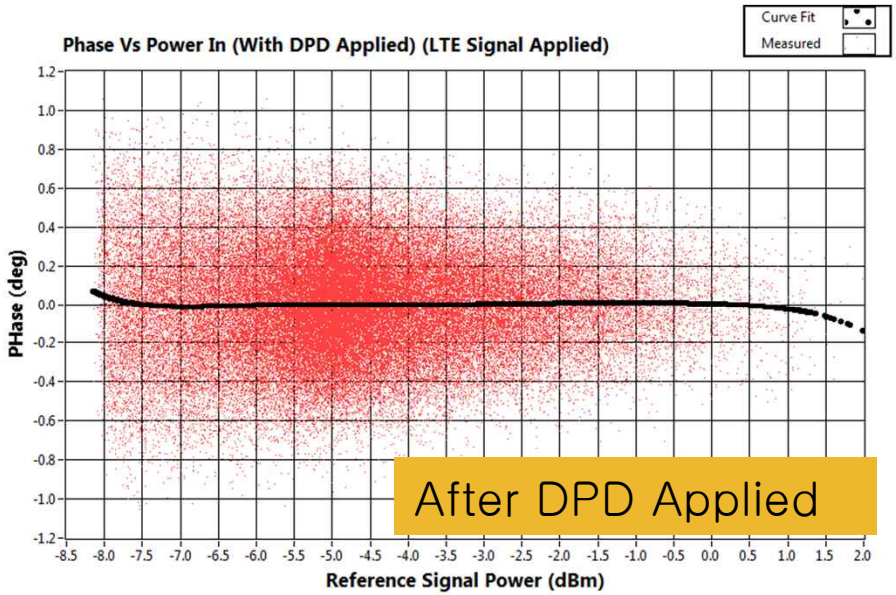


PA Modeling with AM–AM/PM

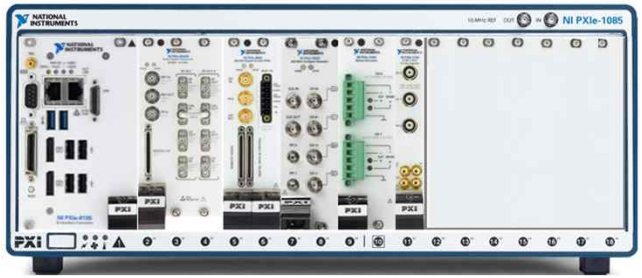


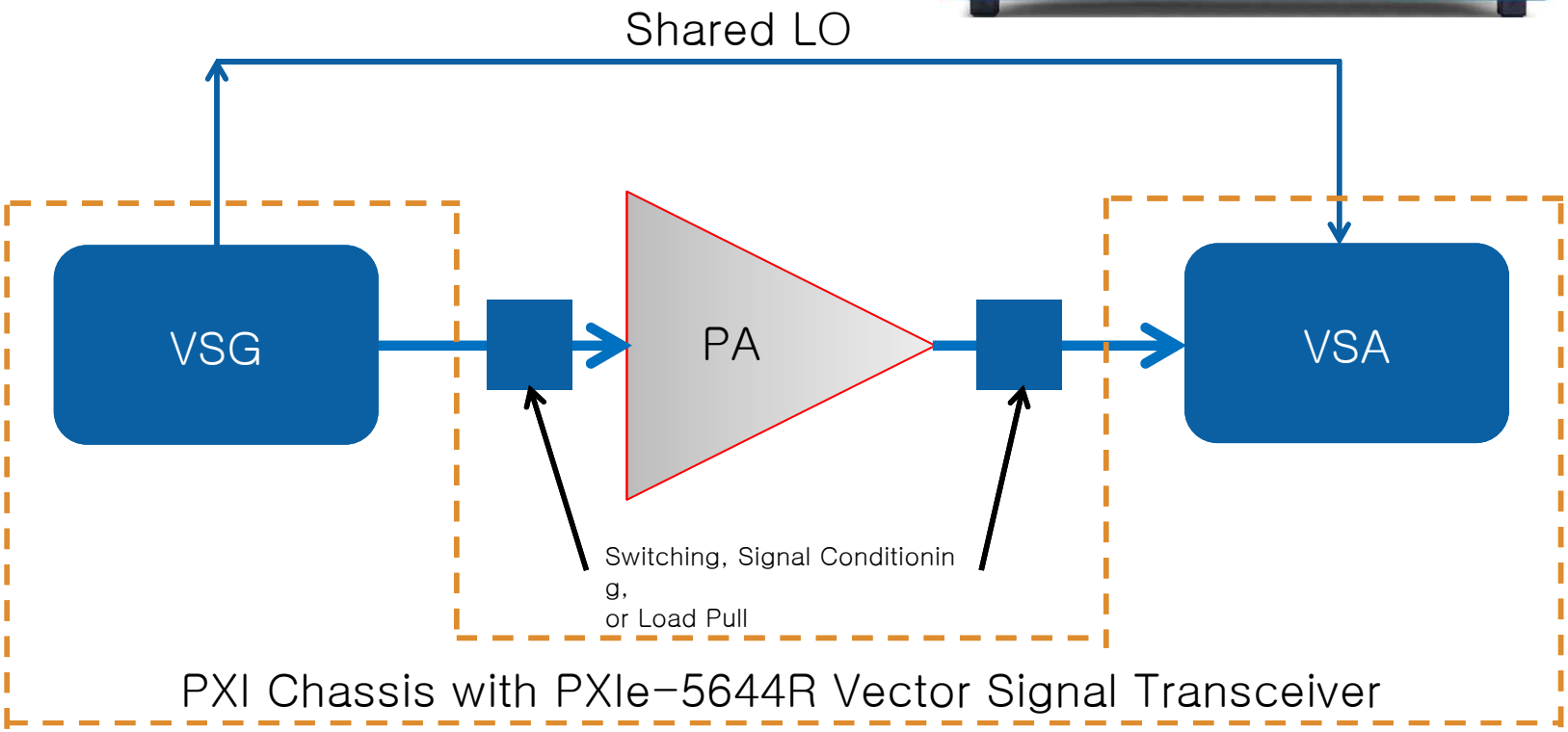






NI DPD Test Setup





- AM/AM AM/PM Measurement With Modulated Signal
  - Captures Memory Effects of PA & Behavior not seen with CW A M/AM Sweep

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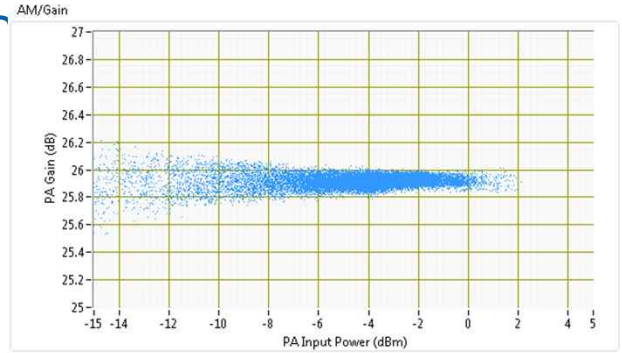
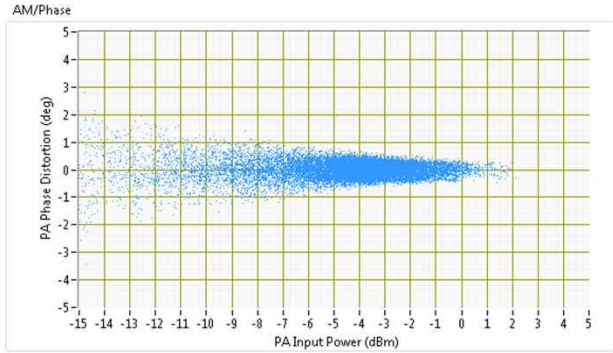
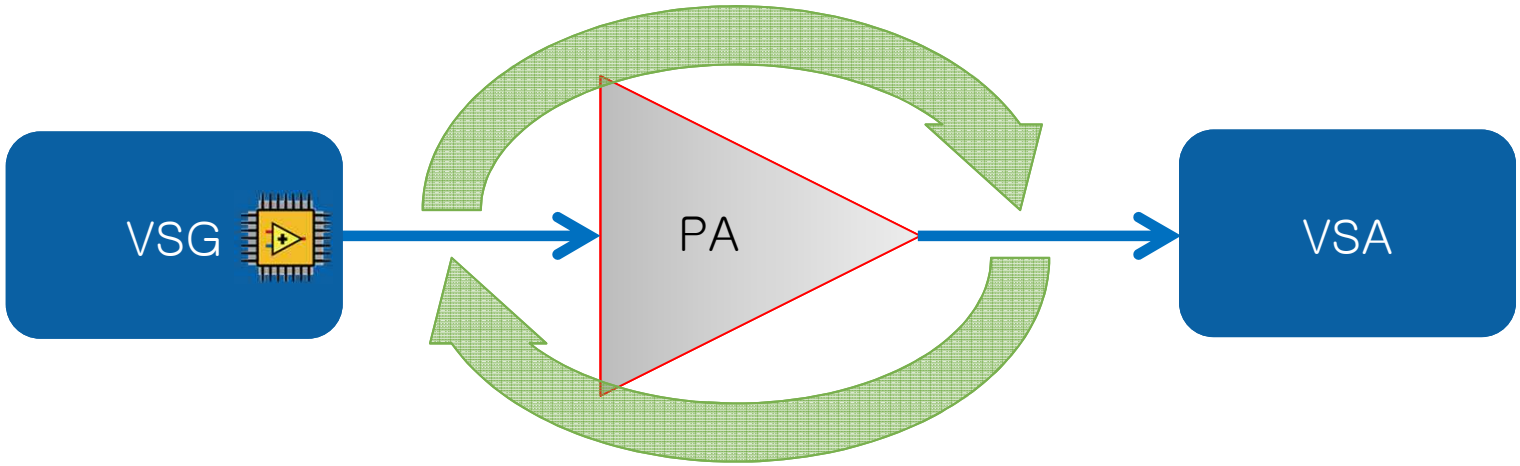
Automated DPD Model Extraction Typical Results

- Extends PA Linear Range
- Up to 10dB EVM Improvement
- At Least 10dB ACP Improvement







- Improvements are DUT Specific (How Non-Linear is your DUT ?)
- Speed is gated by the Measurements Performed (EVM / ACP)
- Possible to push corrections onto FPGA for
  - Hardware Emulation

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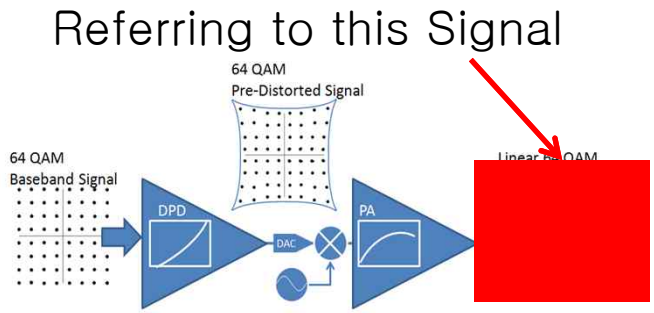
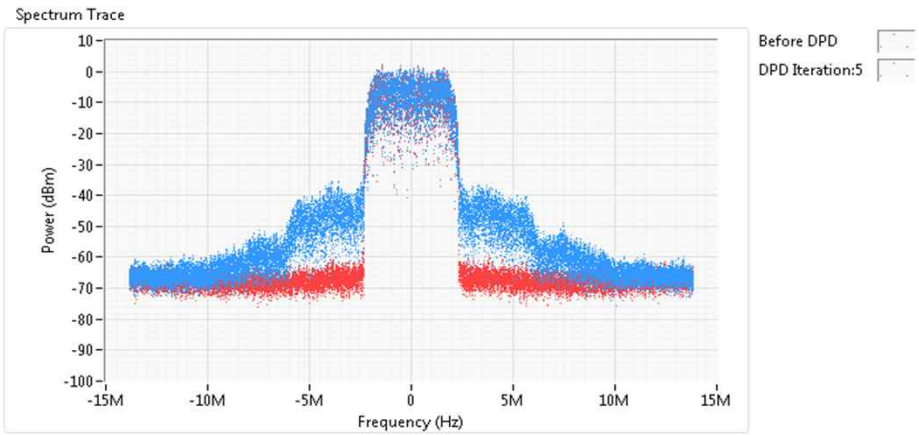
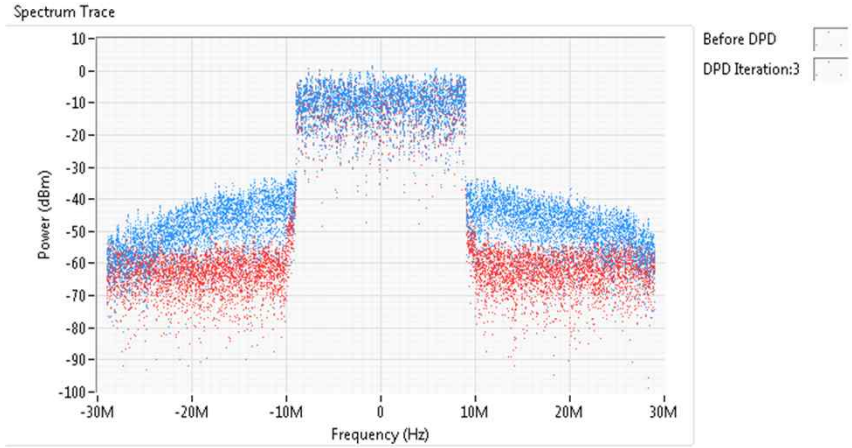
DPD Results

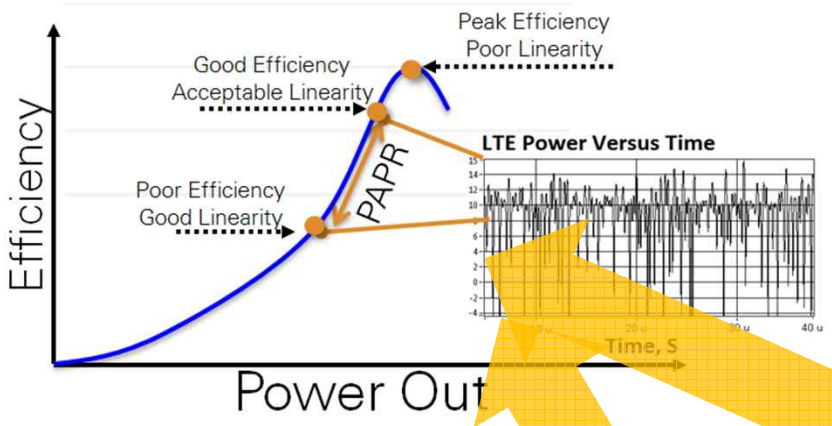


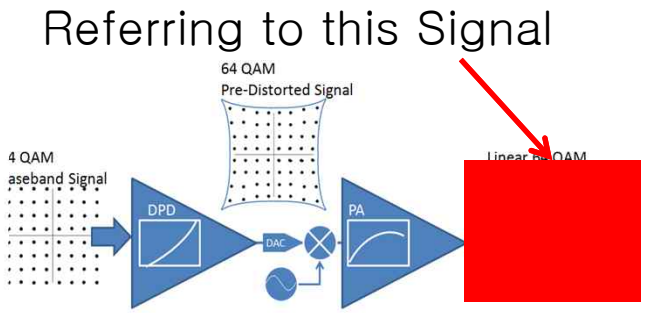
	ACP1 (dBc)	ACP2 (dBc)	EVM (dBc)	Pout (dBm)	Standard
No DPD	-42.6, -42.7	-44.7,-45.2	-34.8	24.0	LTE 20MHz
LUT DPD	-56.2,-54.4	-55.5,-54.1	-45.0	24.0	LTE 20MHz
No DPD	-41.1,-41.1	-60.9,-60.2	-39.7	24.0	WCDMA
LUT DPD	-65.2,-64.8	-65.9,-65.6	-49.8	24.0	WCDMA





DPD Results LTE Pout, EVM, ACP and PAE





LTE Average Channel Power Out
Power Added Efficiency
Error Vector Magnitude
Adjacent Channel Power

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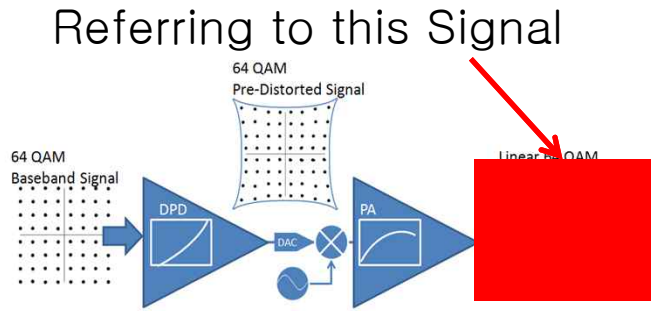
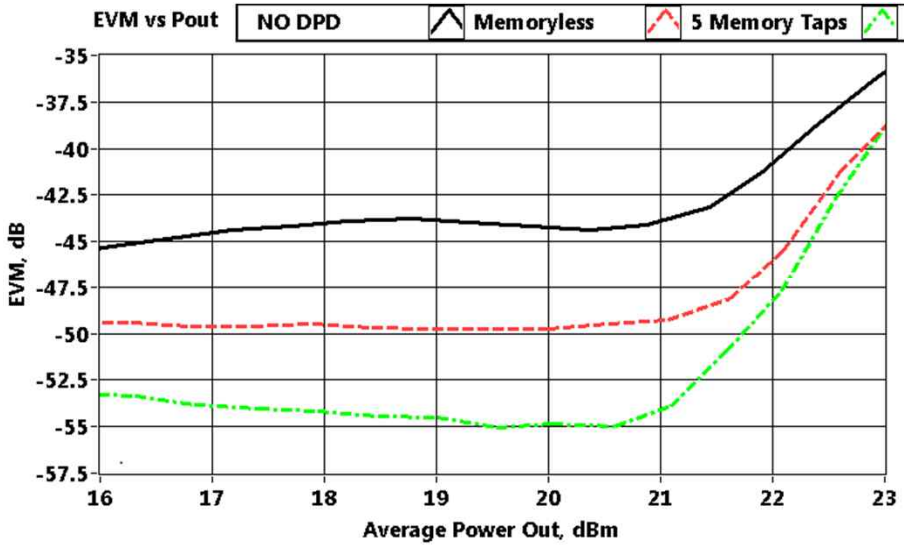
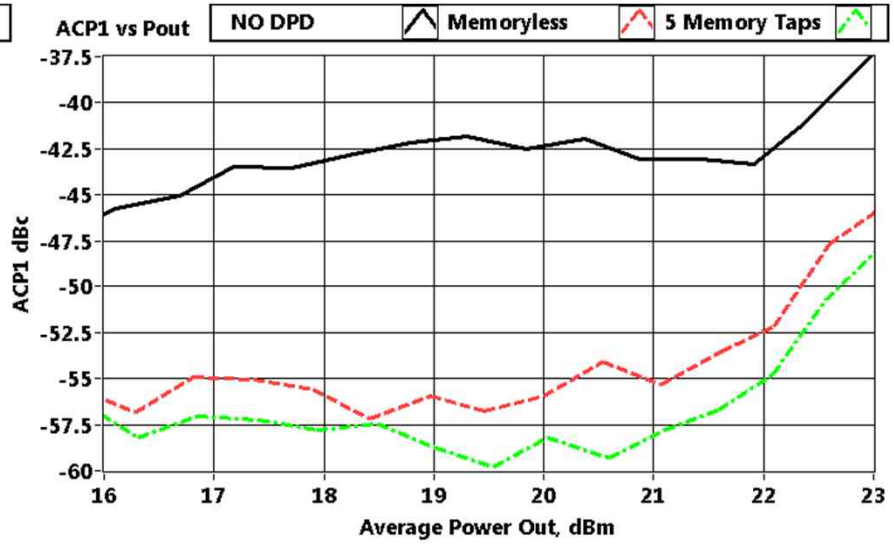
DPD Across Power
(Memoryless and 5-Tap Memory Model)

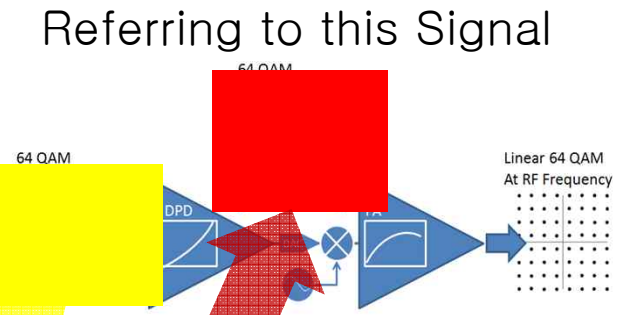


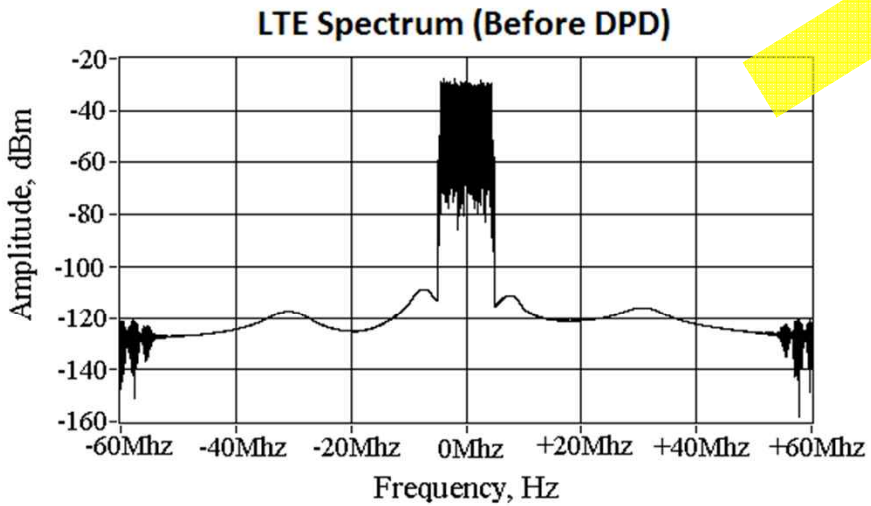




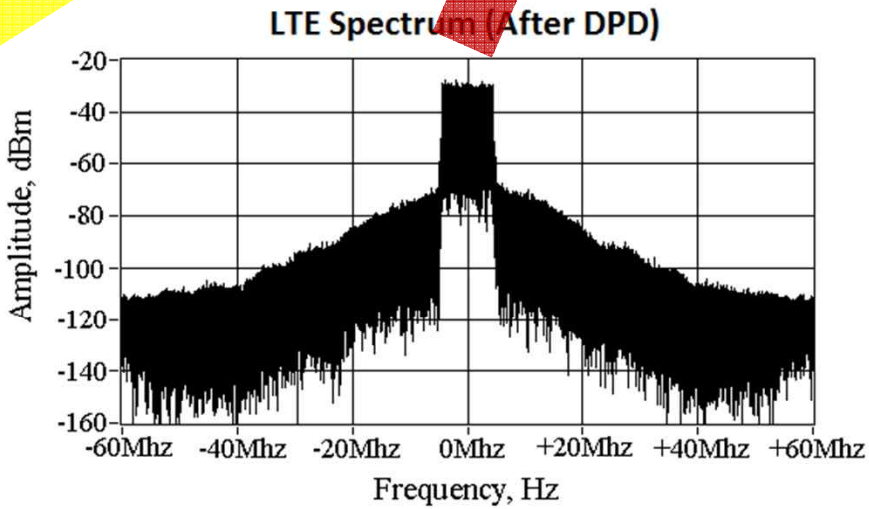
Instrumentation Requirements for DPD

- Post DPD signal
  - Up to 10X Bandwidth required for Generation
  - Increase PAPR → More dynamic range requir
- Greater Analysis / Generation Synchronization Required





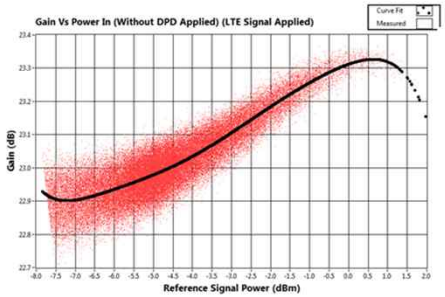
Bandwidth Greater than -100 dBm: 10 Mhz
PAPR = 8.5 dB

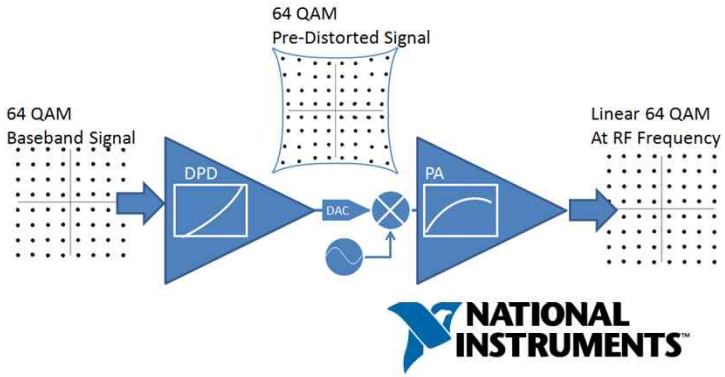


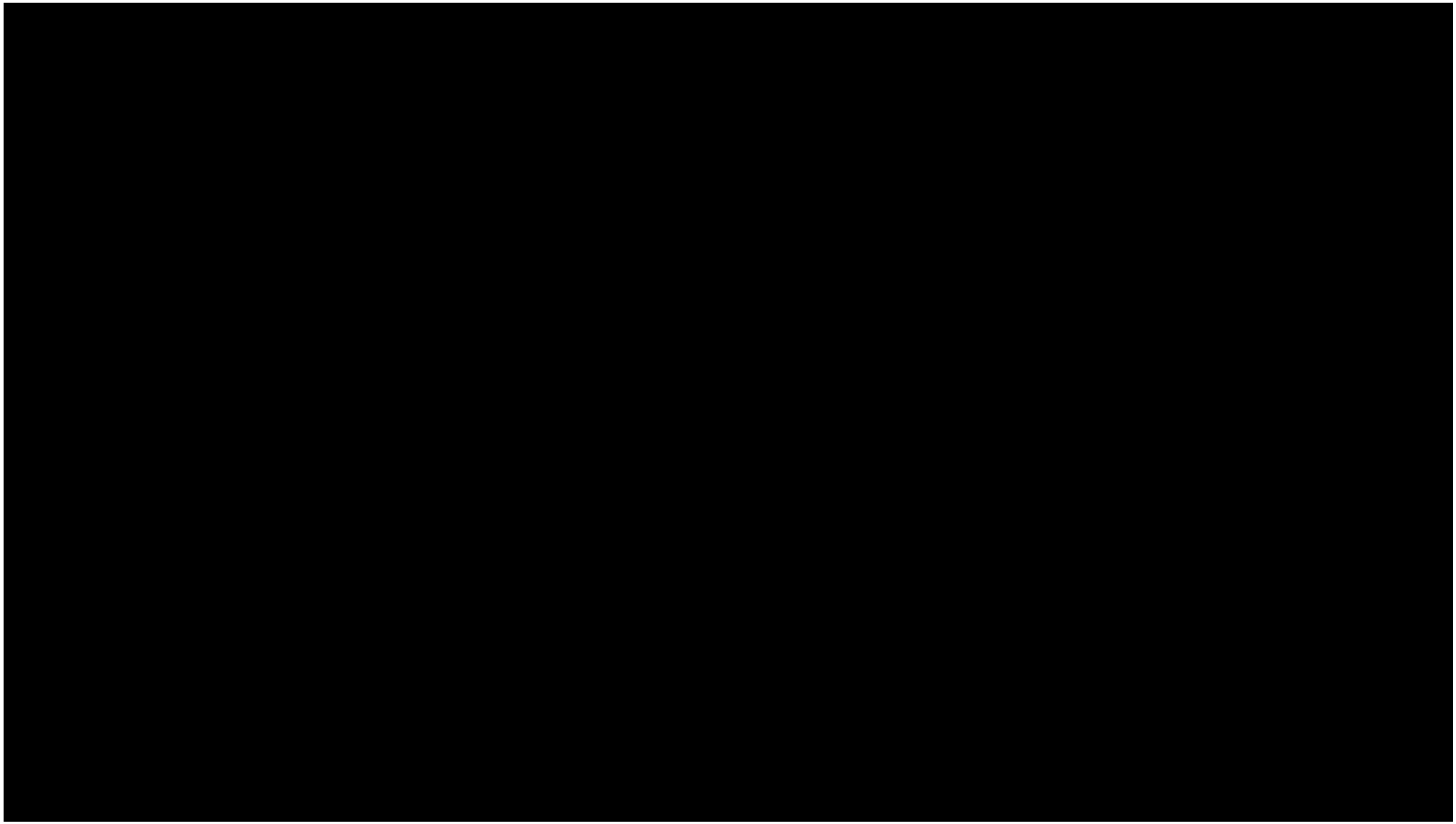
Bandwidth Greater than -100 dBm: 70 Mhz
PAPR = 12.2 dB

NI DPD 장점

- 넓은 분석 대역폭 지원: 200MHz
  - 채널 신호의 7~10배
- 정밀 동기화 및 AMAM, AMPM 분석
  - Stimulus와 response 신호 매칭
- Host 또는 FPGA에 다양한 알고리즘 구현
  - Memory & Memoryless Nth order polynomial
  - Lookup Table







기존 측정 시스템 환경

- Cost of Test Equipment
- Test Time
- Development Time
- Space in Lab

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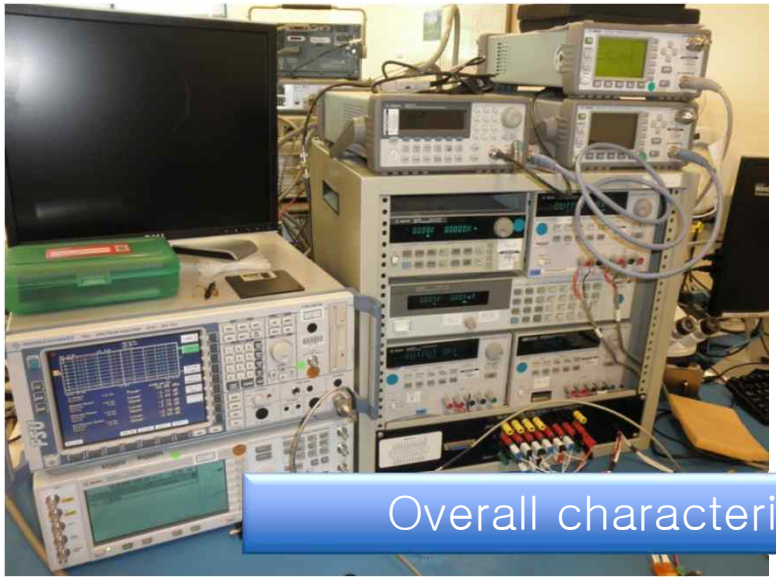
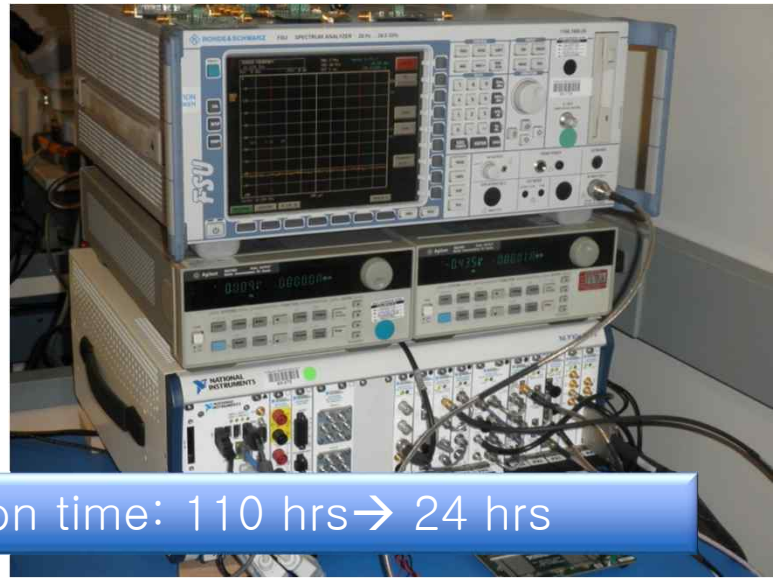
RF – PA Validation/Characterization

TriQuint SEMICONDUCTOR

Previous Characterization Test Bench



PXI-Hybrid Characterization Test Set



Overall characterization time: 110 hrs→ 24 hrs

	Original Test Time	PXI Test Time	Difference
EDGE Test	14 sec	1.1 sec	14x

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High-Power Amplifier Transistor Module Test

Box형 계측기
Rack & Stack Test Platform

- RF Signal Generator
- RF Signal Analyzer
- Vector Network Analyzer
- Power Supply
- DMM
- RF Switch

Test Items

- Tx Power
- Power Versus Time
- Gain
- Power Efficiency
- Power Servo
- Adjacent Channel Leakage Ratio (ACLR)
- S Parameter(Phase)
- Open/Short Test
- Current
- Leakage Current
- Resistor

60 sec → 30 sec

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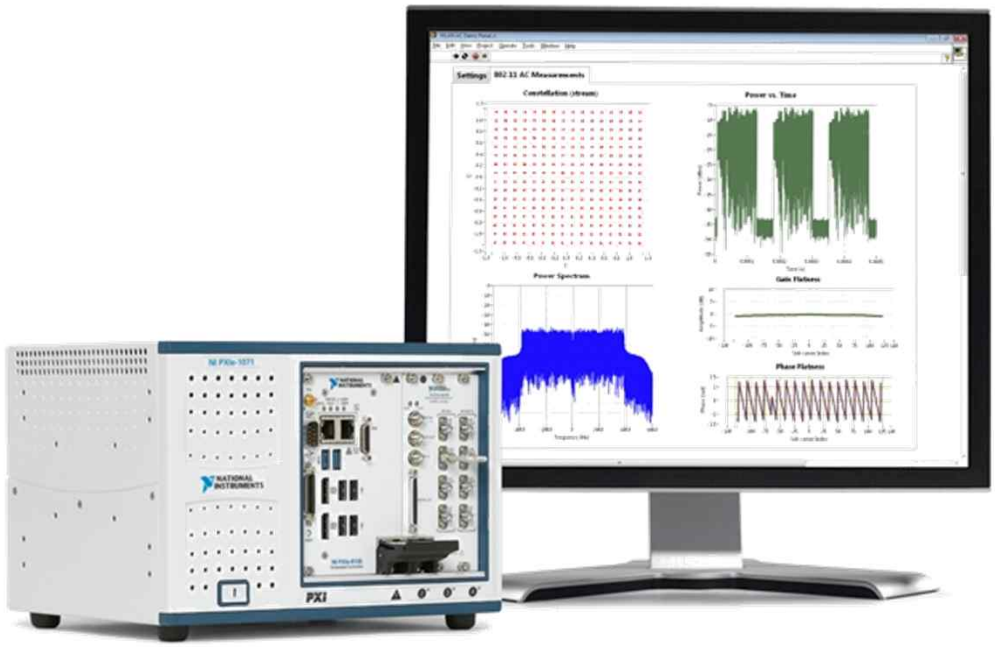
What Makes It Possible:

World's First PXI Vector Signal Transceiv



PXIe-5644R	
Configuration	VSA and VSG w/ independent LOs 24 DIO lines @ 250 Mbps
Frequency Range	65 MHz to 6 GHz
Bandwidth	200 MHz
Features	• Programmable FPGA w/ LabVIEW • Fast Tuning Mode: <400 µs

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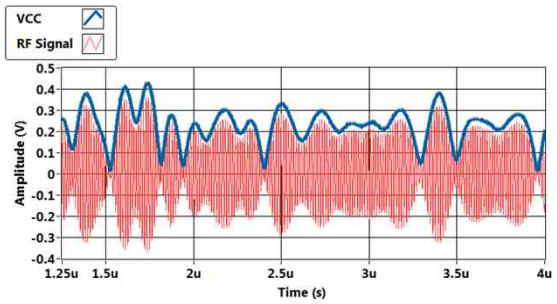
결론

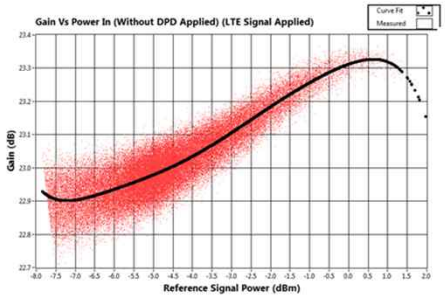
Envelope Tracking

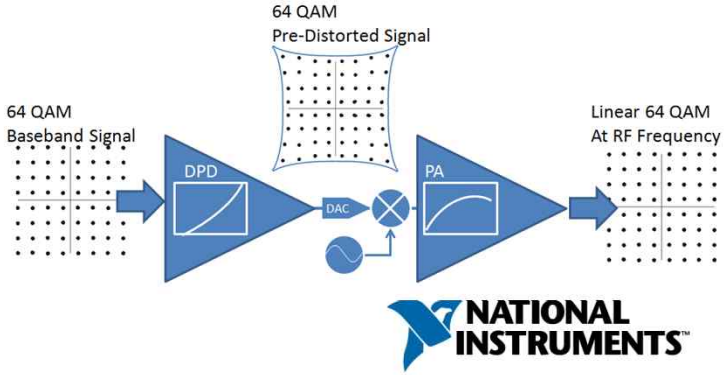
- 손쉽고 빠르게 Shaping Table 생성
- NI-Tclk을 통한 RF와 Envelope간 정밀 동기: 20ps
- 실시간 Delay 제어 및 EVM/ACP 분석

Digital Predistortion

- 넓은 분석 대역폭 지원: 200MHz
- 정밀 동기화 및 AMAM, AMPM 분석
- Host 또는 FPGA에 다양한 알고리즘 구현







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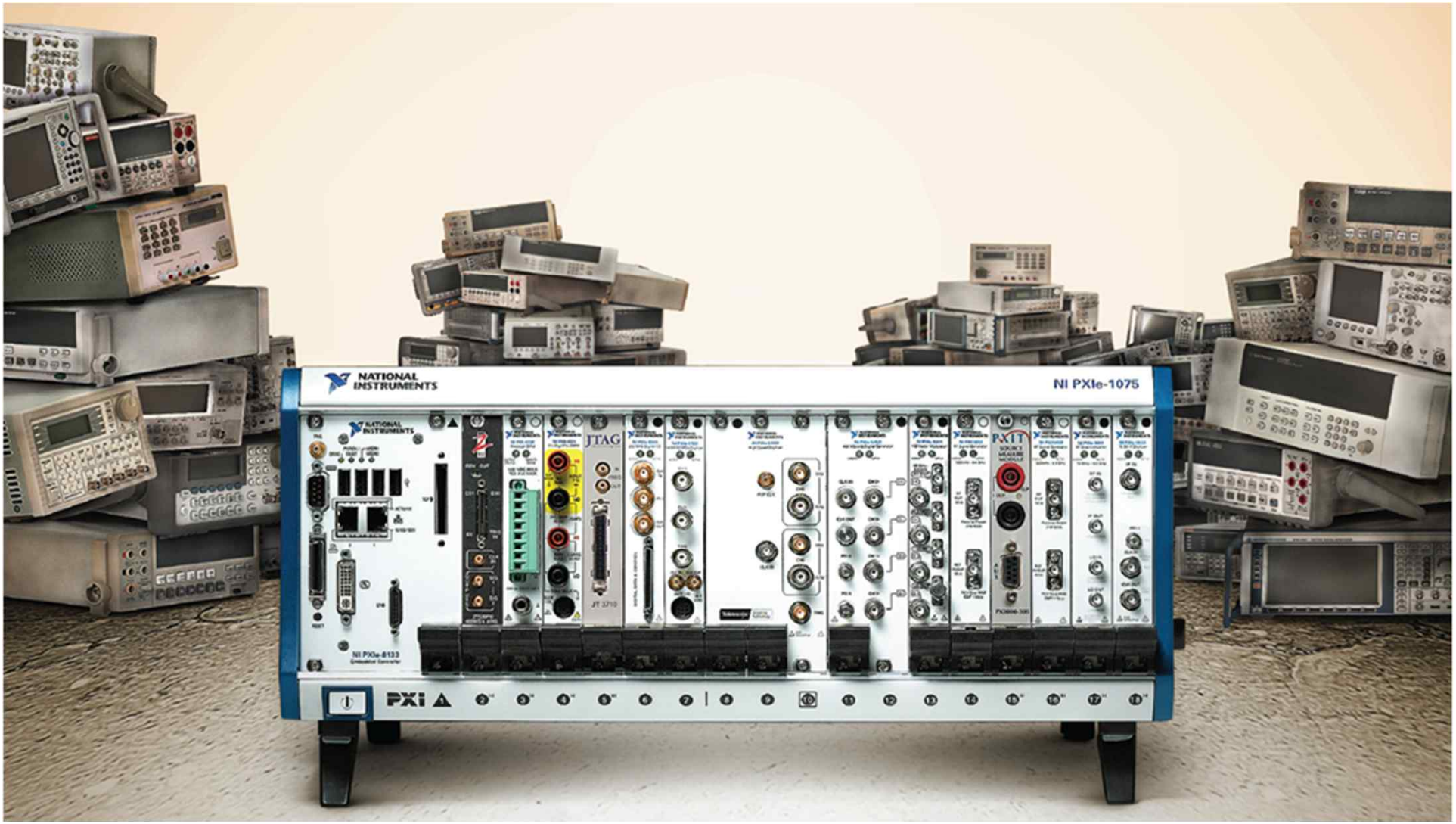
감사합니다.



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