5G Power Amplifier Digital Pre-Distortion Measurement

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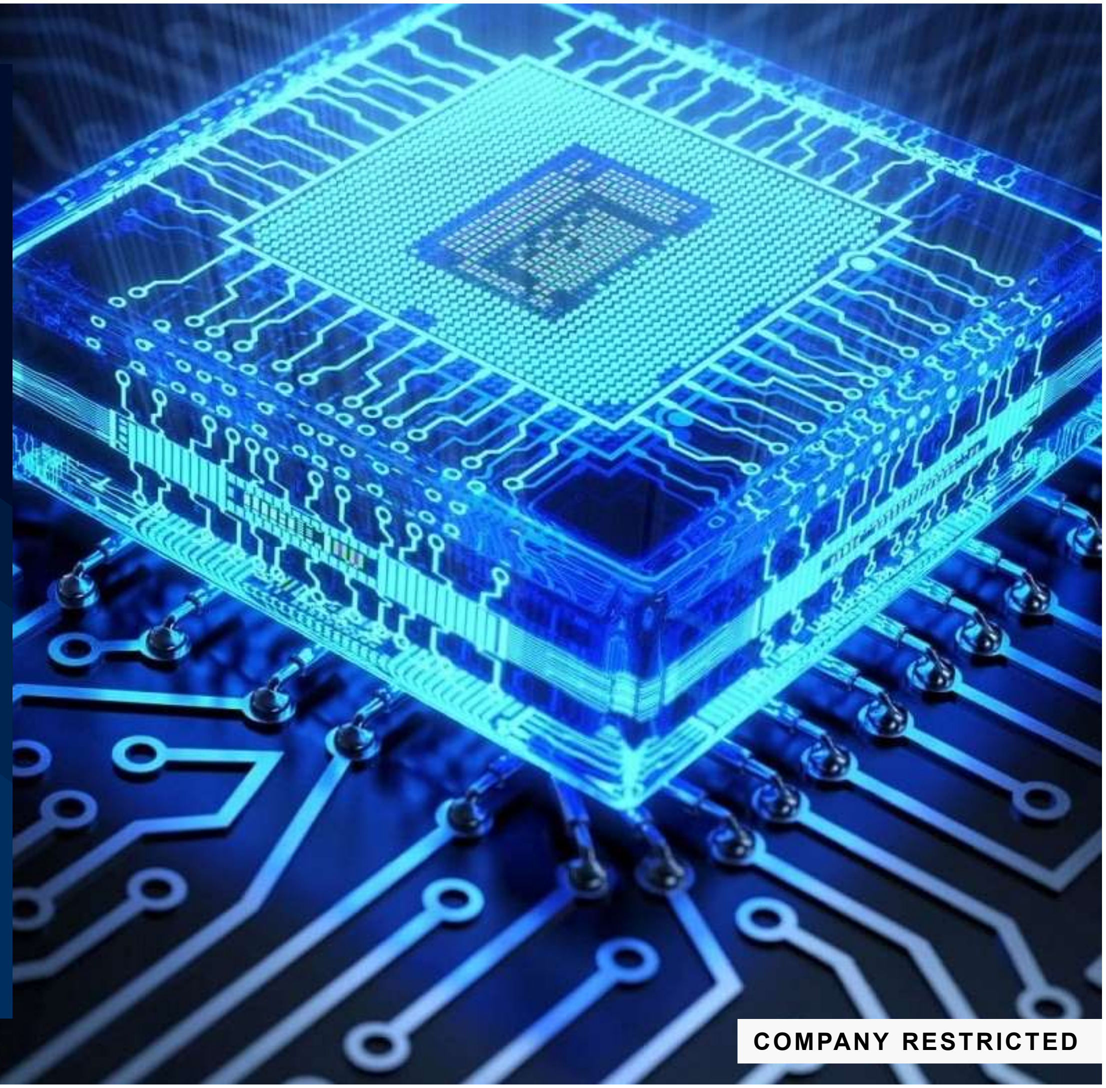
Make ideas real

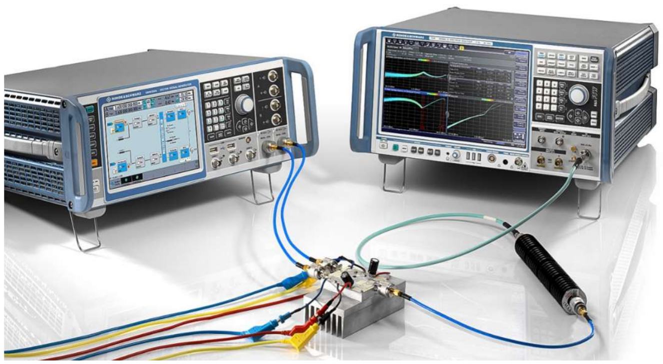
COMPANY RESTRICTED

Agenda

- ▶ 5G Front End Challenging
- ▶ Amplifier Key Test Item
- ▶ Digital Pre-Distortion
- ▶ Solution for DPD
- ▶ Summary



5G Frontend Challenging



- ► Challenging RF designer on RF Frontend
  - 5G in mmWave , MIMO, Beamforming
  - Increasing Bandwidth , Higher Order Modulation
  - FR2 (24.25 – 71Ghz) 400Mhz 1024QAM
  - EIRP = Tx RF Power(dBm) + G(dB) - L(dB)
  - EIRP : Equivalent Isotropic Radiated Power
  - Tx : RF Power , G : Antenna gain , L : Feeder loss (Cable loss)
- ► Power Amplifier **Gain** in **Efficiency** but remains **Highly Non-Linear**
- ► To address these **Linearity** and **Efficiency** requirements
  - Operating close to saturation offers best energy efficiency
  - Power added efficiency

$$PAE\ (Power\ added\ efficiency) = 100\% \cdot (P_{out} - P_{in})/P_{dc} \qquad P_{out} \uparrow \quad PAE \uparrow \quad Heat \downarrow$$

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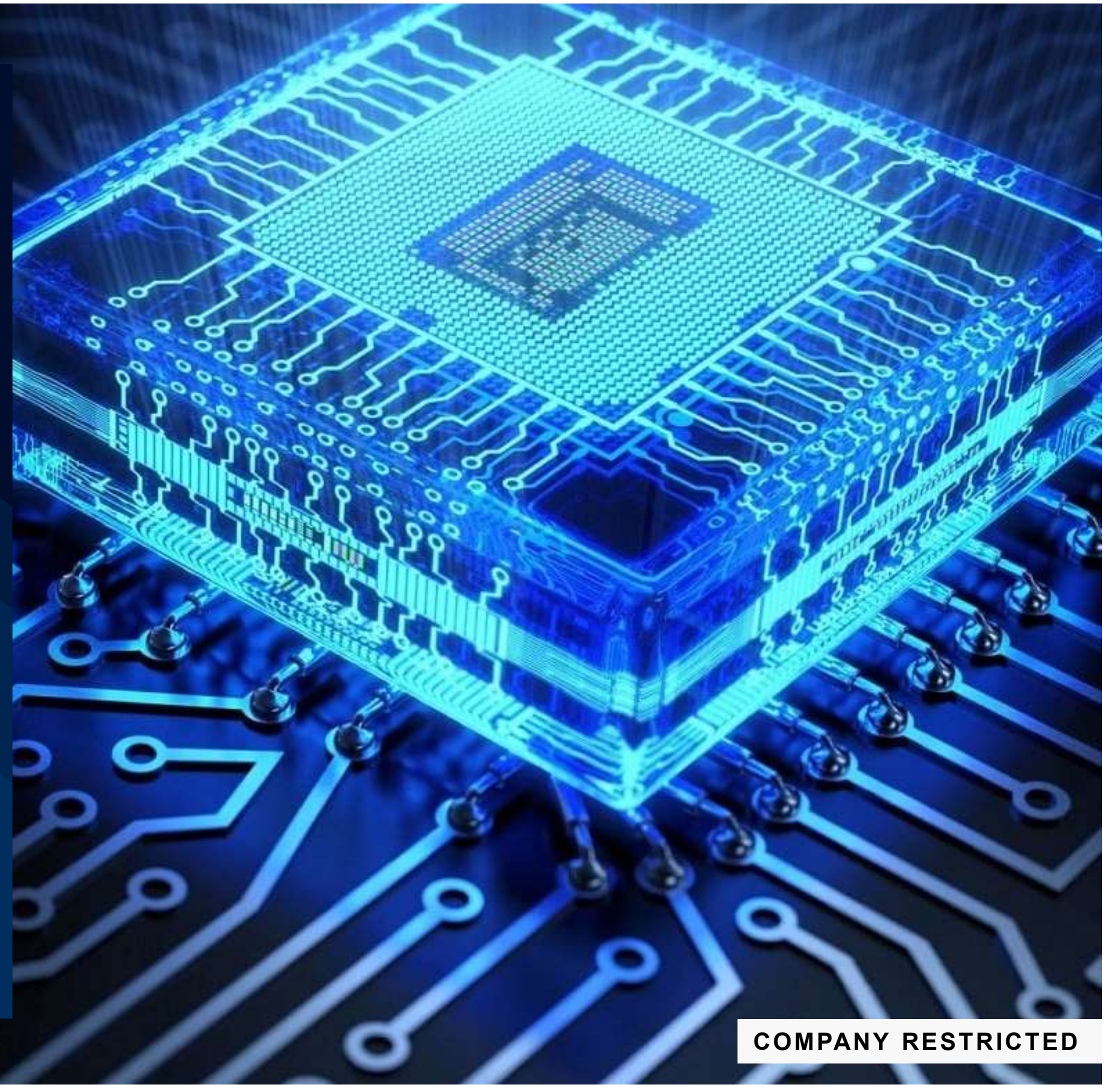
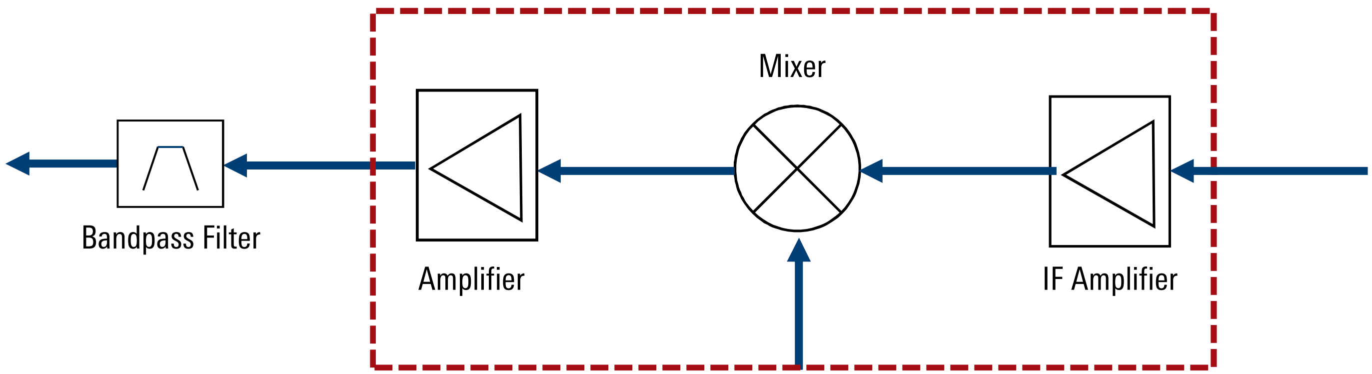
- ▶ **Amplifier Key Test Item**
- ▶ Digital Pre-Distortion
- ▶ Solution for DPD
- ▶ Summary



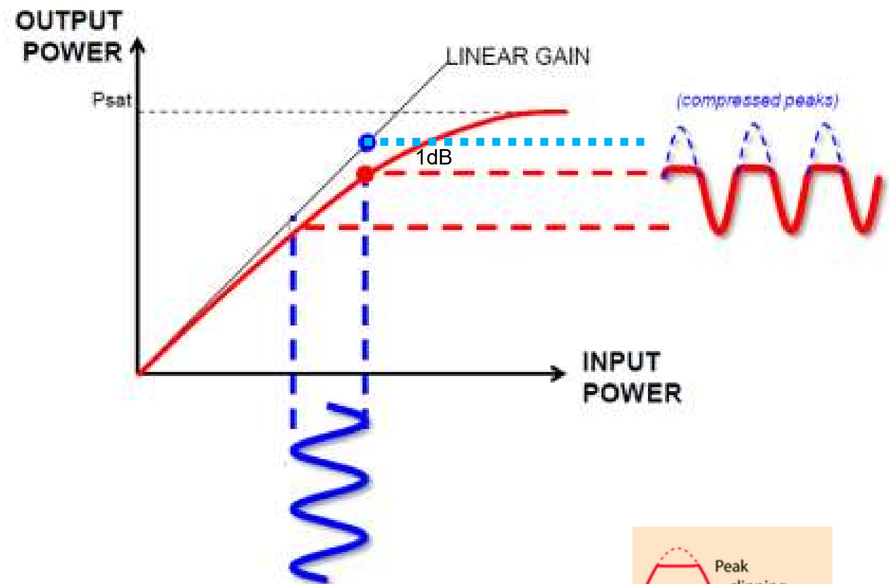
Active devices and linearity

- Distortion is generally created in **active** devices, such as amplifiers or mixers.
- **Linearity** means that the output of a device is directly proportional to its input.
- Active devices are typically linear over a defined input power range, but above a certain input power (*high power signals*) they can become non-linear and produce distortion.

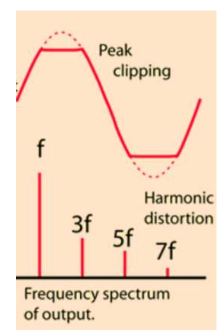


Compression

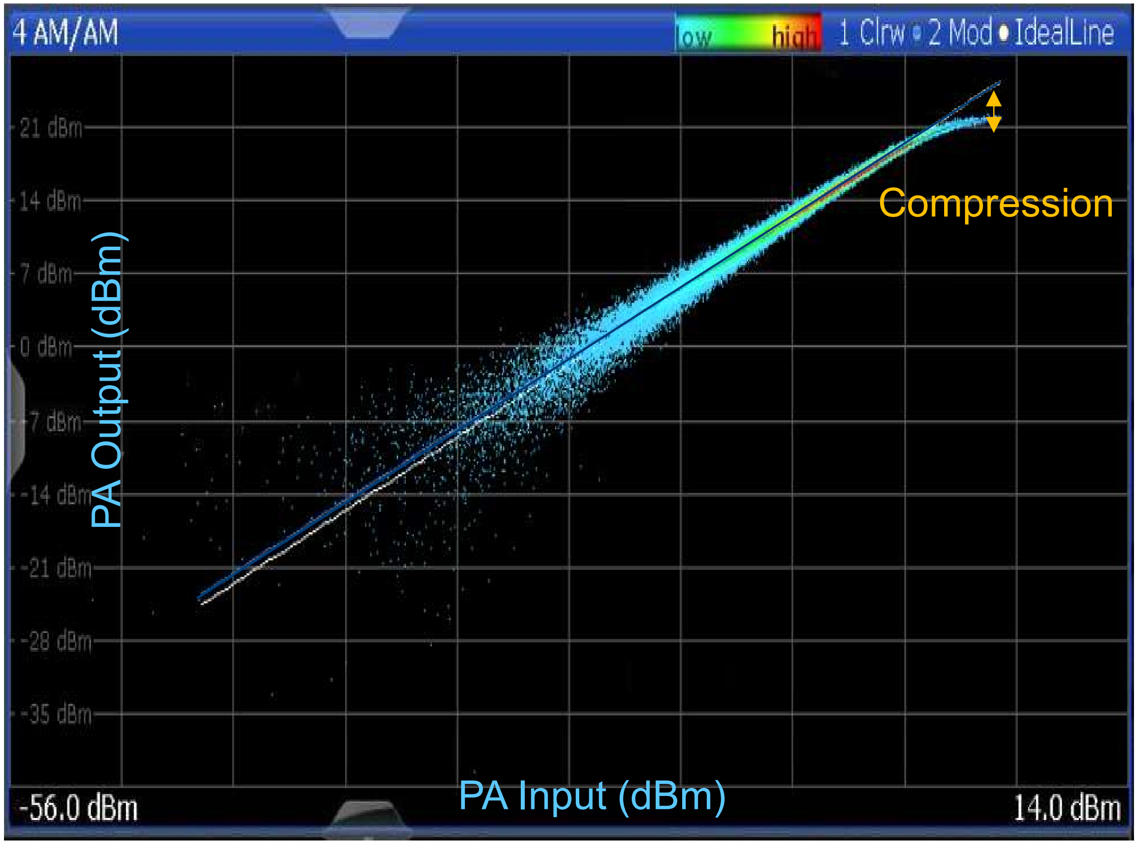
- When an active device is operated above a given input power level, there is no longer a linear relationship between the increase in input power and the increase in output power – this is called **compression**.
- The most commonly measure of compression is the **1 dB compression point (P1dB),** where the actual output power is 1 dB less than the expected (linear) output power.

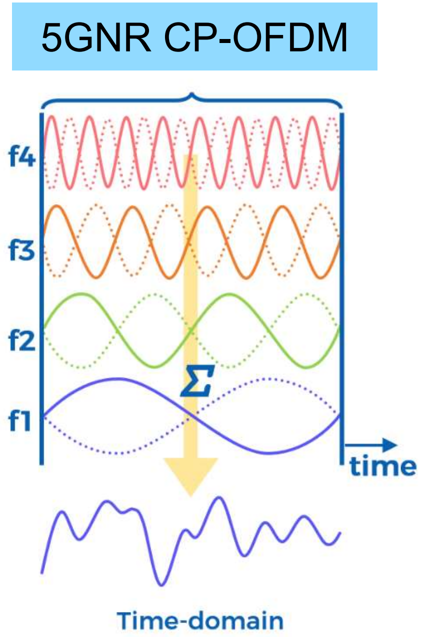


Parseval's Theorem.

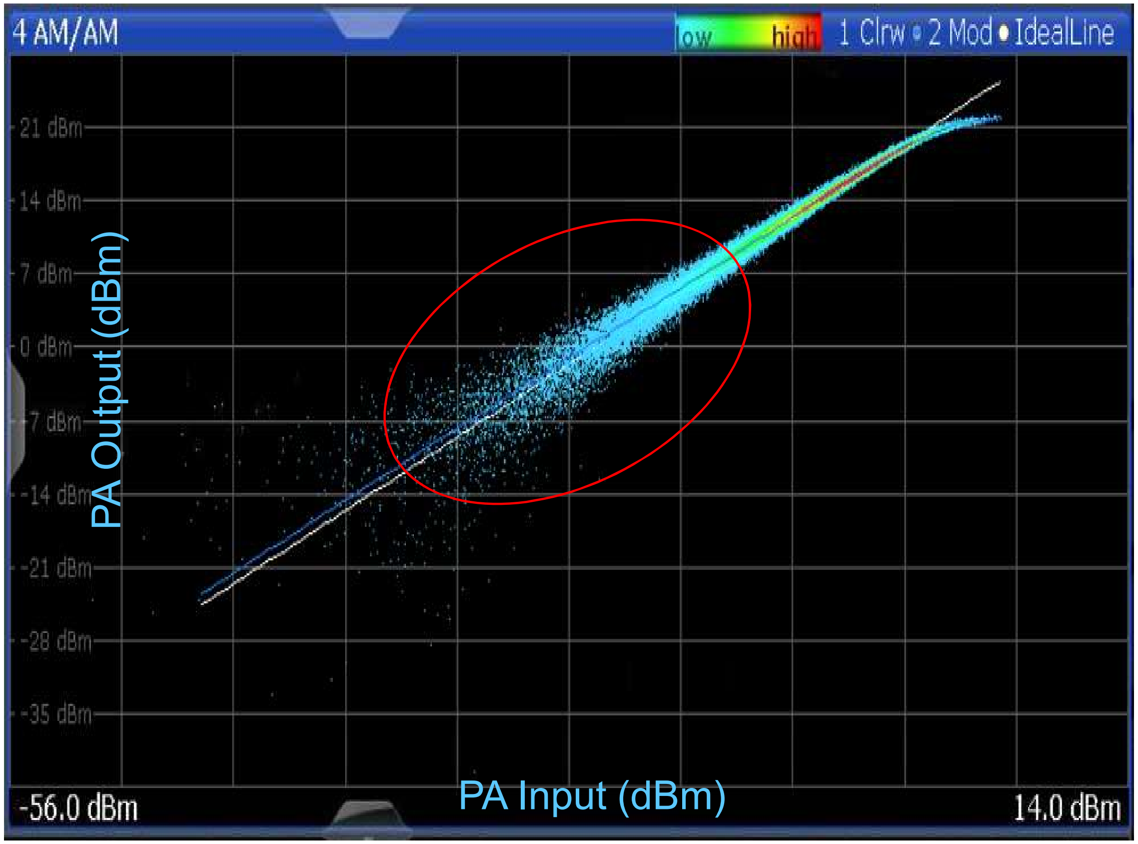


AM-AM (Amplitude Modulation To Amplitude Modulation)





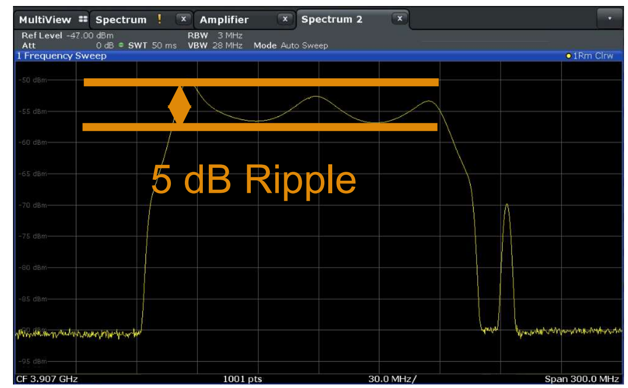
Memory Effect



Memory Effect

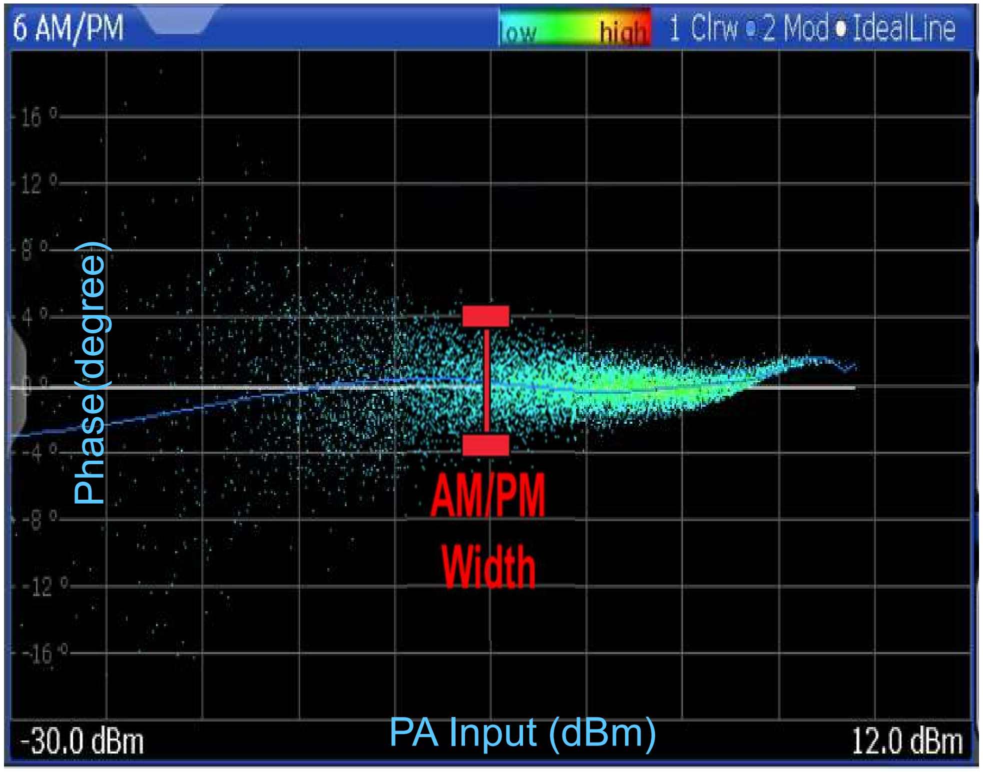
- **Frequency Response(Uneven)**

  Bandwidth ↑ *Memory Effect (Spread)* ↑

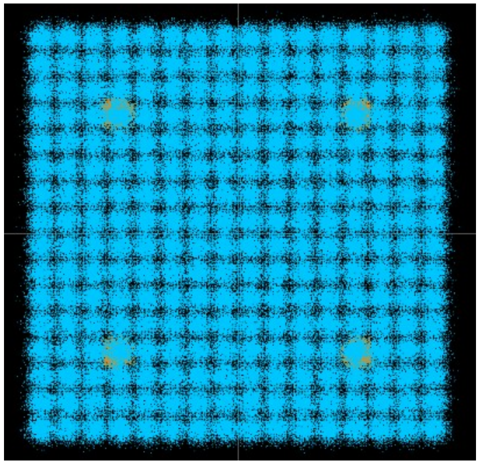


- **Supply Voltage Ripple**
- **Power Amplifier Self-Heat**

AM-PM (Amplitude Modulation to Phase Modulation)



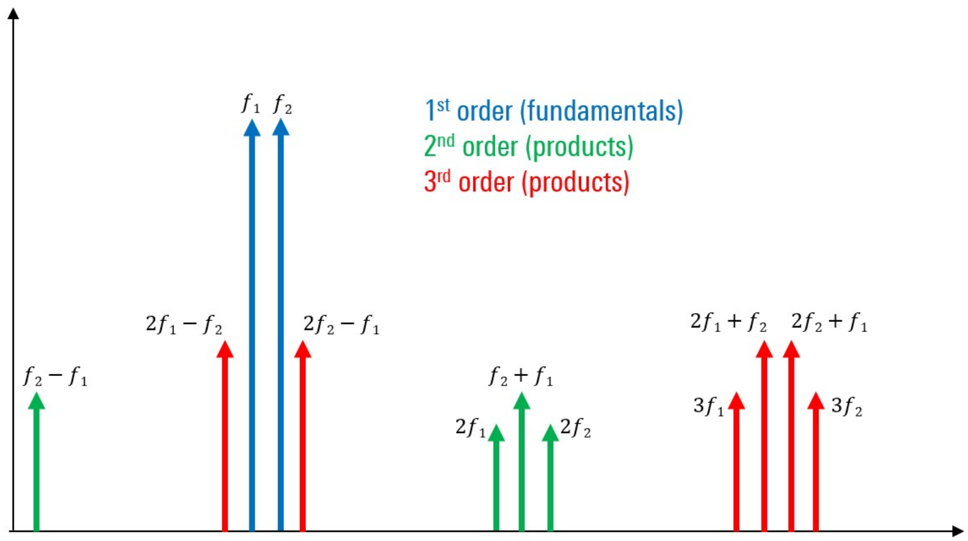
- AM-to-PM conversion is one of the fundamental contributors to (**BER bit error rate**)
- It is important to quantify this parameter in communication systems



256QAM EVM 2.68% BER

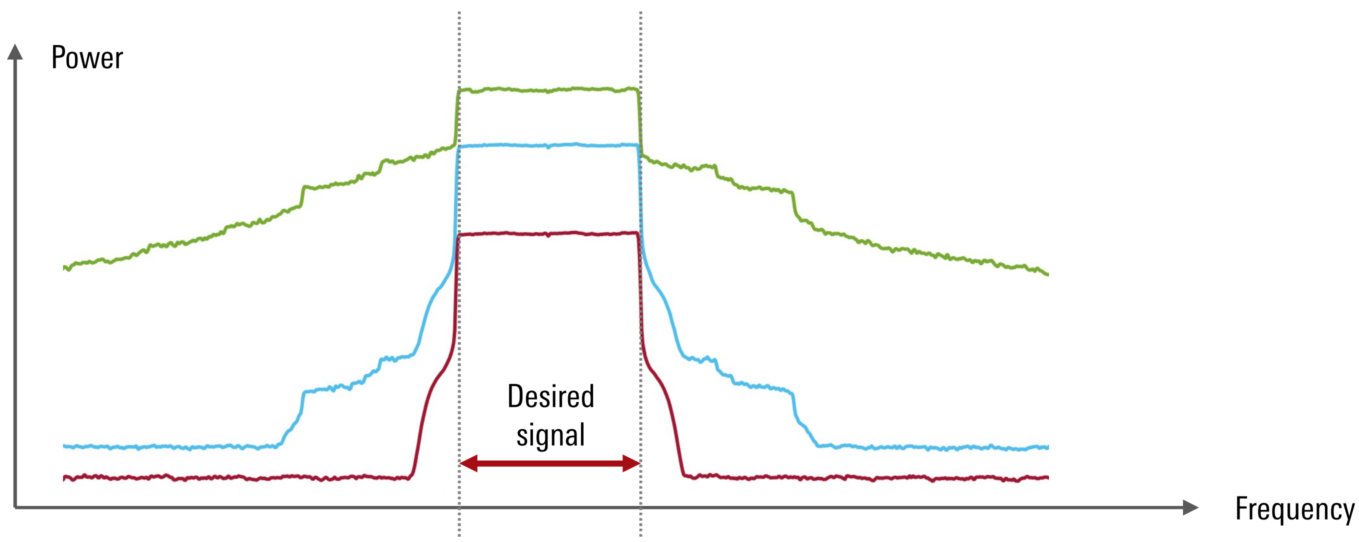
Distortion due to compression

► An active device that has been pushed into compression by high input signal levels will also create **distortion** in the form of significant levels of harmonics and intermodulation products.



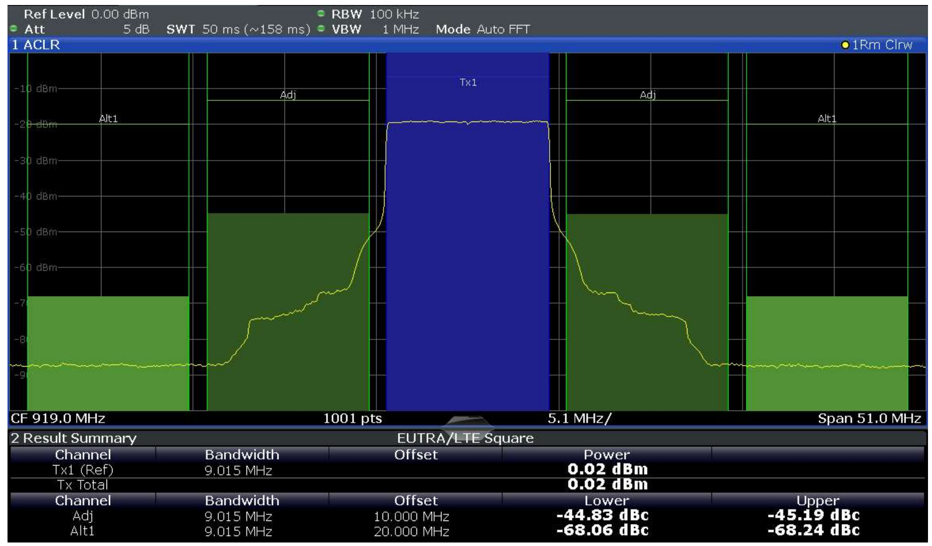
Spectral regrowth

► Intermodulation products created by compression lead to what is known as **spectral regrowth**, in which the power of the desired signal appears to spread or “grow” into adjacent spectrum or channels. This is relatively easy to recognize from spectrum.



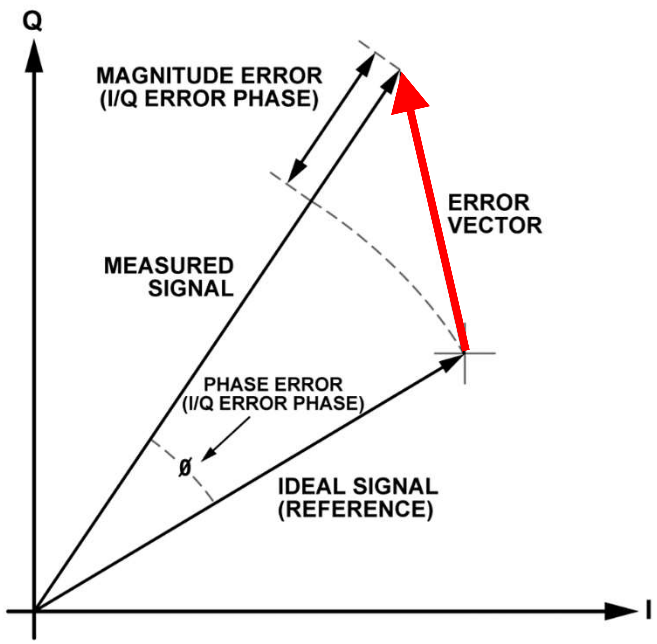
(ACLR) Adjacent Channel leakage ratio

- An important measurement of spectral regrowth is adjacent channel leakage ratio (ACLR), or ACP (adjacent channel power), which compares the level of the desired signal to the signal level in adjacent channels (-X dBc)



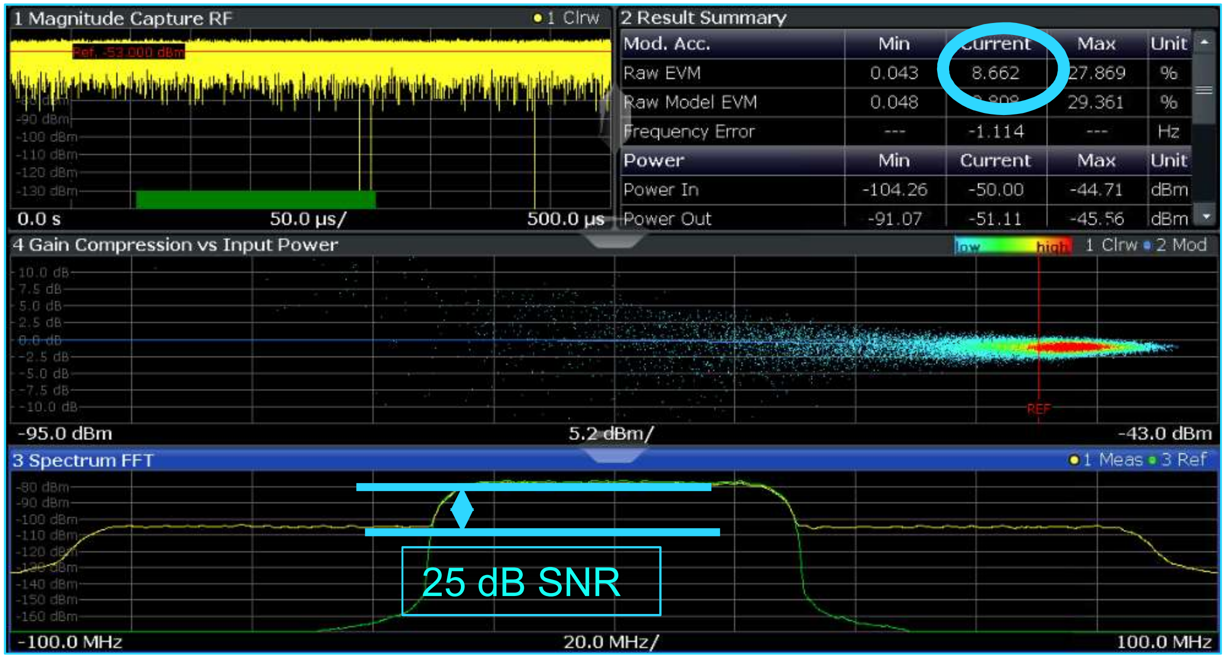
Modulation quality - Error Vector Magnitude

- The most important modulation quality measurement is EVM – **error vector magnitude**
- EVM measures how much a received symbol (amplitude + phase) deviates from the ideal symbol … i.e. how far away it is from the intended constellation point.
- Minimizing EVM is a one of the major goals in wireless system design and operation.

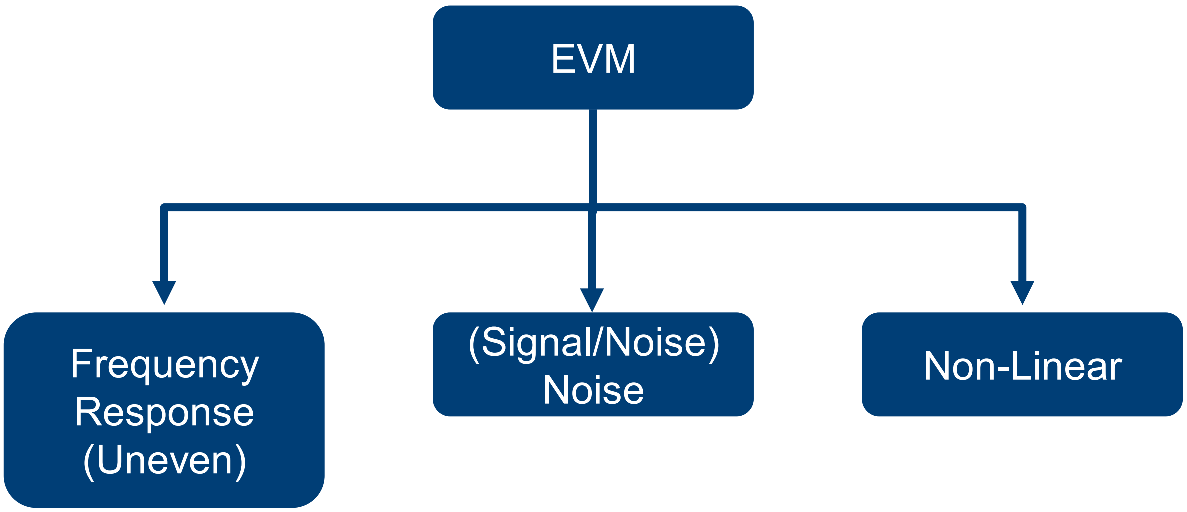


Error Vector Magnitude

$$SNR = -[PAPR + 20 * Log_{10} (^{EVM\%} / _{100})]$$



Error Vector Magnitude



$$EVM_{meas} \geq \sqrt{EVM_{FR}^2 + EVM_{Noise}^2 + EVM_{NL}^2}$$

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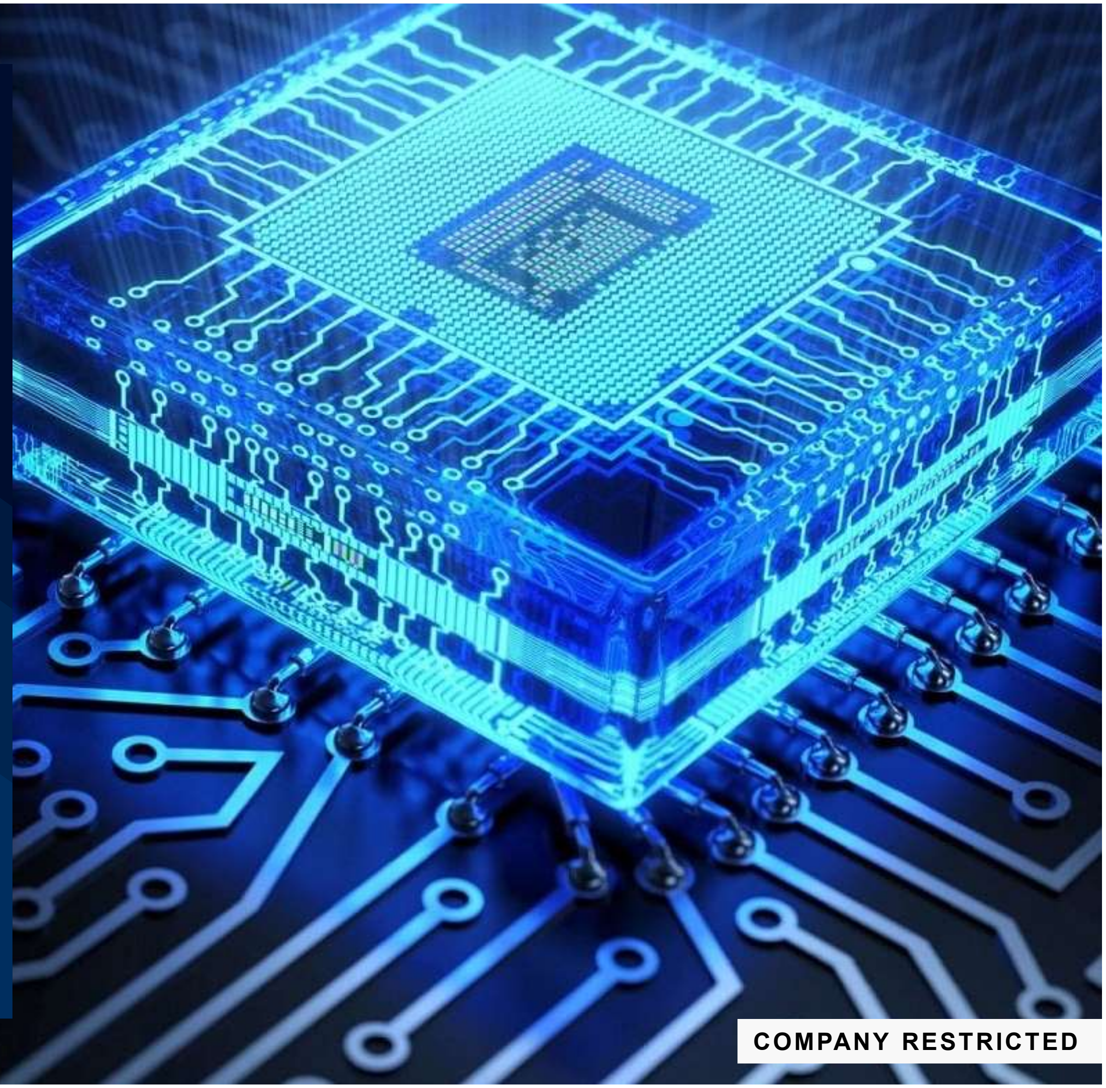
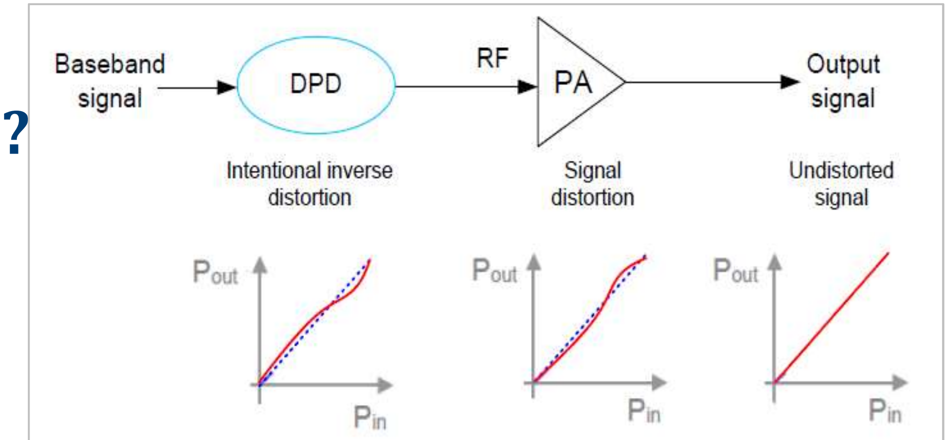


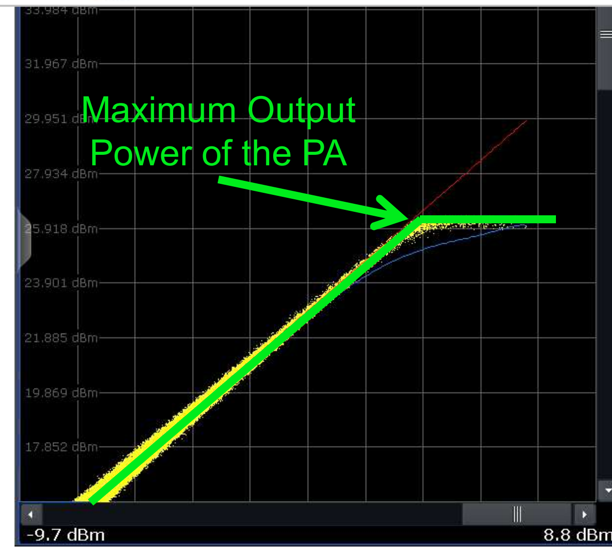
What is
Digital PreDistortion (DPD)?



- Key parameters for PA Performance are:
  - Compression Point
  - Linearity

- Non linearity's can be corrected for by pre distorting the input signal.

- The right correction will result in
  - Higher the compression point,
  - More linearity performance
  - Consistent EVM / ACLR across PA operating range



R&S DPD TYPES

Polynomial DPD

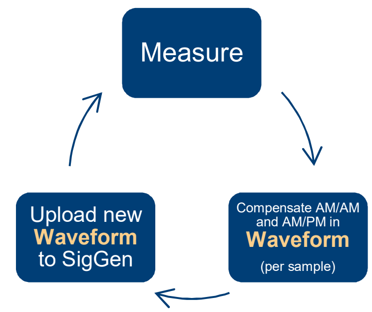
- Faster
- Applied in real time to any test signal
- Parameters can be used for other types of signals
- **Limited performance for amplifiers with memory effects**
- Compensate **AM to AM** , **AM to PM**
- Typically used in lower power, low bandwidth amplifiers
- Mostly UE work

Memory Polynomial DPD

- Select optimal iteration step of Direct DPD
- Define model complexity
- Create model
- Verify model: create waveform with model and compare with K18D results
- Access all model parameters for further external use

Direct DPD

- Iterative approach
- Slower than polynomial DPD
- Compensates for memory effects
- Better performance especially for amplifiers with **Memory effects**
- Compensate **AM to AM** , **AM to PM**
- Compensate Magnitude / Phase over Frequency
- Mostly Infrastructure work



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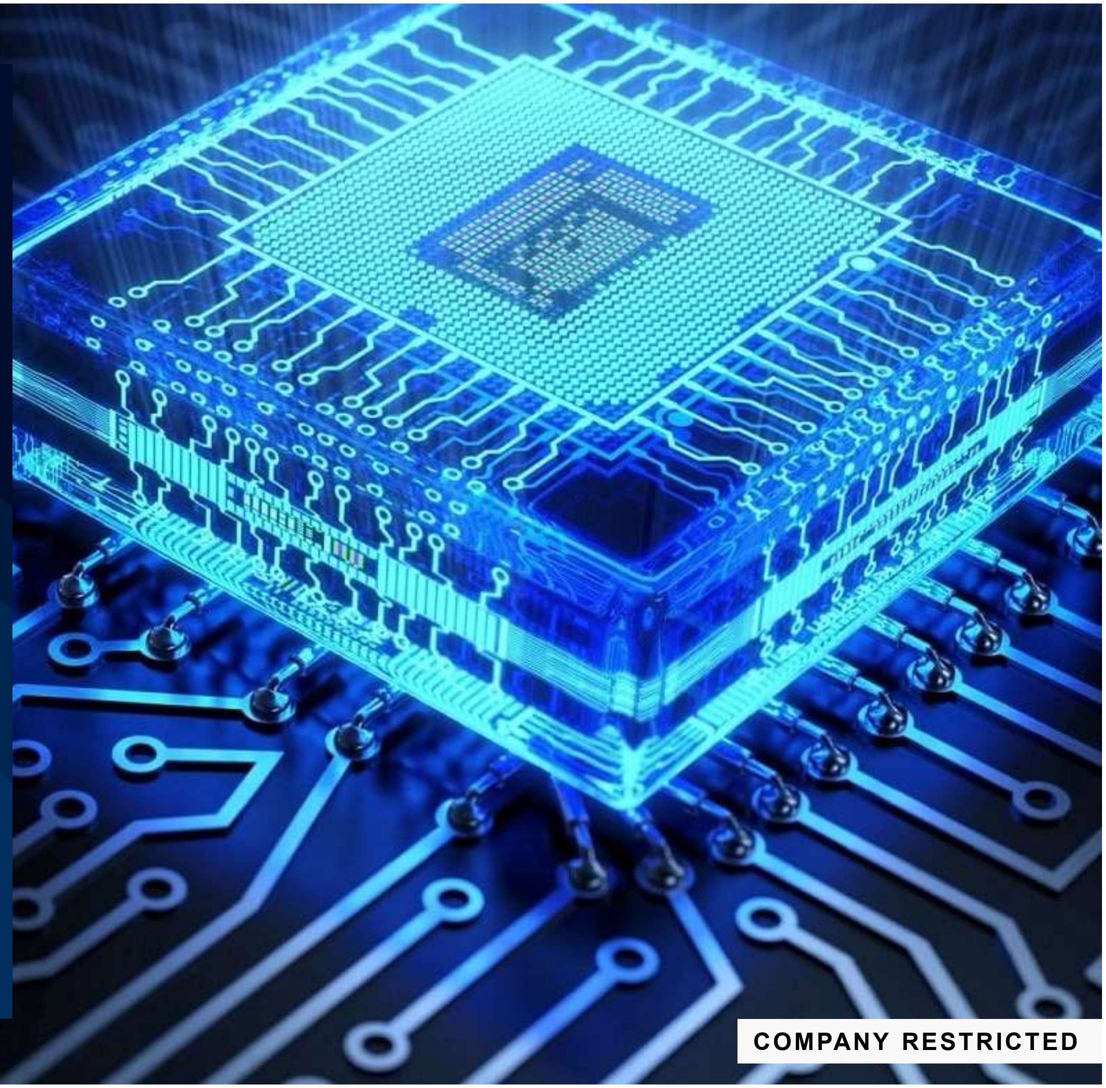

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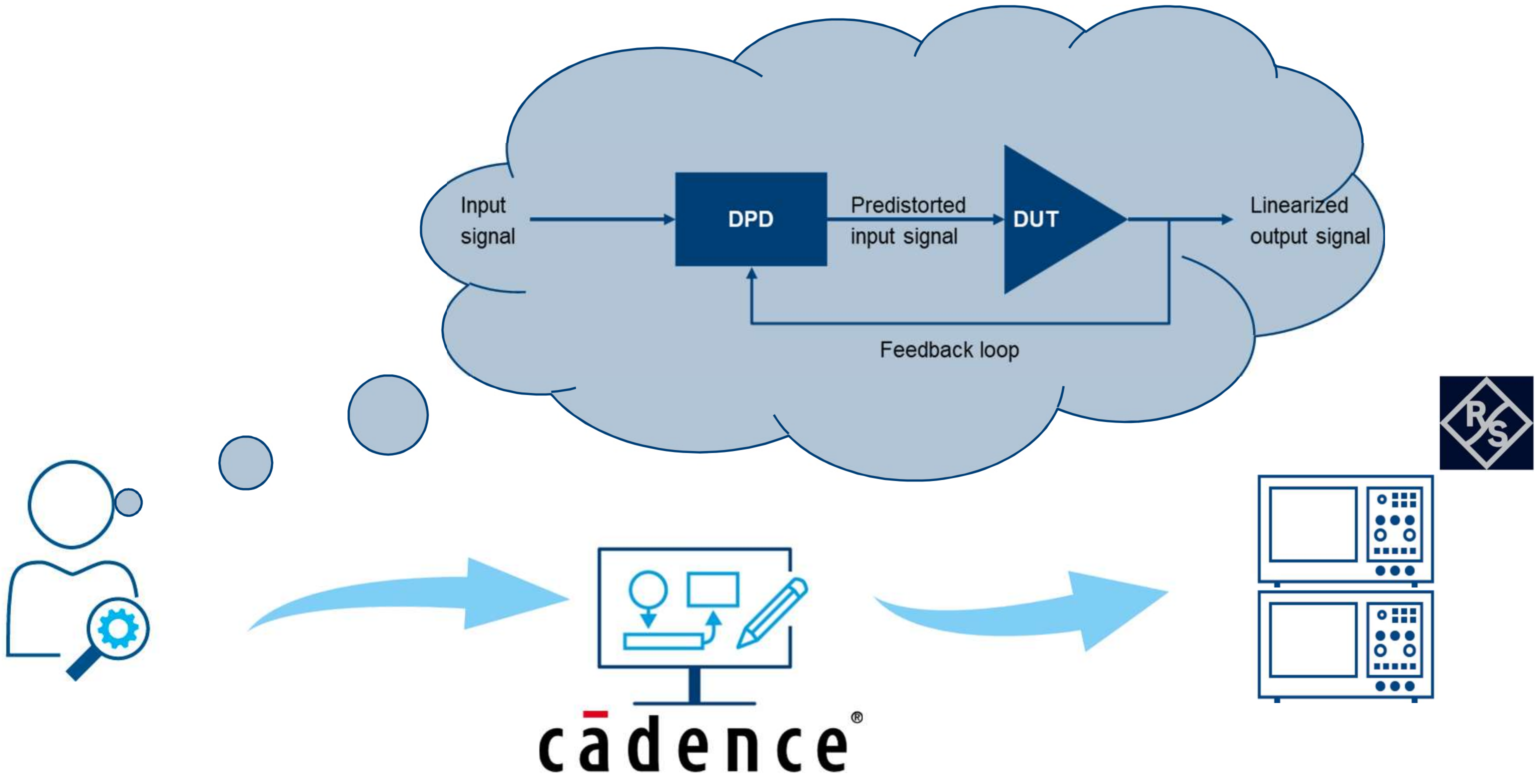
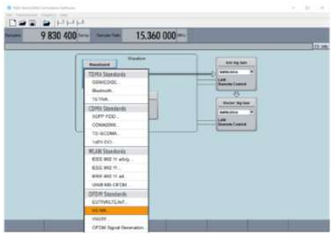
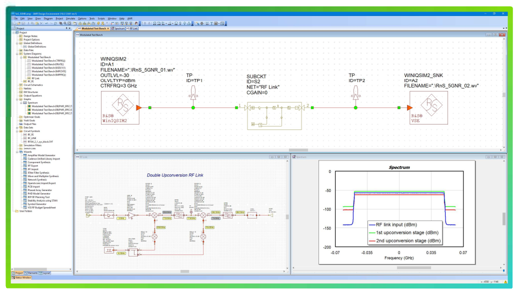
Designer Task



Joint solution:

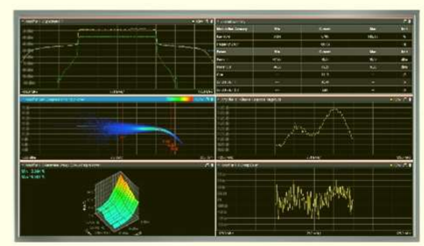


WinIQSIM2
Signal Generation



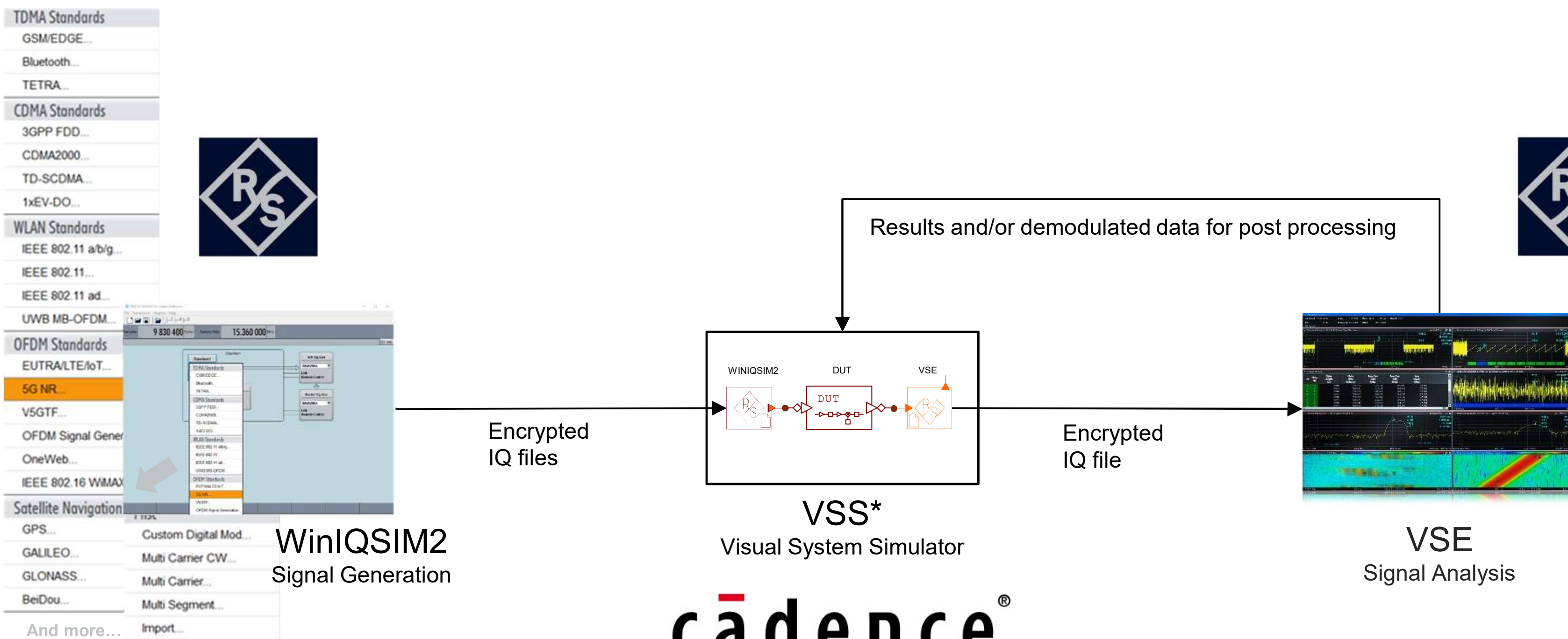
Cadence VSS
RF Design/Analysis

VSE
Signal Analysis

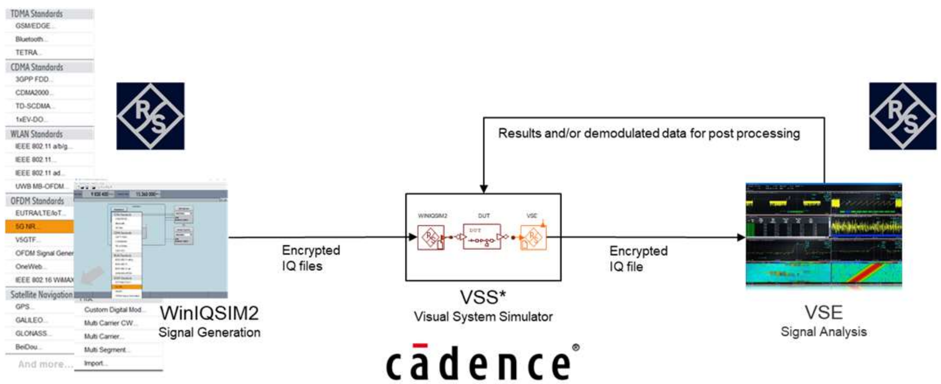


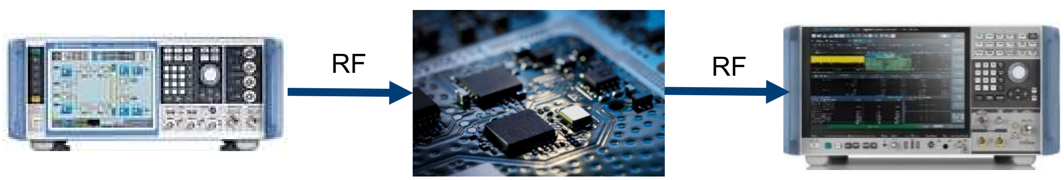
Direct DPD
Linearization

Joint solution:



Joint solution:





Simulation vs. Measurement

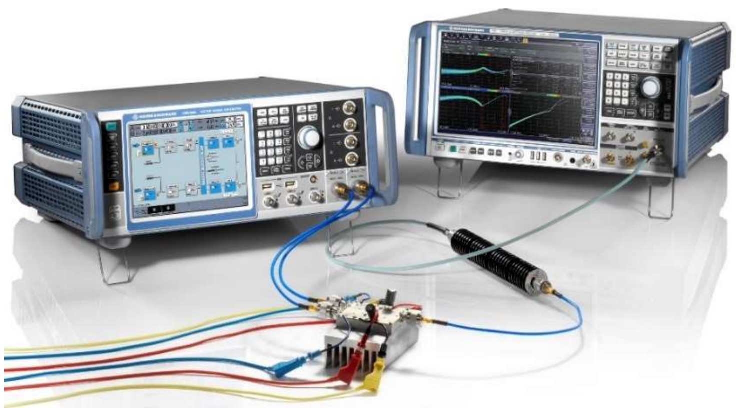
Simulation cādence®

Measurement

Solutions for PA R&D – modulated tests

Goals
- Check compliance with design targets
- Optimize design
- Shorten design cycle

Test considerations
- No compromises
- Maximum flexibility
- Right tools
- Speed



Excellent performance out of the box for modulated tests during R&D and design validation

Selected instruments for modulated measurements

R&S®SMW200A

- Single & dual RF up to 2x 44 GHz, single 67 GHz
- 2 / 4 GHz RF BW
- DPD, ET, Doherty suites

R&S®FSW

- Up to 85 (90) GHz
- 8.3 GHz internal analysis BW
- 60 dBc SF dynamic range
- PA measurement suites

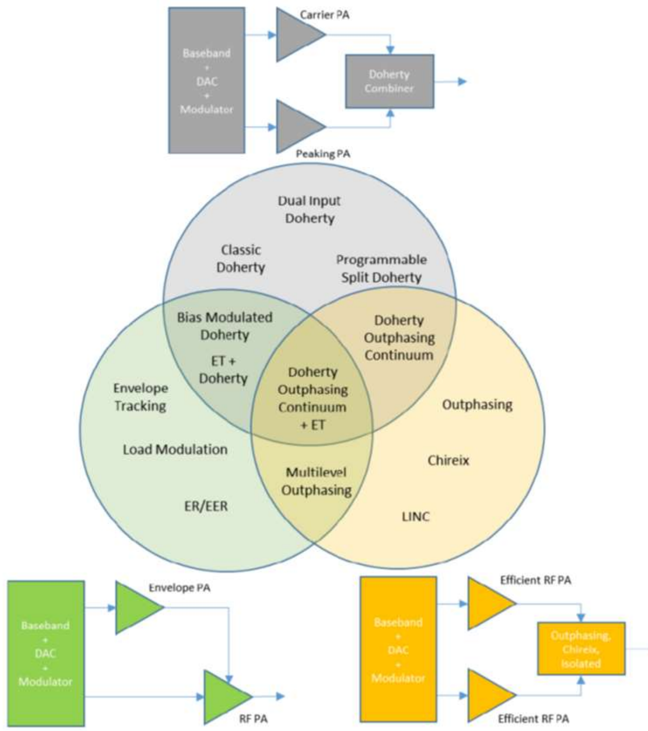
Solutions for PA R&D

Dedicated applications to speed up the design cycle

K541 Digital Pre-distortion
- Realtime polynomial/ table DPD

K540 Envelope Tracking
- Realtime envelope calculation, shaping, delay and DPD

K546 Doherty
- Two precisely aligned signals, with adjustable phase, timing and amplitude relationship
- Realtime shaping and DPD



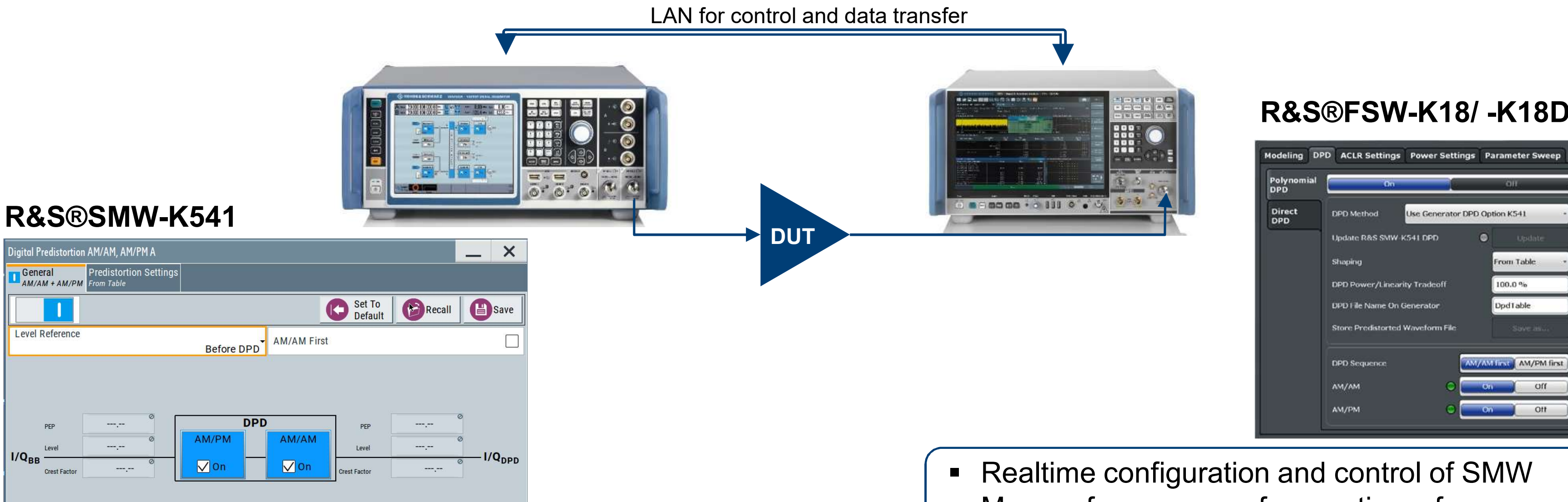
K18 Amplifier Measurements
- Realtime polynomial DPD together with SMW-K541
- EVM, ACLR, AM/AM, AM/PM, PAE, gain compression, …
- SMW control for PA tests

K18D Direct DPD
- Ideal pre-distortion (including memory effect)

K18M Memory Polynomial
- Verify linearization via model of K18D result

Solutions for PA R&D

Simple setup for real-time Digital Pre-distortion (DPD)



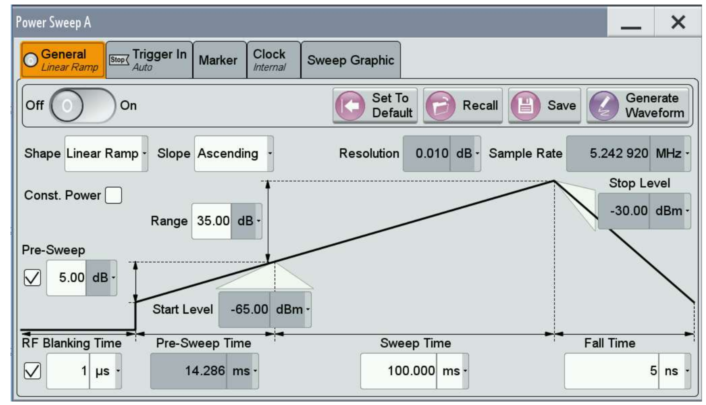
- Realtime amplitude and phase offset on every I/Q sample
- Polynomial shaping, manual DPD Table
- Automatic DPD Table transfer from FSW-K18

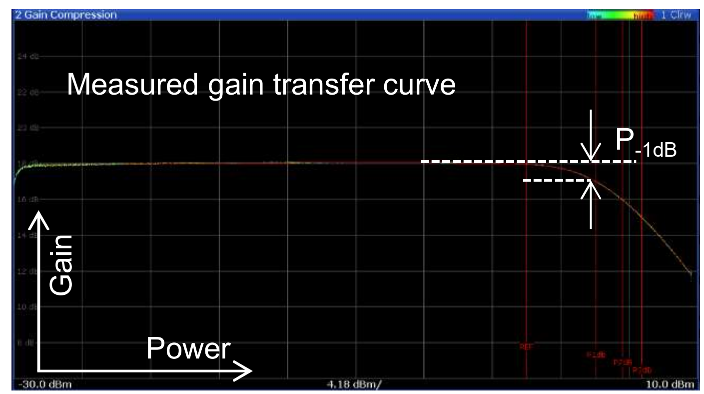
- Realtime configuration and control of SMW
- Many reference waveform options: from generator, customized, user-generated
- (Ideal) Memory DPD with upper performance bound characterization (FSW-K18D)
- Extraction of pre-distorted waveform

Basic Gain/Compression point measurement with SMW baseband power sweep and FSW-k18

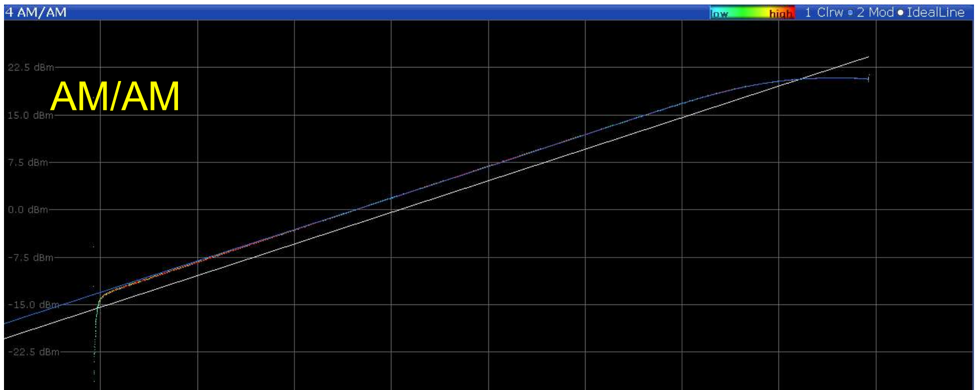
- ► Use SMW baseband power sweep and FSW-K18
- ► Highly linear test signals are required to measure AM/AM and AM/PM or gain transfer function of transponders

- ► Digital baseband in R&S SMW200A is perfect solution
  - – Maximum linearity for a CW tone level sweep
  - – No blanking of RF output
  - – High linearity of level sweep
  - – Max sweep range of 50 dB
  - – Pre-Sweep to get the transponder or payload equipment to the working point
  - – Linear, Triangle and Step shape





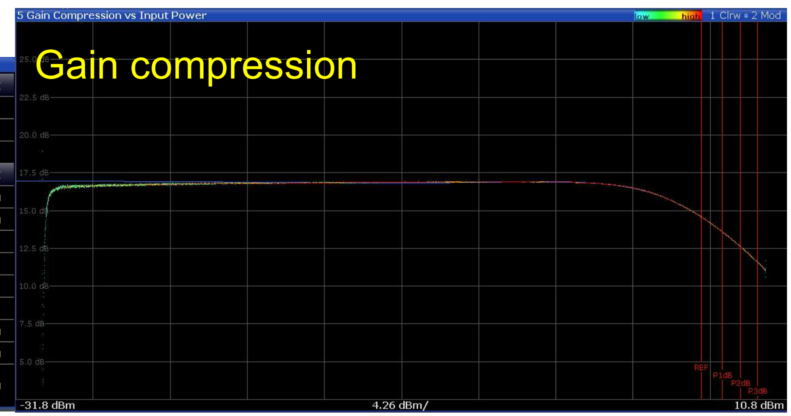
Basic Gain/Compression point measurement with SMW baseband power sweep and FSW-k18



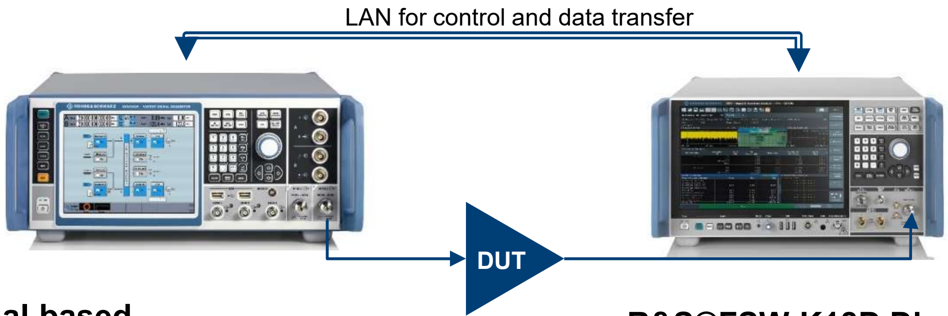
2 Result Summary

Modulation Accuracy	Min	Current	Max	Unit
Raw EVM	0.308	21.879	107.949	%
Raw Model EVM	0.003	1.009	90.604	%
Frequency Error	---	58.985	---	Hz
Power	**Min**	**Current**	**Max**	**Unit**
Power In	-30.36	0.00	9.64	dBm
Power Out	-34.79	14.59	21.38	dBm
Gain	---	14.59	---	dB
Crest Factor Out	---	6.79	---	dB
AM/AM Curve Width	---	0.006	---	Volt
AM/PM Curve Width	---	0.036	---	°
3dB Compression Point	---	9.18	---	dBm
2dB Compression Point	---	8.26	---	dBm
1dB Compression Point	---	7.23	---	dBm

- AM/AM, Gain compression are lines as expected, showing when the DUT enters in compression
- They describe the DUT behavior but do not indicate if the DUT will distort a modulated signal significantly
- Gain @ 2 GHz / 0 dBm input level: 14.59 dB



R&S DPD SOLUTION
Polynomial-based and Direct DPD



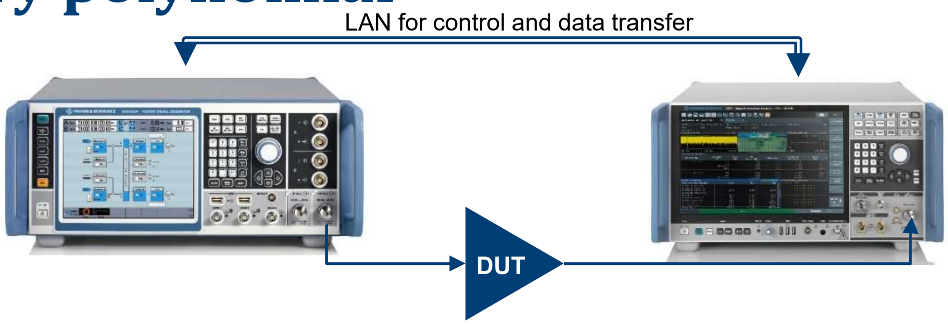
R&S®FSW-K18 polynomial based

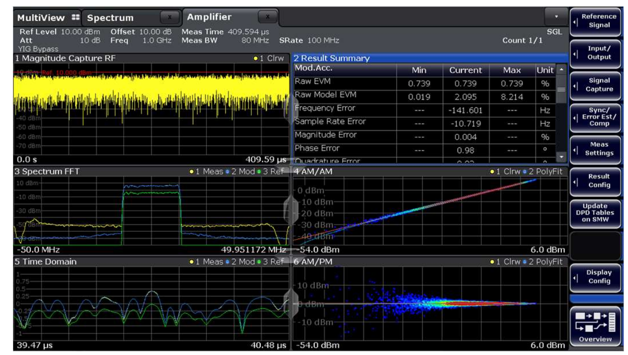
- Faster
- Applied in real time to any test signal
- Parameters can be used for other types of signals
- Limited performance for amplifiers with memory effects
- Typically used in lower power, low bandwidth amplifiers
- Mostly UE work

R&S®FSW-K18D Direct DPD

- Iterative approach for a given test signal
- Slower than polynomial DPD
- Compensates for memory effects
- Better performance especially for amplifiers with memory effects
- Can be used as a reference pre-distortion
  - Suppliers typically do not have access to DPD algorithms used by system integrators
- Mostly Infrastructure work

R&S DPD SOLUTION
Memory polynomial





R&S®FSW-K18D Direct DPD

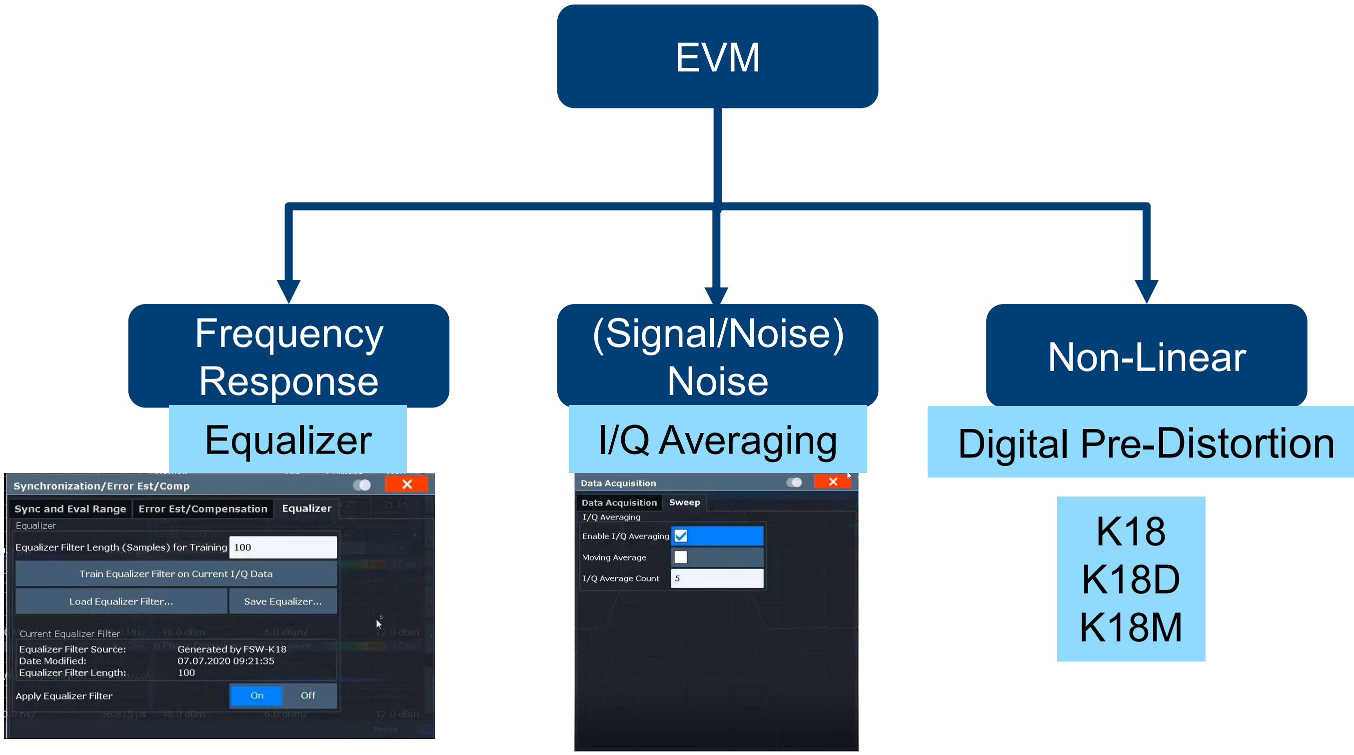
- Iterative approach
- Compensates for memory effects
- Excellent performance especially for amplifiers with memory effects

- Reference for best possible
  - Suppliers typically do not have access to DPD algorithms used by system integrators

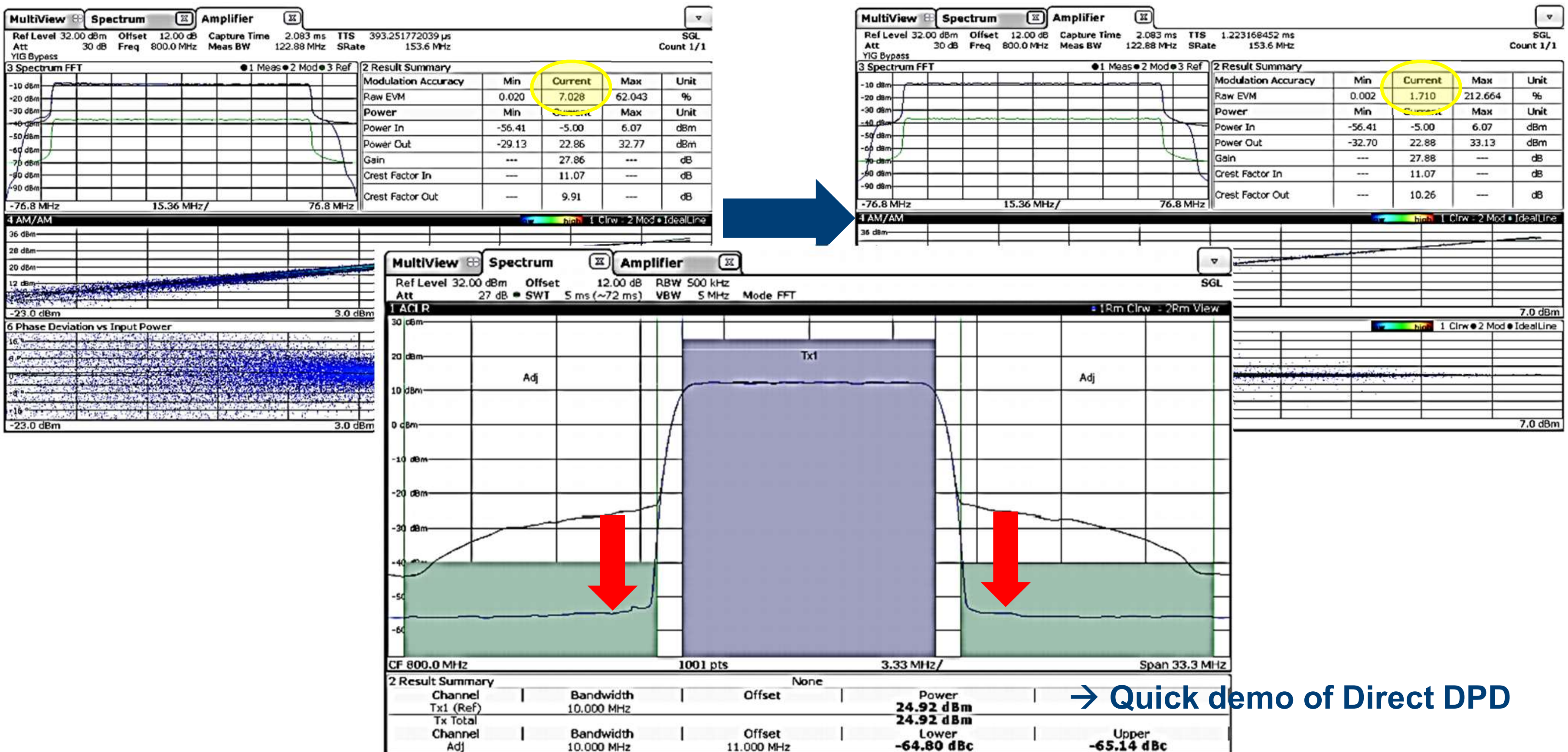
R&S®FSW-K18M memory polynomial

- Memory polynomial model based on Direct DPD result
- Modeling can be adopted in order and memory depth
- Model verification on DUT
- Proves easy linearization of RFFE solution

EVM CONTRIBUTIONS



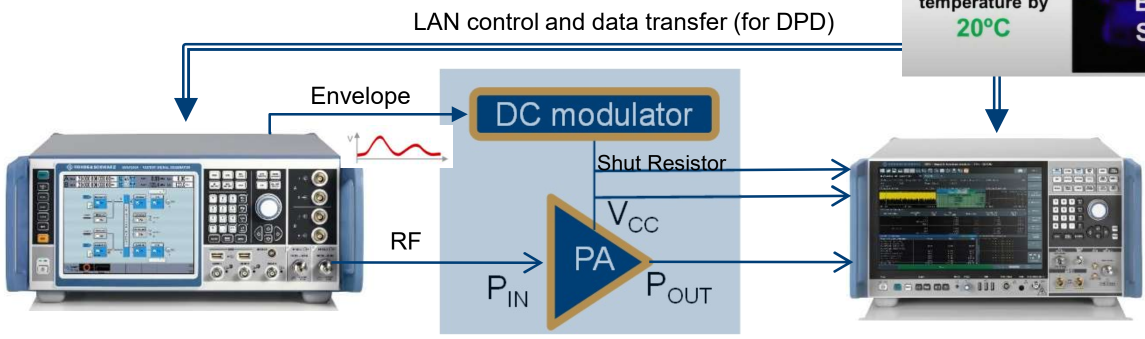
ACLR & EVM

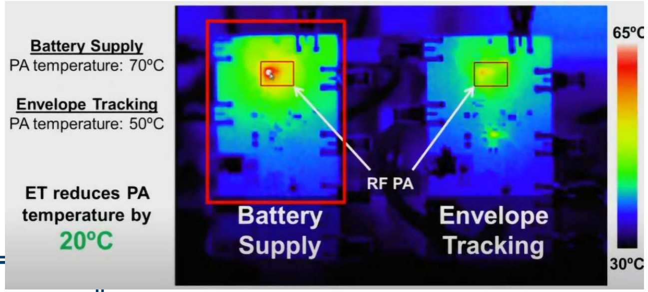


→ Quick demo of Direct DPD

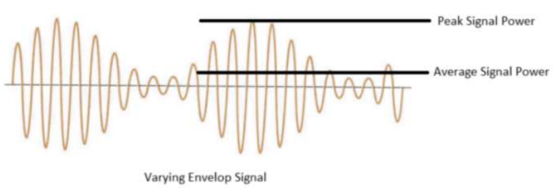
Solutions for Envelope Tracking

- RF signal
- Envelope signal
- Power sweeps
- Realtime DPD

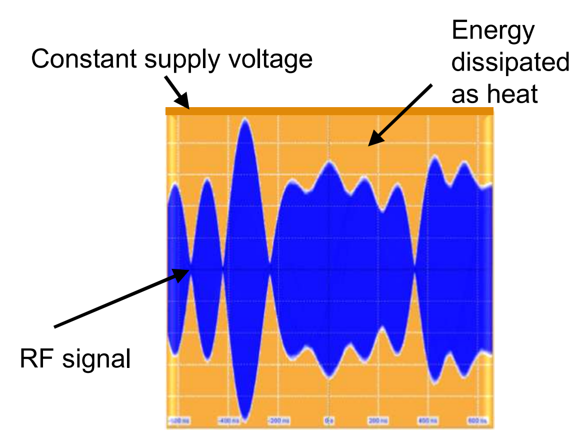




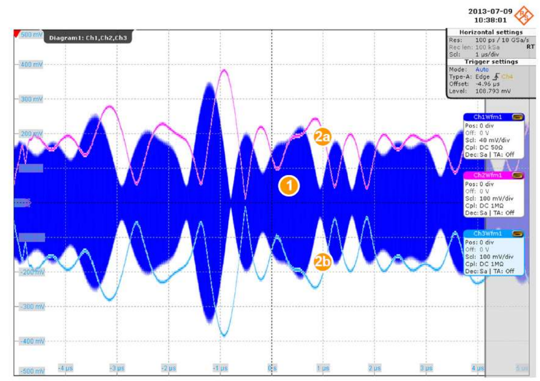
- RF analysis
- Voltage / current analysis
- Distortion analysis
- Realtime DPD

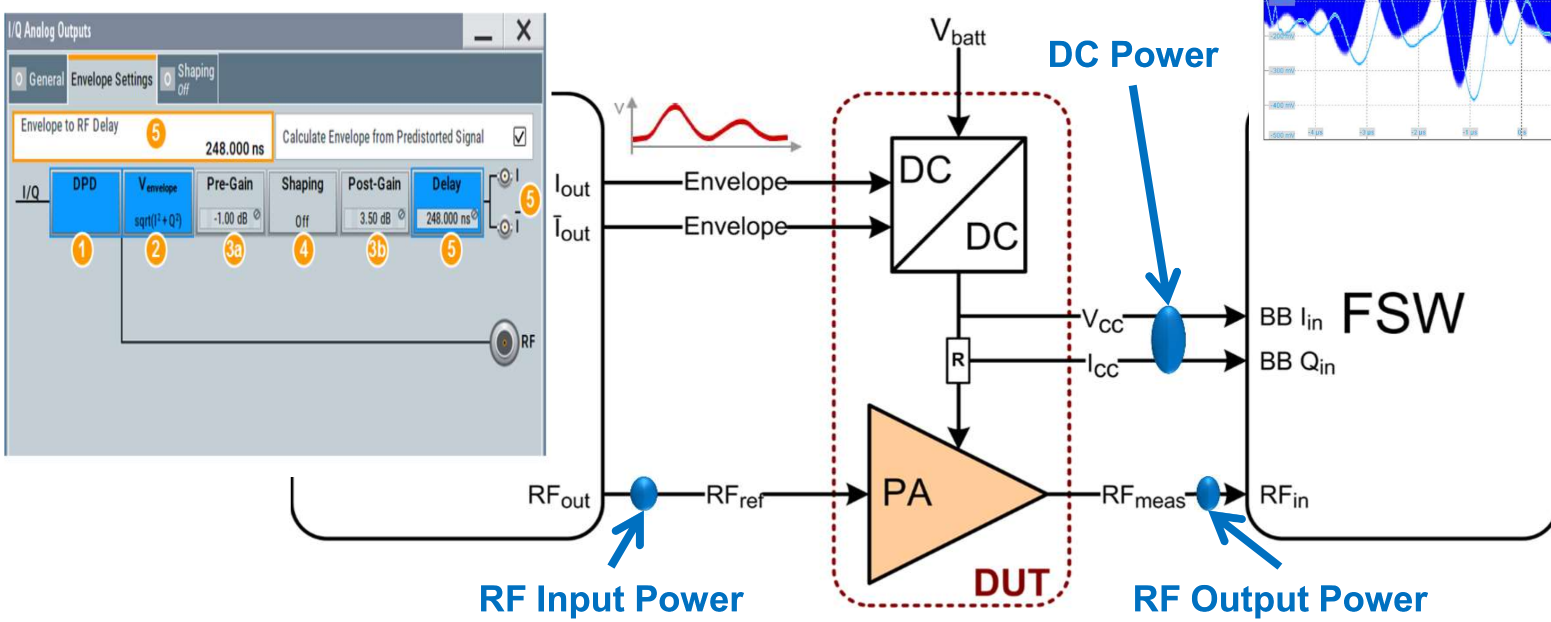


	PAPR (dB)
3G (WCDMA)	3.5
3.5G (HSPA)	6.5
4G (LTE)	8.5
5GNR	12



Solutions for Envelope Tracking





PAE(Power Added Efficiency) = (P_{out} **-** P_{in}**) /** P_{dc}

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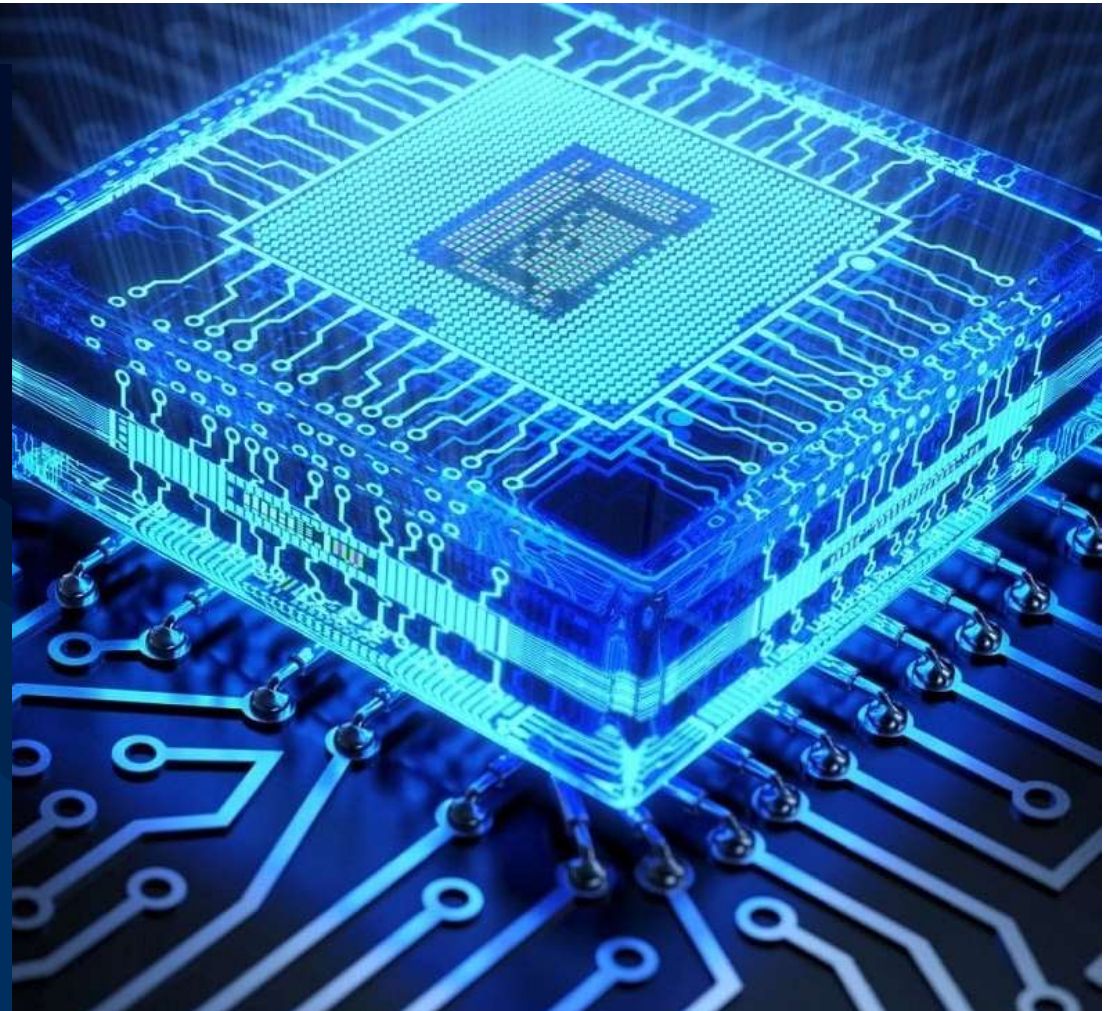
- ▶ Solution for DPD
- ▶ Summary



Summary

- **EVM and ACLR** performance are still key in this application
  - SMW/FSW still lead the way
- **Unique application capabilities** move the discussion beyond specifications
  - SMW/FSW are complete solution in this application
  - Real Time Generation great simplify the whole measurement process

Thank you for your attention