RF Lumination

UNDERSTAND LINEARITY IMPROVEMENT POSSIBILITIES ON A PHYSICAL AMPLIFIER

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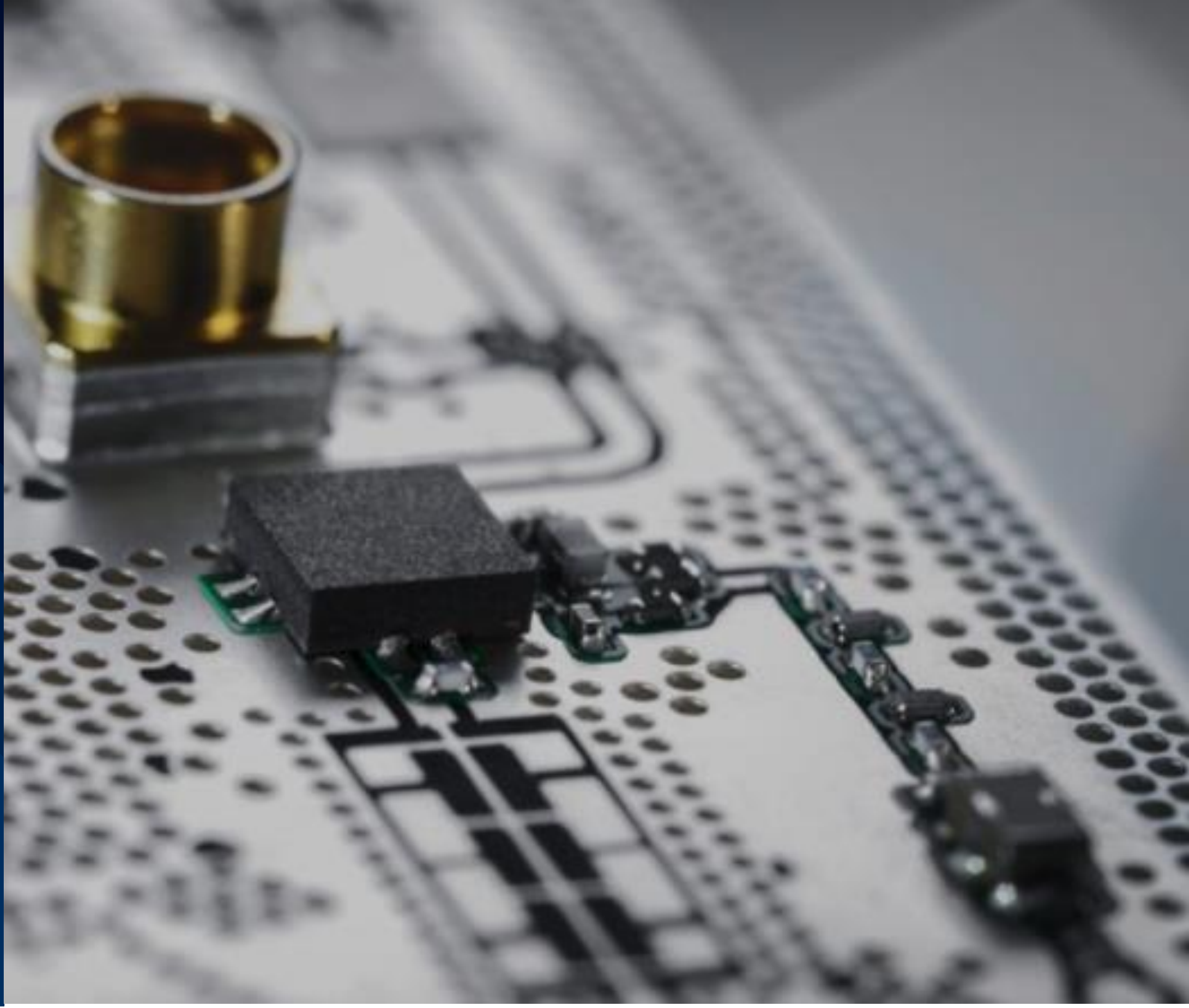
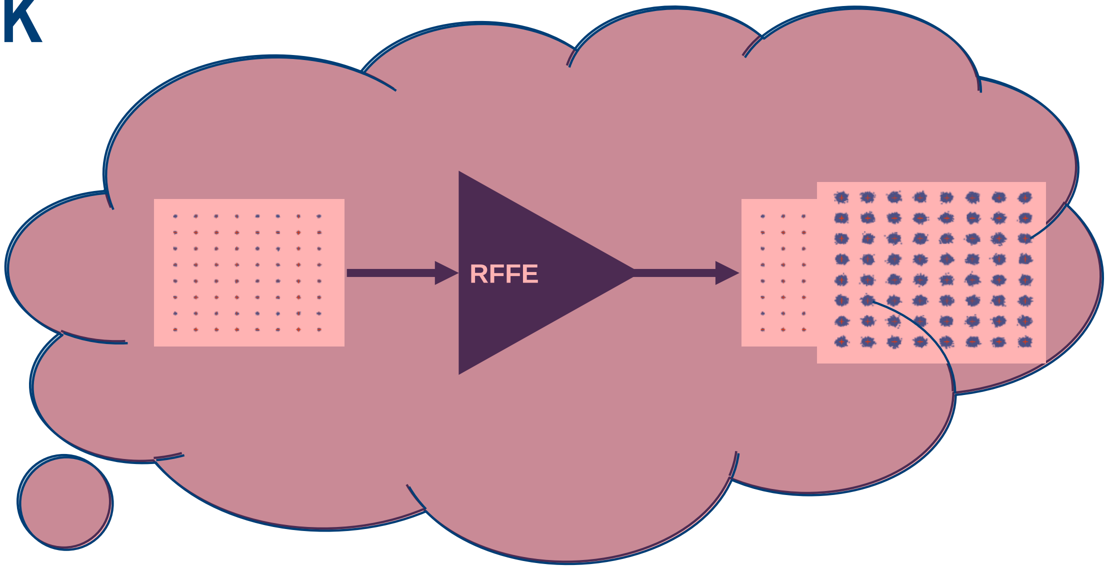
AGENDA

- Intro and motivation
  - Non-Linearities
  - Why modulated signals?
  - Why linearization?
- Amplifier measurements
  - AM/AM AM/PM
  - EVM/ ACLR
- Digital Pre-Distortion
  - Types of Pre-Distortion
  - Deriving models for linearization



YOUR TASK

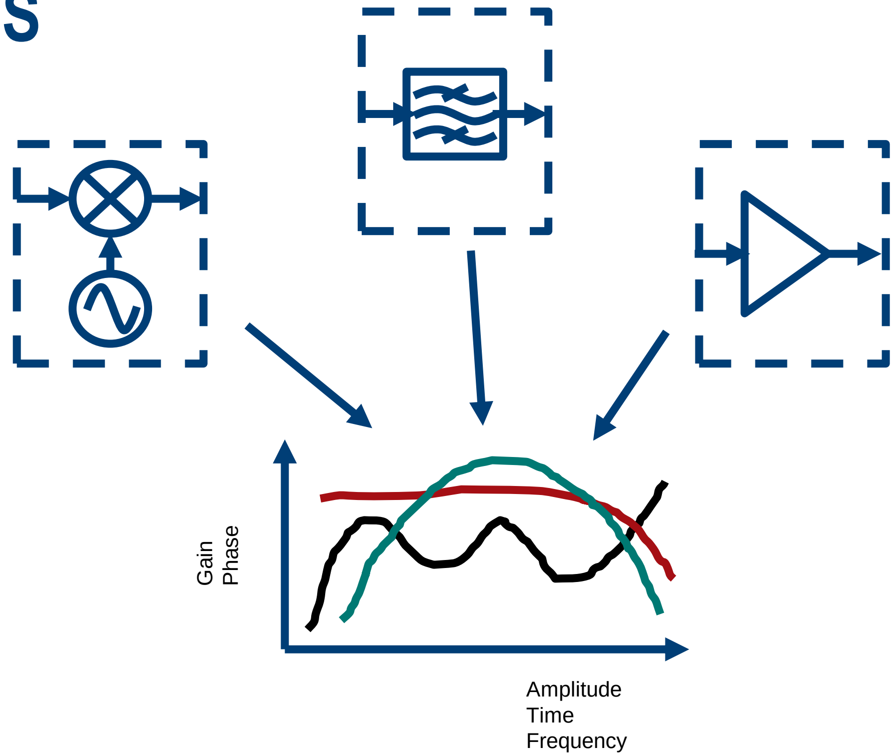


Design

Verification

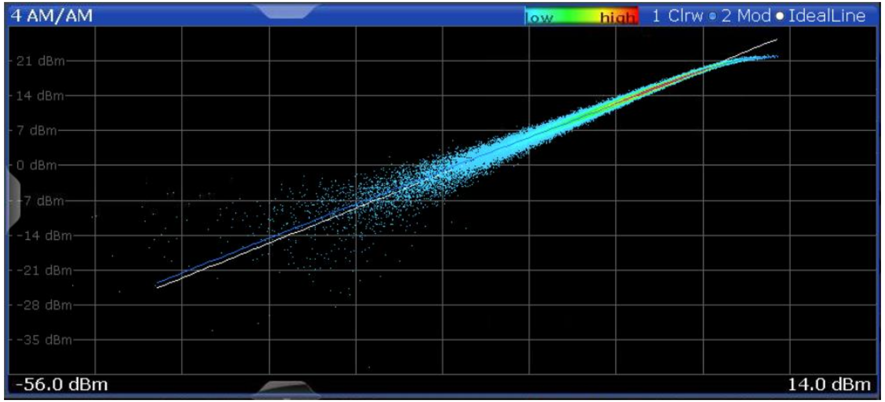
NON-LINEARITIES: UNDERSTANDING DISTORTIONS

- Distortion limits RFFE performance
- Distortions might generally be defined as variations in complex gain (amplitude and phase) in three domains:
  - Amplitude (e.g. non-linear distortion)
  - Frequency (e.g. linear distortions)
  - Time (e.g. memory effects)
- All RFFE components demonstrate all the distortions, in varying proportions:
  - **Mixers** and **Amplifiers** often contribute most to **non-linear** and **memory effect** distortions
  - **Filters** often contribute the most **linear** distortion
- Distortion reduction is called **Linearization**

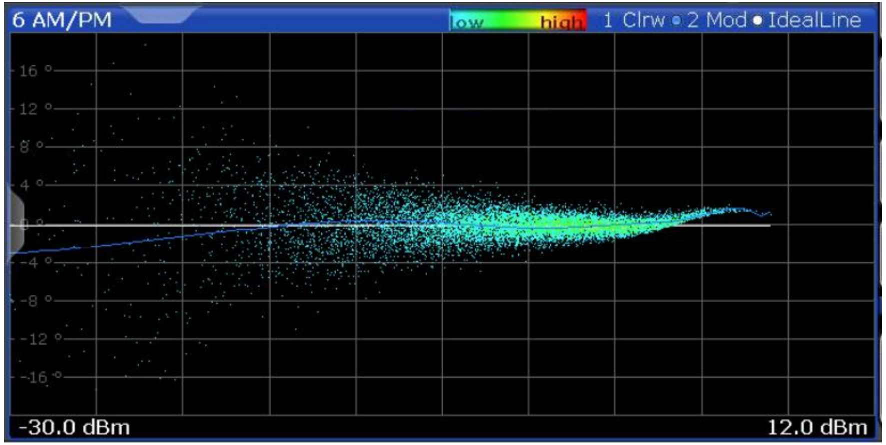


NON-LINEARITIES: AMPLIFIER DISTORTION

AM/AM Distortion

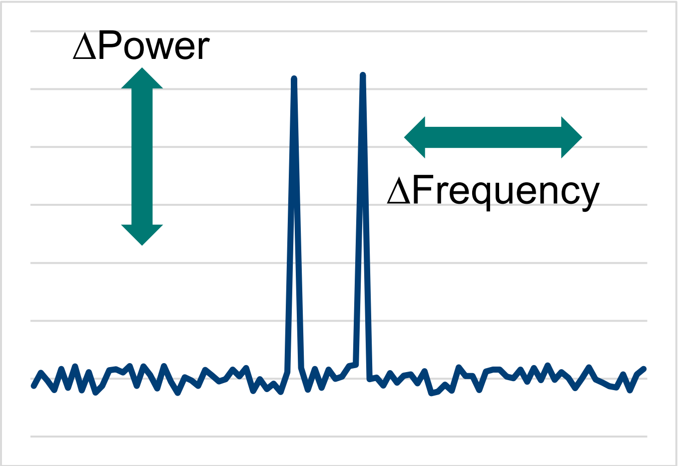


AM/PM Distortion

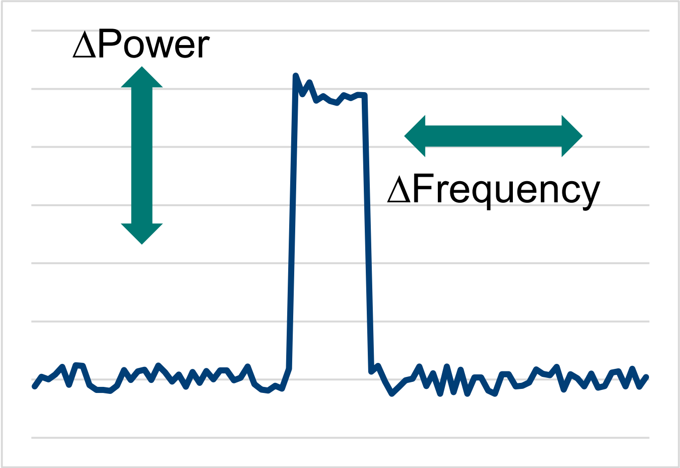


WHY MODULATED SIGNALS?

- Traditional approach – VNA with CW measurements
- CW signals do not accurately represent modern signals

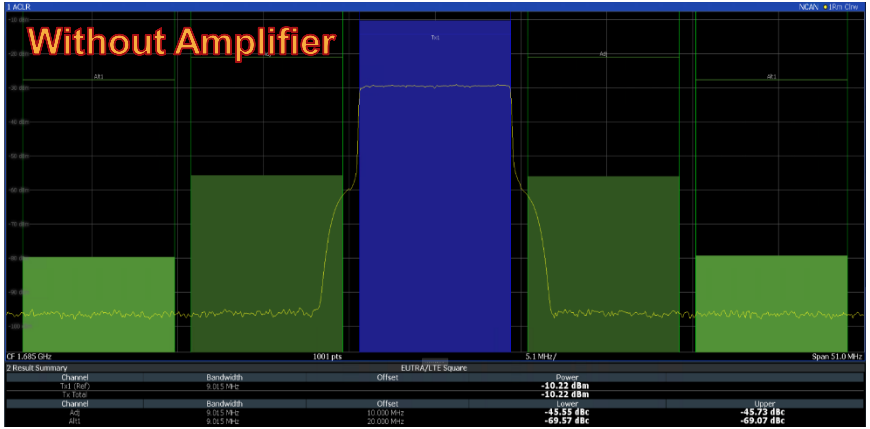


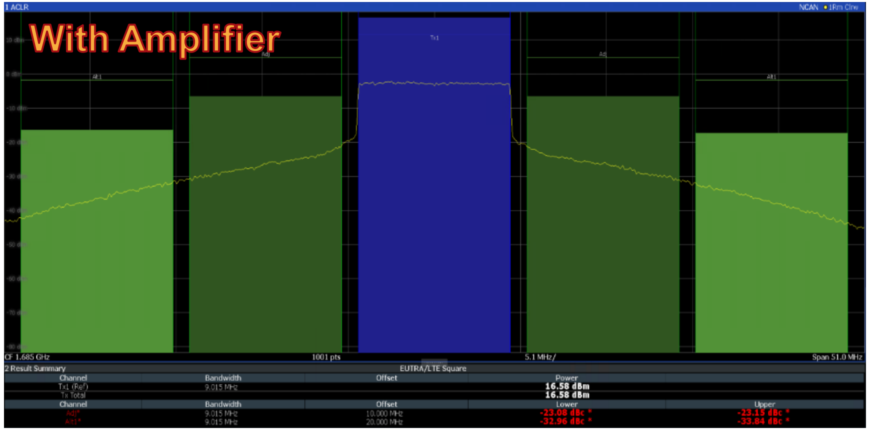
- Alternative approach – use the same signal that will be amplified
- Modern signals are wider BW's, higher crest factors
- <u>**Modulation errors due to distorsions**</u>



ADJACENT CHANNEL LEAKAGE RATIO (ACLR)

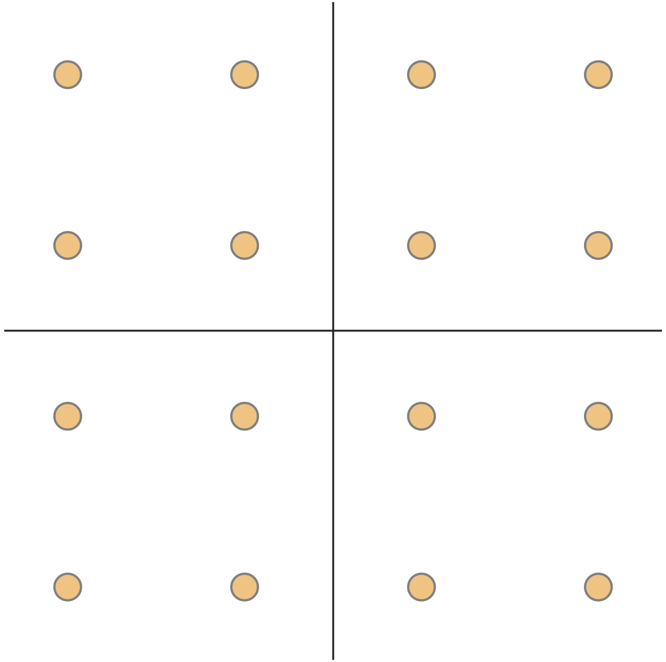
- ACLR measurements determine the channel power and adjacent channel power
- Amplifiers can cause spectral regrowth to occur in adjacent channels resulting in more power



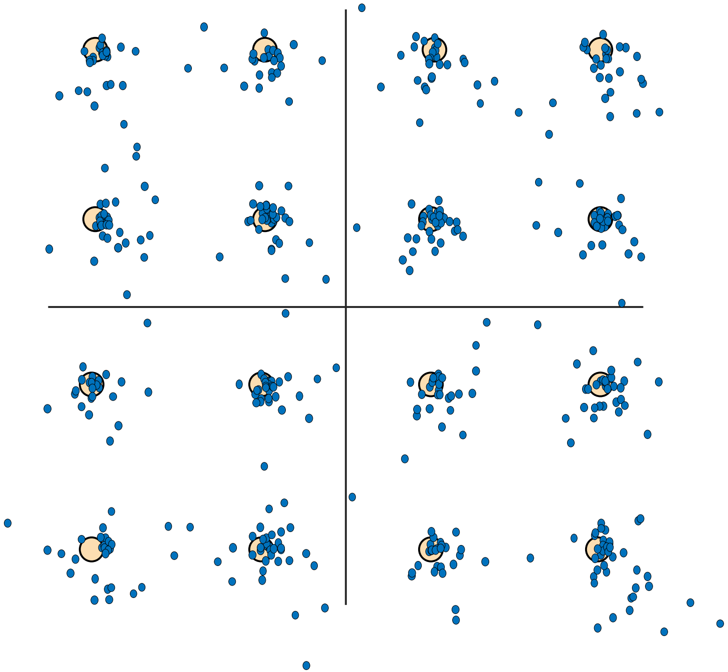


MODULATION QUALITY - ERROR VECTOR MAGNITUDE

- Ideal constellation diagram



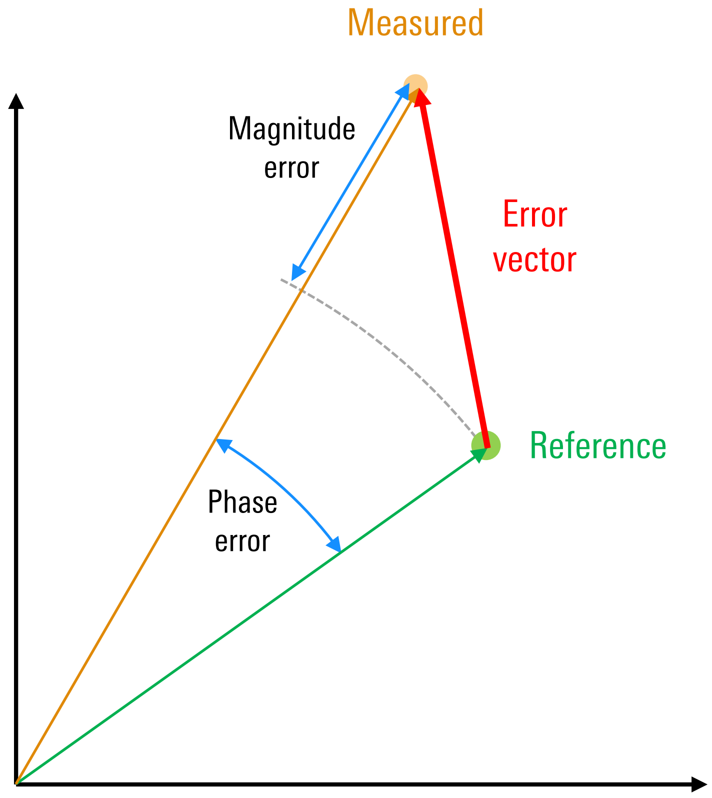
- It might look different after going through the PA



ERROR VECTOR MAGNITUDE

- Error vector: difference between ideal constellation point and actual sample
- EVM to high → BER is increasing
  - Higher modulation scheme → lower EVM required

- EVM: FOM for inband signal performance
  - Compression, non-linearity
  - Noise (low SNR)
  - Frequency response
  - Inter-symbol interference



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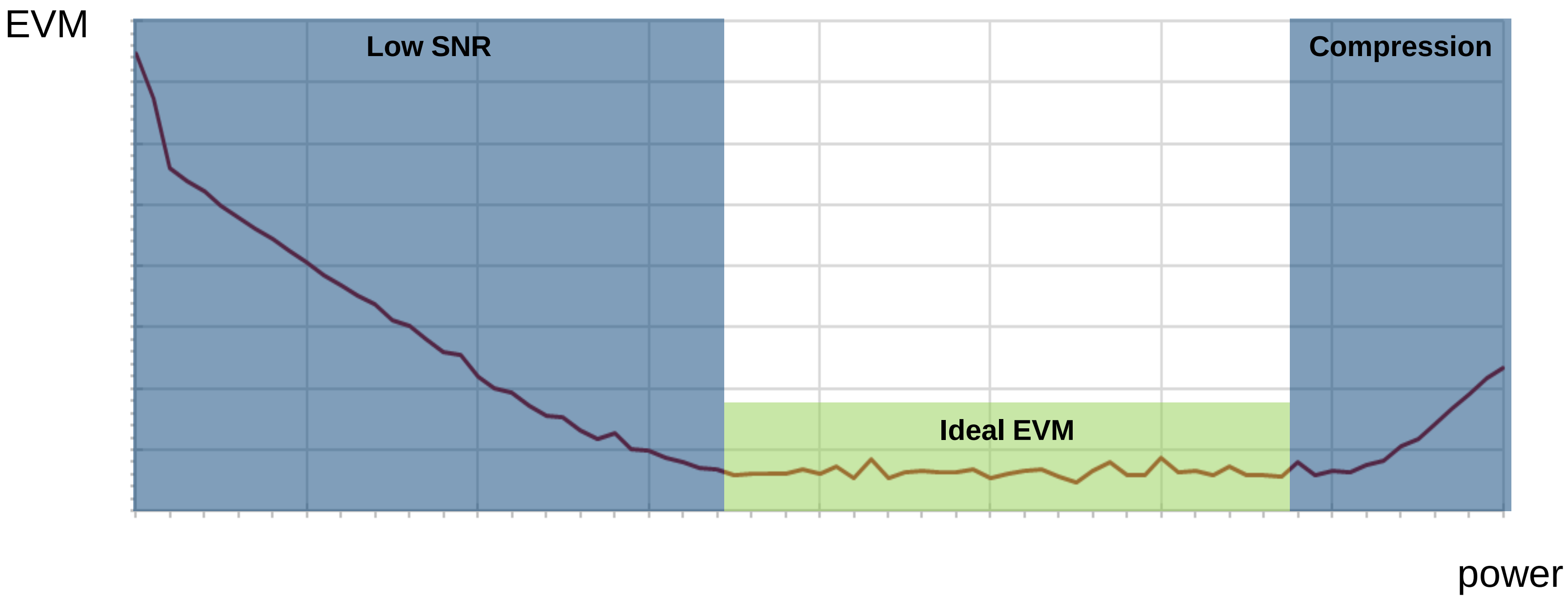
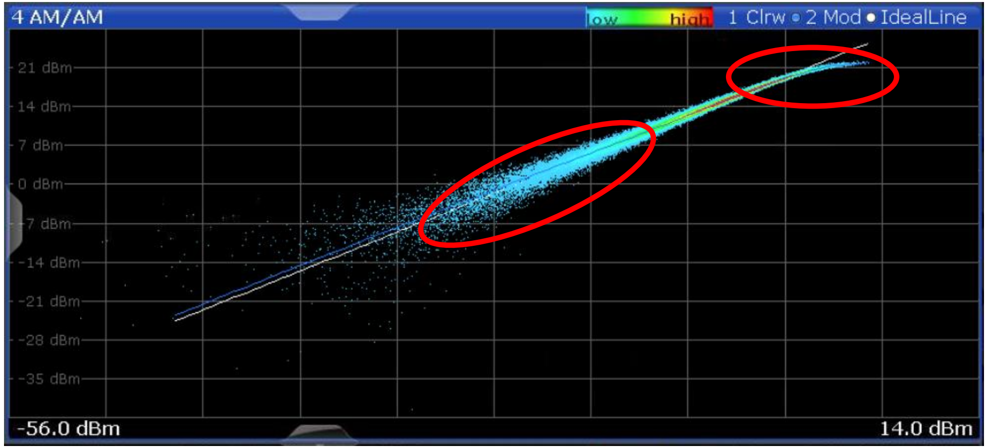


WHY LINEARIZATION?

- Two areas of interest:
  - compression
  - memory effect



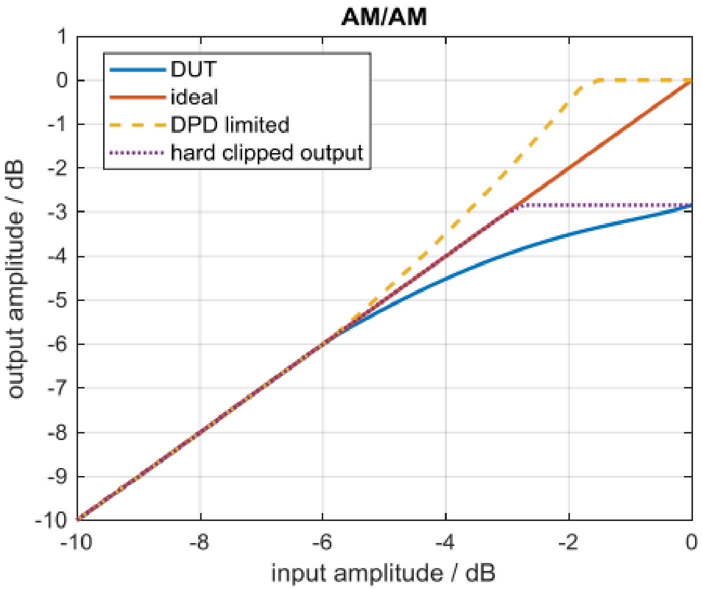
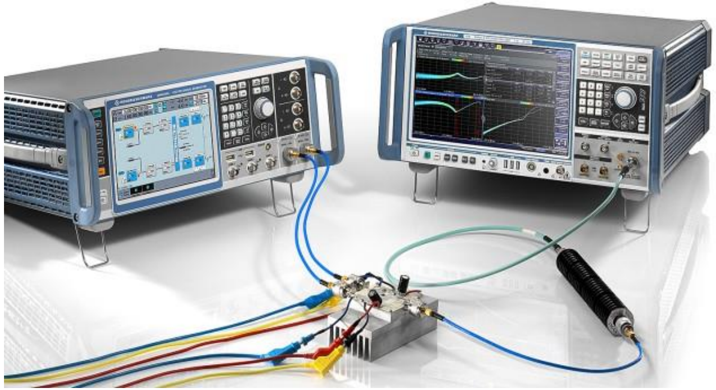


Figure 4 Overview plot: measured AM/AM, ideal output, pre-distorted input signal, and target output signal (hard clipped)

WHY LINEARIZATION?

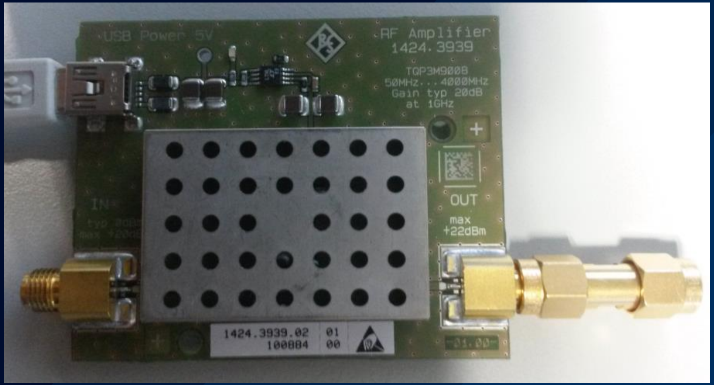
- Challenging RF signals on RF frontends
  - 5G in mmWave and RF, mMIMO, beamforming, increasing bandwidth, higher order modulations, digital payloads, wideband Electronic Warfare (EW)
- Significant power consumption is in the RF Front-End (RFFE)
  - Operating close to saturation offers best energy efficiency
  - Technologies such as GaN absolutely require digital predistortion for linear operation
- Various PA topologies studied
  - Doherty, Load Modulated Balanced Amplifier (LMBA), Outphasing, …



- PA gains in efficiency but is highly non-linear

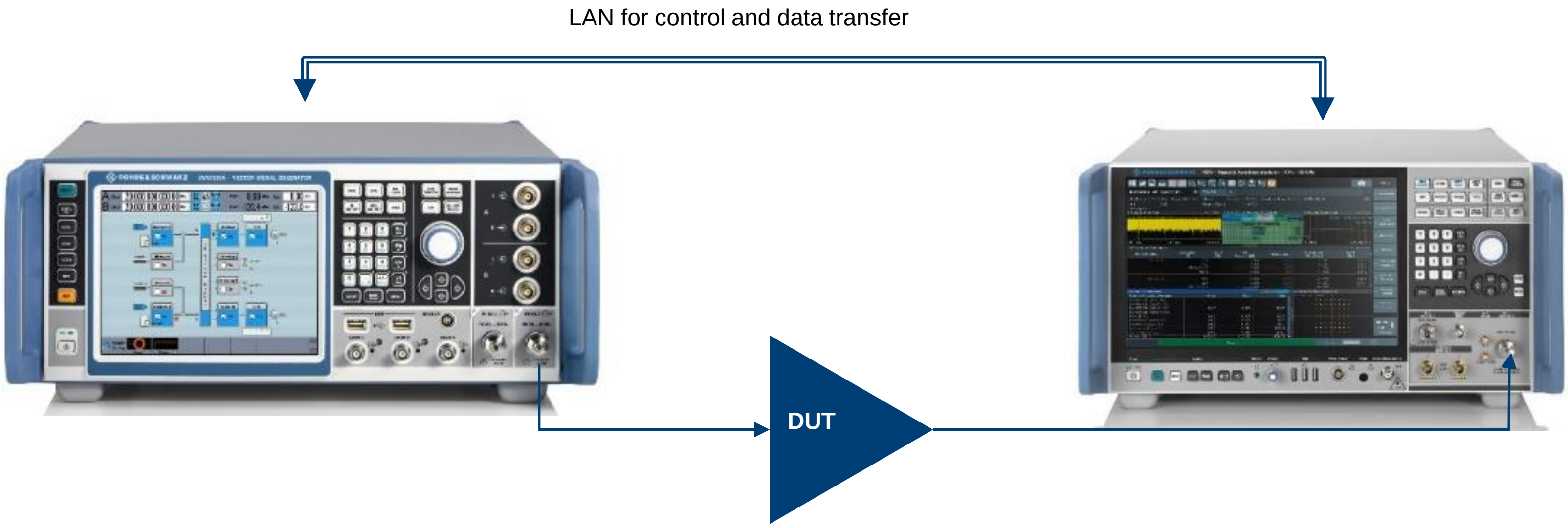
  → Linearization is a _*MUST*_

DEMO AMPLIFIER MEASUREMENT (K18)

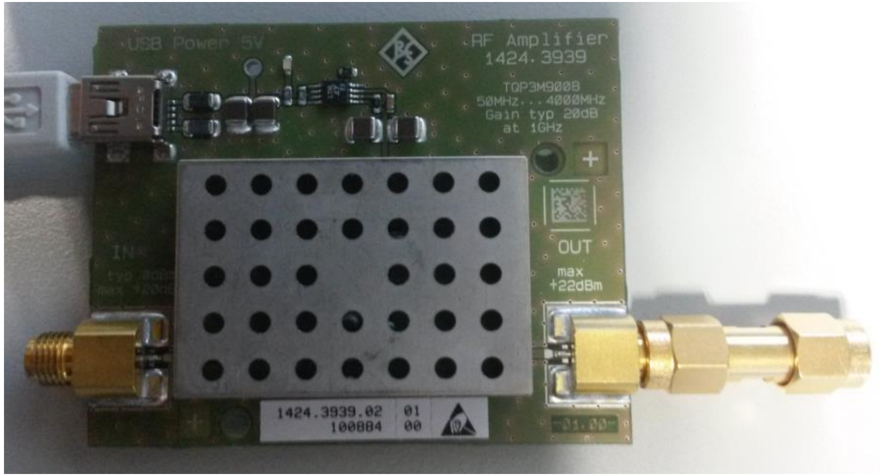


Understand linearity improvement possibilities on a physical amplifier

SETUP



DEMO PA



- Frequency range: 50 MHz – 4000 MHz
- Typ. Gain: 20dB @ 1GHz
- Typ. Inp. Power: 0dBm
- Max. Outp. Power: 22dBm

AMPLIFIER LINEARIZATION BY DIGITAL PRE DISTORSION (DPD)

EVM CONTRIBUTIONS

Statistically independent sources of EVM (in an analog 2-port device)

- ► Frequency response, compensated by e.g. equalizer
- ► Noise (thermal and phase noise), compensated by I/Q averaging
- ► Non-linear effects, compensated by DPD

Due to their statistical independence, the total error power sums up, i.e.

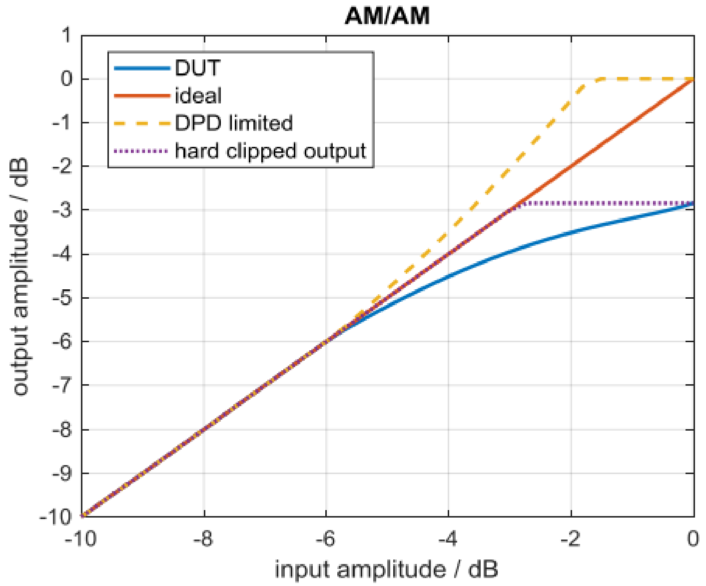
$$EVM_{meas} \geq \sqrt{EVM_{FR}^2 + EVM_{Noise}^2 + EVM_{NL}^2}$$

Where EVM_{FR} is the EVM contribution from frequency response, EVM_{Noise} from noise, and EVM_{NL} from non-linearities respectively.

OPTIMIZATION THROUGH DPD

- ► Pre-distort signal to compensate DUT characteristics
- ► Close to compression: Efficiency ↑ but non-linearity ↑

  → Linearization is a _*MUST*_
- ► PA designer: need understanding of system level performance with ideal predistortion on EVM and ACLR
  - – Iterative Direct DPD provides this information



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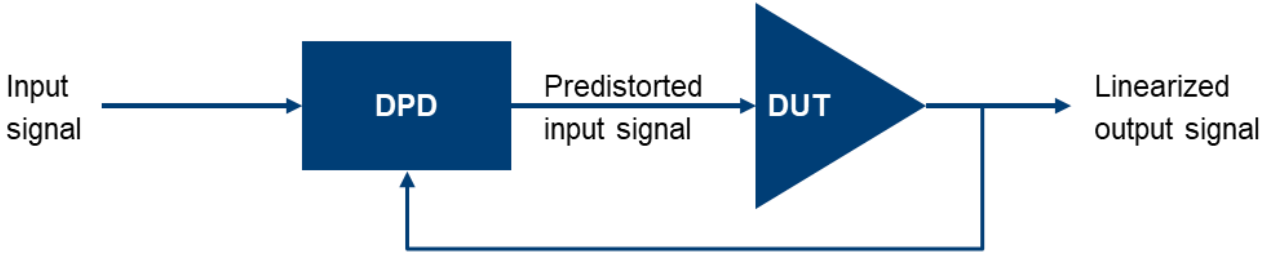
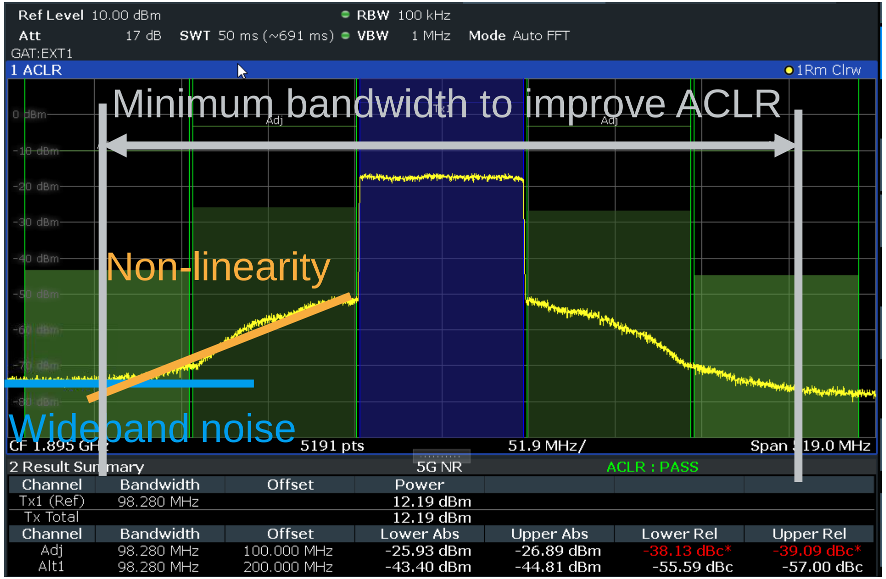


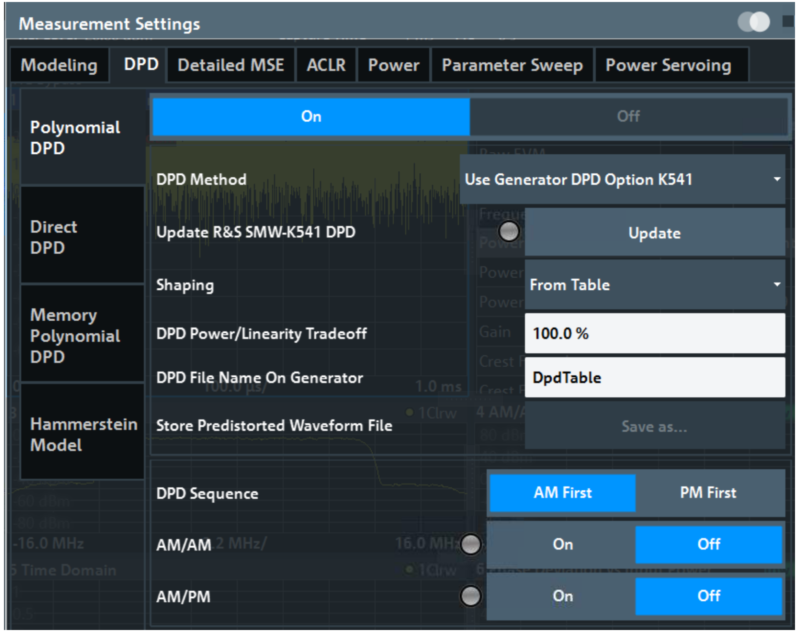
REQUIRED DPD BANDWIDTH

- Significant ACLR that we need to correct
- We‘ll need 4-5 x TX bandwidth for DPD

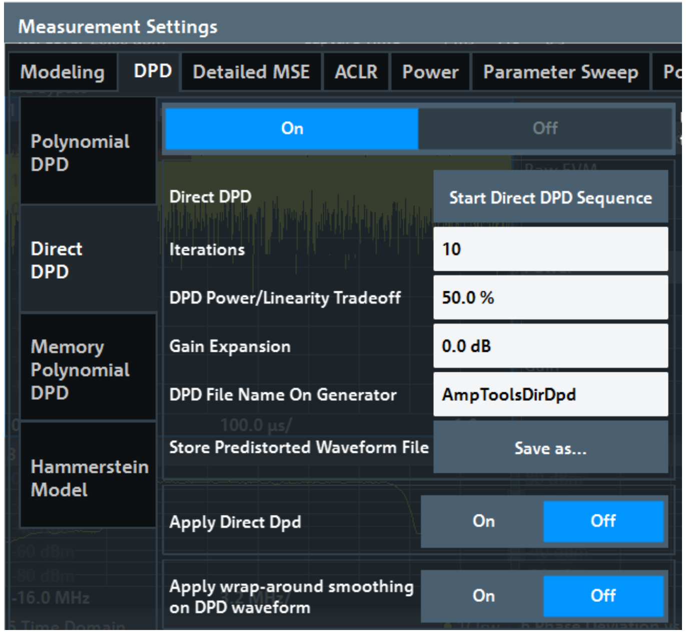


TWO WAYS OF DPD

Polynomial DPD = approximate linearisation by a polynomial



Direct DPD = Iterative approach to achieve best possible linearisation



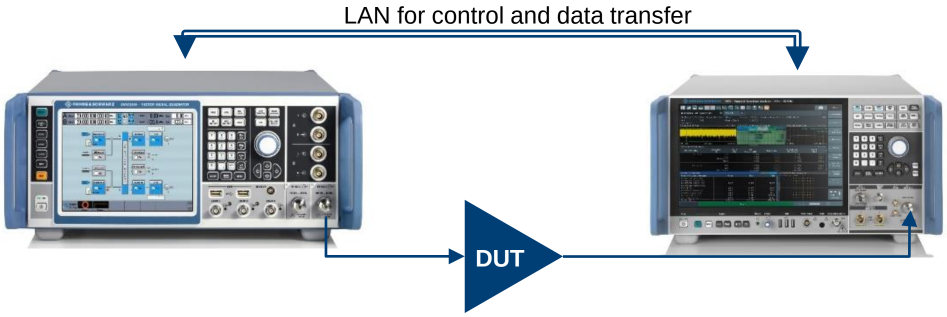
GOAL: HOW GOOD CAN A PA BE?

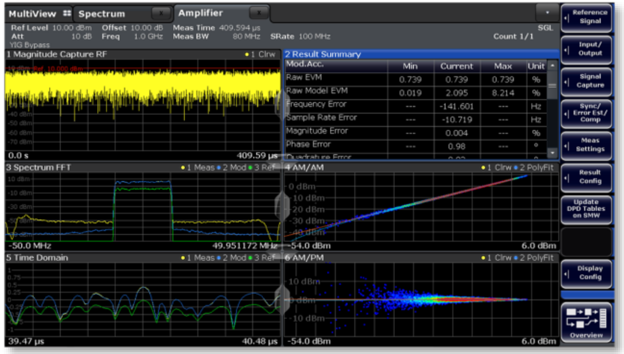
- DPD is used in real systems to optimize the PA performance
- DPD is a specialty of each system manufacturer and the “secret sauce” in between vendors

- PA manufacturer has no access to these sometimes significant size DPD teams
- Looking for an easy way to understand how good their devices can be

- **Direct DPD** is offering this capability
  - Iterative approach
  - Compares ideal input signal to received distorted signal and calculates a new pre-distorted signal on a sample-by-sample base
  - Takes care of non-linearity, memory effect, distortion
  - Provides insight to what can be reached

CREATING A DPD MODEL





R&S®FSW-K18D Direct DPD

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

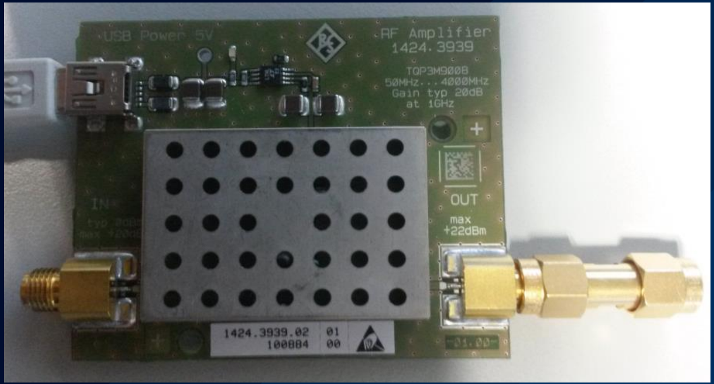
- Reference for best possible
  - Suppliers typically do not have access to DPD algorithms used by system integrators

R&S®FSW-K18M memory polynomial

- Memory polynomial model or Hammerstein model based on Direct DPD result
- Modeling can be adopted in order and memory depth
- Model verification on DUT

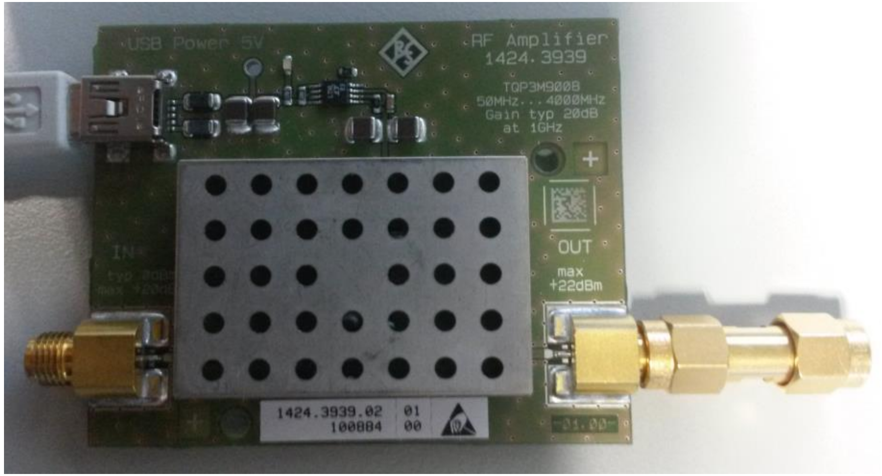
- Proves easy linearization of RFFE solution

DEMO DIGITAL PRE-DISTORTION (K18)



 Understand linearity improvement possibilities on a physical amplifier

DEMO PA



- NR 100 MHz UL signal (1ms)
- 2.3 GHz
- Generator power: -3 dBm
- Marker: restart

MEMORY POLYNOMIAL MODEL

- Derive an algorithm based memory DPD, as described in Application Note 1EF105

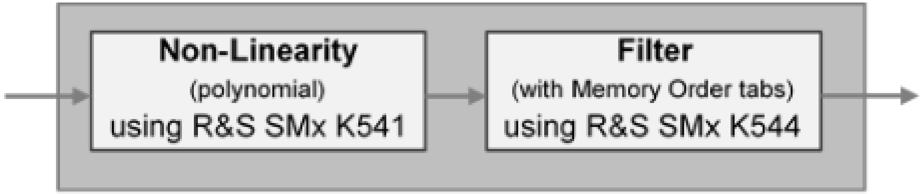
- We use a memory polynomial DPD

$$\tilde{P}(nT) = \sum_{p=1}^{P} \sum_{m=1}^{M} k_{p,m} A(nT - \tau_m) \, |A(nT - \tau_m)|^{p-1}$$

- We use the result of K18D to directly derive the coefficients, rather than modeling the DUT and inverting the model

HAMMERSTEIN MODEL

- Predistortion according to the Hammerstein model, is applied to the IQ sample stream by first applying a non-linear polynomial, followed by a convolution



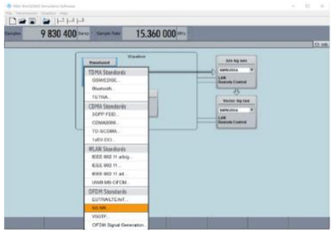
- Easier to be applied in real-time to any IQ stream
- Much less complex → less power needed to apply
- But a bit less efficient in EVM & ACLR improvement

COMPARISON OF MODELS

Predistortion Approach	Measurement Time	EVM Improvement (In-band)	ACLR Improvement (Out-of-band)
Polynomial Model	✓✓✓	✓	✓
Direct DPD (with Meas Bandwidth = Signal Bandwidth)	✓✓✓	✓✓	✓
Direct DPD (with increased Meas Bandwidth)	✓✓	✓✓	✓✓
Direct DPD (with increased Meas Bandwidth and IQ Averaging)	✓	✓✓✓	✓✓✓
Memory Polynomial Model	✓✓	✓✓	✓✓
Hammerstein Model	✓✓	✓✓	✓

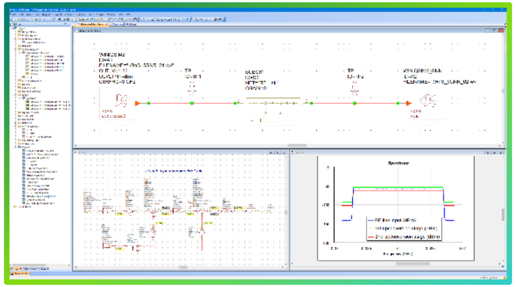
DESIGN: USING EDA TO PIN OUT EXPECTED PERFORMANCE WITH DPD

► Simulate as close to reality for risk mitigation

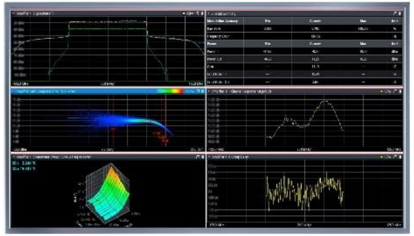


R&S WinIQSIM2
Signal Generation

R&S VSE
Signal Analysis



Cadence Visual System Simulator (VSS)
RF Design/Analysis

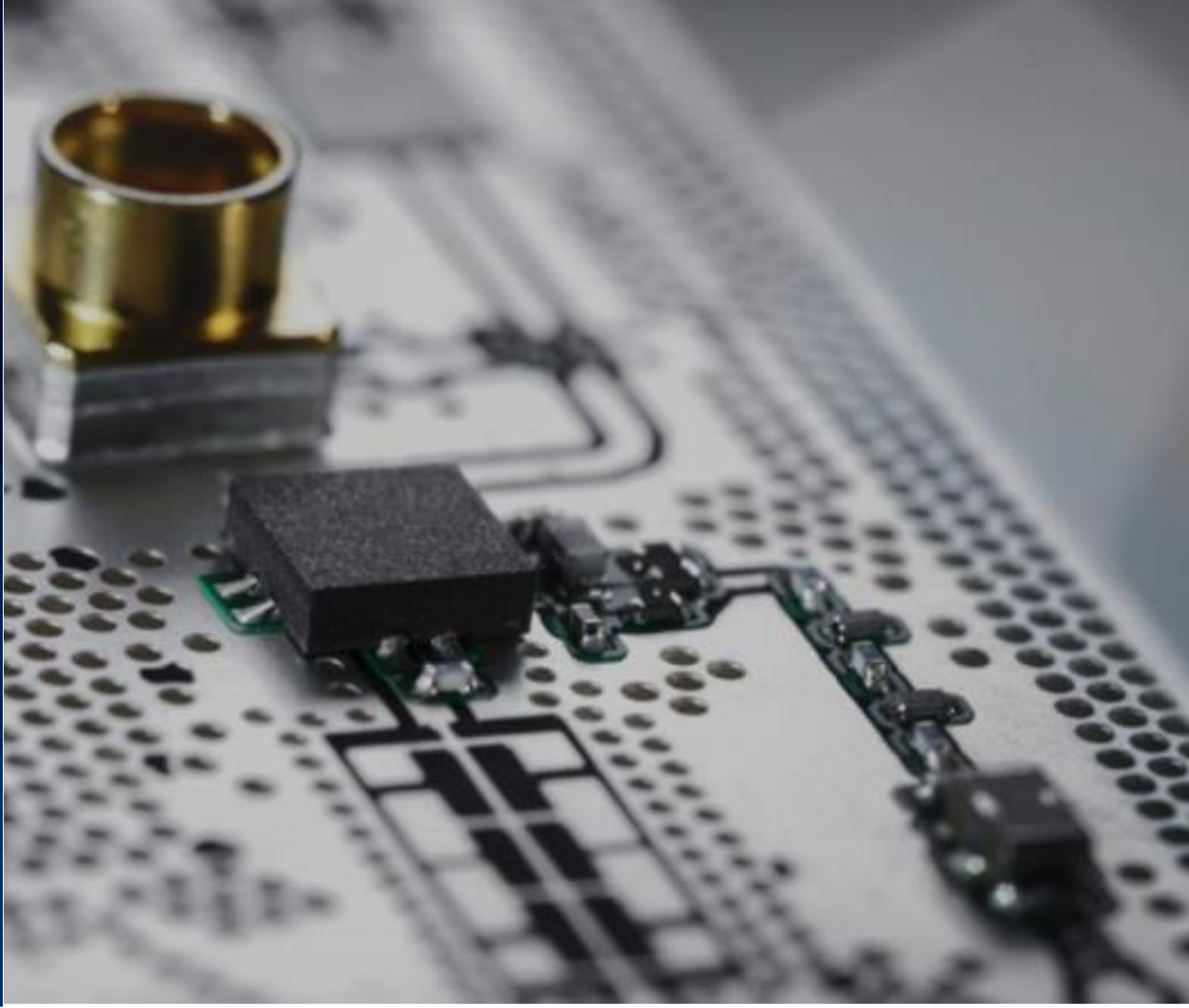


Direct DPD
Linearization

Understand linearity improvement possibilities on a physical amplifier

CONCLUSION

- There is an easy way to understand what is possible
- Works with any non-linear device and any signal
- Various models can be derived
- Works with physical hardware and even in EDA while design



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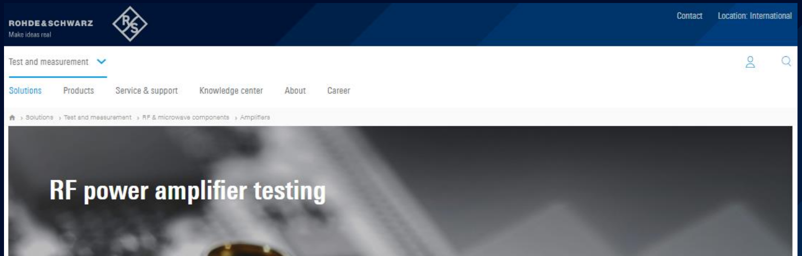

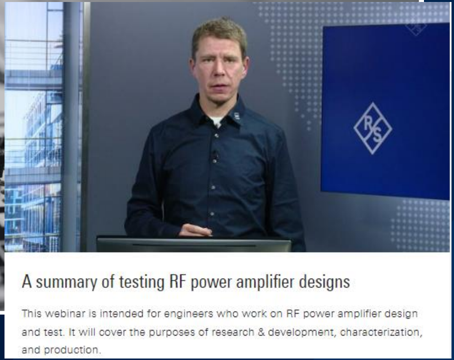

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QUESTIONS