MATLAB EXPO 2021

LINEARIZATION OF RF POWER AMPLIFIERS
CONNECTING SIMULATION AND MEASUREMENTS ON PHYSICAL DEVICES

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ROHDE&SCHWARZ

Make ideas real

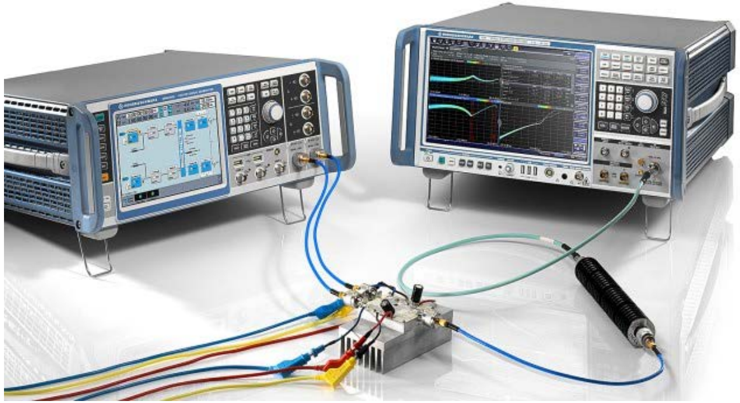
AGENDA

- Intro: Linearization and predistortion on power amplifiers
- Modelling of non linear devices
- Power of combining simulation and real measurements
  - Example with basic Power Amplifier (PA)
  - Example with Gallium Nitride (GaN) Device Under Test (DUT)
- Memory polynomial Digital Predistortion (DPD) with real DUT
- Summary

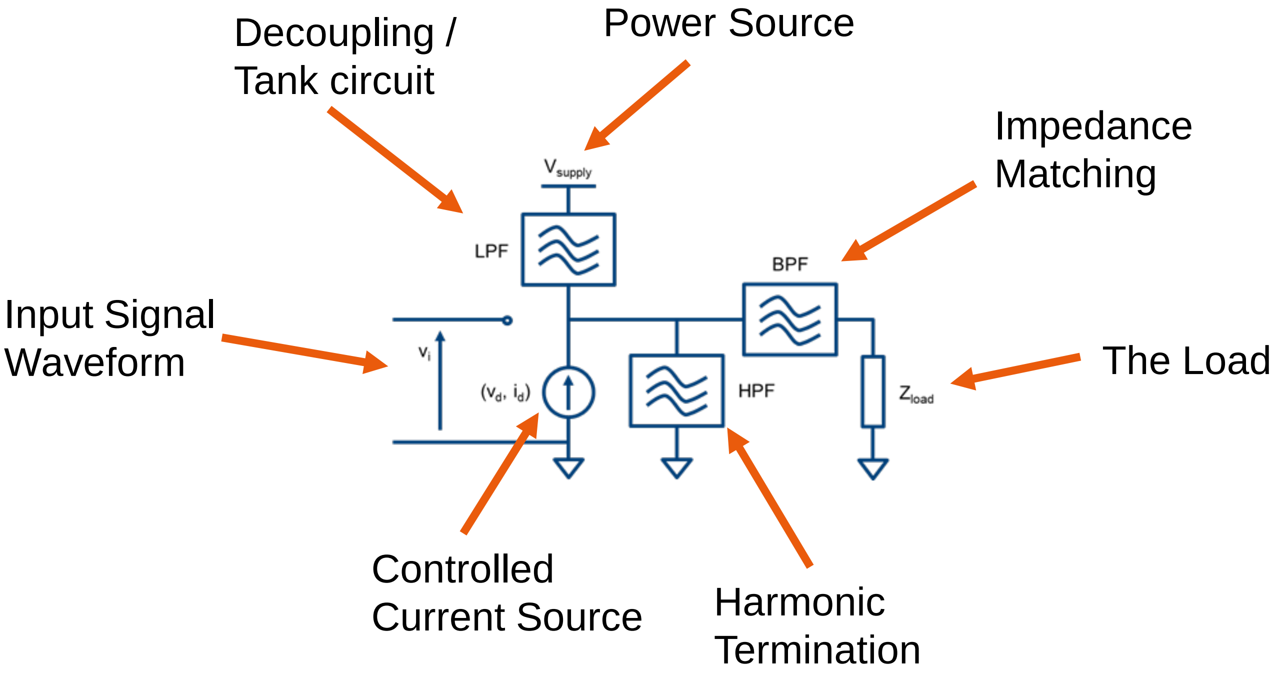
WHY LINEARIZATION?

- 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 remains highly non-linear

  → Linearization is a _*MUST*_

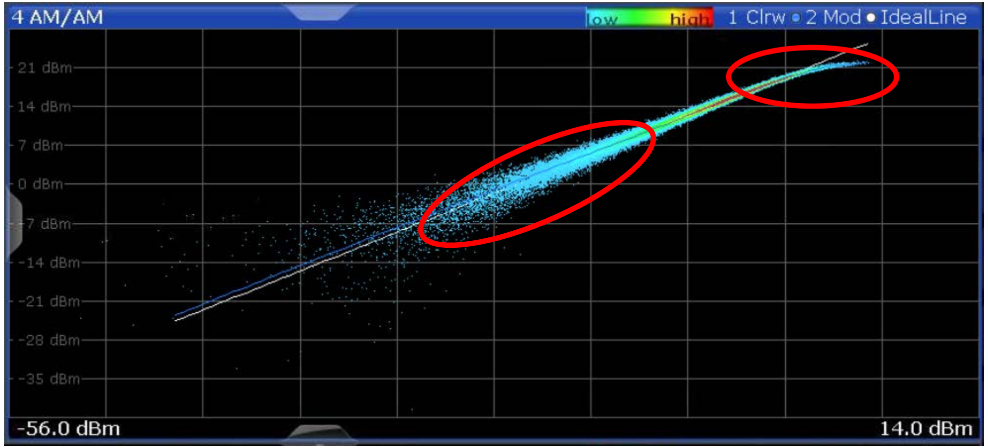


THE RF AMPLIFIER BUILDING BLOCK



WHY LINEARIZATION?

- Two areas of interest:
  - compression
  - memory effect



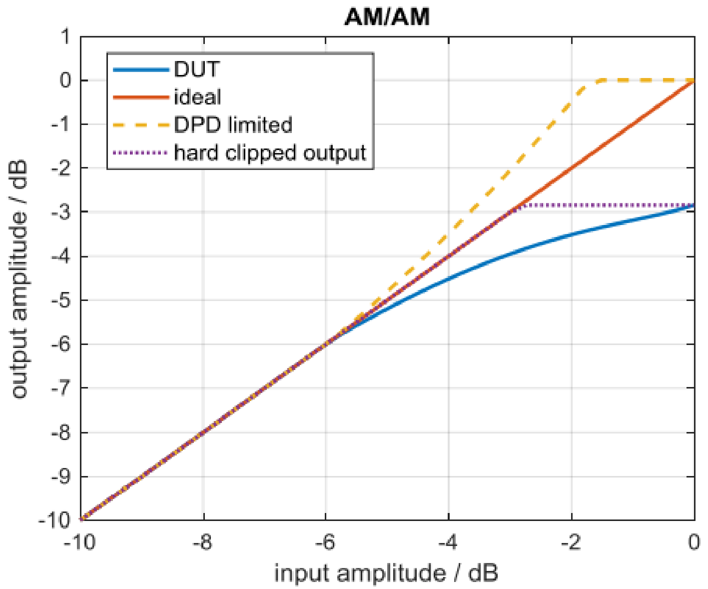
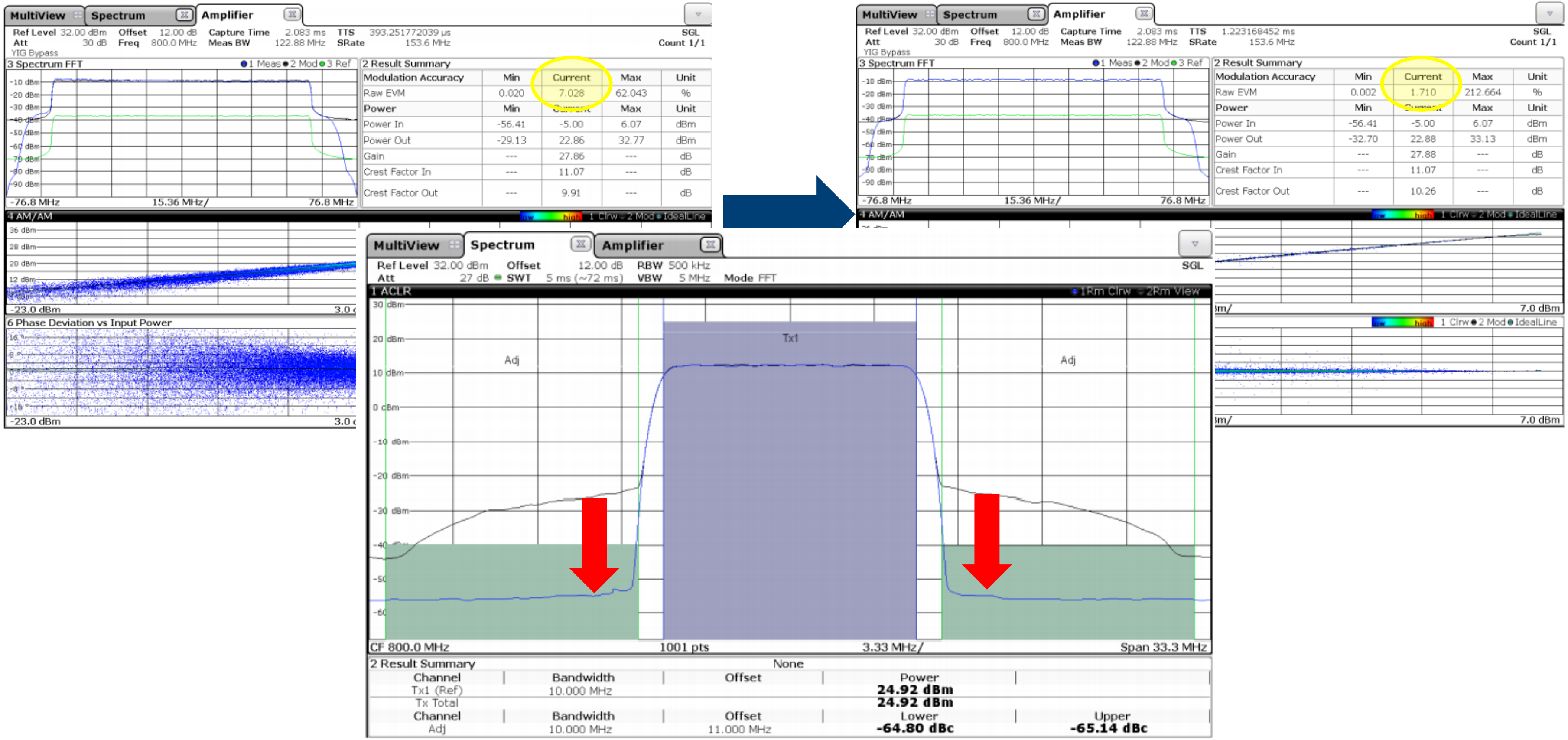


Figure 4 Overview plot: measured AM/AM, ideal output, pre-distorted input signal, and target output signal (hard clipped)

DIGITAL PREDISTORTION: BEFORE AND AFTER



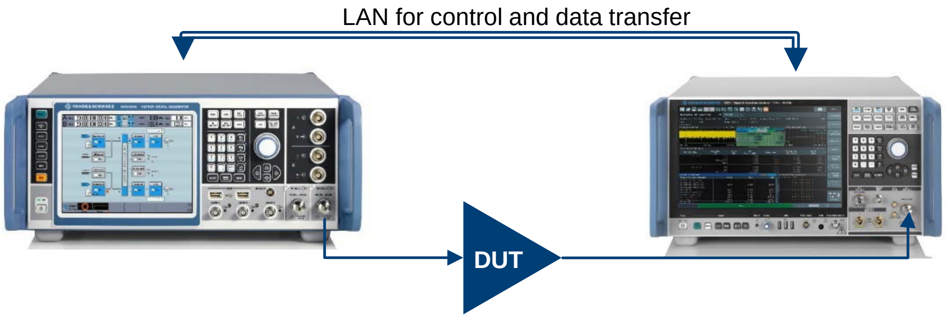
WHY MODELLING?

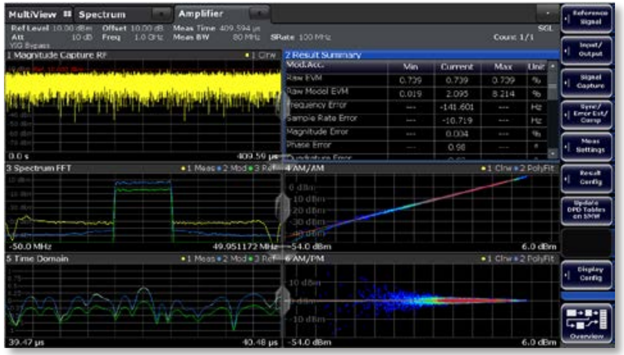
- Modelling is an essential step in PA design, optimization and linearization
  - The more accurate the better
  - Various PA topologies
  - Different linearization approaches

  → Modelling allows us to test various linearization approaches in an easy and efficient way

- MATLAB® / Simulink® is a widely used platform in research and development and offers the tools needed
- Having an accurate model can simplify development widely and allow deeper insight to optimization

COLLECTING DATA ON A REAL POWER AMPLIFIER





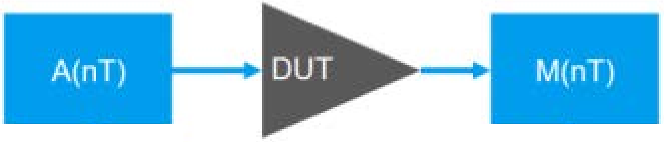
R&S®FSW-K18D Direct DPD

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

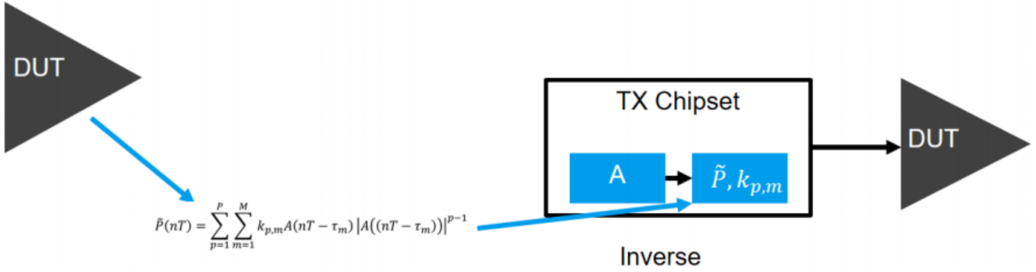
- Reference for best possible
    - Suppliers typically do not have access to DPD algorithms used by system integrators

CREATING ENHANCED MODEL

- No pre-existing PA or DPD model
- Start with measuring input and output signals with and without direct DPD
- Build PA model on power transfer functions
- Refine the model using direct DPD signal to linearize data

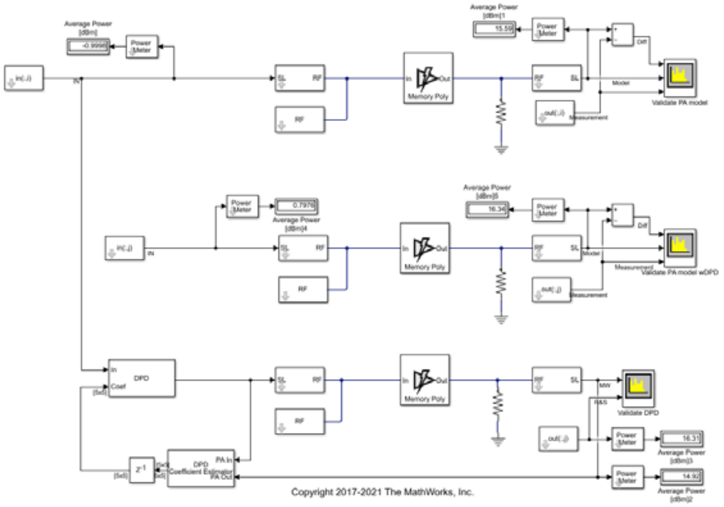


$$\tilde{P}(nT) = \sum_{p=1}^{P} \sum_{m=1}^{M} k_{p,m} A(nT - \tau_m)\,|A(nT - \tau_m)|^{p-1}$$

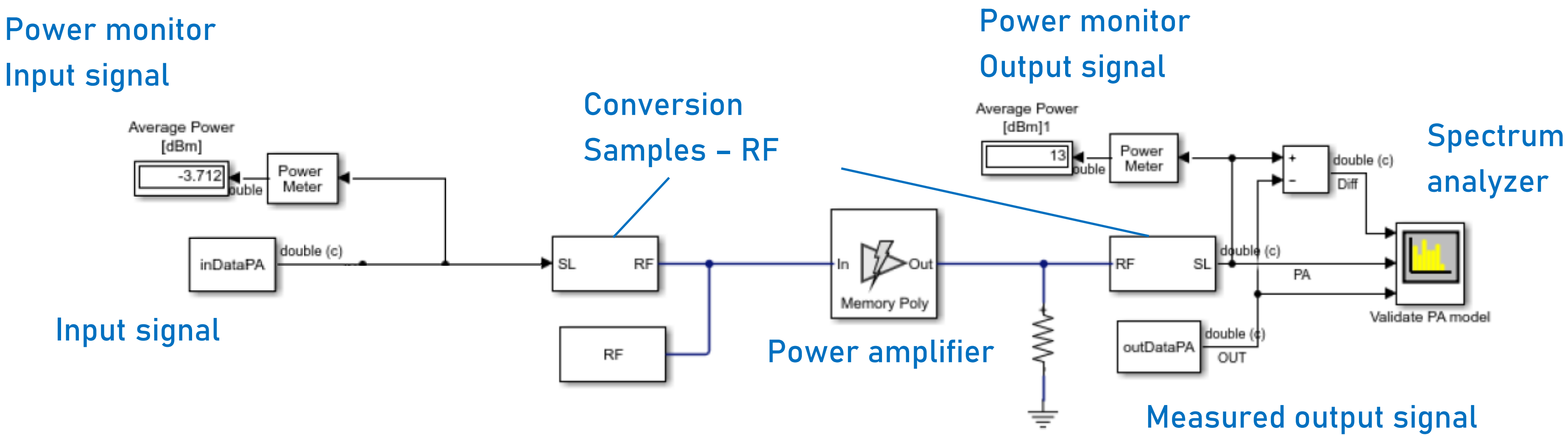


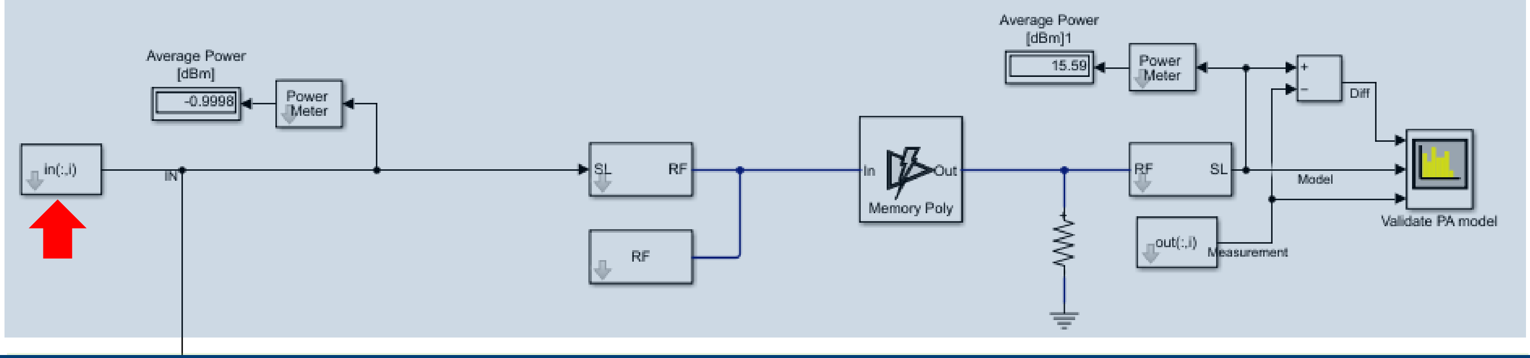
MODELLING IN MATLAB® / SIMULINK®

- ► RF Blockset™ PA model used in Simulink® simulation
- ► Real measurement data used to fit PA model
  - – Teamwork by F. Ramian, G. Lloyd, M. Loerner (Rohde & Schwarz) and G. Zucchelli (MathWorks)
- ► Verifying approach with different data sets from various PA’s and operation conditions
  - – Easy exchange of data sets from measurements into simulation
  - – Straightforward loading IQ data sets into MATLAB®



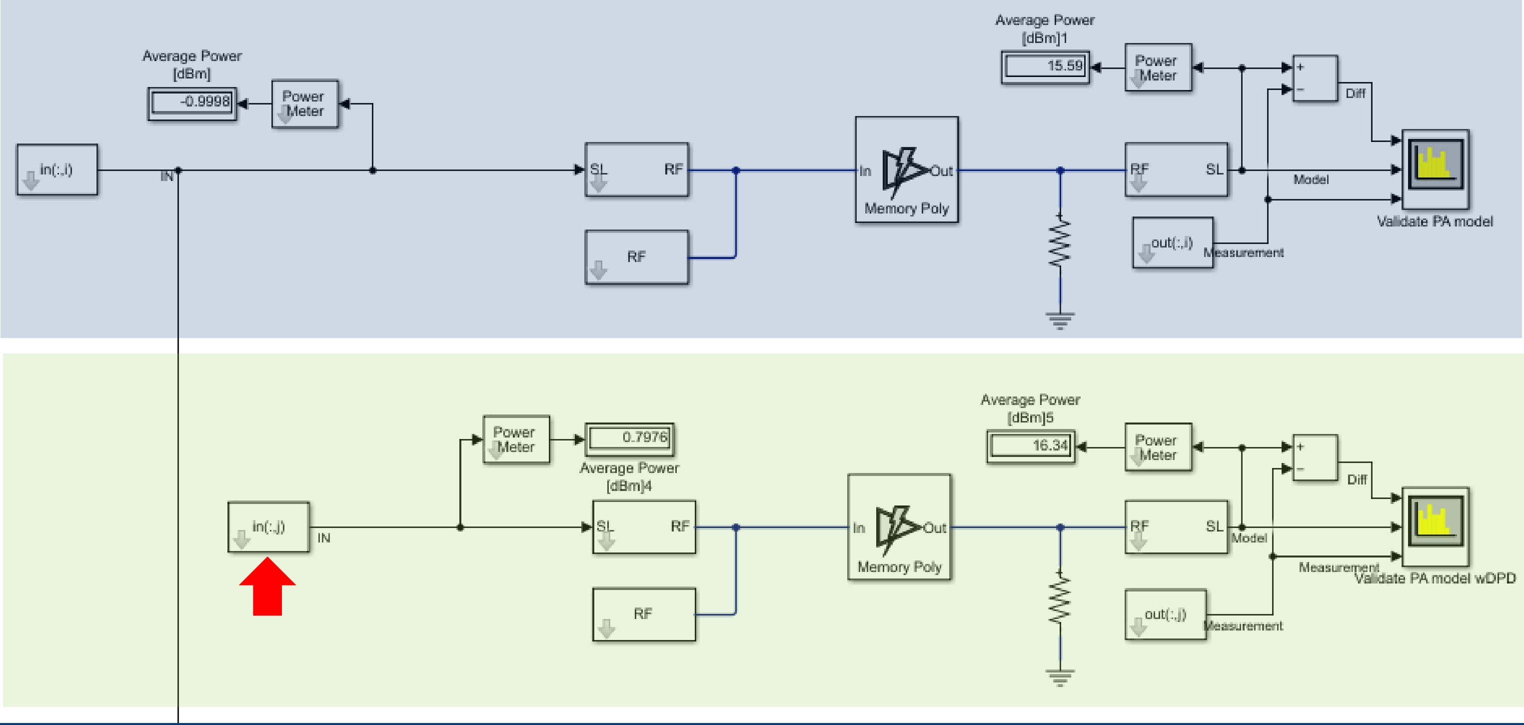
MODELLING IN MATLAB® / SIMULINK®





Model path 1

No Linearization



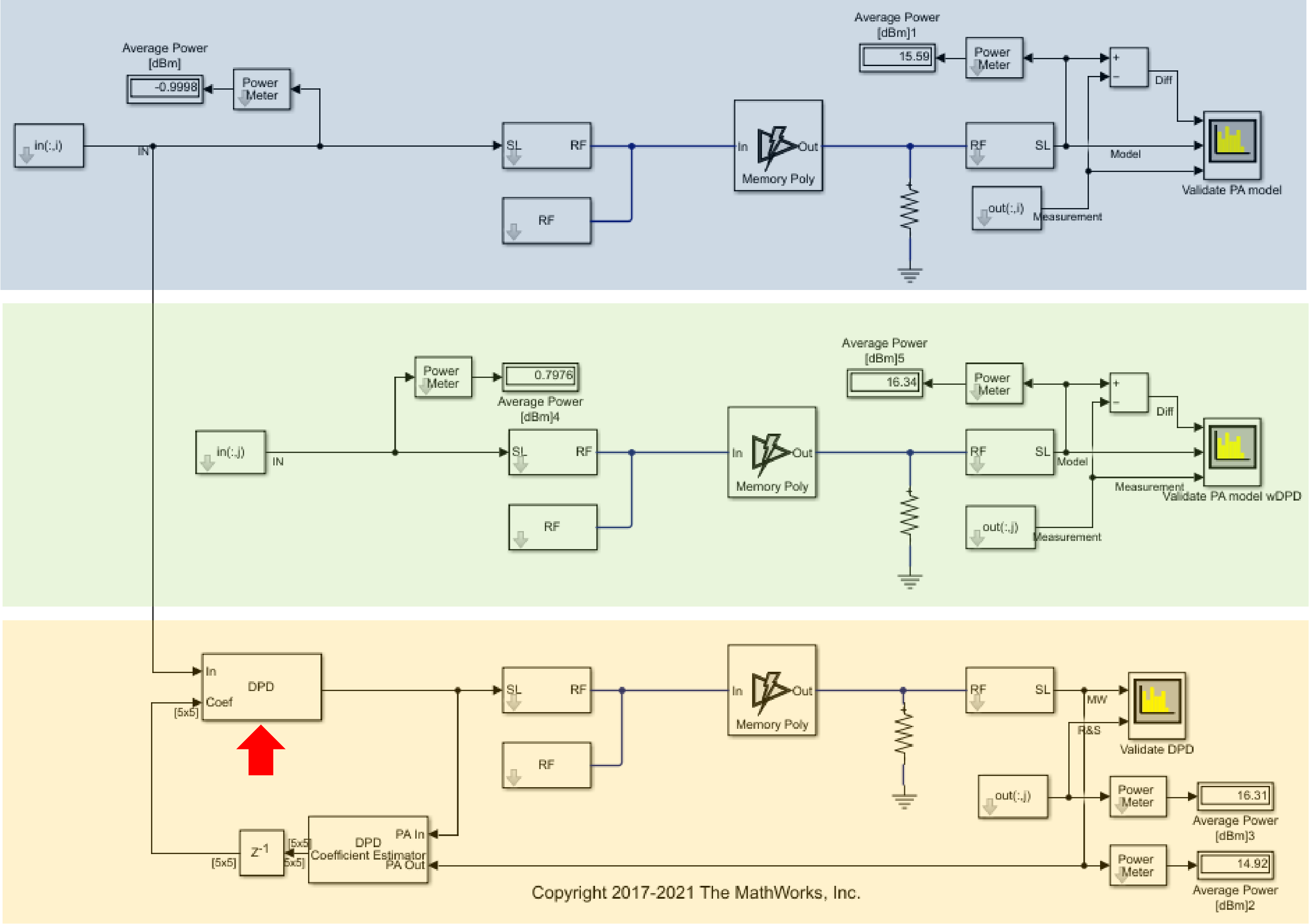
Model path 1

No Linearization

Model path 2

Linearization in

real measurement

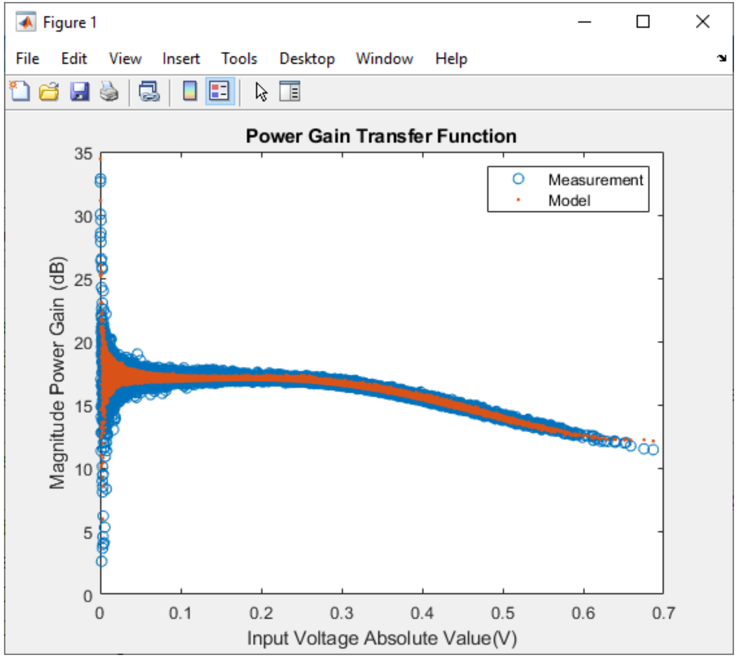


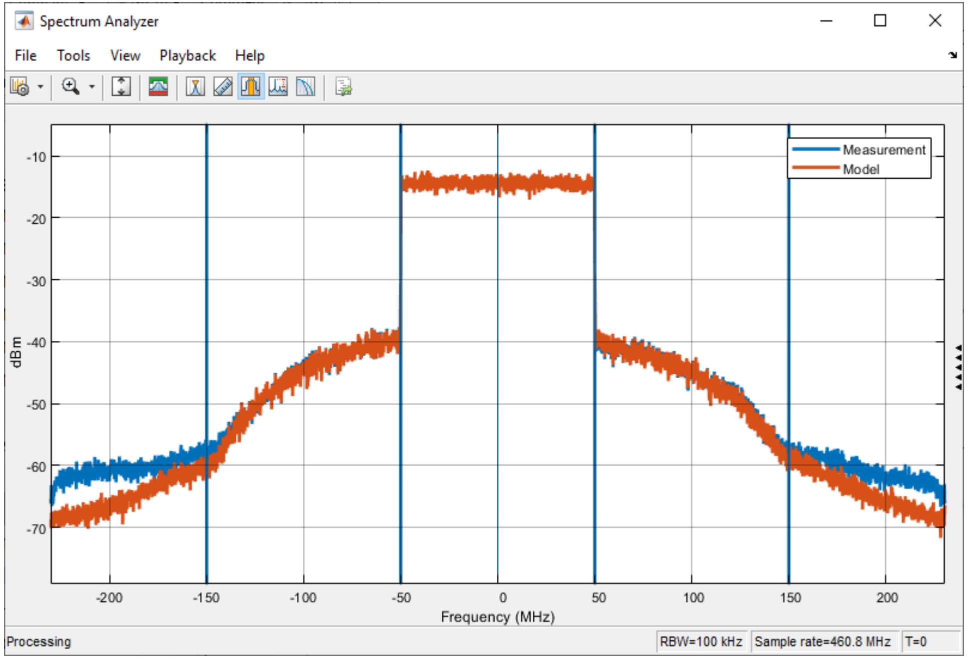
Model path 1
No Linearization

Model path 2
Linearization in real measurement

Model path 3
Linearization in simulation

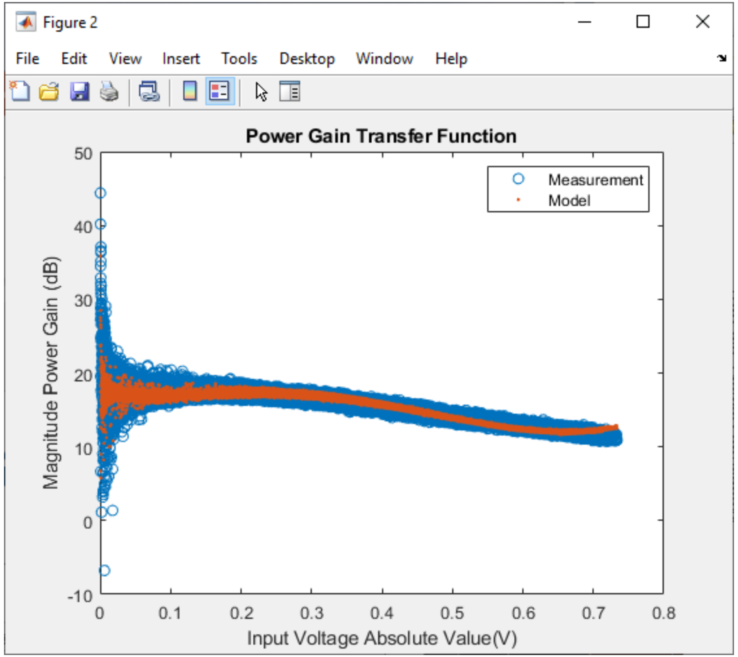
PA MODEL FITTING BASED ON HIGH-POWER SIGNAL

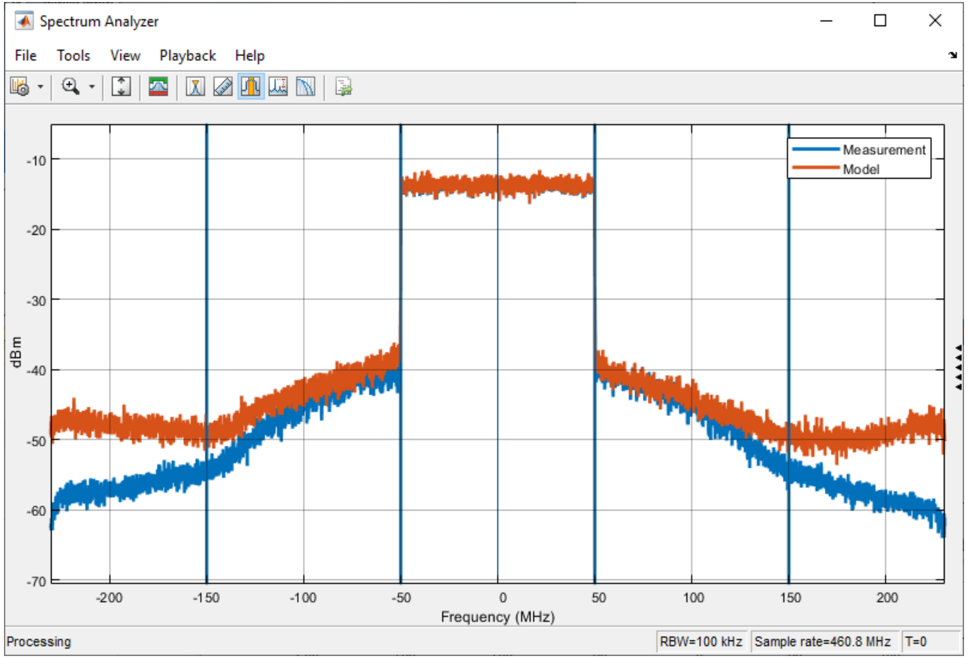





```
Signal standard deviation = 3.2697%
ACPR data = -29.1832 -29.6387
ACPR fit  = -29.2544 -29.6458
```

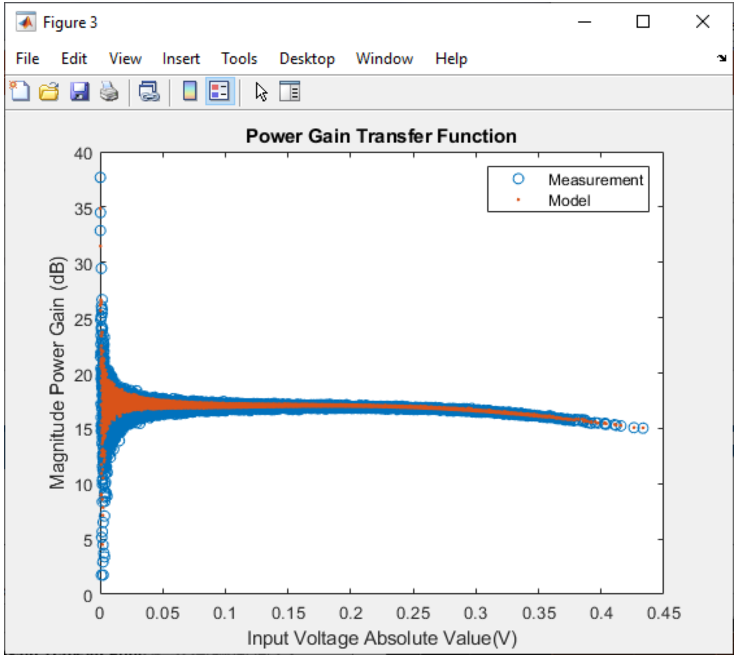
TESTING THE MODEL WITH PREDISTORTED SIGNAL

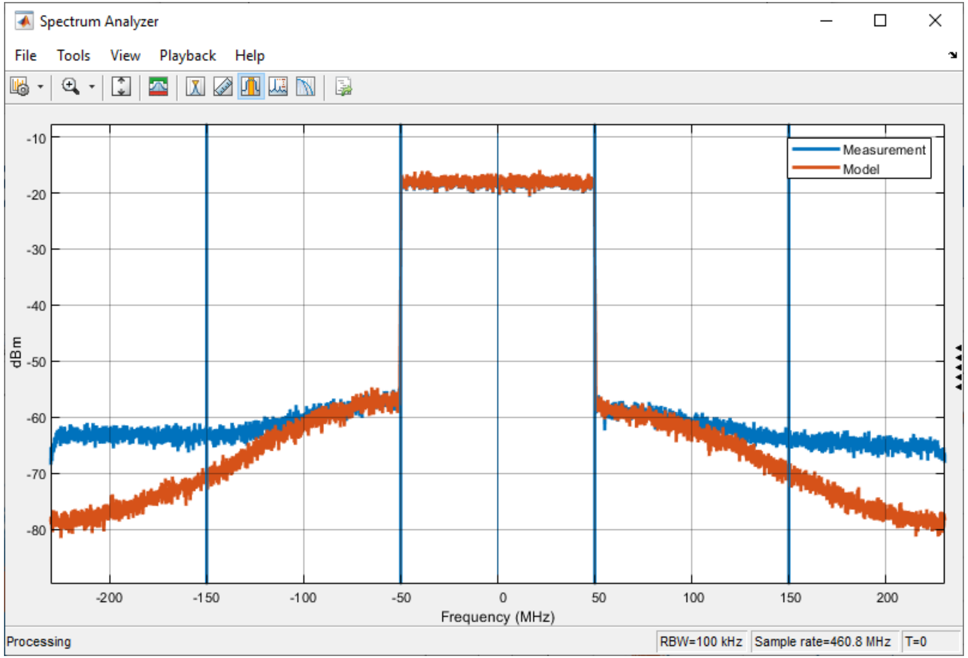





```
Signal standard deviation = 9.1142%
ACPR data = -30.5317 -30.3716
ACPR fit  = -28.5583 -29.6007
```

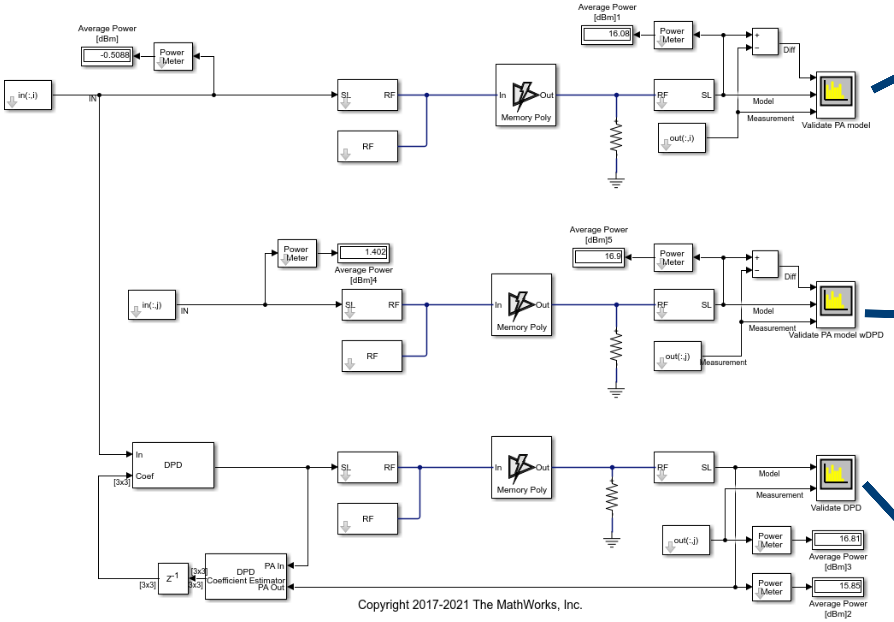
TESTING THE MODEL WITH LOW-POWER SIGNAL

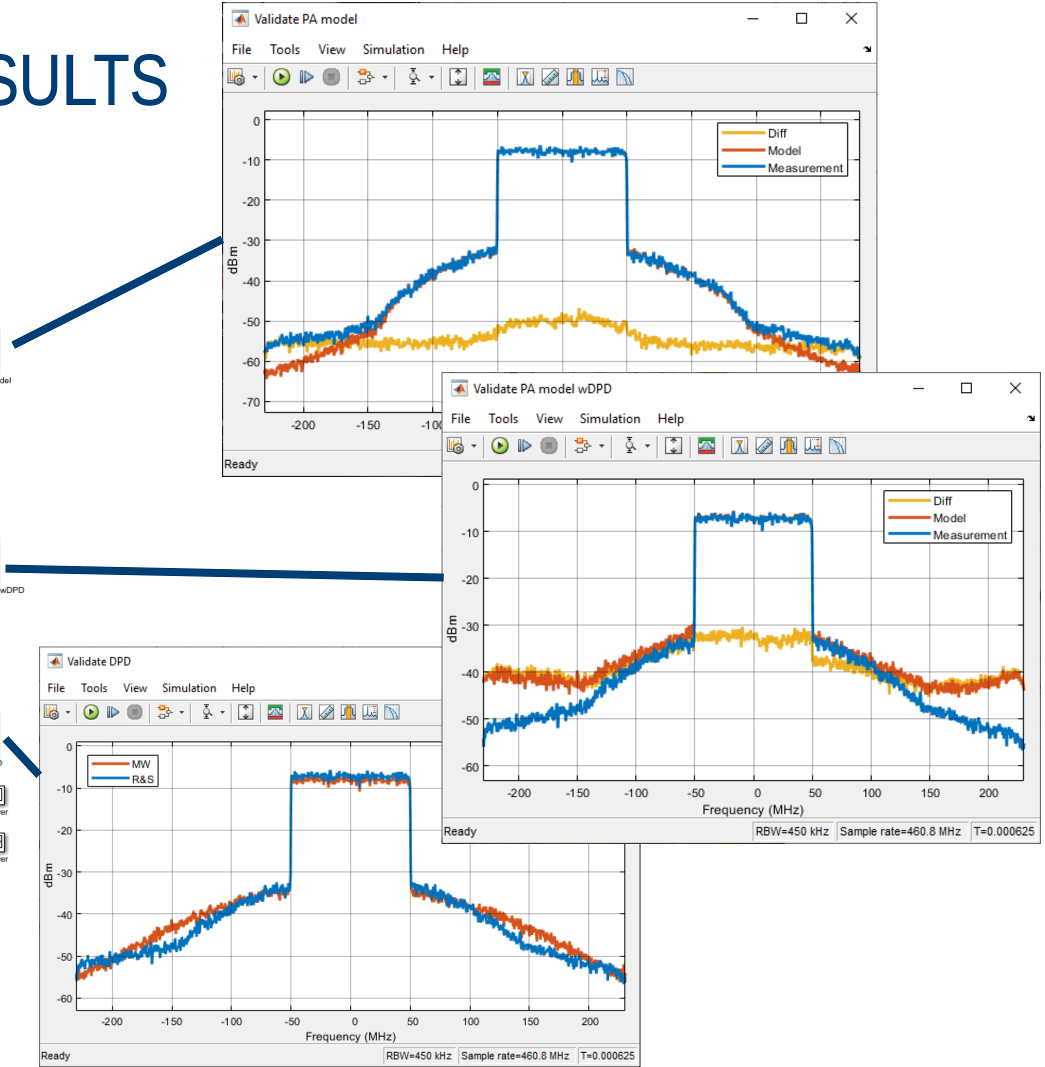





```
Signal standard deviation = 4.533%
ACPR data = -39.8968 -39.7403
ACPR fit  = -40.5179 -40.3225
```

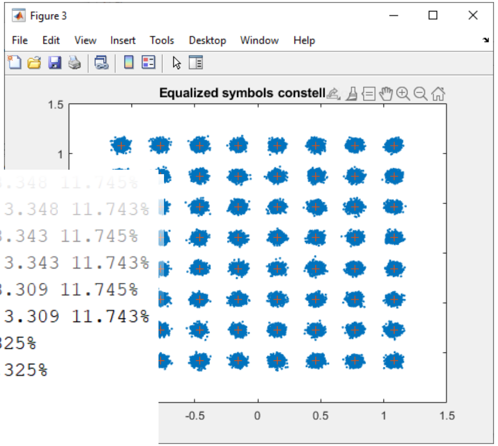
BASIC PA: SIMULATION RESULTS



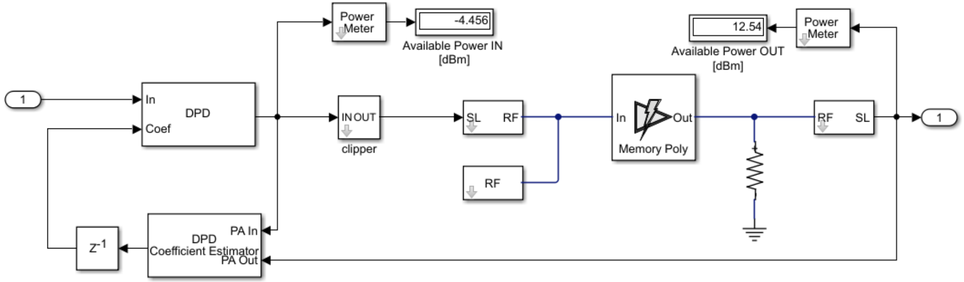


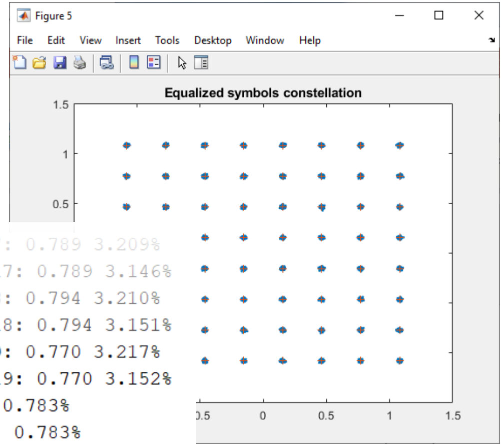
BASIC PA: 5G SIMULATION RESULTS

```
rc = "NR-FR1-TM3.1"; % Reference channel(NR-TM or FRC)
% Select the NR waveform parameters
bw = "100MHz"; % Channel bandwidth
scs = "30kHz"; % Subcarrier spacing
dm = "FDD"; % Duplexing mode
```



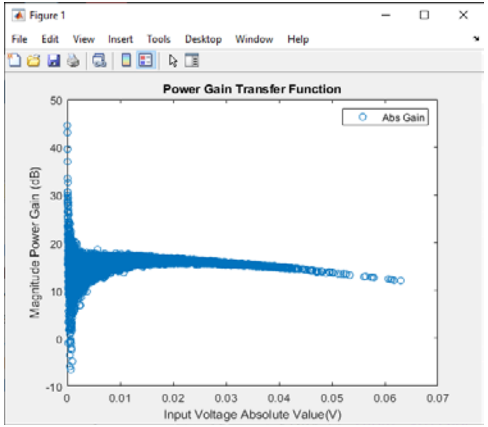

```
Low edge RMS EVM, Peak EVM, slot 17: 3.348 11.745%
High edge RMS EVM, Peak EVM, slot 17: 3.348 11.743%
Low edge RMS EVM, Peak EVM, slot 18: 3.343 11.745%
High edge RMS EVM, Peak EVM, slot 18: 3.343 11.743%
Low edge RMS EVM, Peak EVM, slot 19: 3.309 11.745%
High edge RMS EVM, Peak EVM, slot 19: 3.309 11.743%
Averaged low edge RMS EVM,frame 0: 3.325%
Averaged high edge RMS EVM,frame 0: 3.325%
Averaged RMS 3GPP EVM frame 0: 3.325%
Averaged overall RMS EVM: 3.325%
Peak EVM = 12.1753%
```



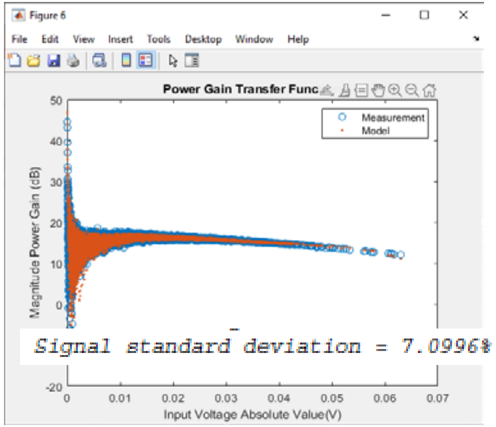



```
Low edge RMS EVM, Peak EVM, slot 17: 0.789 3.209%
High edge RMS EVM, Peak EVM, slot 17: 0.789 3.146%
Low edge RMS EVM, Peak EVM, slot 18: 0.794 3.210%
High edge RMS EVM, Peak EVM, slot 18: 0.794 3.151%
Low edge RMS EVM, Peak EVM, slot 19: 0.770 3.217%
High edge RMS EVM, Peak EVM, slot 19: 0.770 3.152%
Averaged low edge RMS EVM,frame 0: 0.783%
Averaged high edge RMS EVM,frame 0: 0.783%
Averaged RMS 3GPP EVM frame 0: 0.783%
Averaged overall RMS EVM: 0.783%
Peak EVM = 3.7347%
```

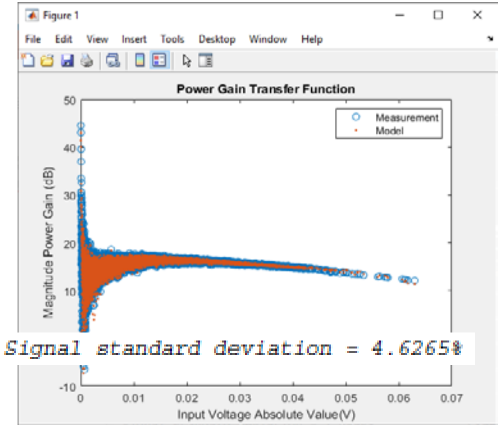
GAN PA, USING PREDISTORTED DATA AS BASELINE VDD=20V

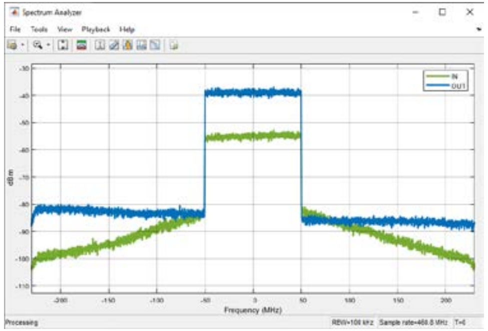


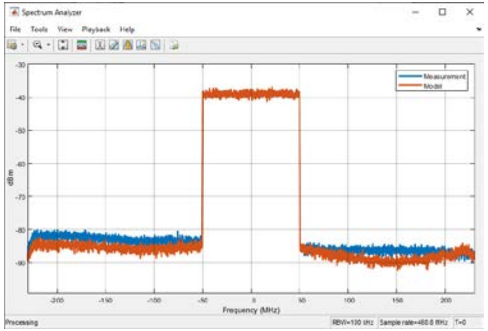
Standard memory polynomial

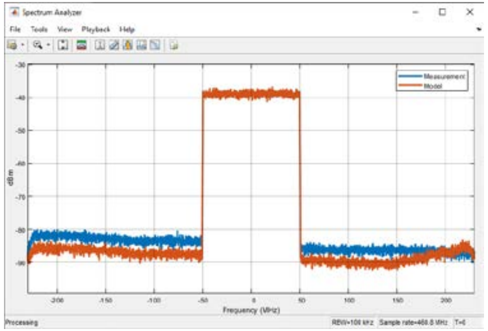


Memory polynomial w/ cross terms

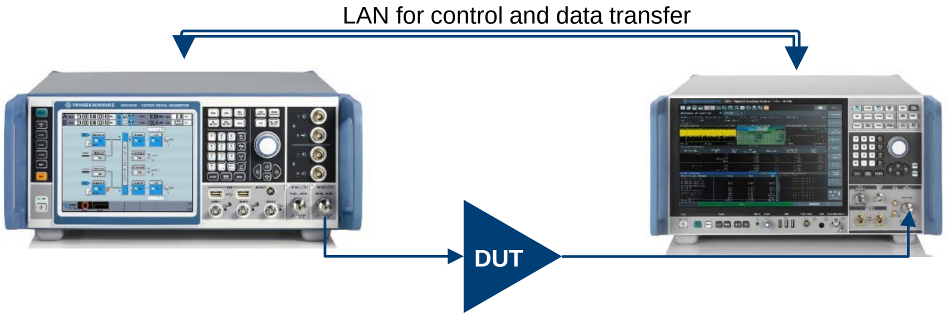


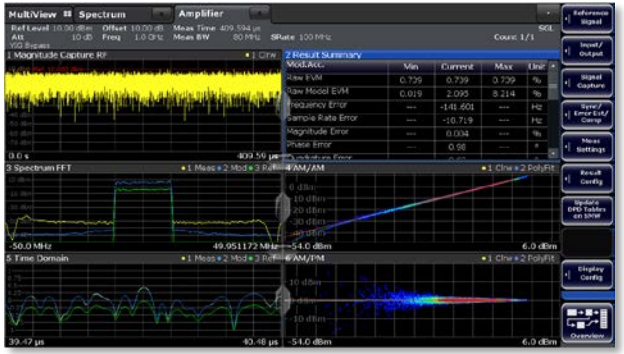






CREATING THE MEMORY POLYNOMIAL DPD IN FSW





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

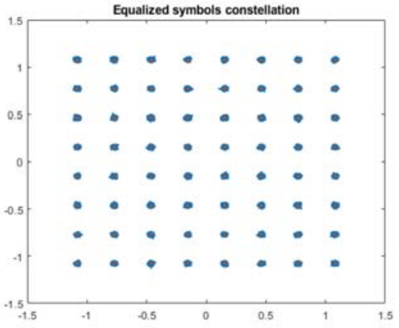
- Memory polynomial model based on Direct DPD result
- Modeling can be adopted in order and memory depth
- Model verification on DUT

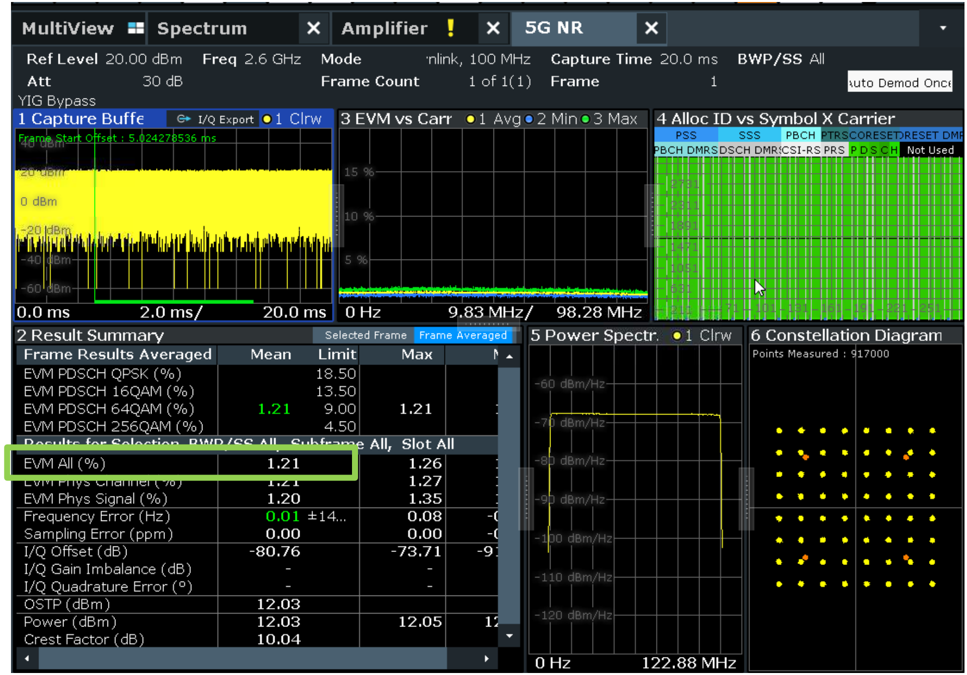
- Proves easy linearization of RFFE solution

MEMORY POLYNOMIAL USING FSW INTERNAL FEATURE

- ▶ Comparing results
  - → good match between memory polynomial on the 2 platforms using fitted PA model in simulation and using measured data in FSW

```
Low edge RMS EVM, Peak EVM, slot 6: 1.203 4.661%
High edge RMS EVM, Peak EVM, slot 6: 1.203 4.664%
Low edge RMS EVM, Peak EVM, slot 7: 1.190 4.661%
High edge RMS EVM, Peak EVM, slot 7: 1.190 4.664%
Low edge RMS EVM, Peak EVM, slot 8: 1.193 4.661%
High edge RMS EVM, Peak EVM, slot 8: 1.193 4.664%
Low edge RMS EVM, Peak EVM, slot 9: 1.206 4.661%
High edge RMS EVM, Peak EVM, slot 9: 1.206 4.664%
Low edge RMS EVM, Peak EVM, slot 10: 1.179 4.661%
High edge RMS EVM, Peak EVM, slot 10: 1.179 4.664%
Low edge RMS EVM, Peak EVM, slot 11: 1.200 4.661%
High edge RMS EVM, Peak EVM, slot 11: 1.200 4.664%
Low edge RMS EVM, Peak EVM, slot 12: 1.203 4.661%
High edge RMS EVM, Peak EVM, slot 12: 1.203 4.664%
Low edge RMS EVM, Peak EVM, slot 13: 1.211 4.661%
High edge RMS EVM, Peak EVM, slot 13: 1.211 4.664%
Low edge RMS EVM, Peak EVM, slot 14: 1.202 4.661%
High edge RMS EVM, Peak EVM, slot 14: 1.202 4.664%
Low edge RMS EVM, Peak EVM, slot 15: 1.203 4.661%
High edge RMS EVM, Peak EVM, slot 15: 1.203 4.664%
Low edge RMS EVM, Peak EVM, slot 16: 1.221 4.661%
High edge RMS EVM, Peak EVM, slot 16: 1.221 4.664%
Low edge RMS EVM, Peak EVM, slot 17: 1.209 4.661%
High edge RMS EVM, Peak EVM, slot 17: 1.209 4.664%
Low edge RMS EVM, Peak EVM, slot 18: 1.211 4.661%
High edge RMS EVM, Peak EVM, slot 18: 1.211 4.664%
Low edge RMS EVM, Peak EVM, slot 19: 1.191 4.661%
High edge RMS EVM, Peak EVM, slot 19: 1.191 4.664%
Averaged low edge RMS EVM,frame 0: 1.200%
Averaged high edge RMS EVM,frame 0: 1.200%
Averaged RMS 3GPP EVM frame 0: 1.200%
Averaged overall RMS EVM: 1.200%
Peak EVM = 4.6607%
```





SUMMARY

- RF PA‘s use dedicated topologies and linearization to improve efficiency
- Modeling is essential in speeding up development and optimization of RF PA capabilities
  - Predict behavior with different linearization techniques
  - Optimize DPD for a given PA
- Comparison with real world behavior allows qualification of model and DPD possibilities
- Reached goal of faster and more accurate design process for an efficient RF front end

- ***BIG THANKS to Giorgia Zucchelli and Florian Ramian for the hard work to make this happen!***