Tu2A-1

Beam-Dependent Active Array Linearization by Global Feature-Based Machine Learning

M. Mengozzi[1], G. P. Gibiino[1], A. M. Angelotti[1], C. Florian[1], A. Santarelli[1]
[1] DEI, University of Bologna, Bologna, Italy

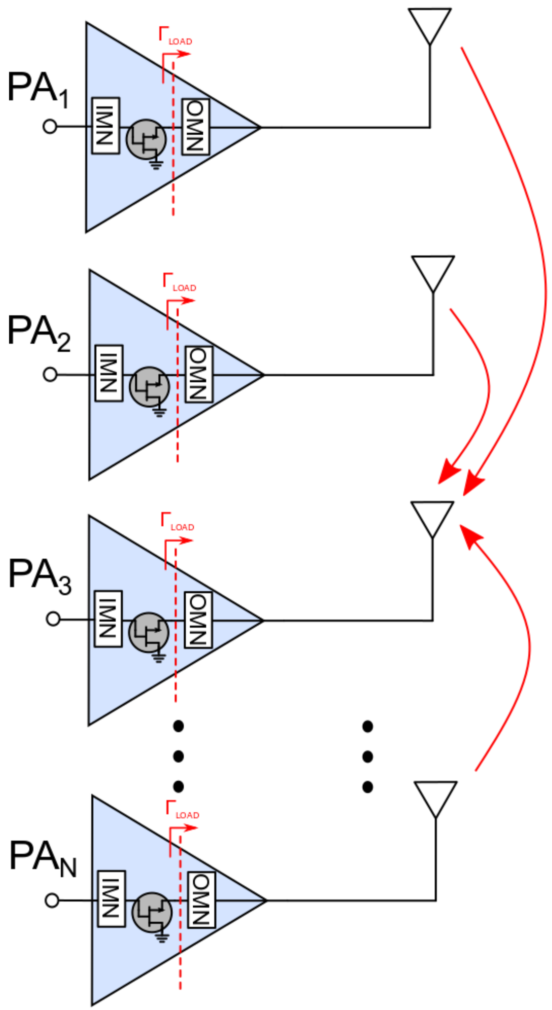
Outline

- Introduction
- Feature-based model reduction
- Beam-Dependent DPD coefficients prediction
- Experimental setup
- Experimental results
- Conclusions

IMS
Connecting Minds. Exchanging Ideas.

Issues in Beamsteering Array

- Active phased array behavior depend on beam angle:
  - Over-the-Air antenna coupling inducing PA load modulation
  - Different response of PAs depending on beam angle
- Digital predistortion (DPD) should encompass
  - Different beam orientations
  - Different input power levels
- Need a strategy for DPD in OTA transmitters

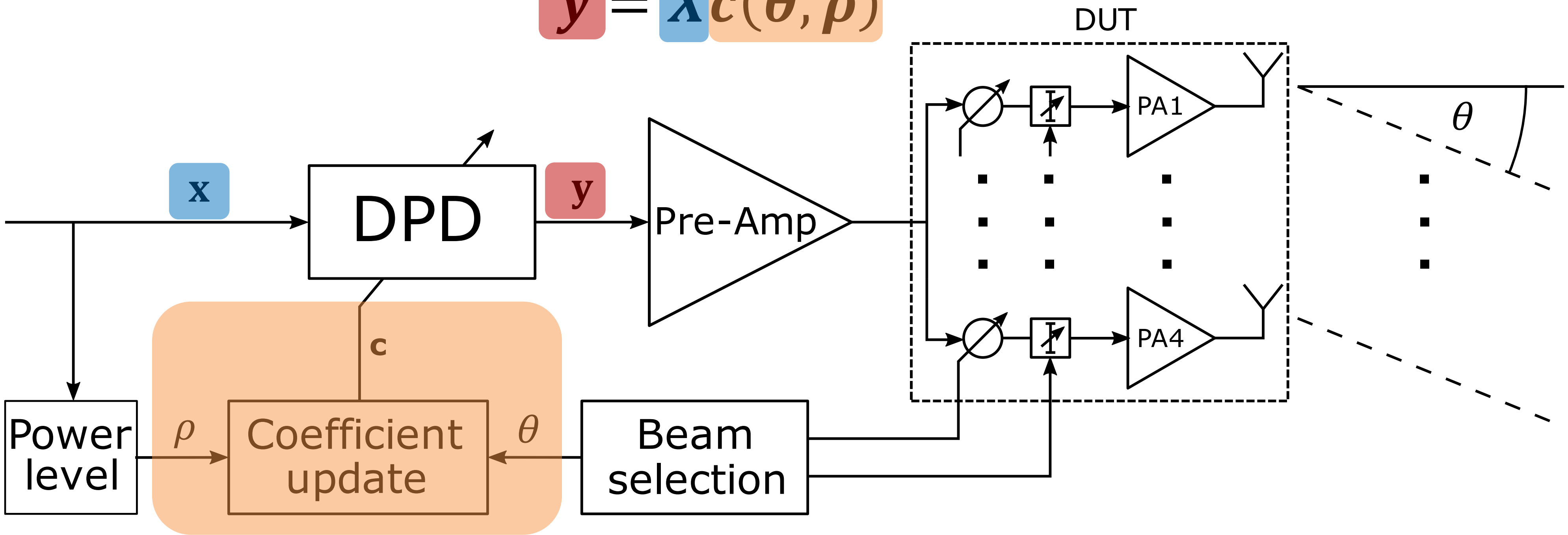


Problem Statement

Predict DPD coefficients while operating conditions change:

- Input signal *x* power level (ρ)
- Beam angle $\boldsymbol{\theta}$

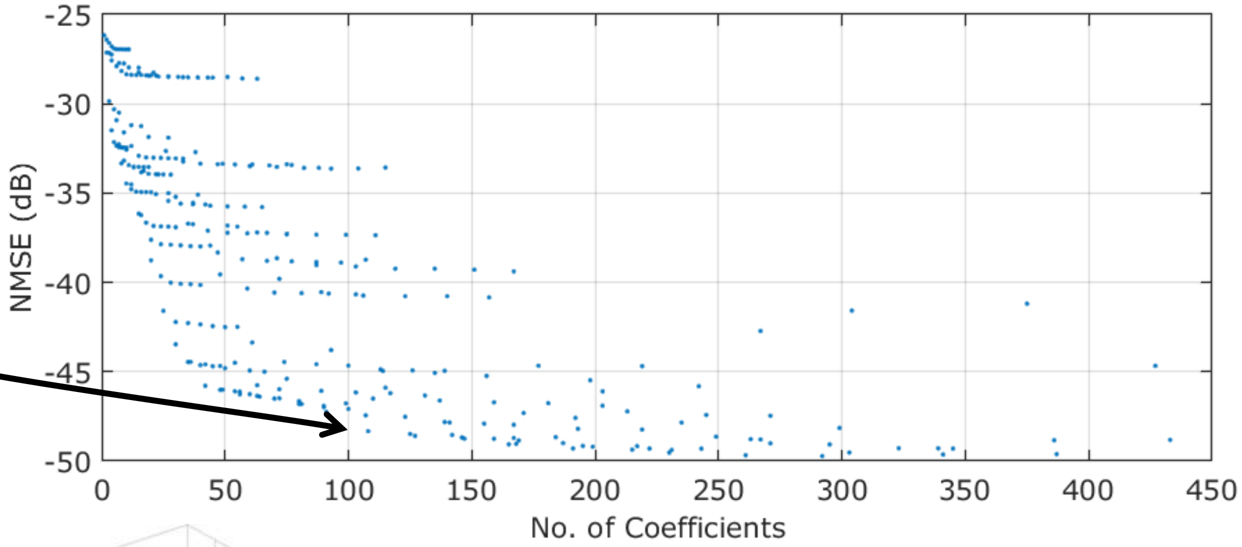
$$\boldsymbol{y} = \boldsymbol{X}\boldsymbol{c}(\boldsymbol{\theta}, \boldsymbol{\rho})$$



Main Challenge: Coefficients Overfitting

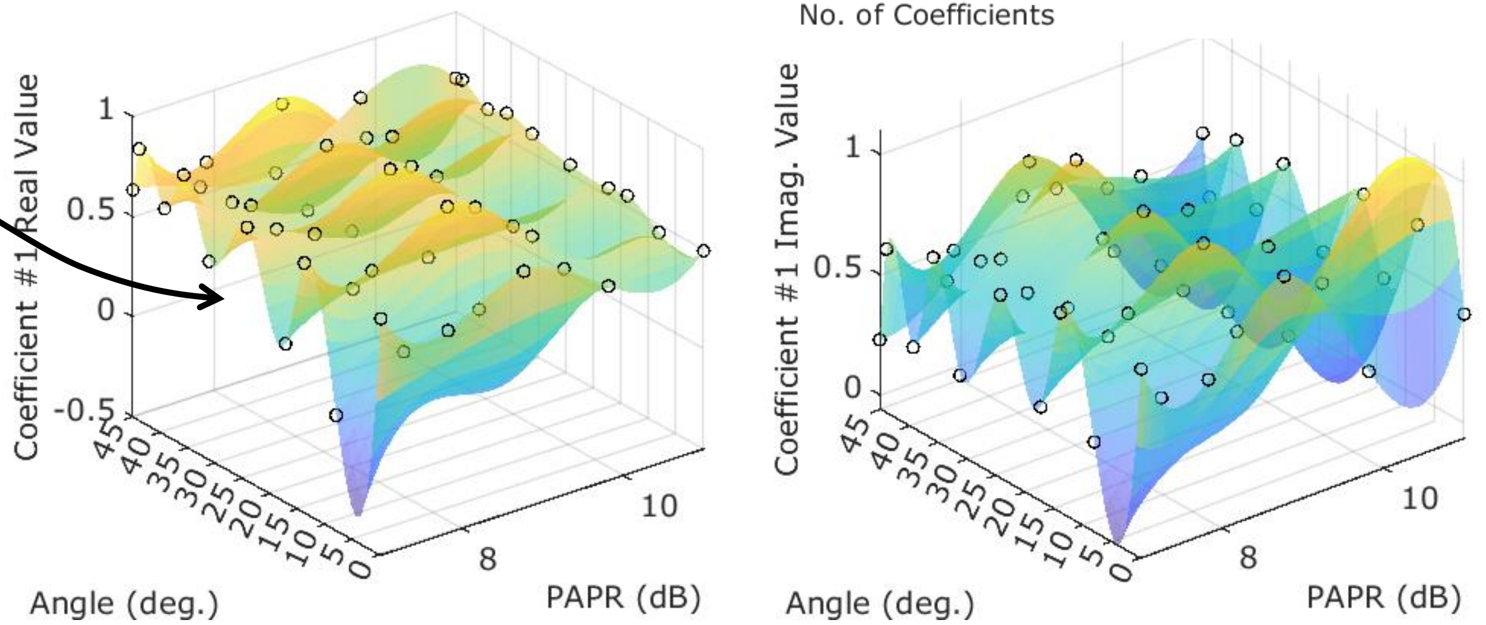
DPD coefficients ***c*** are chosen to minimize fitting error:

- High number of coefficients (> *100*)
- Local minimization → overfitting



Main challenges;

- Unpredictable changes due to overfitting
- Inefficient prediction: every coefficient relationship with operating conditions must be modelled



Feature-Based Model Reduction

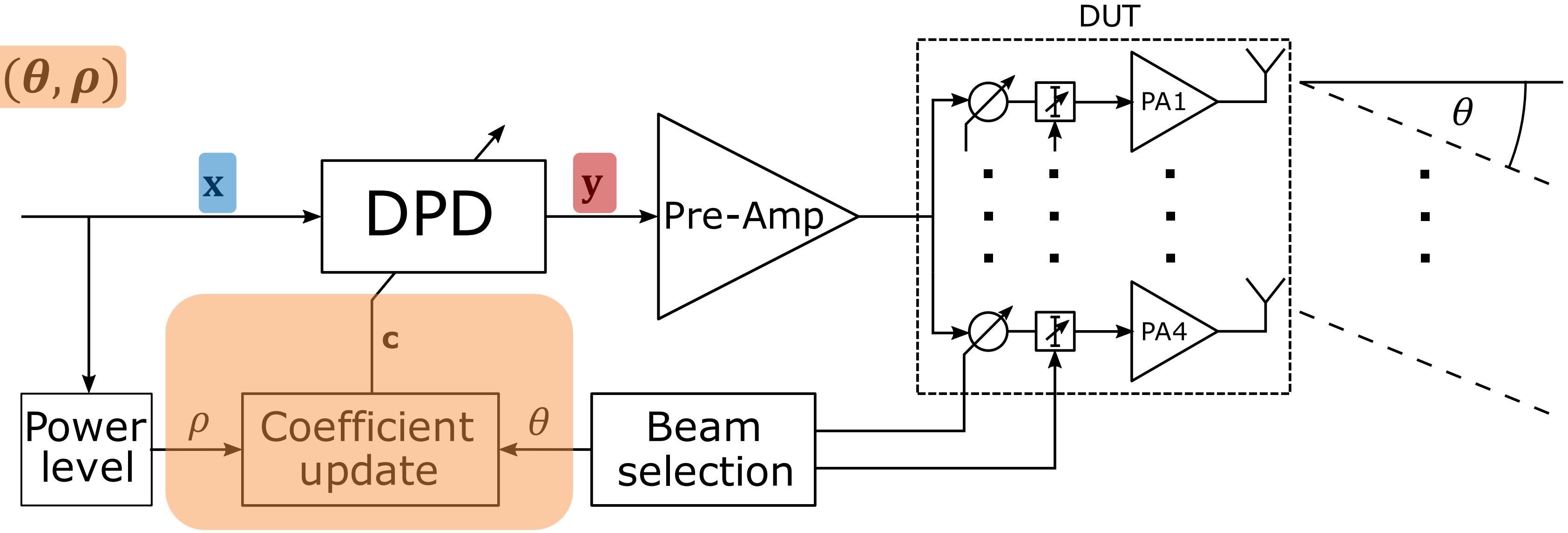
DPD coefficients number is too high to be efficiently predicted among different operating conditions:

- Feature-Based model reduction:

$$\boldsymbol{y} = \boldsymbol{X}\boldsymbol{c}(\boldsymbol{\theta}, \boldsymbol{\rho}) \simeq \boldsymbol{X}\boldsymbol{A}\boldsymbol{\omega}(\boldsymbol{\theta}, \boldsymbol{\rho})$$

- Machine learning derived technique

- *How to identify transformation matrix A?*

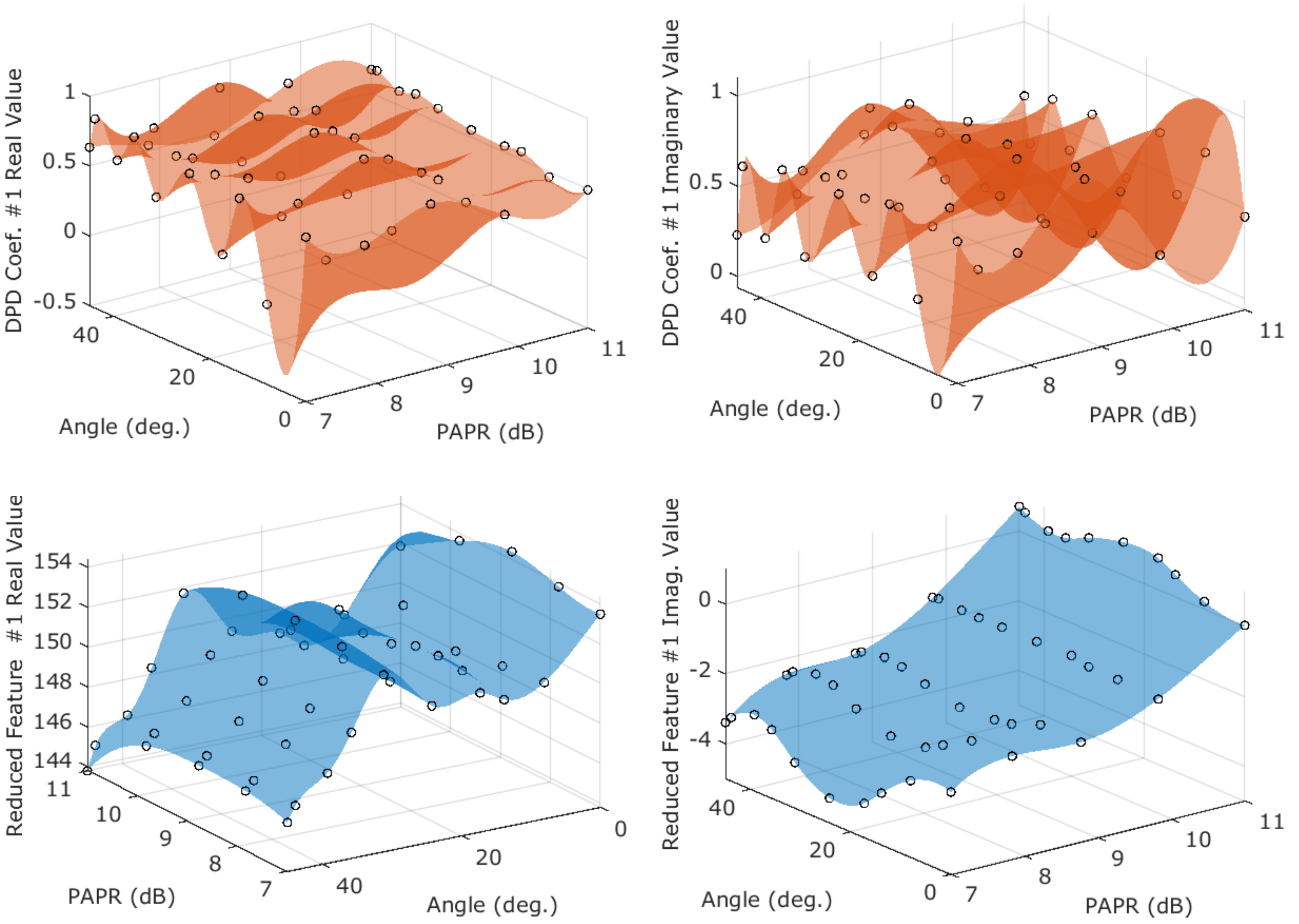


Reduced-Model Interpolation

- Feature reduction allows prediction:

$$y = Xc(\theta,\rho) \simeq XA\omega(\theta,\rho)$$

- 2 interpolation methods tested:
  – Polynomial (Cubic)
  – Cubic spline



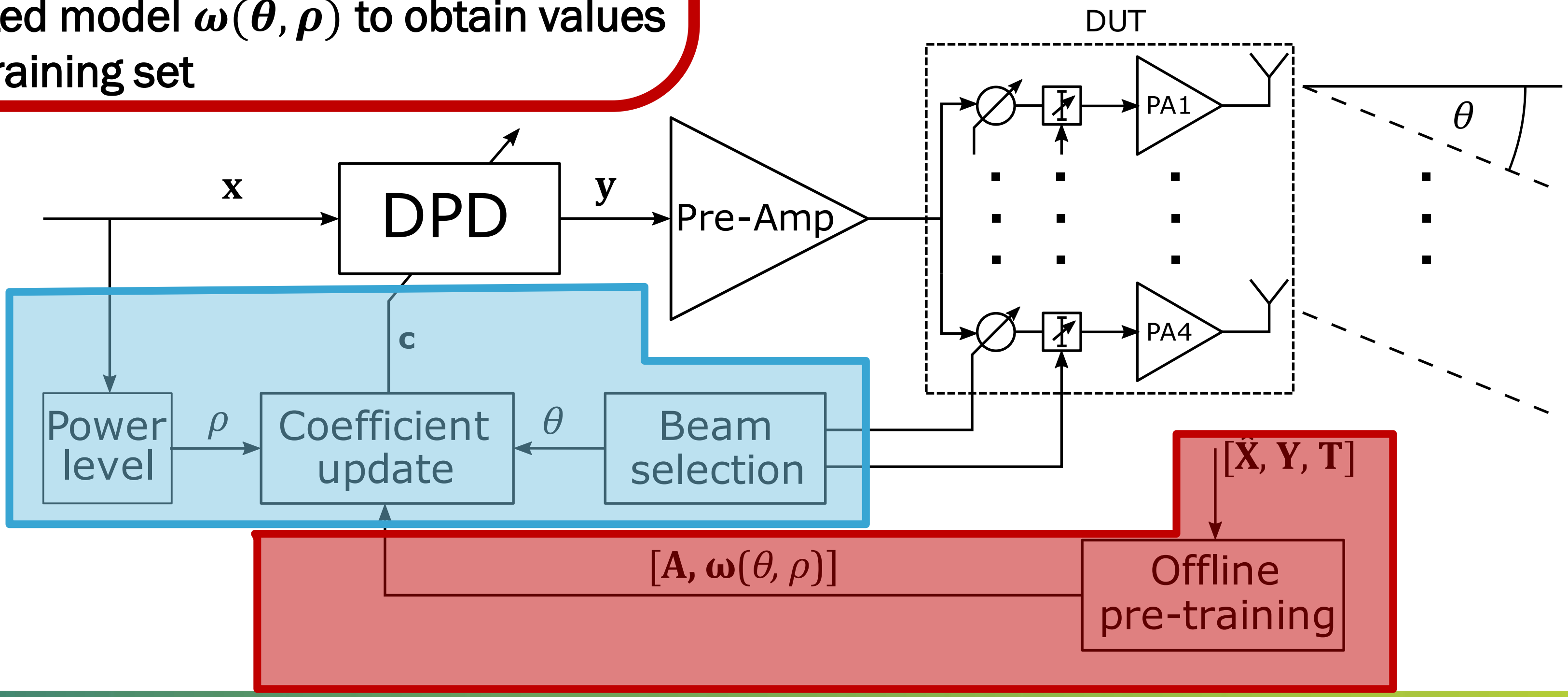
Beam-Dependent Digital Predistortion (BD-DPD)

Offline pre-training procedure:

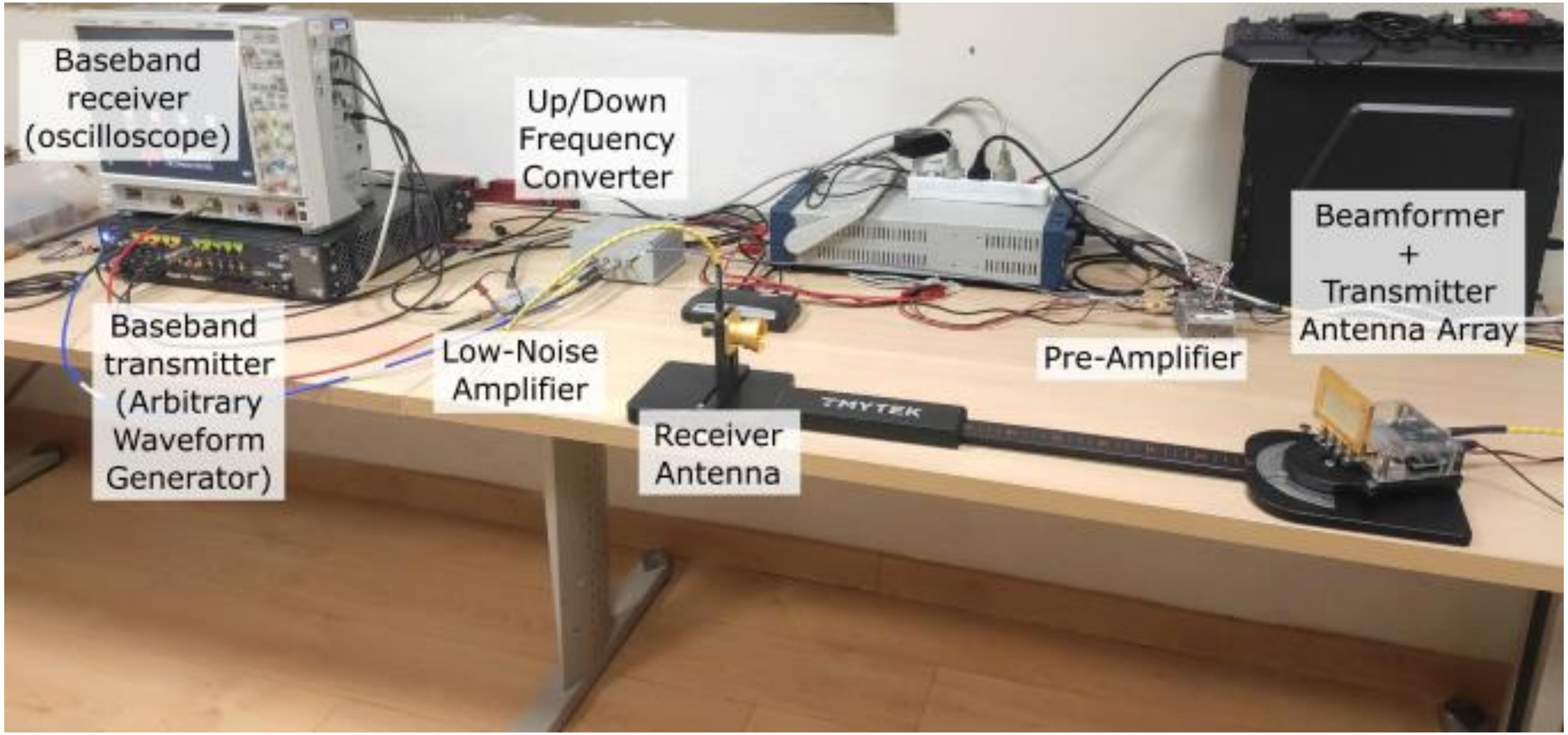
1. Extract DPD coefficients from the pre-training set
2. Calculate transformation matrix A using QR-SVD features reduction
3. Obtain reduced features $\boldsymbol{\omega}$ from the pre-training set
4. Extract interpolated model $\boldsymbol{\omega}(\boldsymbol{\theta}, \boldsymbol{\rho})$ to obtain values outside the pre-training set

Real-time DPD beam adapter operation:

- Predict $\boldsymbol{\omega}(\boldsymbol{\theta}, \boldsymbol{\rho})$ using interpolated model
- Obtain predistorted signal $\boldsymbol{y} = \boldsymbol{XA\omega}(\boldsymbol{\theta}, \boldsymbol{\rho})$
- Open-loop: no feedback in real-time operation



Over-the-Air Measurement Setup

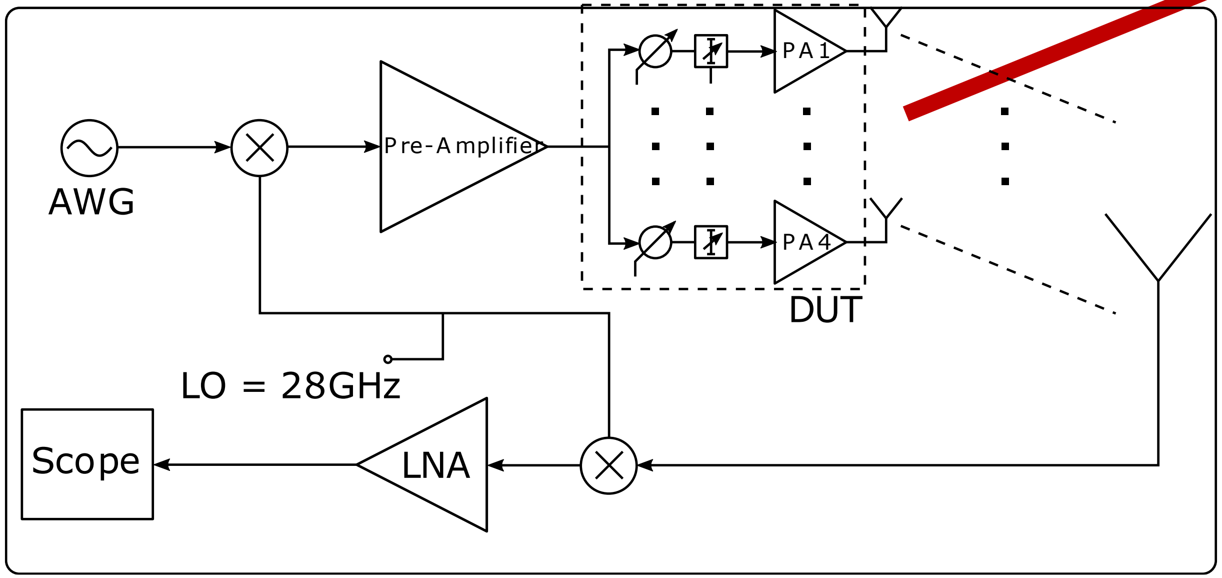


DPD Architecture (Block Diagram)

DPD coefficients extraction:

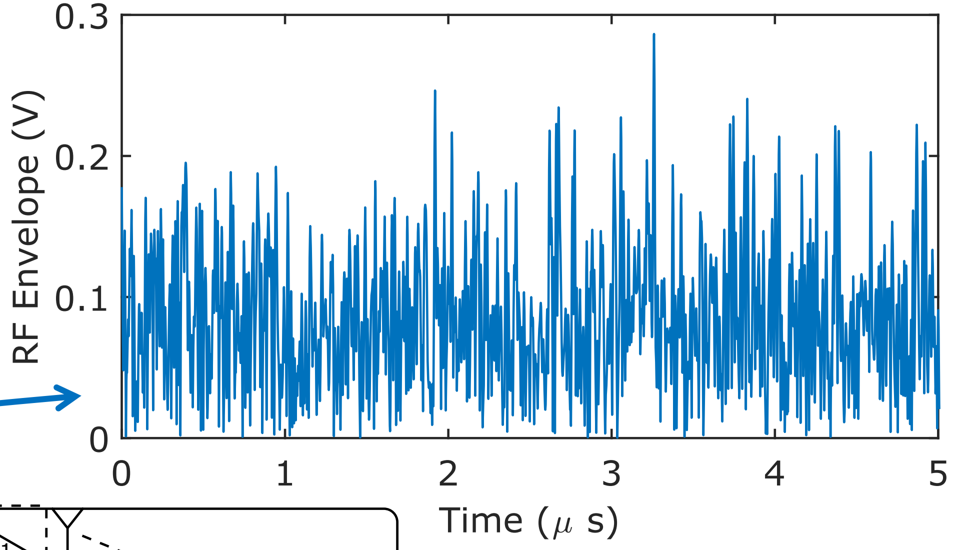
- DPD includes the whole transmitter/receiver hardware
- Generalized Memory Polynomial (GMP) model
- GMP coefficients extracted from iterative learning control predistorted signal

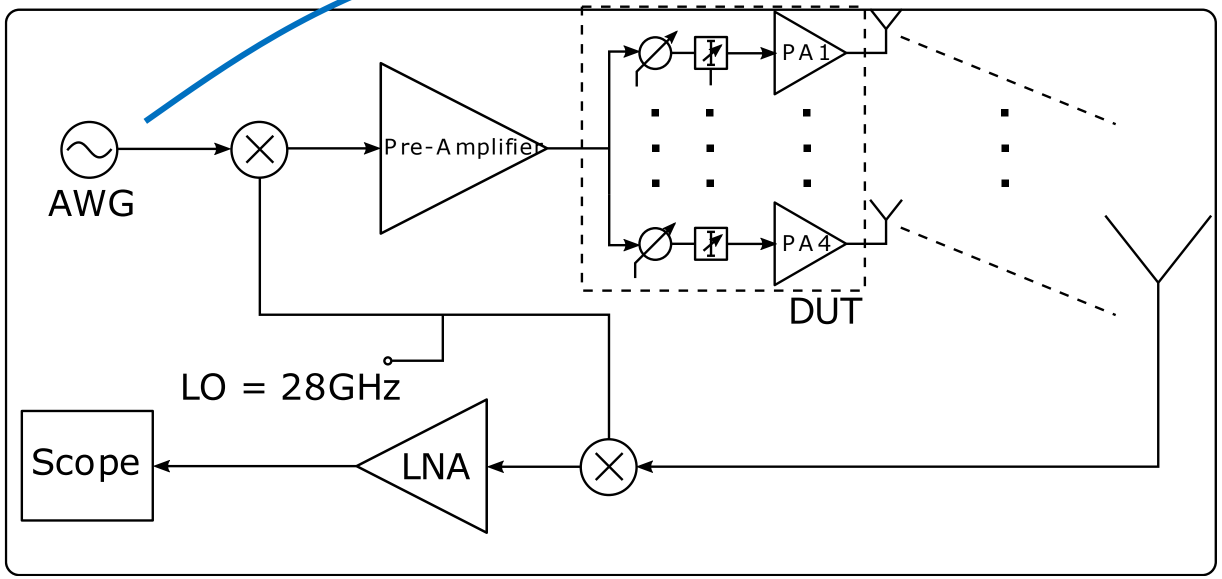
beamformer + antenna array



Test Signals

- Random phase 1k-tone test signals (5G FR2):
  - Bandwidth = 100 MHz
  - LO frequency = 28 GHz
- TX/RX bandwidth = 500 MHz





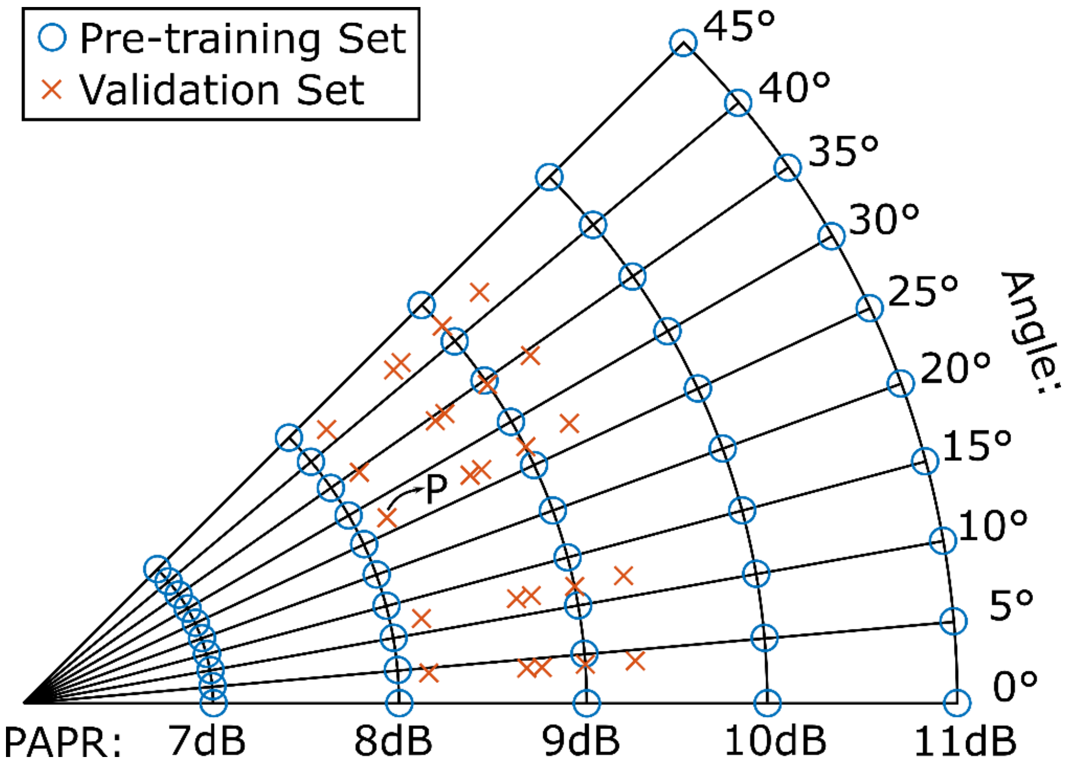
Pre-Training & Validation Set

Pre-training set:

- 5 input signal power levels:
  PAPR = {7, 8, 9, 10 ,11} dB
- 10 beam angles:
  θ = {0, 5, 10, 15, 20, 25, 30, 35, 40, 45} °

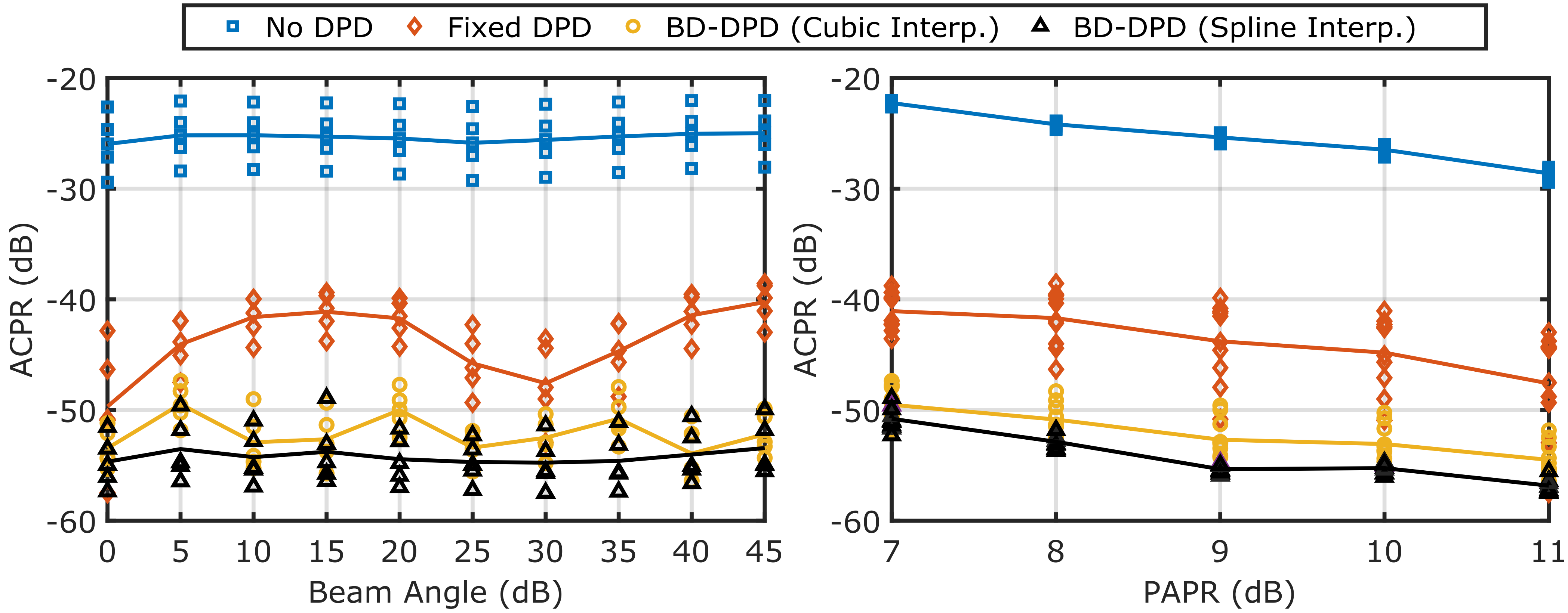
Validation set (to test real-time conditions):

- 5 input signal with random power levels:
  PAPR = {8, 10 } dB
- 5 random beam angles:
  θ = [0, 45] °



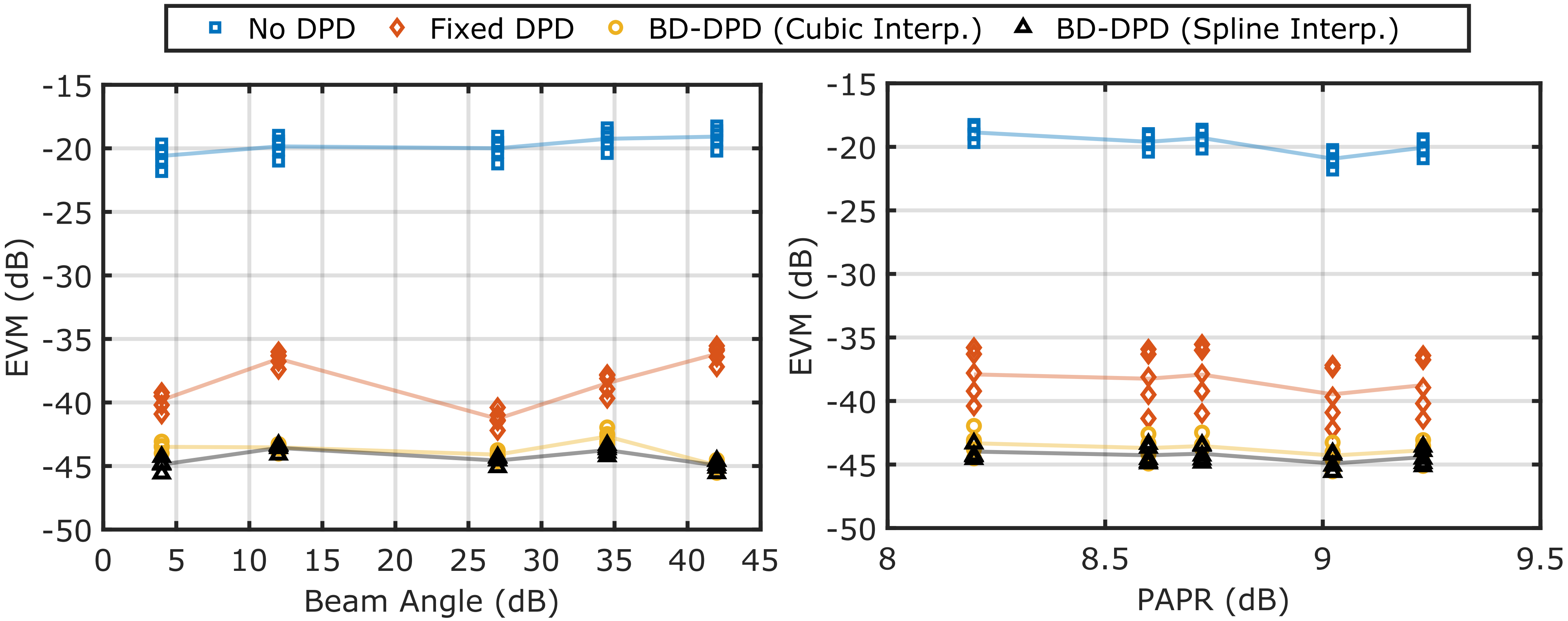
BD-DPD Performance Verification

- Fixed DPD: Unique set of coefficient identified @ 0° and PAPR = 9 dB
- EVM and ACPR PAPR dependency is not appreciably corrected



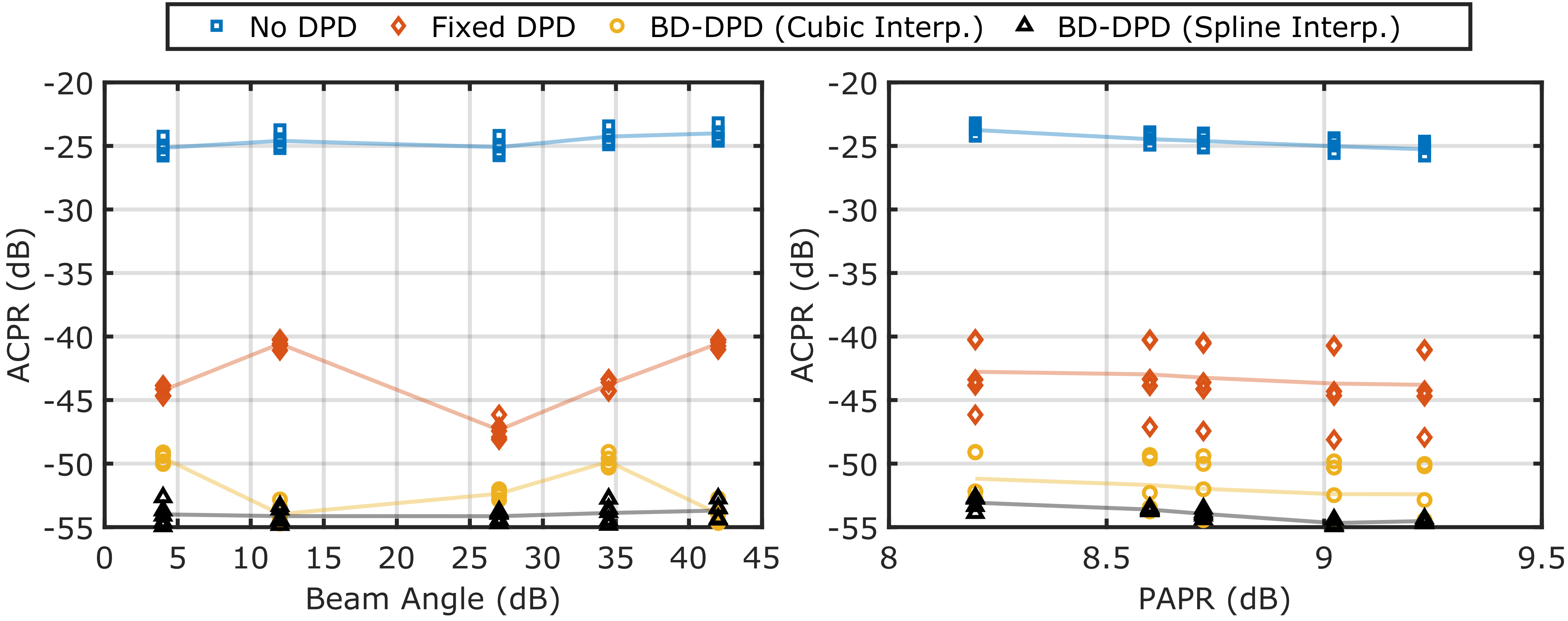
BD-DPD Performance Results (EVM)

The BD method outperforms the comparison with the fixed DPD



BD-DPD Performance Results (ACPR)

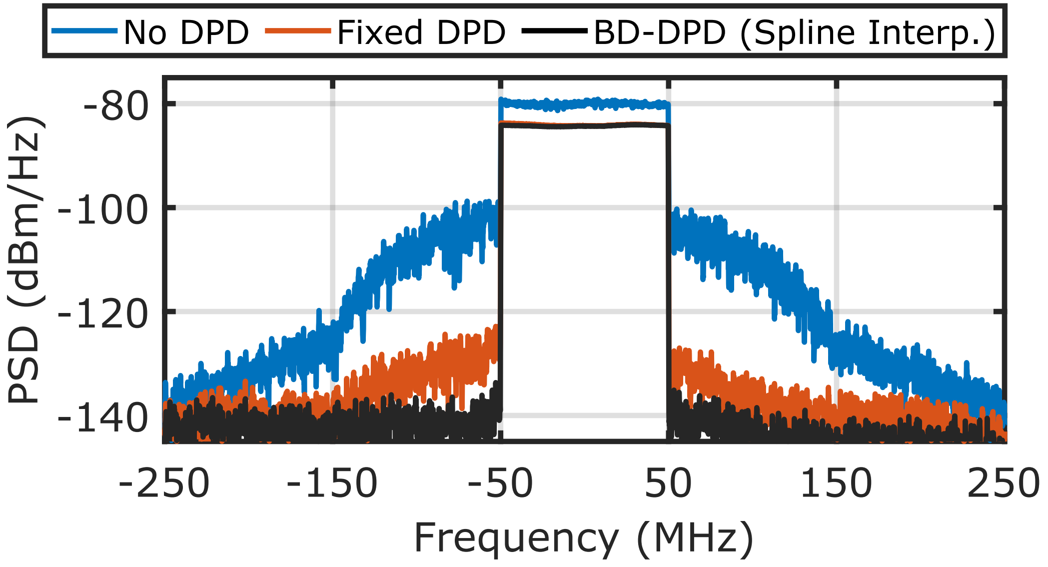
The reduced feature interpolation method has a noticeable effect on performance

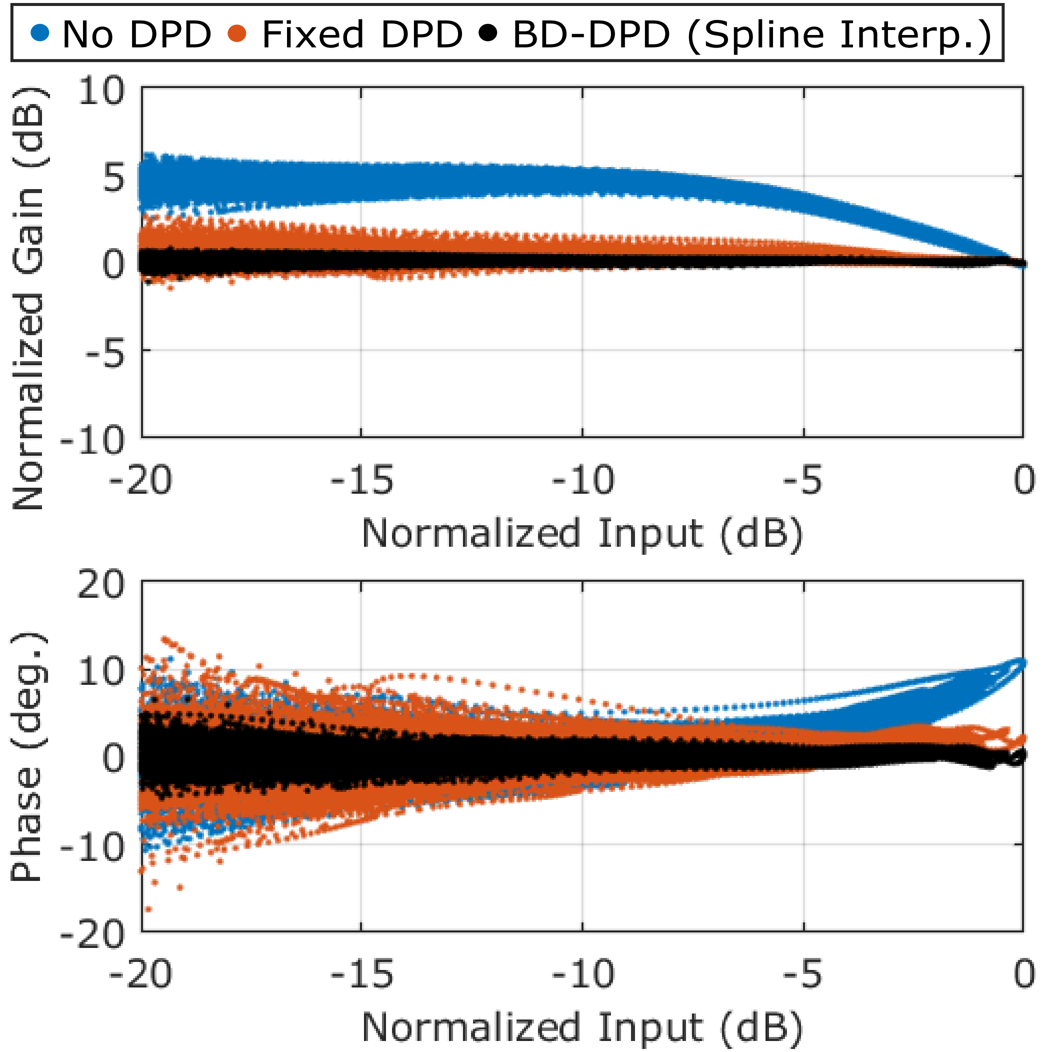


Linearization Performance

Performance in a significative point
(θ = 27 °, PAPR = 8.2 dB):

- No DPD: EVM = -20 dB, ACPR = -25 dB
- Fixed DPD: EVM = -37 dB, ACPR = -47 dB
- BD-DPD: EVM = -43 dB, ACPR = -54 dB





Conclusions

Achievements:

- A BD-DPD architecture exploiting feature-based model reduction for beamformer arrays has been proposed
- Globalization of the DPD model
- Low-complexity update the DPD of the array according to the beam direction and RF power level

Future Work:

- Improve pre-training set with a more efficient design of experiment (Latin Hypercube)

Many thanks to

Vincent Lee (<u>TMYTEK</u>) and

Dion Gallinat (<u>bq-microwave</u>)

for providing the TMYTEK hardware

TMYTEK

bq microwave

Thank You

For Your Attention

Mattia Mengozzi

DEI, University of Bologna, Bologna, Italy

mattia.mengozzi3@unibo.it