Spectral Structure Analysis of FFT-based Digital Predistortion for Wideband 5G Applications

Tayeb H. C. Bouazza, **Dang-Kièn Germain Pham**, Reda Mohellebi, and Patricia Desgreys

C2S Team, ComElec Dept., LTCI, Télécom Paris, Institut Polytechnique de Paris, France

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Outline

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Introduction

In wireless networks, the radio frequency transmitter is an important element.

It must fulfill two criteria:

- Good linearity to avoid distortions and transmission errors
- Good efficiency to reduce energy consumption

In RF transmitters, the RF power amplifier (PA) is a critical component because

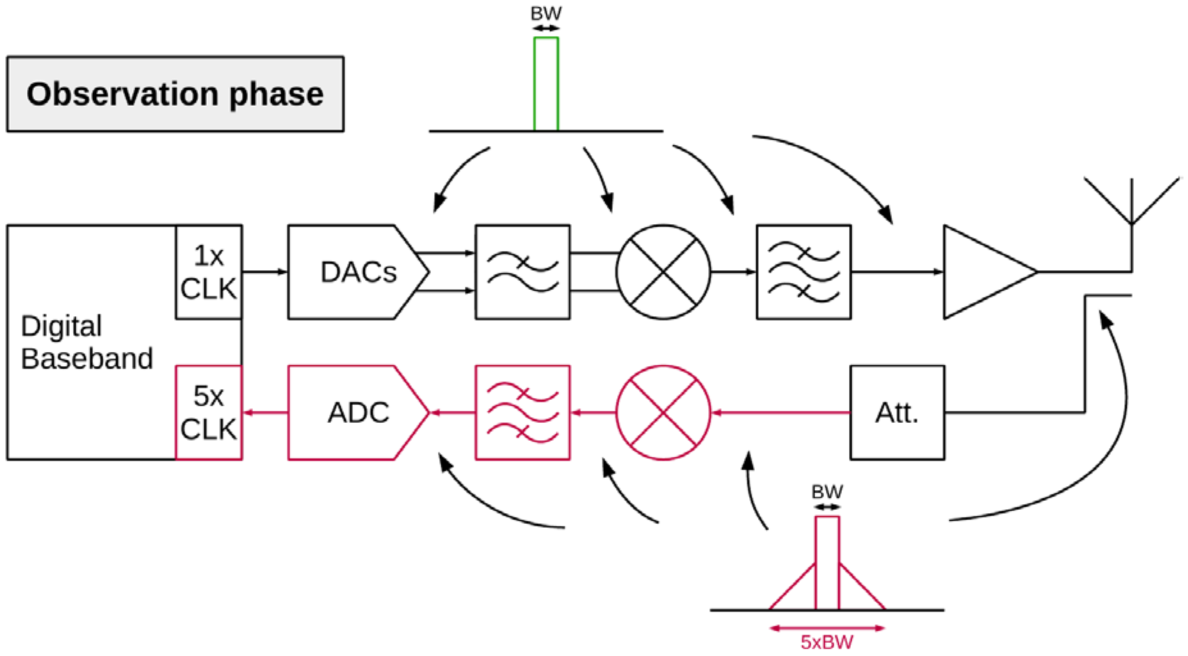
In PA classes, we find:

- **Linear** PAs are **poorly energy** efficient
- **High** efficiency PAs are **non-linear**

Introduction

❑ One solution is to **linearize** a high efficiency **non-linear** PA

- *Baseband Digital PreDistortion (DPD) allows good linearization performances by digital processing on the complex envelope signals without additional RF elements (forward path).*
- *DPD techniques require an accurate capture of the PA output signal with a span over a minimum of five times the input signal bandwidth.*



High dynamic range wideband ADCs:

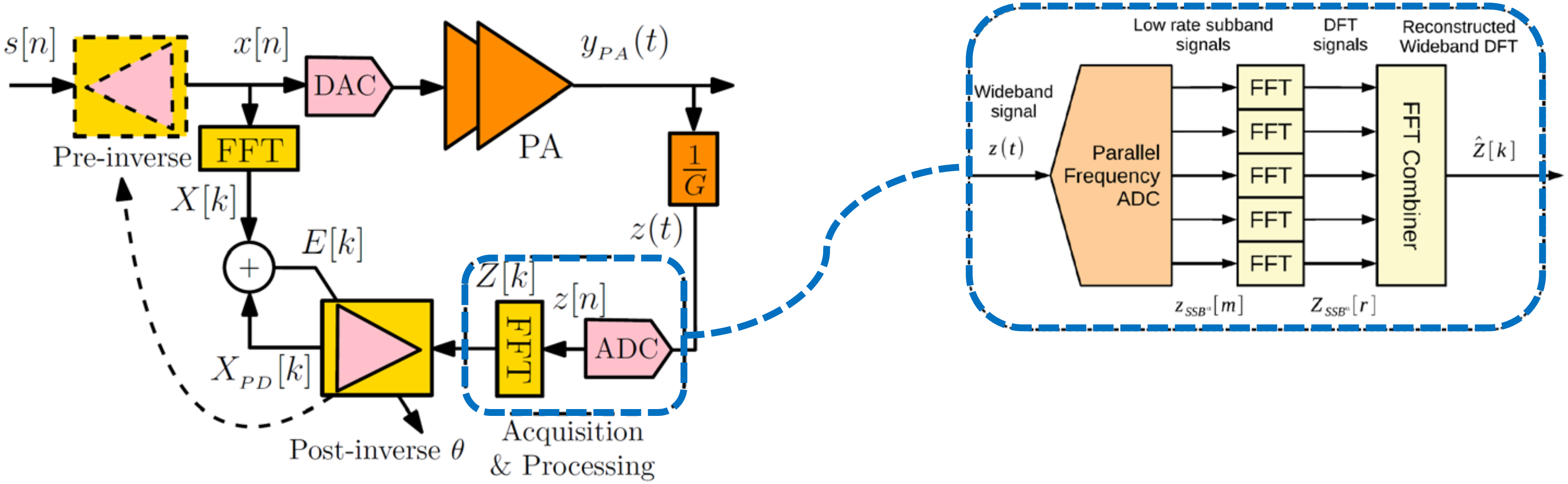
- Complex
- Expensive
- Power-hungry

Introduction – Existing solutions

- Several solutions have been proposed to relax the bandwidth of the feedback path
  - Developing low sampling rate DPD techniques [1-3];
  - Reducing the bandwidth requirements [4-6];
  - Dealing with spectrum as multiple subband (multiple ADCs):
    - *In time-domain as in [7] → Fullband sampling rate or oversampling and interpolation are required*
    - *In frequency-domain as in [8] → Direct identification from the frequency domain is possible*

FFT-based Subband DPD [8]

1. Principle



Using frequency parallel low speed ADCs digitize to PA output signal → *Reconstructing the full spectrum signal using FFT* → *Identification of the DPD in frequency domain using $X[k]$ & $Z[k]$ by means of LS approach*

FFT-based Subband DPD [8]

2. Theory

Case of an Memory Polynomial (MP) model:

Time domain

$$x_{PD}[n] = \sum_{p=0}^{P-1} \sum_{m=0}^{M_h-1} h_{2p+1}[m] v_{2p+1}[n-m]$$

with:

$$v_{2p+1}[n] = z[n]|z[n]|^{\,2p}$$

Frequency domain

$$X_{PD}[k] = \sum_{p=0}^{P-1} \sum_{m=0}^{M_h-1} h_{2p+1}[n] e^{-j\frac{2\pi}{M}nk} V_{2p+1}[k]$$

with:

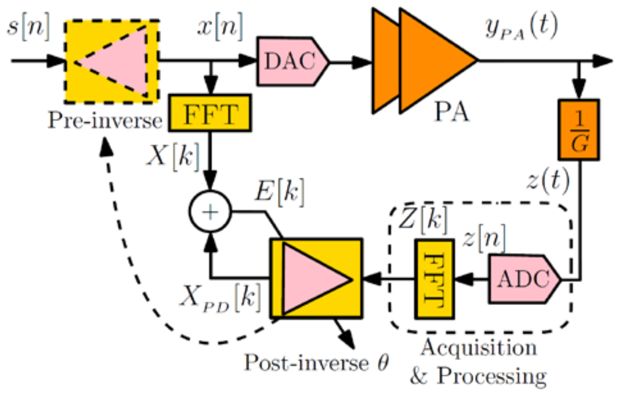
$$V_{2p+1}[k] = DFT\left(v_{2p+1}[n]\right)$$

Identification of complex coefficients:

$$X_{PD}[k] = \sum_{p=0}^{P-1} \sum_{m=0}^{M_h-1} h_{2p+1}[n] e^{-j\frac{2\pi}{M}nk} V_{2p+1}[k]$$

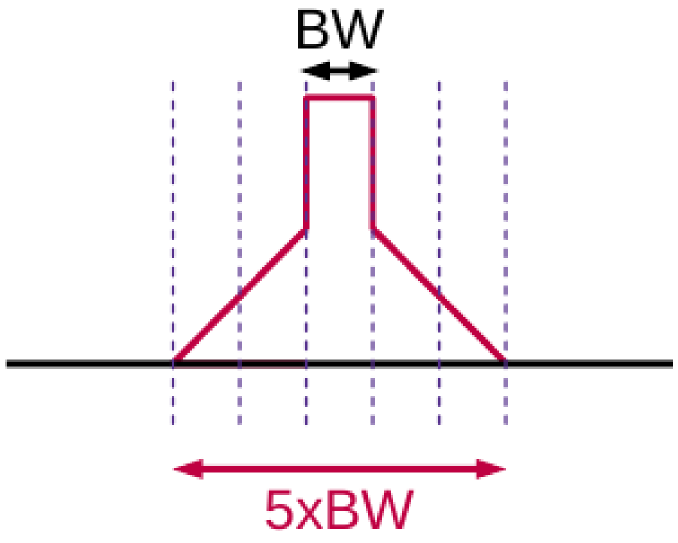
$$\Rightarrow \quad \vec{X}_{PD} = \Phi_V \vec{\theta} \quad \xrightarrow{\text{LS}} \quad \hat{\vec{\theta}} = (\Phi_V^H \Phi_V)^{-1} \Phi_V^H \vec{X}_{PD}$$

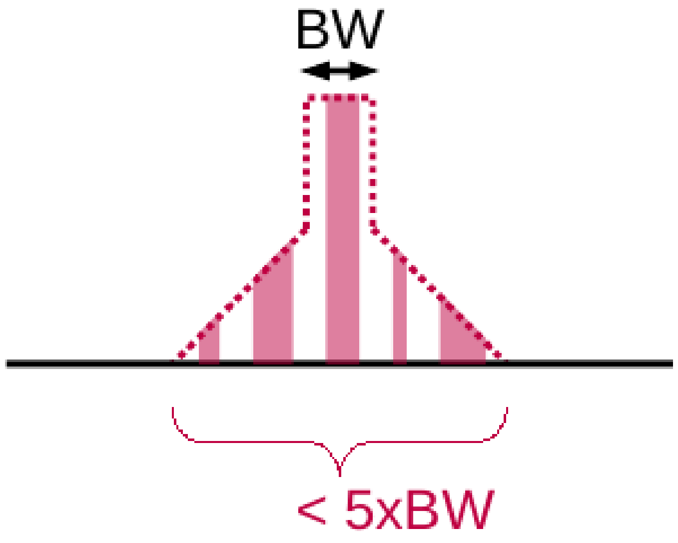
Problem statement



How to relax ADC feedback constraints ?

- Reduce sampling frequency of each subband ADC
  - What is the best sampling scheme of the spectrum ?
  - Full spectrum uniform division ?
  - Scattered acquisition ?

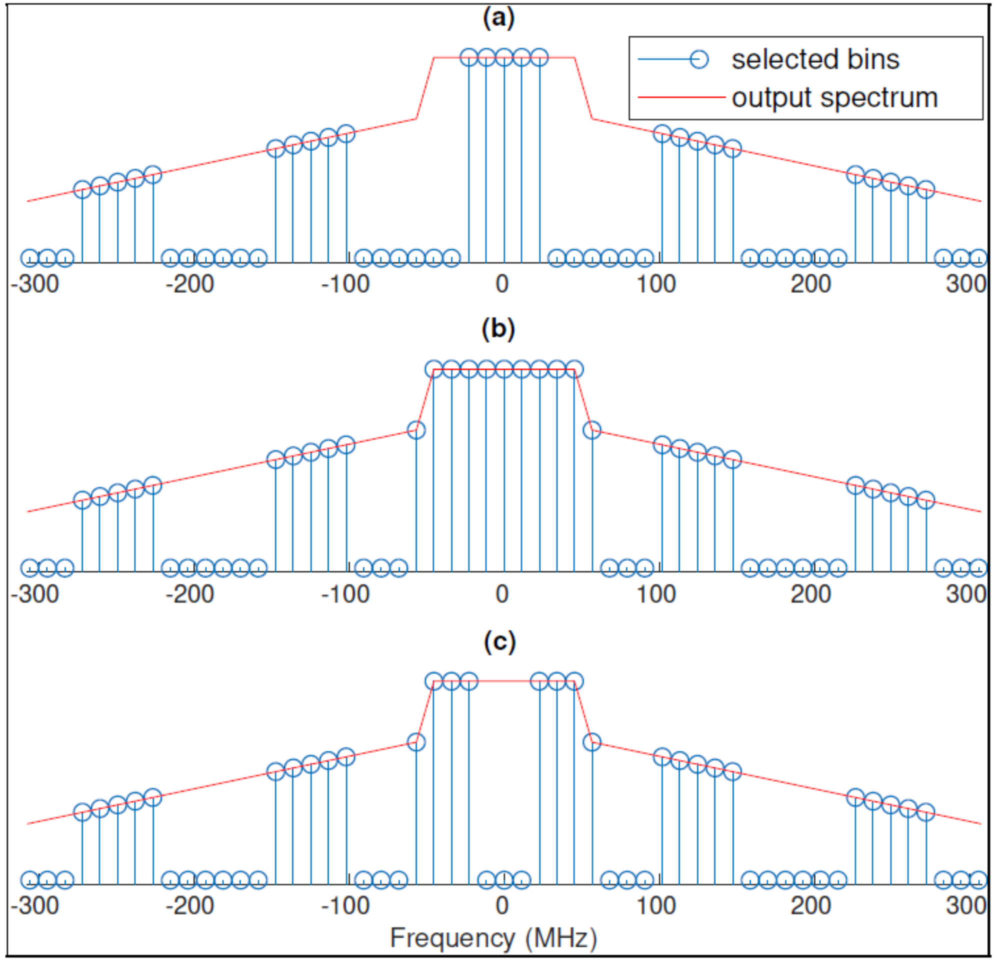




- Are there parts of the spectrum with more significance ?
  - How to quantify ?

Scenarios definition

MC bins selection



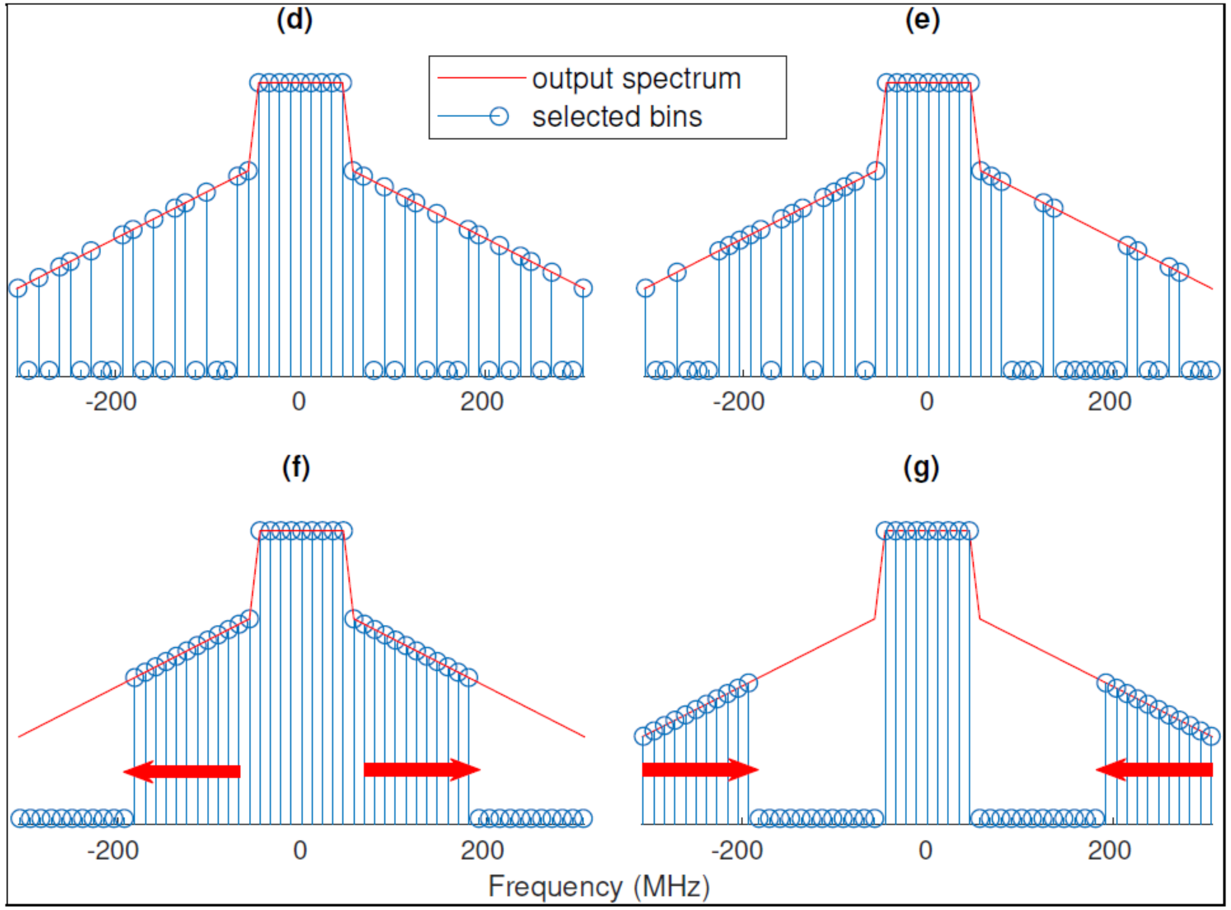
Consider that the spectrum at the PA output is composed of:

- an amplified version of the input signal (MC)
- spectral regrowth in adjacent channels

Selection Scheme		Main Channel		
		Center	*Full*	*Outer Edge*
Adj. Subbands	*Center*	**(a)**	**(b)**	**(c)**

Scenarios definition

Adjacent channels bins selection



Selection Scheme			Main Channel
			Full (Contiguous)
Adj. Subbands	Non-contiguous	*Random*	**(d)/(e)**
	Contiguous	*Close to MC*	**(f)**
		Far from MC	**(g)**

Simulation results and experimental validation

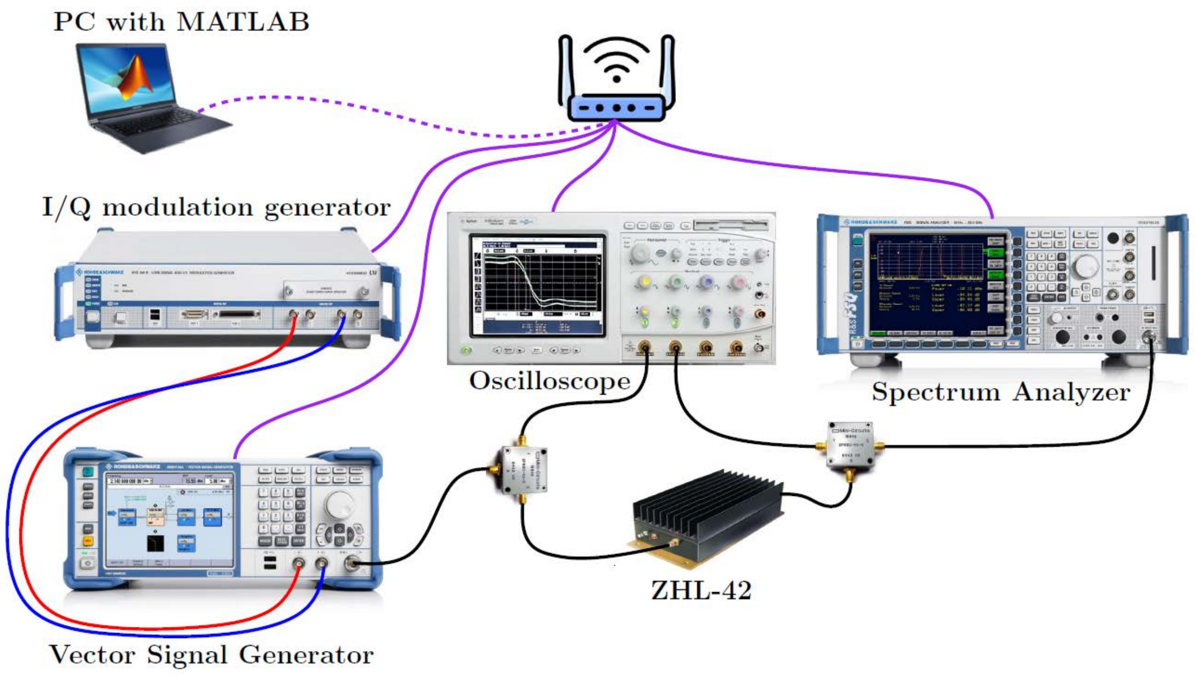
Test bench

Class A RF PA @ 700 - 4200 MHz, 14% of *PAE* and 32.9 dB of gain.

I/Q baseband signals generator

Vector Signal Generator, as an analog modulator

Oscilloscope, to digitize at 20 GS/s the PA's input and outputs RF signals.

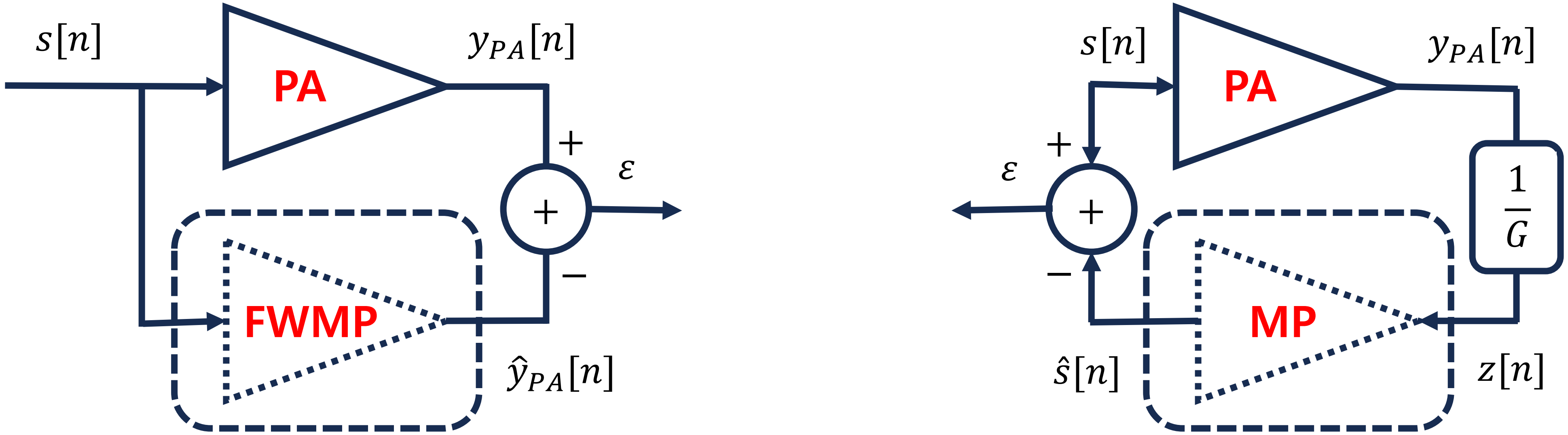


- ✓ *The carrier frequency is fixed to 2140 MHz*
- ✓ *A 40 MHz IBW 5G-like OFDM waveform of a PAPR of 9.34 dB, sampled at 215.04 MHz, is used as the reference signal.*

Simulation results and experimental validation

PA and DPD identification

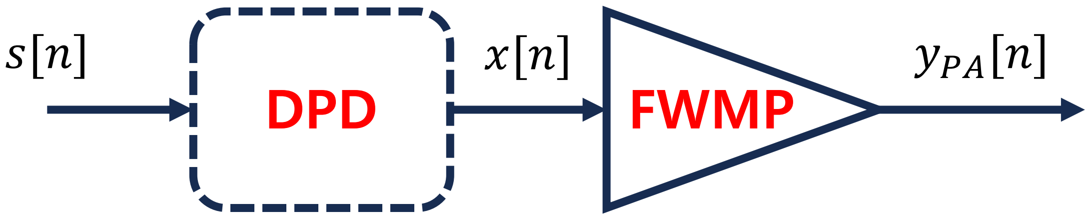
The simulation phase requires an accurate PA model of the DUT



- ✓ *The obtained PA model has a normalized mean square error (NMSE) less than -46 dB*
- ✓ *An exhaustive grid search is performed, using the full bandwidth signal, to optimally size the DPD ($M_h = 2$ and $P = 9$)*

Simulation results and experimental validation

DPD identification performances

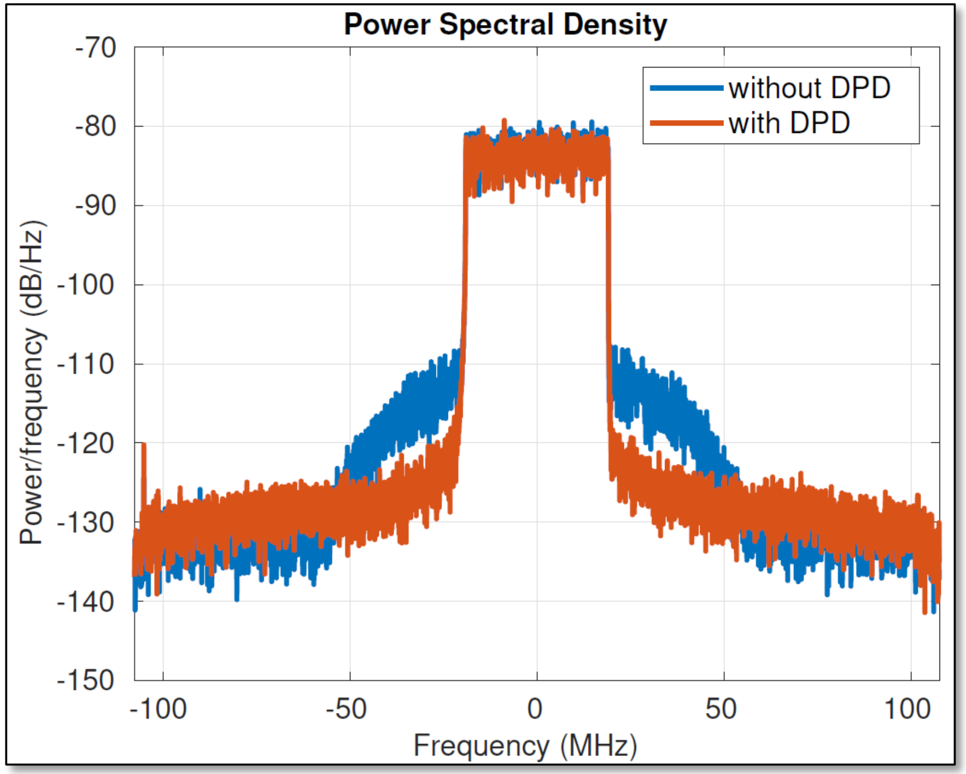


The Adjacent Channel Power Ratio (ACPR) is used to evaluate the performances, as follow:

$$ACPR_{dBc} = \frac{\int_{\Delta W_{MC}} Y(\omega)d\omega}{\int_{\Delta W_{L/U}} Y(\omega)d\omega}$$

with: ΔW_{MC} is the MC bandwidth

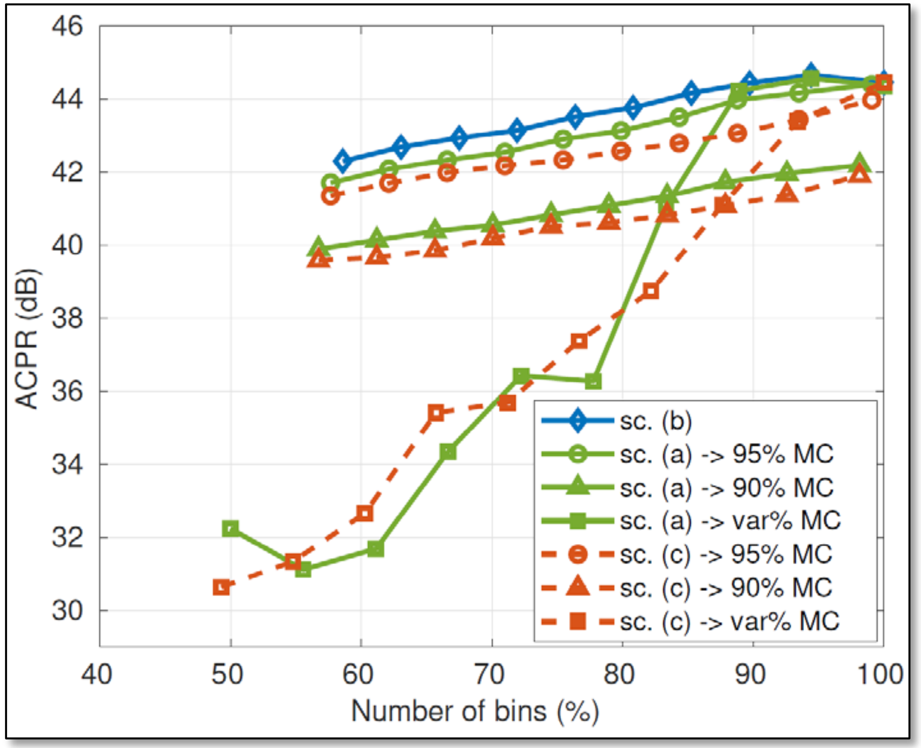
$\Delta W_{L/U}$ is the adjacent channel bandwidths

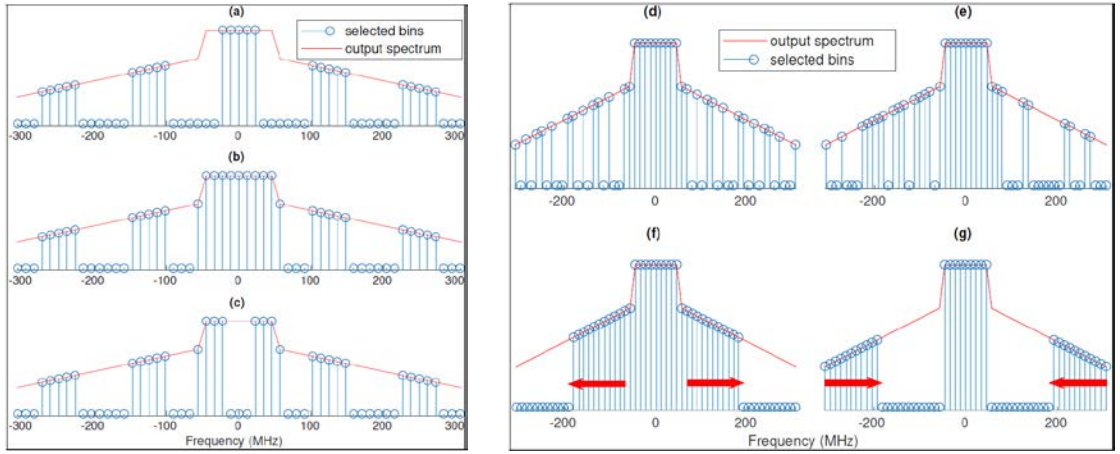


The linearized system improves the ACPR by around 9.7dB

Simulation results and experimental validation

Simulation results

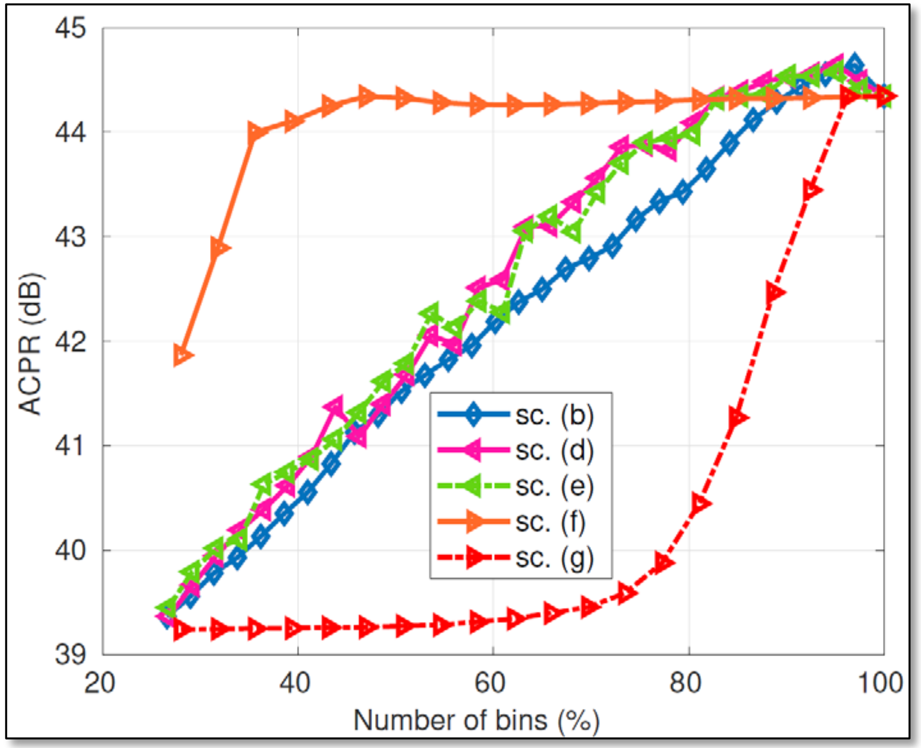


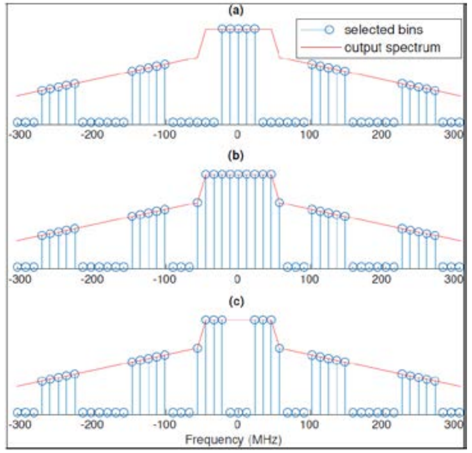


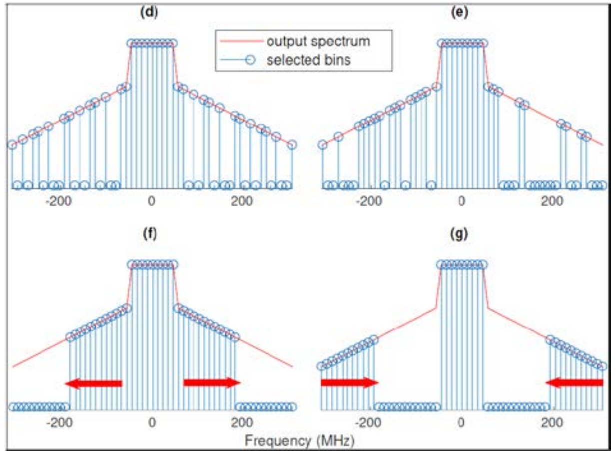
- *Neglecting bins in the MC, either middle or edges, degrades linearization performance*
- *Removing bins from the MC has a stronger impact than removing bins from adjacent subbands*
- *Removing bins from the middle of the MC has a stronger impact than from its edges*

Simulation results and experimental validation

Simulation results





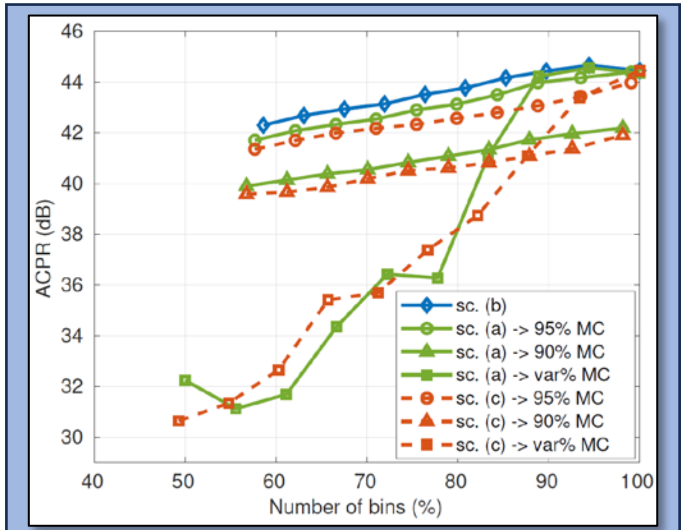


- *Scenarios (d) and (e) are quite similar*
- *Scenarios (d) and (e) are slightly better than the subband contiguous selection in scenario (b)*
- *Neglecting distant bins has no significant effect on linearization performance*
- *Scenario (f) is much better than scenarios (d)/(e) for small number of bins*

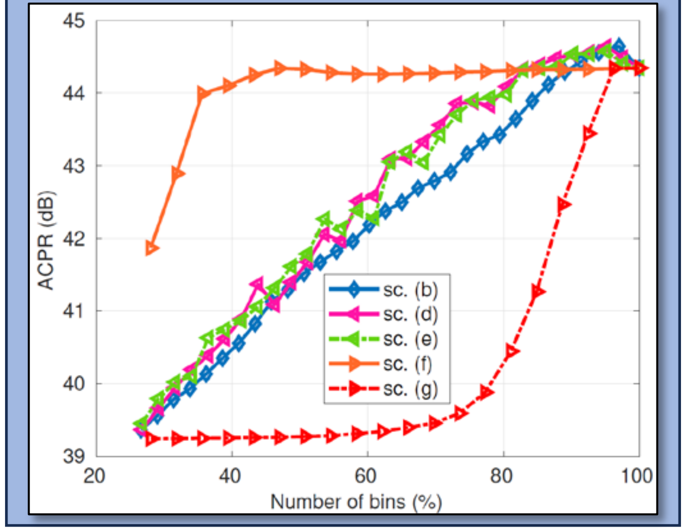
Simulation results and experimental validation

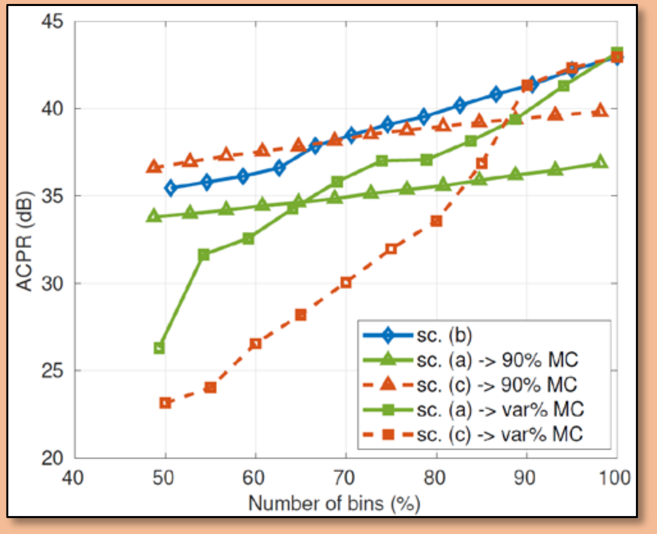
Experimental validation

- *Measurements are slightly below the simulations but the trends are well matching*
- *Scenario (c) is unexpectedly better than scenario (a)*

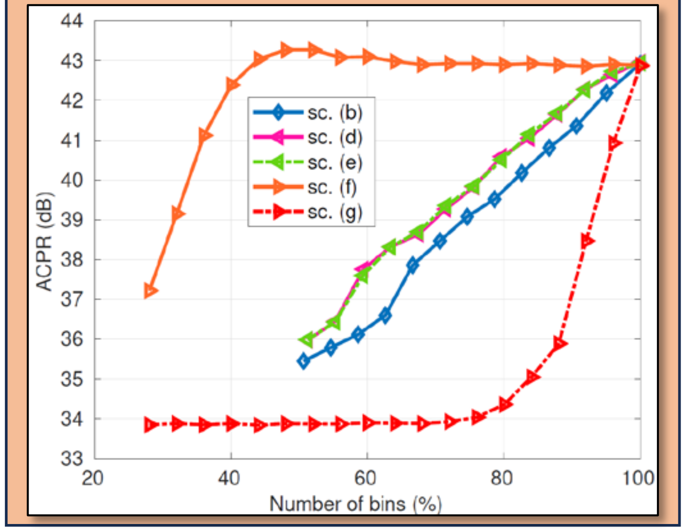


Simulations





Measurements



Conclusion and future works

Conclusion

- A spectral structure analysis of the FFT-based DPD was presented;
- Different scenarios of bins selection were tested to investigate how the information is distributed in the spectrum;
- An analysis was carried out by simulation, then validated by experiments on a real PA;

- ***The MC and its close adjacent frequencies are the most critical spectral zone → Neglecting bins from this zone lead to significant degradation of linearization performances;***

Future works

- Investigate a selection scheme based on the power spectral density of the PA output signal;

Thank you for your kind attention

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