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Empowering Wireless

PA Linearization Technology in 5G NR Small Cells

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Agenda

- Functional Blocks of 5G NR Small Cell

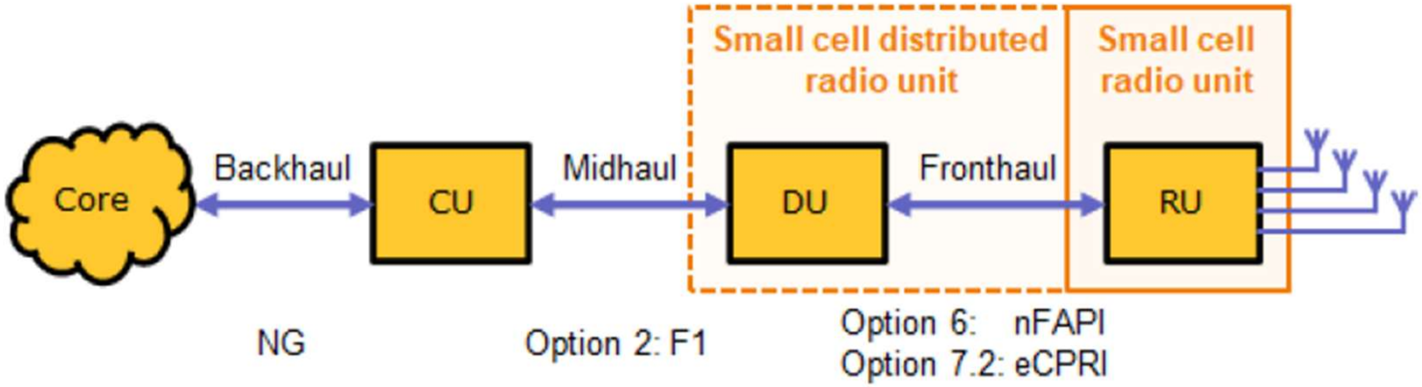
- Importance of PA
  - PA efficiency
  - Linearity

- Techniques to Enhance Efficiency & Linearity
  - CFR (Crest Factor Reduction)
  - DPD (Digital Pre-Distortion)

- RF Front-End Design for DPD
  - OTA self-interference to DPD
  - OTA TX EVM simulation

5G Small Cell Disaggregated RAN

- **Central unit (CU)**, which implements RRC and PDPC functions and interfaces to the core network over the 3GPP F1 interface.
- **Distributed unit (DU)**, which implements RLC, MAC and optionally PHY functions (complete PHY for Split-Option-8, Upper-PHY for Split-Option-7.2).
- **Radio unit (RU)**, which implements some PHY functions (Lower-PHY for Split-Option-7.2, complete PHY for Split-Option-6), and integrates physical radios and antennas. The RU interfaces to the DU using either nFAPI as specified in SCF225[3] or eCPRI as used in the Open Fronthaul specified by the O-RAN Alliance [4].

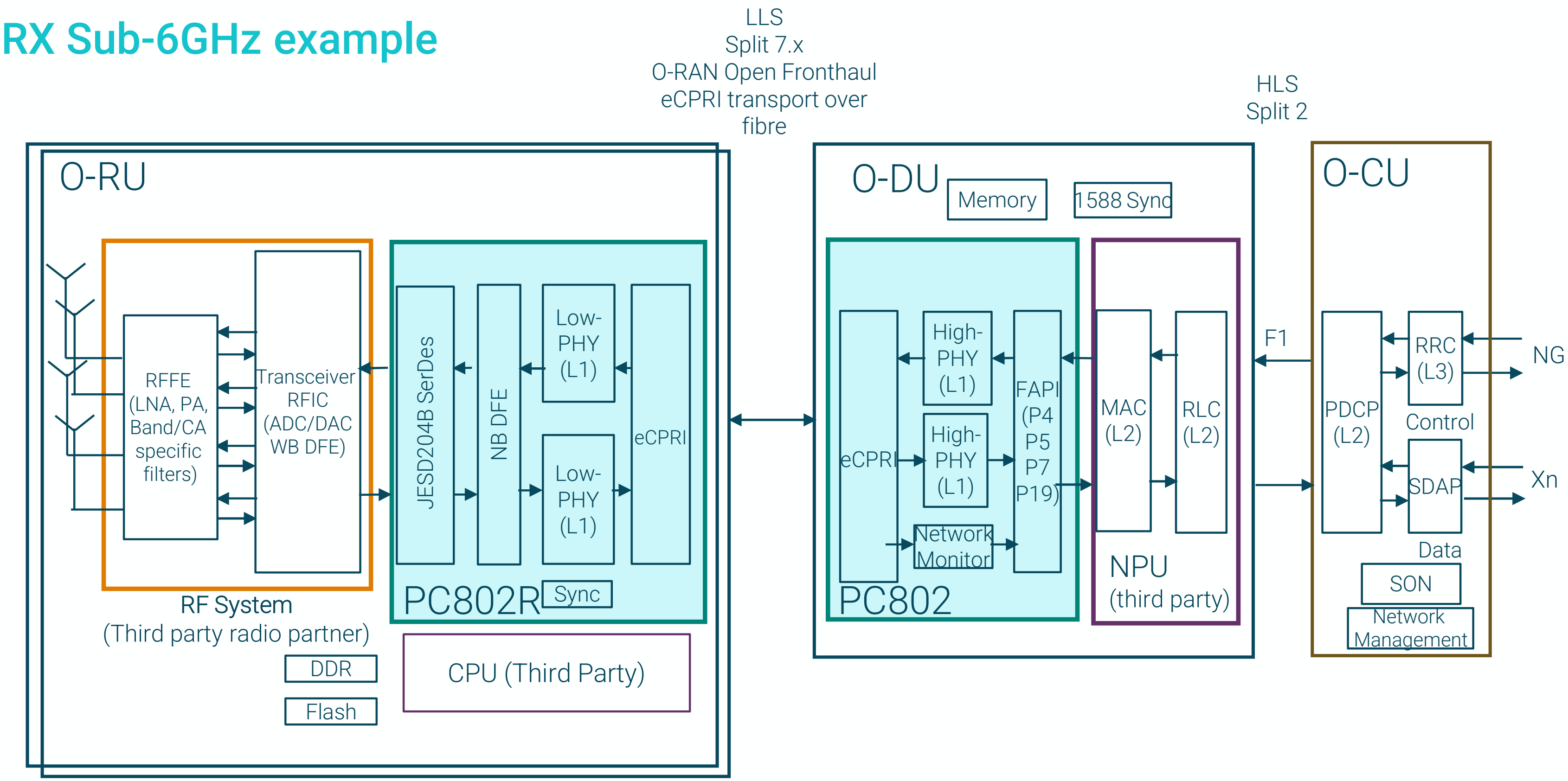


Option 8: CPRI

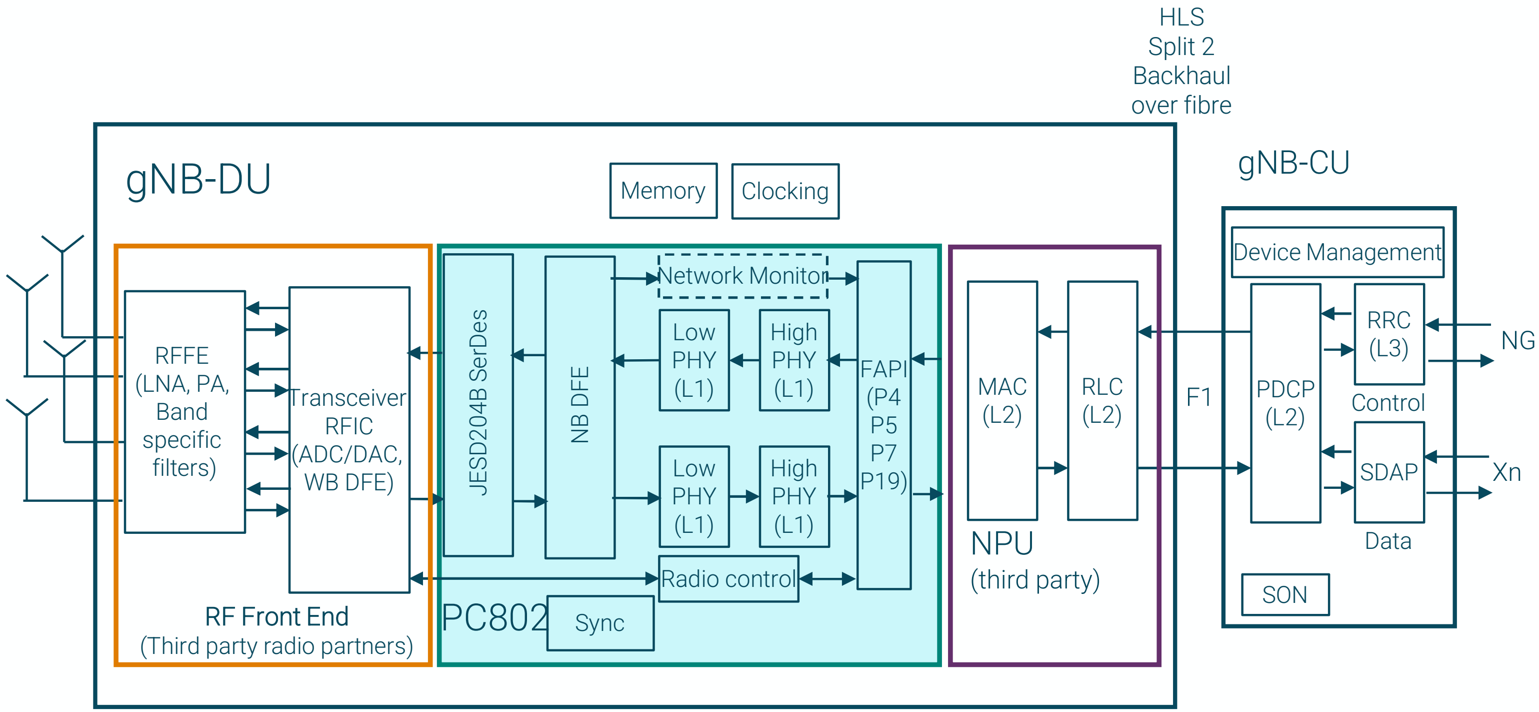
Source: scf251_5g_nr_fr1_reference_design_DEC-2021

Picocom PC802 in O-RU and O-DU

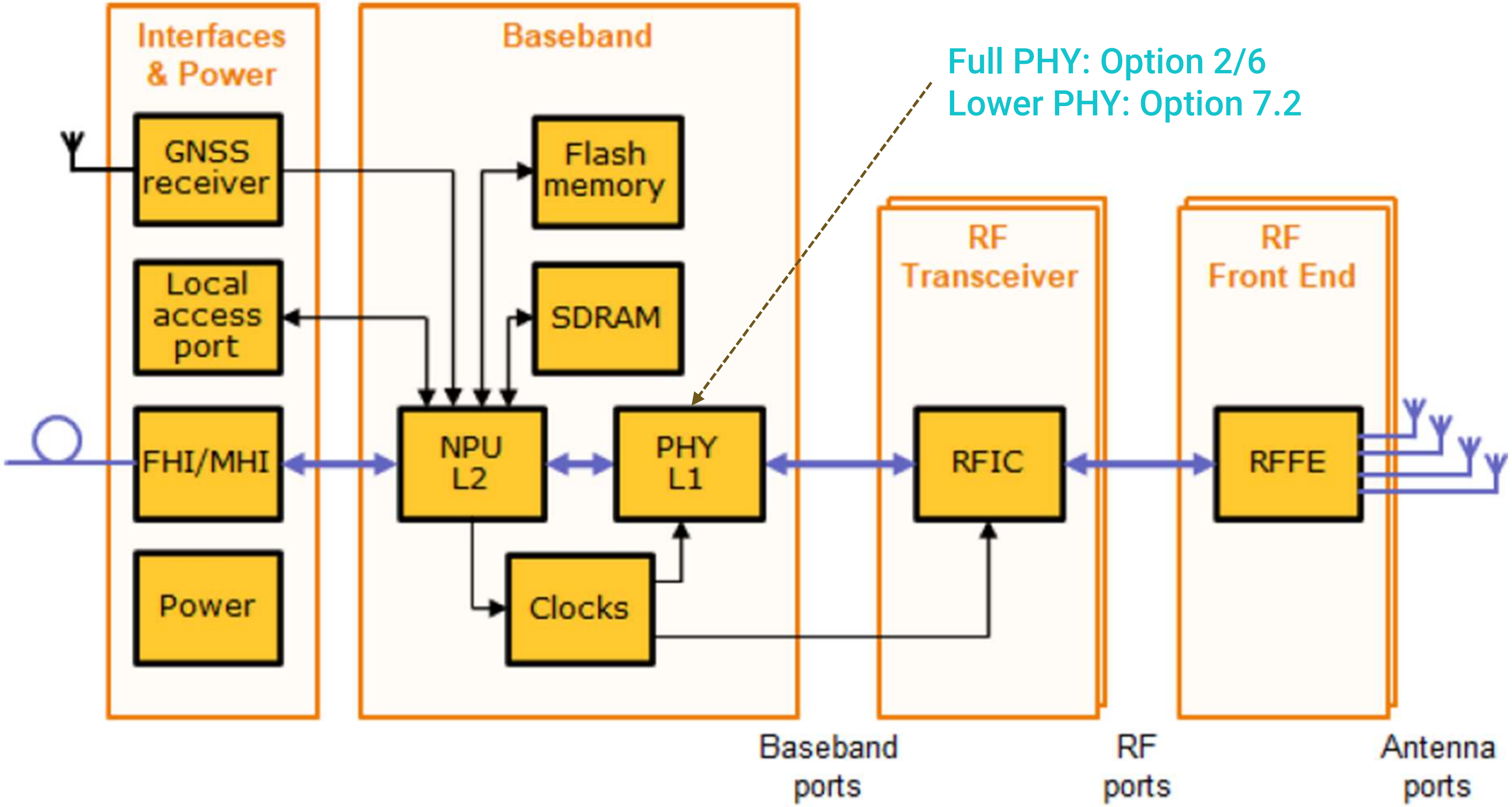
4TX4RX Sub-6GHz example



Picocom PC802 in 3GPP Split 2 gNB-DU



5G Small Cell Functional Blocks – Option 2/6/7.2



Source: scf251_5g_nr_fr1_reference_design_DEC-2021

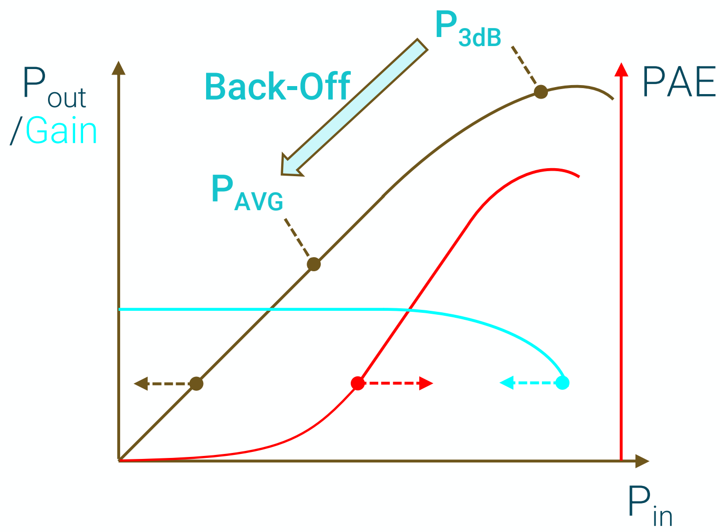
5G NR Small Cell PSU Options

Type	Voltage	Delivered Power	Application
DC adaptor	12-24V	≤60W	Indoor residential small cell
PoE 802.3af Type 1 PoE 802.3at Type 2 PoE 802.3bt Type 3 PoE 802.3bt Type 4	37-57V 42.5-57V 42.5-57V 41.1-57V	≤12.95W ≤25.5W ≤51W ≤71W	Indoor enterprise small cell with Cat5e/6a cabling
Hybrid fibre/power (currently no specification)	100V	>100W	Outdoor small cell
High power DC	<60V	>100W	Outdoor small cell
Mains (AC)	110-240V	>100W	Outdoor small cell

Source: scf251_5g_nr_fr1_reference_design_DEC-2021

Power-Added Efficiency (PAE)

- $\eta = (\frac{P_{out} - P_{in}}{P_{DC}}) * 100\%$
  - P_{out} = output power (Watts)
  - P_{in} = input power (Watts)
  - P_{DC} = DC power consumption (Watts)
    - All are average power by RMS



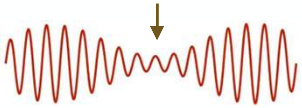
- The higher the output power, the higher the PAE
  - For single-carrier PM, $P_{out} = P_{3dB}$ (e.g IEEE 802.11b)
  - For OFDM, $P_{out} = P_{AVG} = P_{3dB}$ – PAPR ← Power Back-Off
    - The lower the PAPR, the higher the PAE

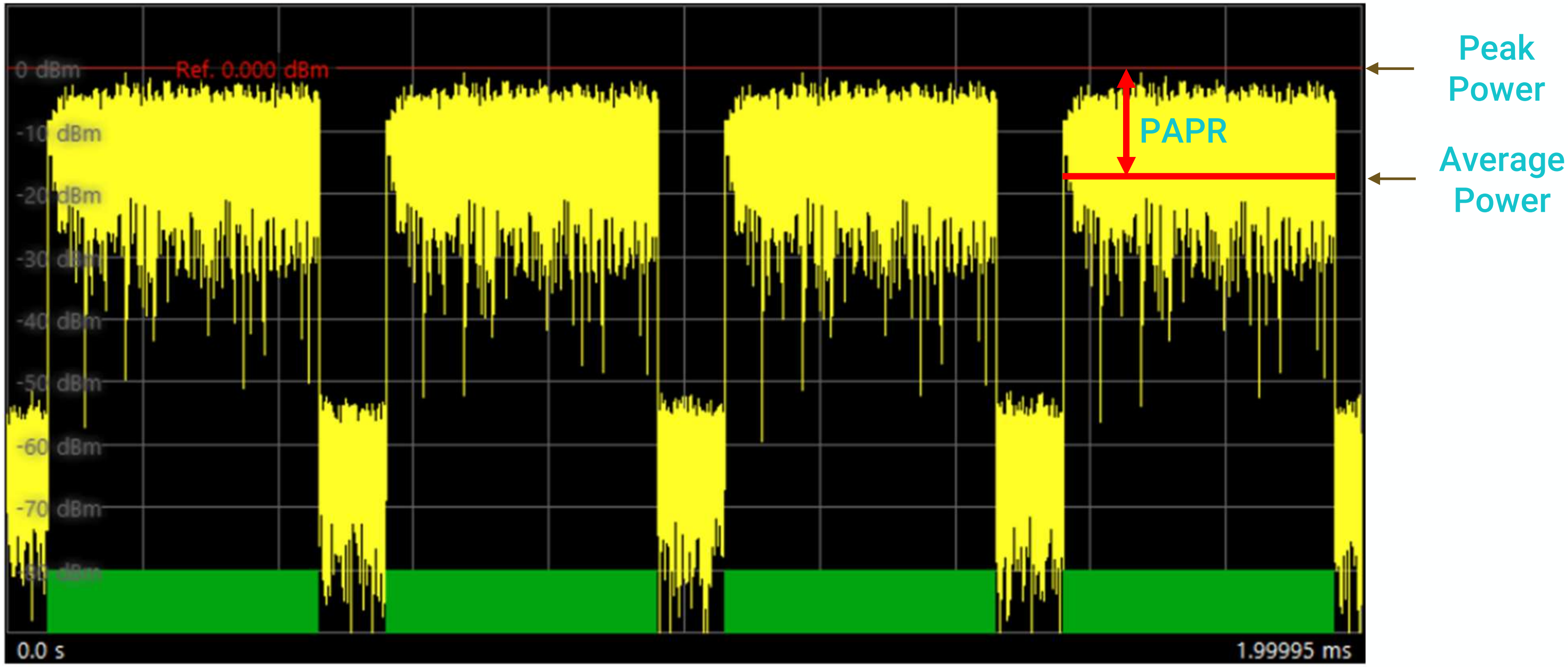
- How to decide P_{3dB} ?
  - $P_{3dB} = P_{AVG}$ + PAPR, where PAPR is 8.5dB ~ 9.5dB. (e.g 36dBm = 4 Watts = 27dBm + 9dB)
  - An over-kill PA results in lower PAE

PAPR (Peak-to-Average Power Ratio)

- OFDM Power vs. Time

Envelope





Source: R&S®FSW-K96 OFDM VSA user manual

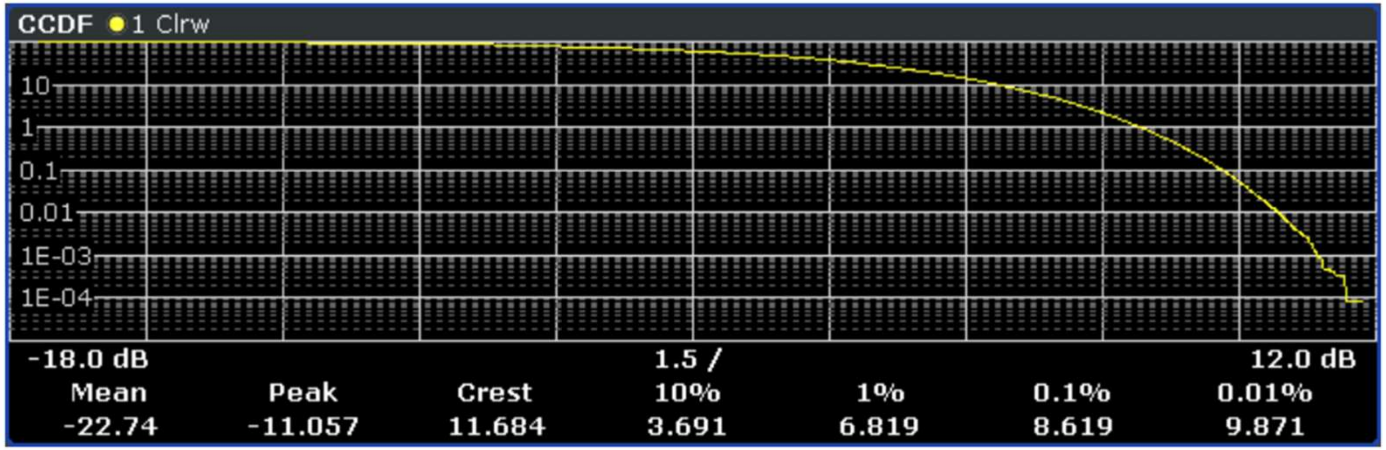
CCDF (Complementary Cumulative Distribution Function)

- How to measure PAPR?

CCDF

The "Complementary Cumulative Distribution Function (CCDF)" shows the probability of an amplitude exceeding the mean power. For the measurement, the complete capture buffer is used.

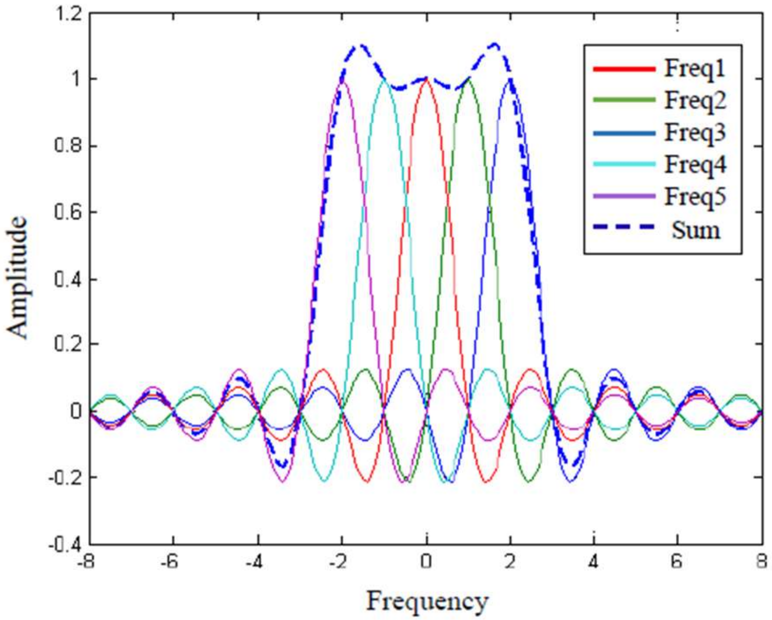
The x-axis represents the power relative to the measured mean power. On the y-axis, the probability is plotted in %.

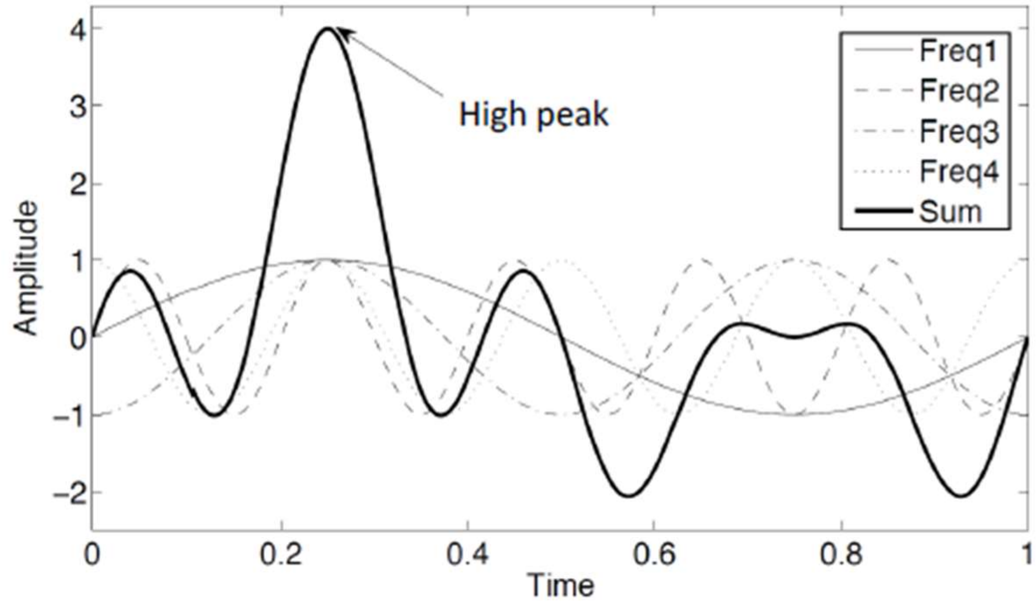


Source: R&S FSV-K144 3GPP 5G NR Downlink Measurement Application

Multi-Carrier Scheme

- Why does OFDM have high PAPR?

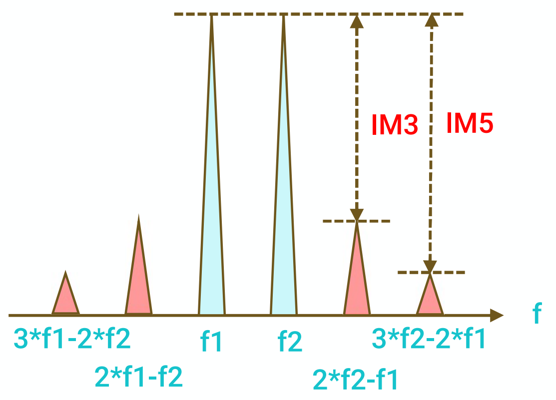


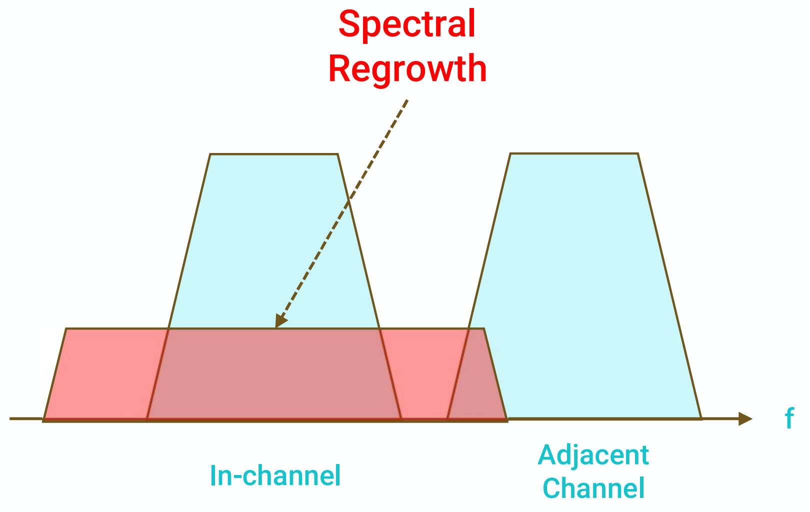


Reference: Waveform Design for 5G and Beyond, Author: Ali Fatih Demir

Spectral Regrowth

- The 3rd-Order and 5th-Order products
  - Spectral regrowth can't be reduced by any filters
  - ACLR and EVM both degrade





ACLR Limits Defined by 3GPP

Table 6.6.3.5.2-1: Base station ACLR limit

BS channel bandwidth **of lowest/highest NR carrier transmitted $BW_{Channel}$ (MHz)**	**BS adjacent channel centre frequency offset below the lowest or above the highest carrier centre frequency transmitted**	**Assumed adjacent channel carrier (informative)**	**Filter on the adjacent channel frequency and corresponding filter bandwidth**	**ACLR limit**
5, 10, 15, 20	$BW_{Channel}$	NR of same BW (Note 2)	Square (BW_{Config})	44.2 dB
	2 x $BW_{Channel}$	NR of same BW (Note 2)	Square (BW_{Config})	44.2 dB
	$BW_{Channel}$ /2 + 2.5 MHz	5 MHz E-UTRA	Square (4.5 MHz)	44.2 dB (NOTE 3)
	$BW_{Channel}$ /2 + 7.5 MHz	5 MHz E-UTRA	Square (4.5 MHz)	44.2 dB (NOTE 3)
25, 30, 40, 50, 60, 70, 80, 90, 100	$BW_{Channel}$	NR of same BW (Note 2)	Square (BW_{Config})	43.8 dB
	2 x $BW_{Channel}$	NR of same BW (Note 2)	Square (BW_{Config})	43.8 dB
	$BW_{Channel}$ /2 + 2.5 MHz	5 MHz E-UTRA	Square (4.5 MHz)	43.8 dB (NOTE 3)
	$BW_{Channel}$ /2 + 7.5 MHz	5 MHz E-UTRA	Square (4.5 MHz)	43.8 dB (NOTE 3)

NOTE 1: $BW_{Channel}$ and BW_{Config} are the *BS channel bandwidth* and transmission bandwidth configuration of the lowest/highest NR carrier transmitted on the assigned channel frequency.
NOTE 2: With SCS that provides largest transmission bandwidth configuration (BW_{Config}).
NOTE 3: The requirements are applicable when the band is also defined for E-UTRA or UTRA.

Source: 3GPP TS38.141-1 V15 Clause 6.6.3

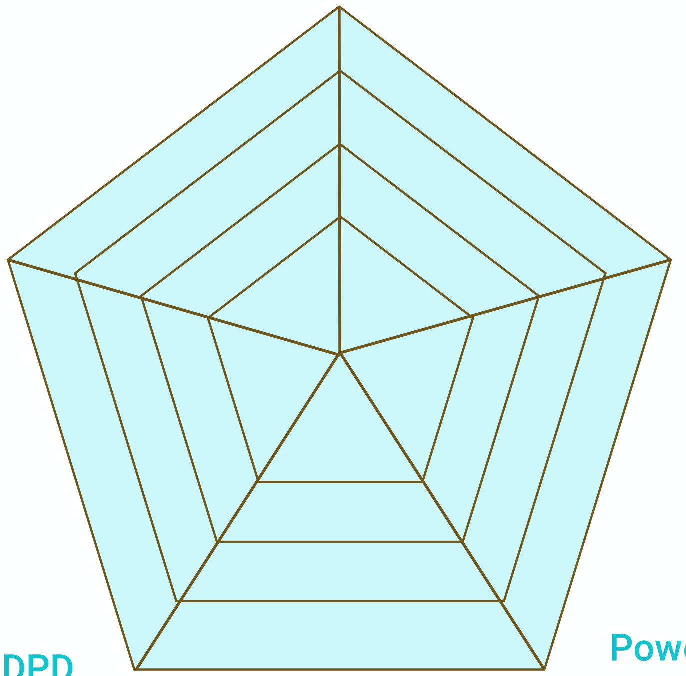
EVM Limits Defined by 3GPP

Table 6.5.3.5-1 EVM requirements for *BS type 1-C* and *BS type 1-H*

Modulation scheme for PDSCH	Required EVM (%)
QPSK	18.5 %
16QAM	13.5 %
64QAM	9 %
256QAM	4.5 %

Source: 3GPP TS38.141-1 V15 Clause 6.5.3

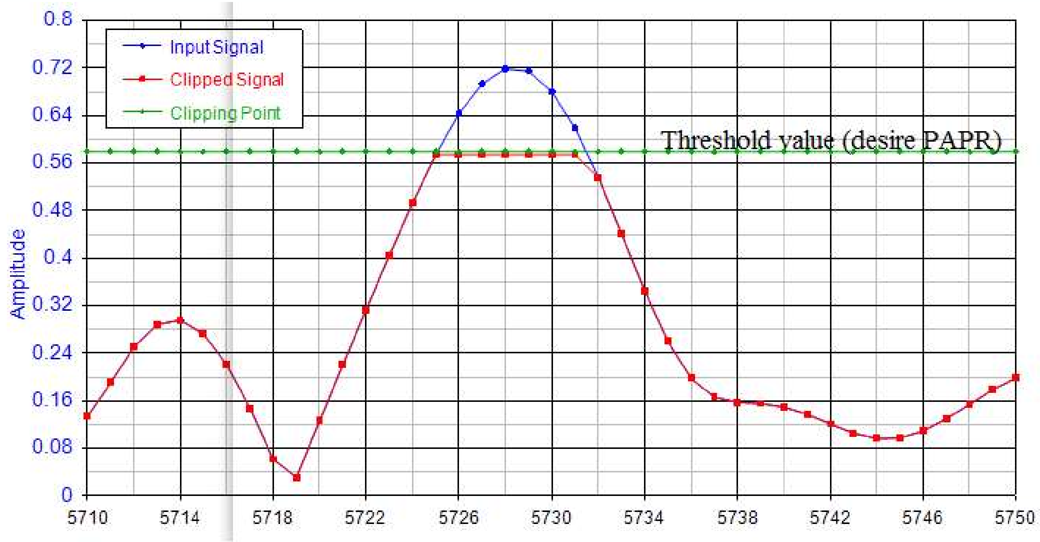
Techniques to Enhance PA Efficiency



Note: ET (Envelope Tracking) is currently applied to UE only

CFR (Crest Factor Reduction) Concept

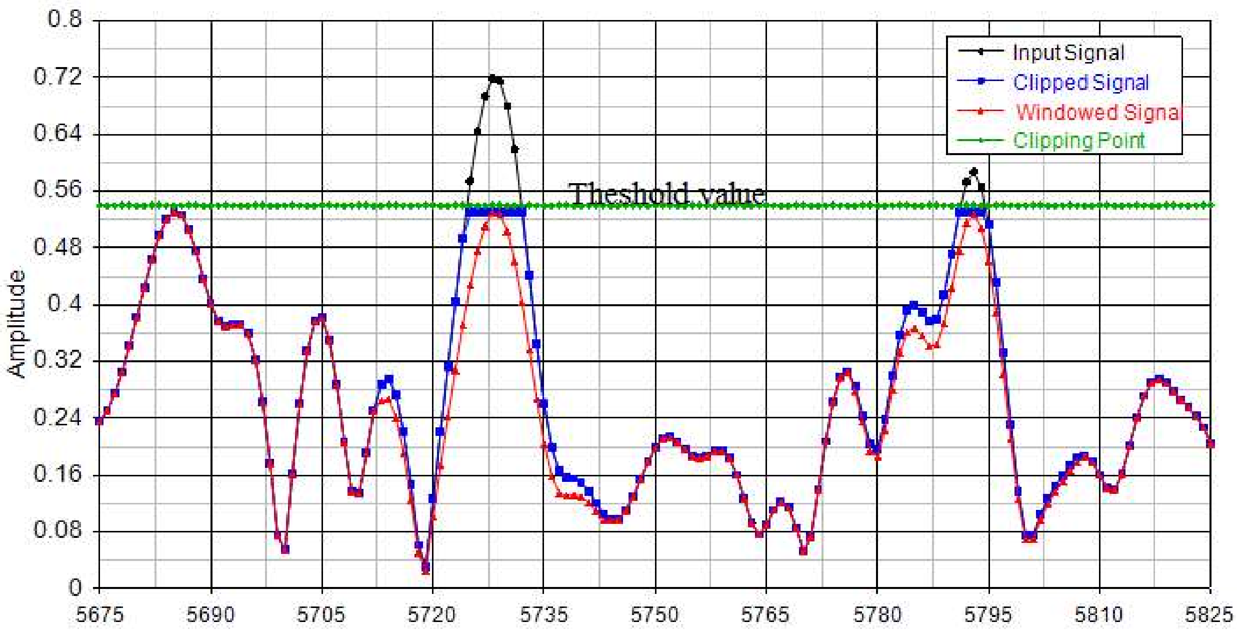
- CAF (Clipping and Filtering)
  - the conventional method that clips the signal peak to achieve the desired PAPR
  - leads to sharp corners in a clipped signal which, in turn, leads to an unwanted out-of-band emission
  - to reduce this unwanted emission, the clipped signal is passed via a low-pass filter. The major drawback of clipping and filtering (CAF) is the peak regrowth caused by filtering



Source: https://www.everythingrf.com/community/what-is-crest-factor-reduction

CFR (Crest Factor Reduction) Concept

- PW (Peak-Windowing)
  - aims to provide a smooth peak signal with desired PAPR
  - clipping is implemented by **multiplying** the original signal in the region of the peak with a windowing function



Source: https://www.everythingrf.com/community/what-is-crest-factor-reduction

CFR (Crest Factor Reduction) Concept

- PC (Peak Cancellation)
  - reduces the PAPR of a signal by subtracting spectrally shaped cancellation pulses from original input signal peaks that exceed a specified threshold
  - these cancellation pulses are designed to have a spectrum that matches that of the input signal and therefore introduce less distortion

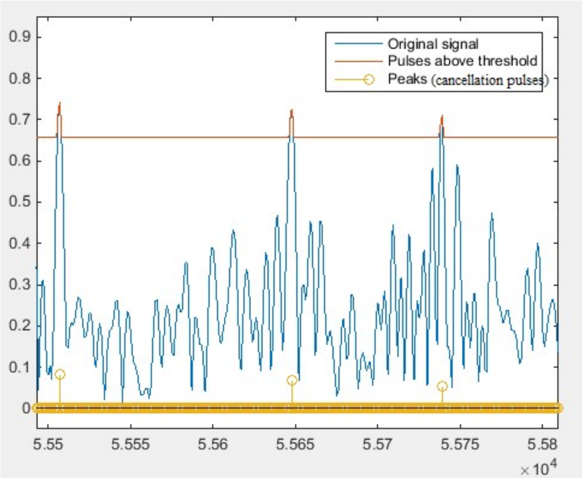


Figure 3: Showing peak cancellation pulses, original signal & threshold limit

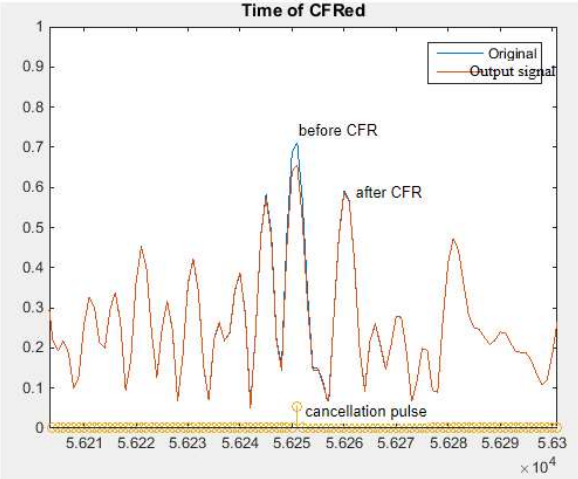


Figure 4: Showing peak cancellation pulse & signal before and after CFR

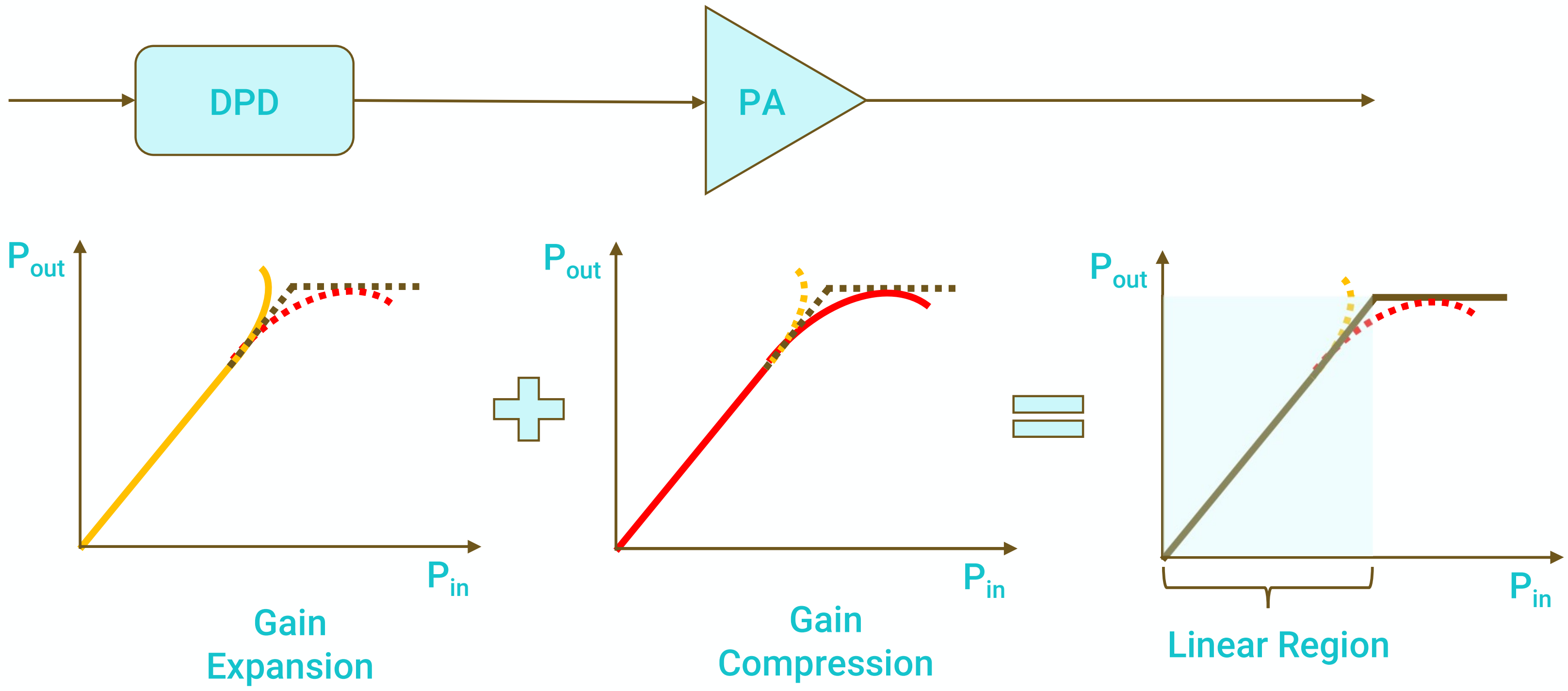
Source: https://www.everythingrf.com/community/what-is-crest-factor-reduction

Comparison of PA Linearization Techniques

	Complexity	Bandwidth	Efficiency
Back-Off	Low	Narrowband, 15~20MHz	Low
LINC (Linear Amplification with Nonlinear Components)	High since separation and combining signals is difficult	Narrowband, 20MHz	High
Feedforward	high because it subtracts harmonic and intermodulation distortions from amplifier	Wideband, 25 to 65MHz	High
Feedback	Low	Narrowband, 15 to 20MHz	Low
Pre-Distortion	Low	Wideband	High

Source: PUNEETH S., RANGARAJU H. G., "Linearization Techniques to Overcome Nonlinear Effects of RF Power" Amplifier

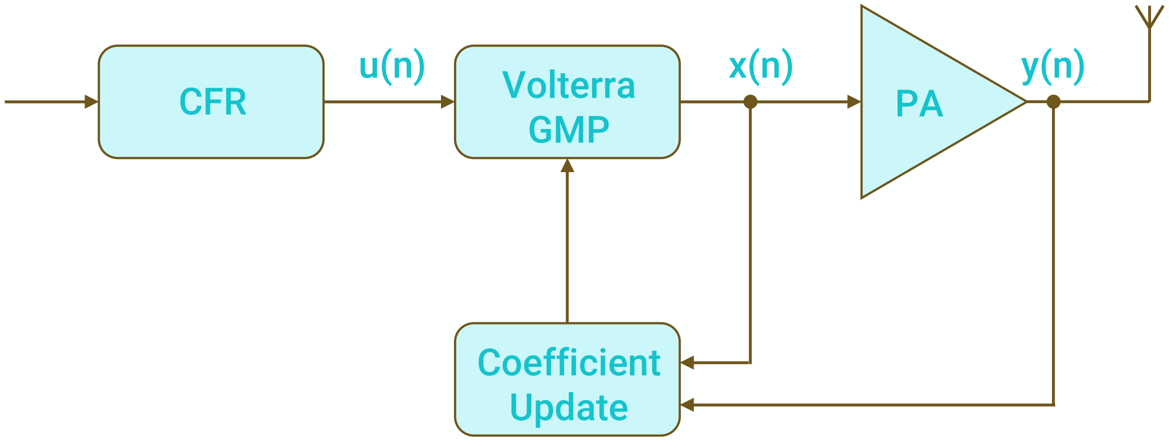
DPD (Digital Pre-Distortion) Principle



Challenges to DPD

- AM-AM
  - The amplitude of output signal is a function of the amplitude of input signal
- AM-PM
  - The phase of output signal is a function of the amplitude of input signal
- Memory effect
  - The output signal is a function of the previous input signal
- GaN
  - Charge trapping effect which self-bias the PA from Class B to deep Class C
- Computational load of the Volterra Model, which is simplified into:
  - Memory polynomial model, diagonal terms are kept in Volterra Model

DPD Modeling



GMP: Generalized Memory Polynomials

DPD in practice for 5G NR Small Cells

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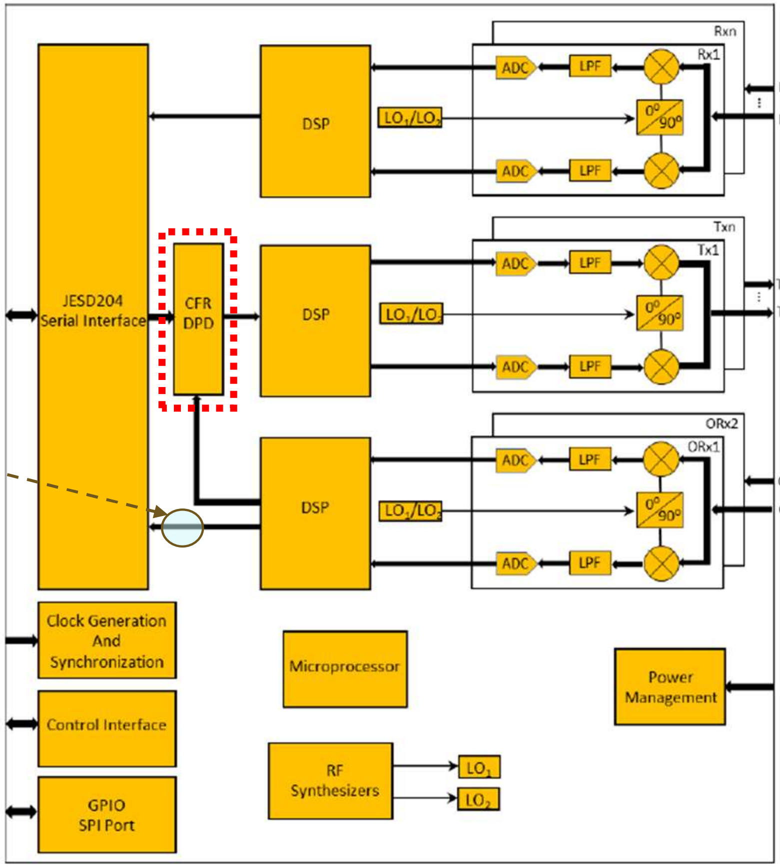
RFIC Functional Blocks w/ DPD & CFR

Feedback to PHY



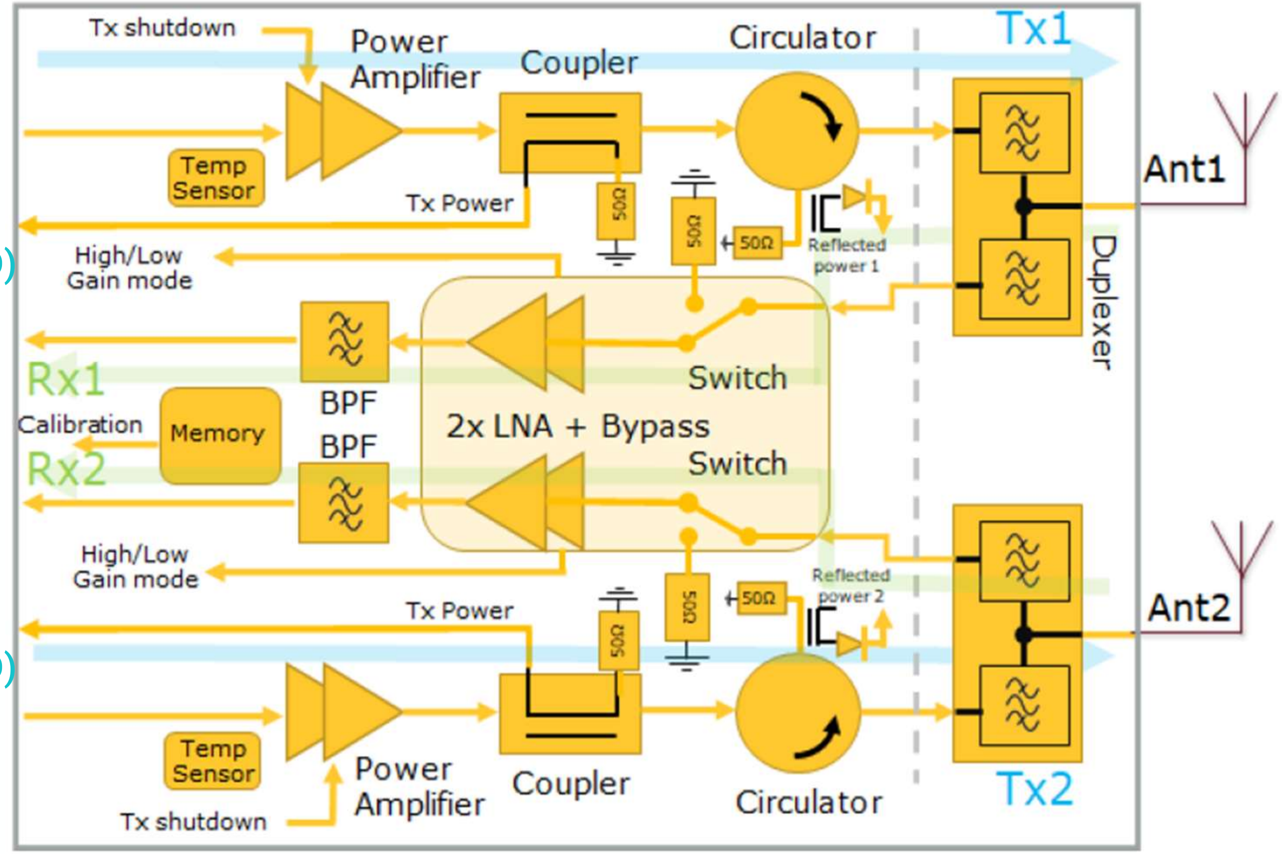
ORX (Feedback Port for DPD)

Source: scf251_5g_nr_fr1_reference_design_DEC-2021

RFFE Functional Blocks - FDD

ORX (Feedback Port for DPD)

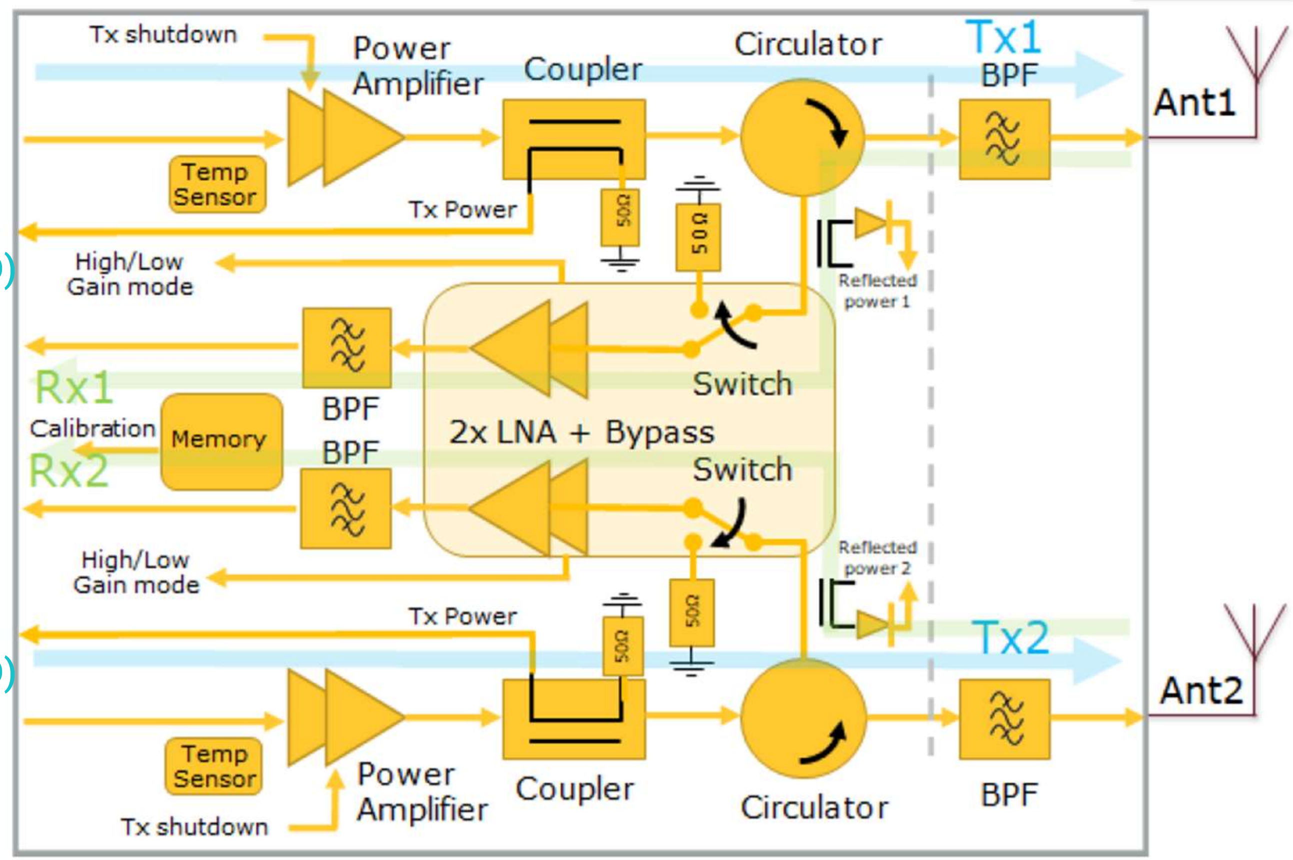
ORX (Feedback Port for DPD)



Source: scf251_5g_nr_fr1_reference_design_DEC-2021

RFFE Functional Blocks - TDD

ORX (Feedback Port for DPD)



ORX (Feedback Port for DPD)

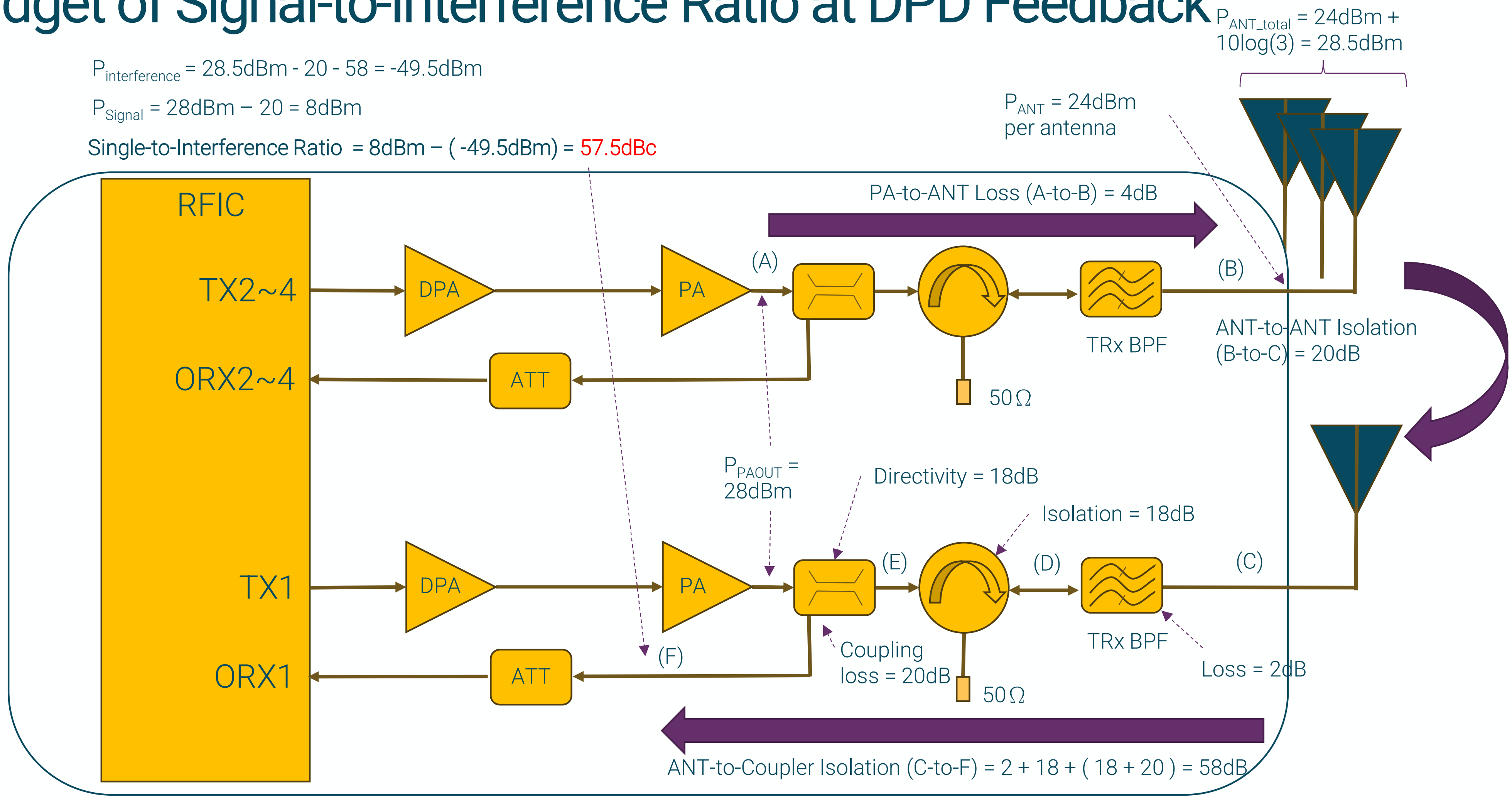
Source: scf251_5g_nr_fr1_reference_design_DEC-2021

Budget of Signal-to-Interference Ratio at DPD Feedback

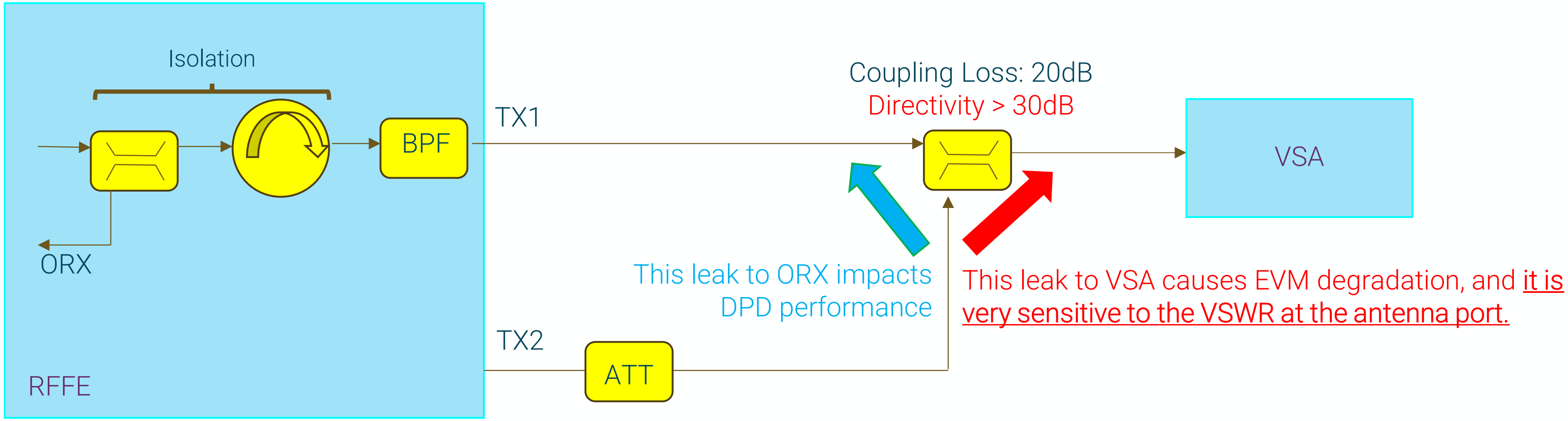
$P_{interference}$ = 28.5dBm - 20 - 58 = -49.5dBm

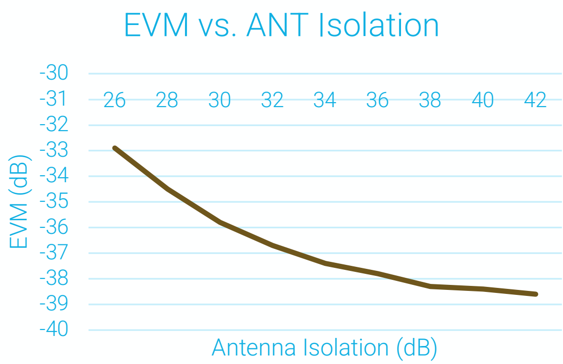
P_{Signal} = 28dBm – 20 = 8dBm

Single-to-Interference Ratio = 8dBm – (-49.5dBm) = 57.5dBc



Setup of OTA TX EVM Simulation





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Thank you