Digital predistortion with bandwidth limitations for a 28 nm WLAN 802.11ac transmitter

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Outline

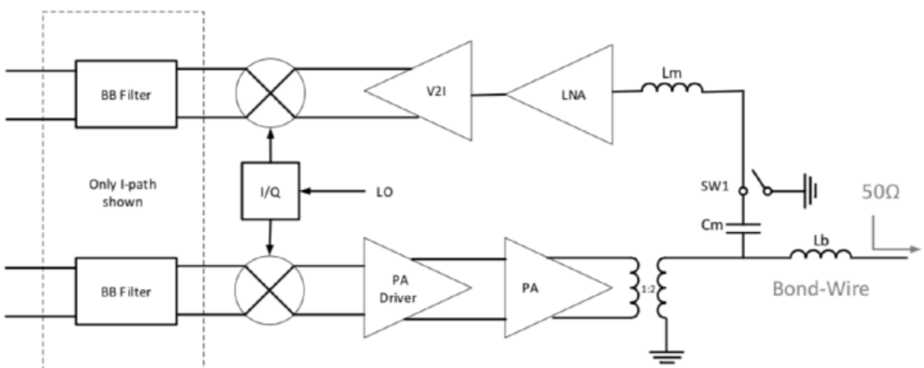
- Introduction
- Problem to be studied
- DPD basics
- Theory
- Results: Measurements, simulations
- Summary and conclusions

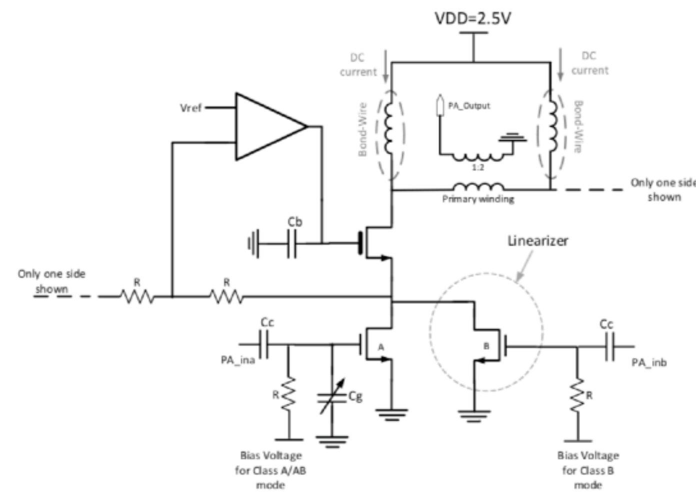
Introduction

- Increased demand for high-speed data rate and limited availability of RF spectrum require spectral-efficient transmissions.
- Modulation: high-density constellations of the data symbols, with high peak-to-average power ratio (PAPR).
- Linearity is a major concern to for high-quality data transfer.
- Main linearization methods: feedforward, feedback, predistortion.
- This work: digital predistortion (DPD).

Problem to be studied

- Can we improve the linearity (higher output power with a certain linearity (EVM) level) of an existing WLAN 802.11ac transmitter in 28 nm CMOS?
- Theory, measurement, and simulations results are presented to validate the analysis.



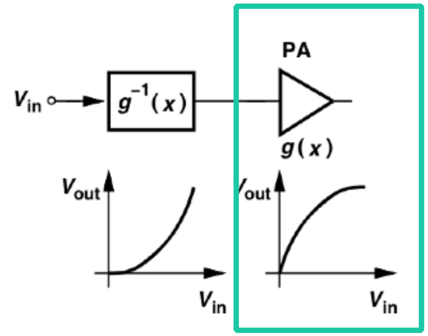


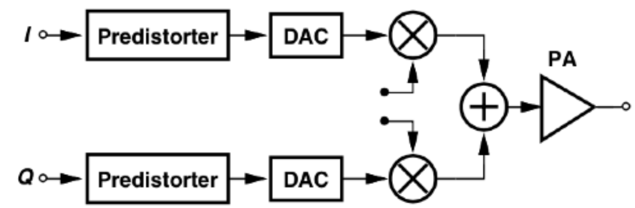
Integrated transceiver

PA core

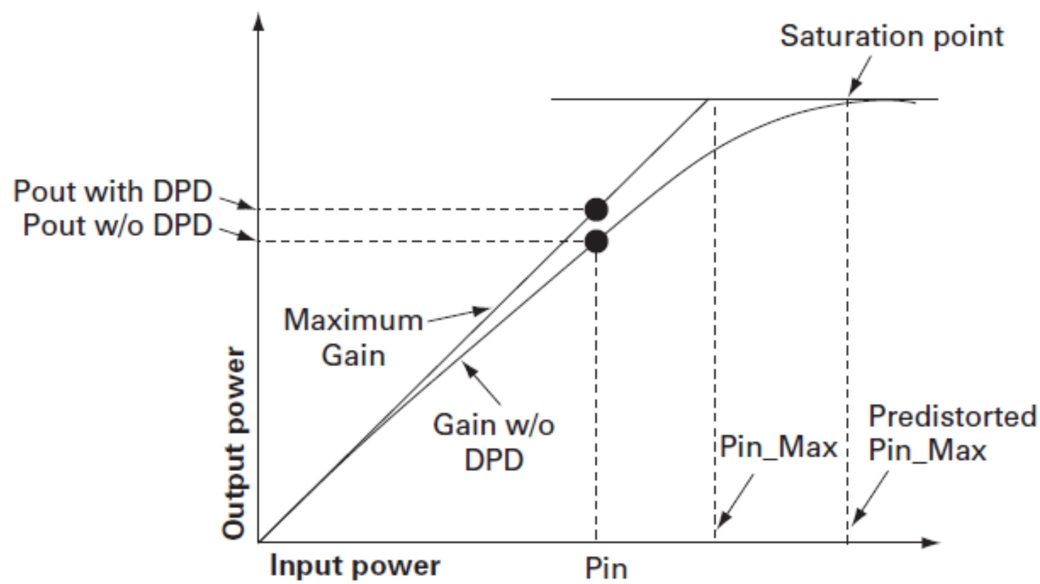
DPD basics

- DPD principle: A predistorted baseband signal is estimated and used to compensate for the magnitude and phase distortions of the PA.





- With DPD, we can achieve higher output power with the high linearity required for high data rates. The predistorter can successfully correct distortion up to the full saturation level of the amplifier.



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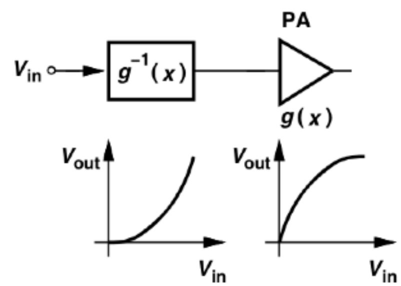

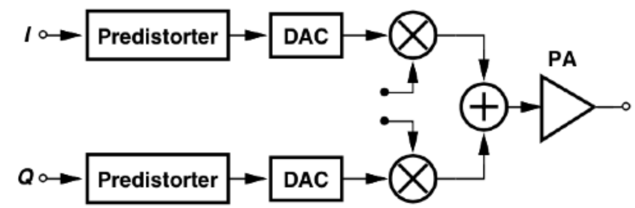

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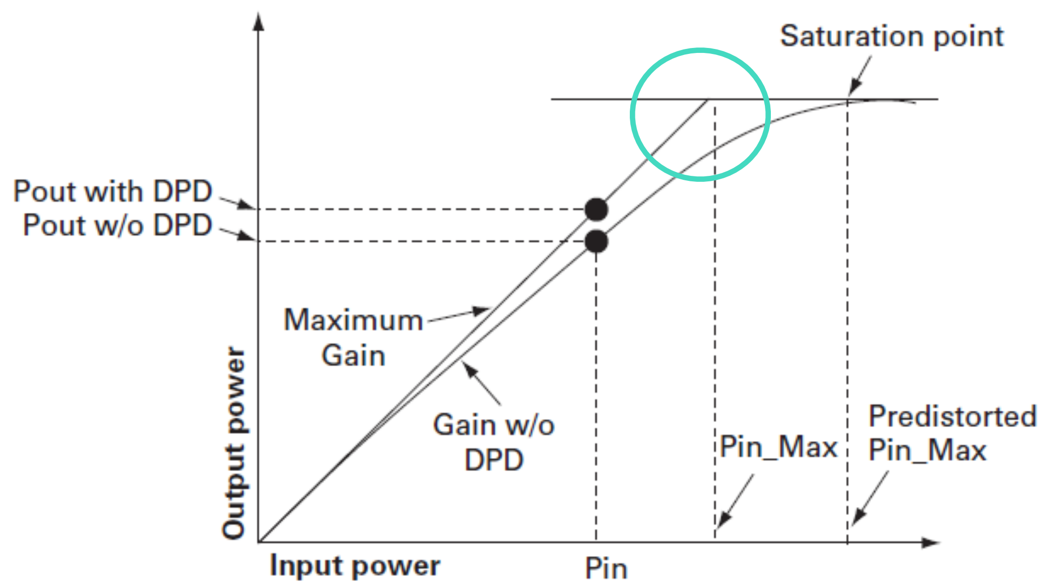
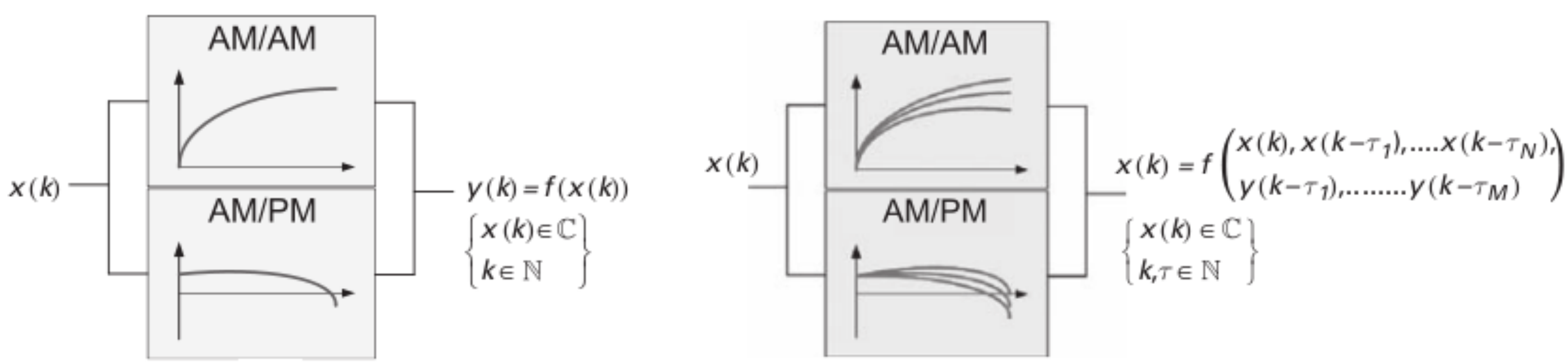


DPD basics

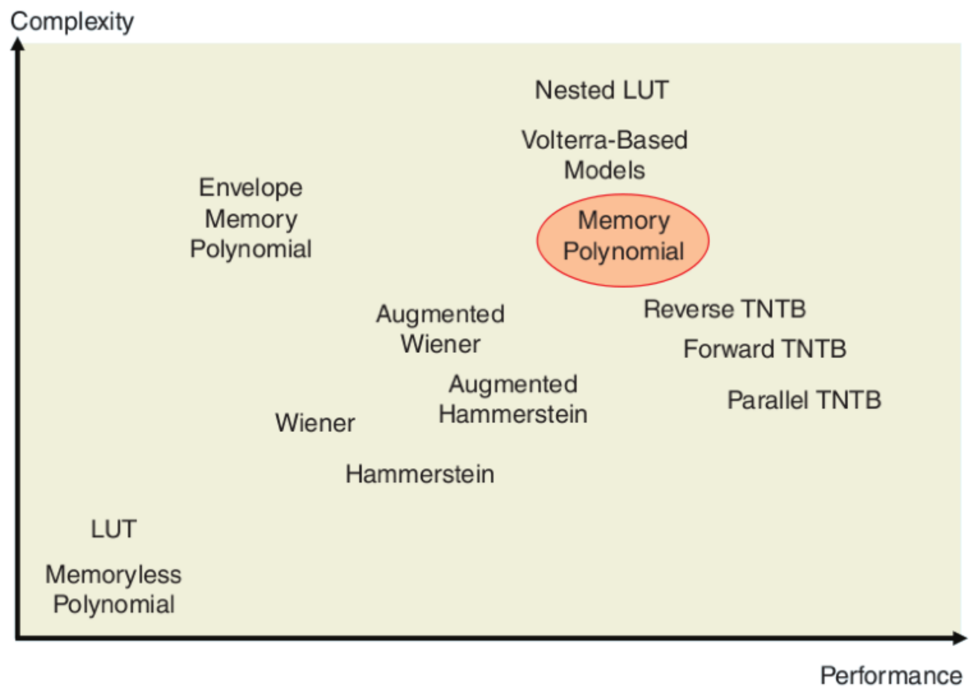
- Simple DPD: use a model of nonlinear PA using AM-AM and AM-PM behavior. Put this in a look-up table (LUT), or create a simple "curve-fitted" polynomial and use it for predistortion. Drawback: *memoryless* (a), not adaptive.
- Better DPD: *memory effects* (b) have to be included. The model output also depends on the recent history of the input-output signals. Memory effects caused by bandpass characteristics, temperature, and circuit biasing.



(a) (b)

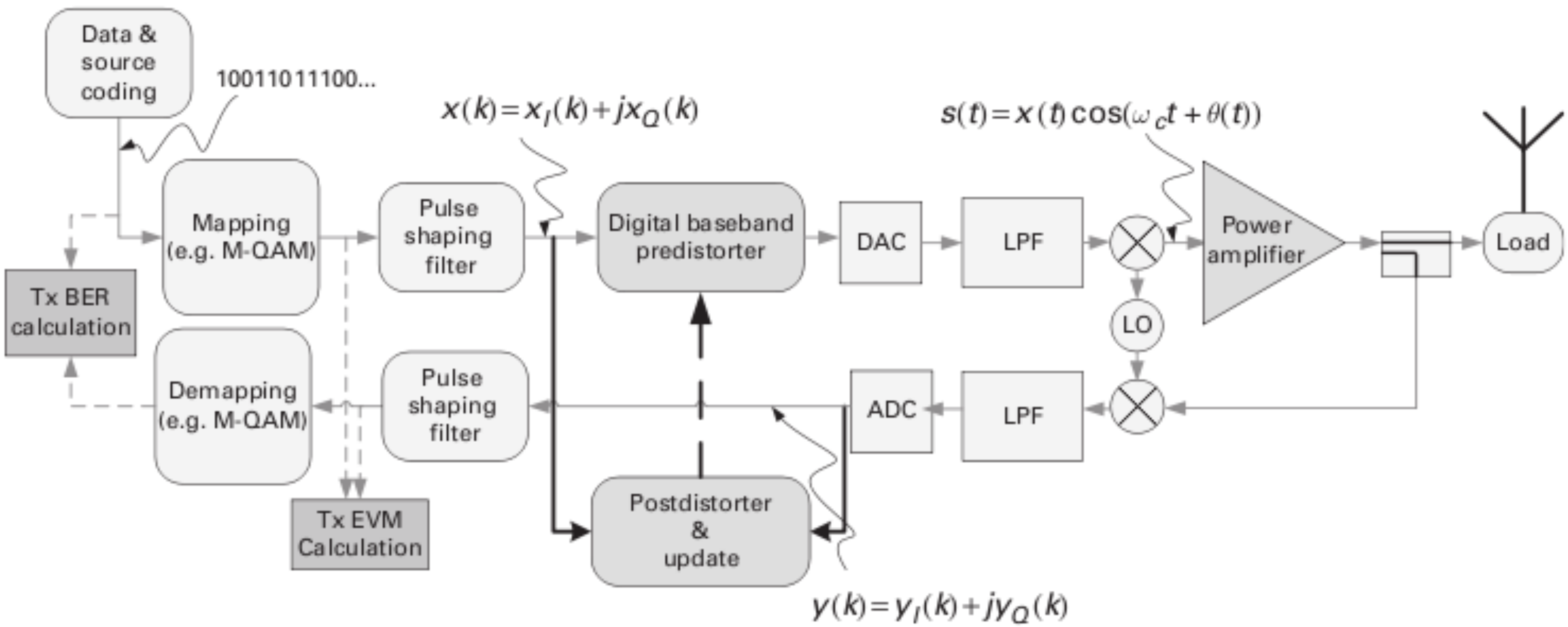
DPD basics

- For nonlinear system with memory, *Volterra series* can be used to describe the input/output relationship. Considered to be an accurate approach to model the PA nonlinear behavior with memory effects.
- A full Volterra produces a huge computational load, so other models are used instead: Weiner Model, Hammerstein Model, Weiner-Hammerstein, memory polynomial, among others.
- In this work, *memory polynomial* is used (simplified variant of Volterra series).



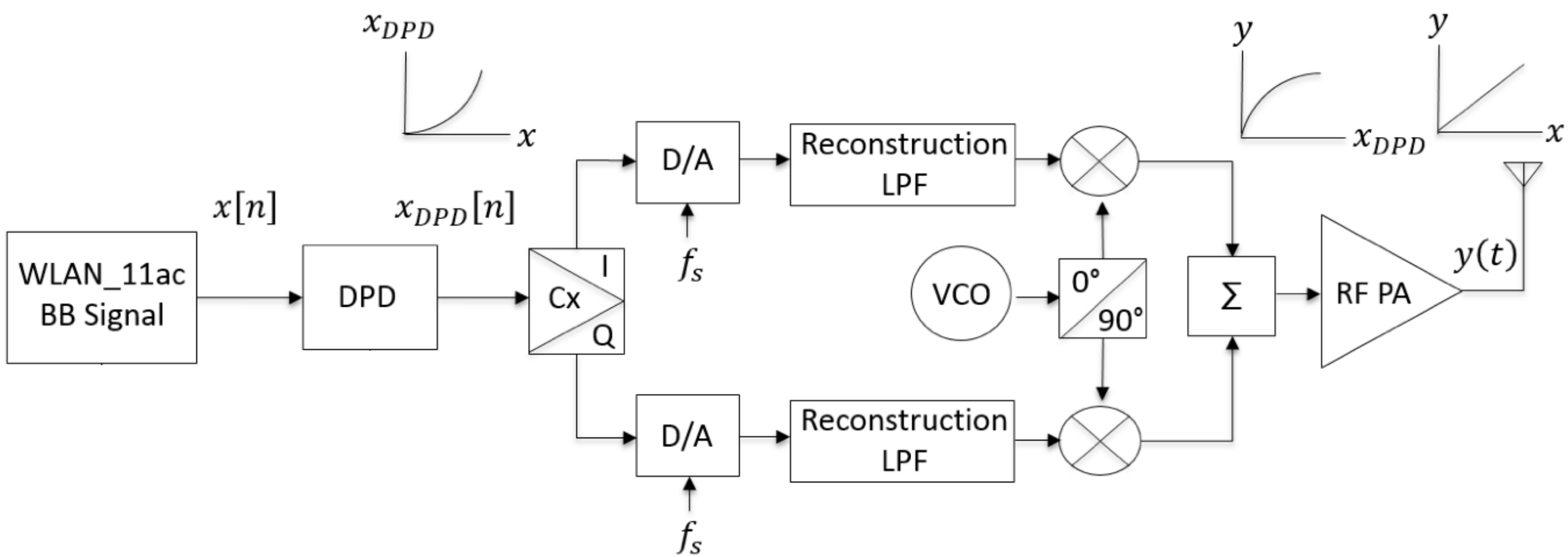
DPD basics

- Closed-loop (adaptive) DPD: common in base stations.



DPD basics

- In this work, we use an Open-loop DPD.



Theory

- The physical layer in the 802.11ac WLAN standard is based on OFDM. The baseband signal is represented by:

$$\tilde{x}_n(t) = \frac{1}{\sqrt{T}} \sum_{\substack{k=-N/2 \\ k\neq 0}}^{N/2} \tilde{s}_{k,n} e^{j2\pi f_k t}$$

- When a Memory Polynomial DPD is applied to an OFDM signal, a series expansion of the baseband signal takes place.
  With a nonlinear order of 3 and no memory effects, the predistorted baseband signal can be expressed as:

$$\tilde{x}_{DPD,n}(t) = \frac{1}{\sqrt{T}} \sum_{\substack{k=-N/2 \\ k\neq 0}}^{N/2} a_1 \tilde{s}_{k,n} e^{j2\pi f_k t} + \left(\frac{1}{\sqrt{T}}\right)^3 \sum_{\substack{k_1=-N/2 \\ k_1\neq 0}}^{N/2} \sum_{\substack{k_2=-N/2 \\ k_2\neq 0}}^{N/2} \sum_{\substack{k_3=-N/2 \\ k_3\neq 0}}^{N/2} a_3 \tilde{s}_{k_1,n} \tilde{s}_{k_2,n} \tilde{s}^*_{k_3,n} e^{j2\pi(f_{k_1}+f_{k_2}-f_{k_3})t}$$

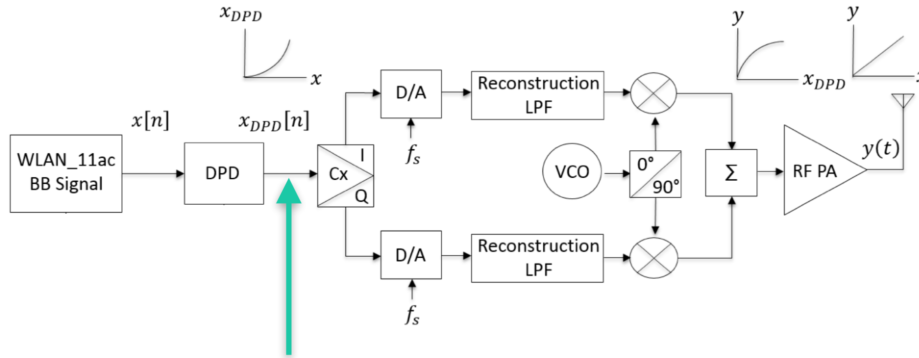
  where the second term corresponds to IMD products.

Theory

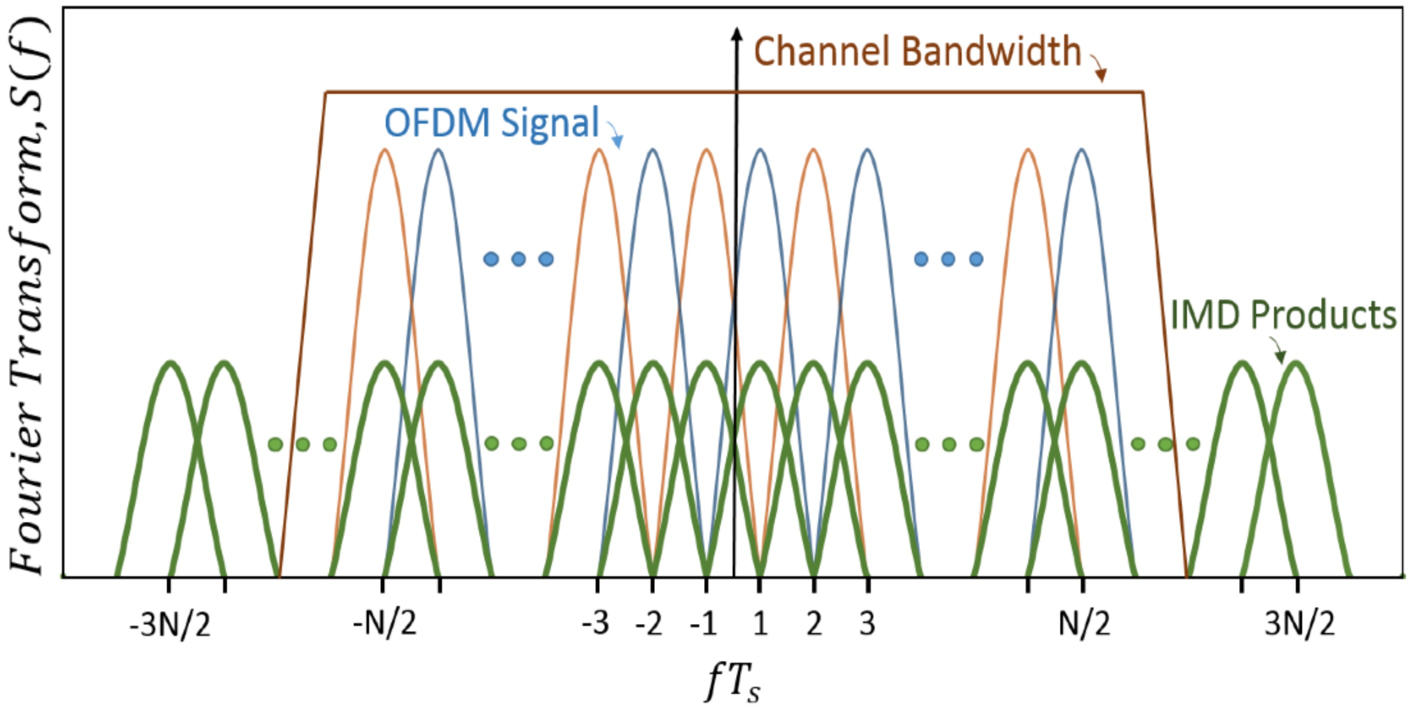
- The DPD baseband signal will be *n* times wider than the original signal bandwidth, *n* is the highest nonlinear order of the model.
- This imposes a challenge in the bandwidth requirement in the transmitter and feedback paths (DAC and ADC sample rates, filter settings, etc.)

At PA input

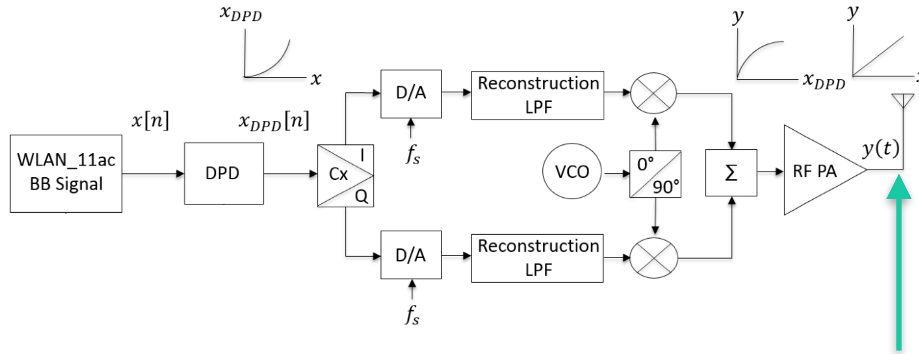
Theory



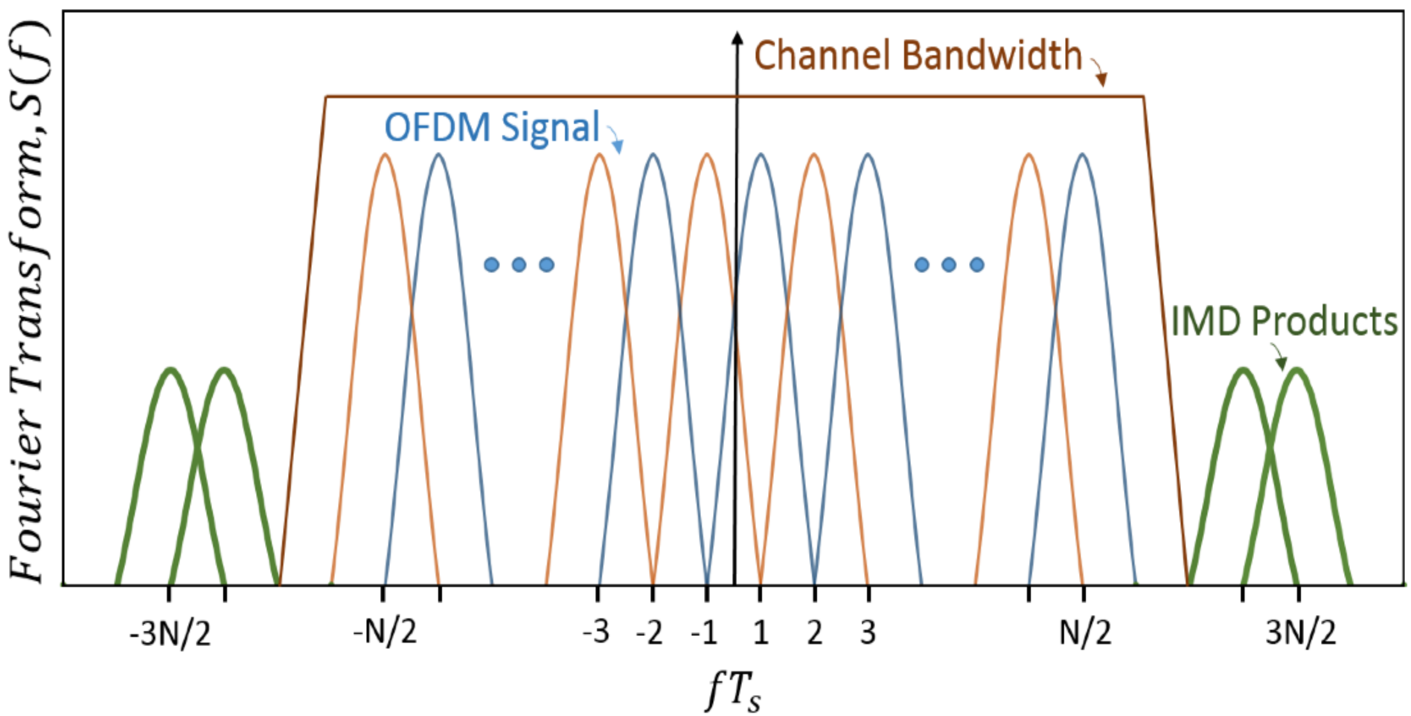
- OFDM signal in the frequency domain, DPD output.



Theory

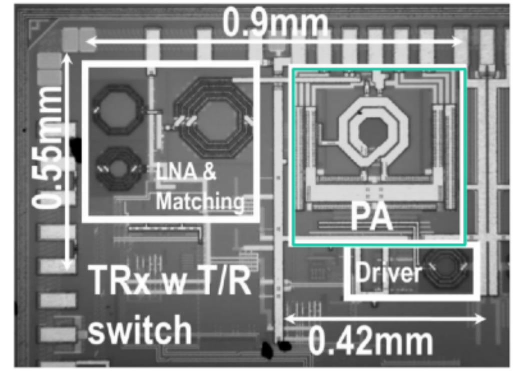


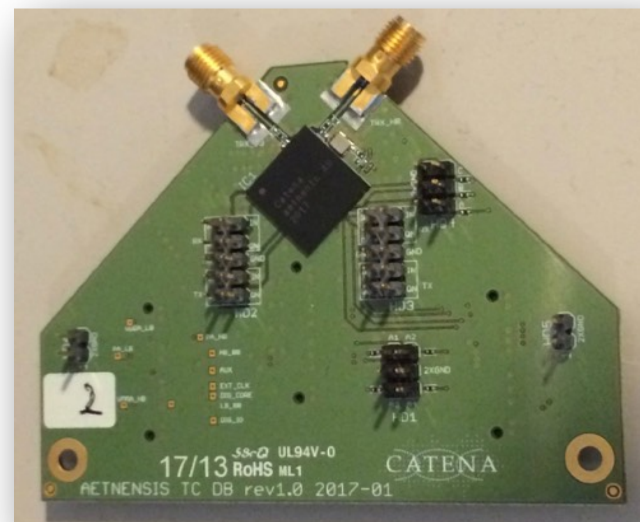
- OFDM signal in the frequency domain, PA output.



Experimental and simulation setup

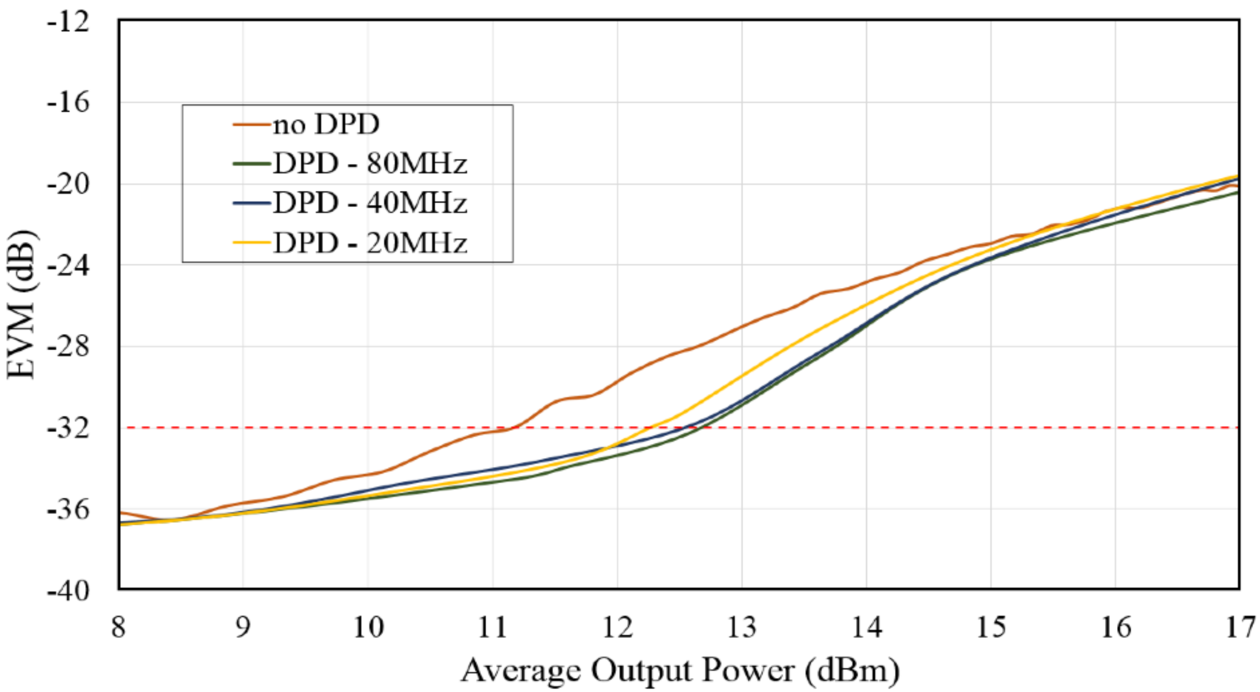
- Input Signal: WLAN 802.11ac, BW=20, 80 MHz, MCS=8 (256QAM), f=4.9 GHz.
- DAC sampling rate: 160 MHz.
- LPF: 3rd order Chebyshev. 20, 40, 80 MHz.
- PA: class-A/AB with additional features for linearity.
- DPD Model: Memory Polynomial, Nonlinear Order = 3, Memory Order = 8.
- EVM requirement: -32 dB (2.5%).
- R&S SMV200A VSG and FSW13 Spectrum Analyzer.
- Keysight GoldenGate and SystemVue.





Measurement Results

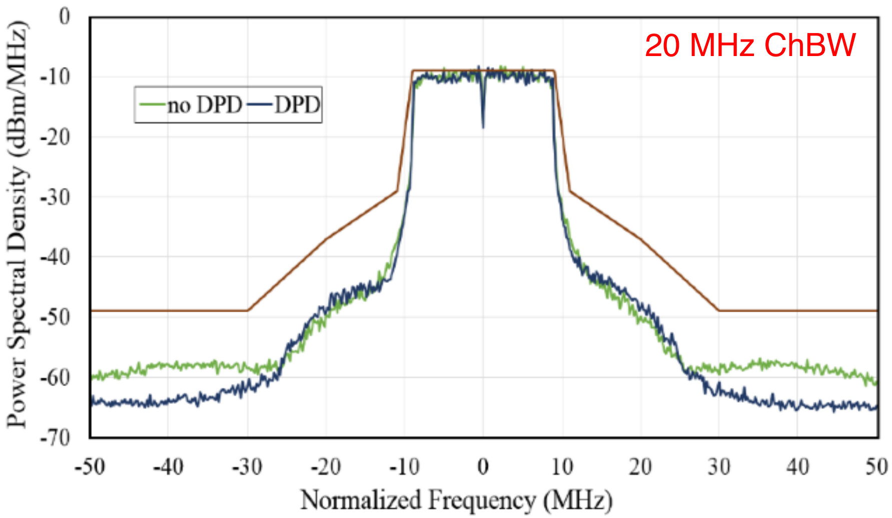
- Signal: 20 MHz. Filters: 20, 40, 80 MHz.

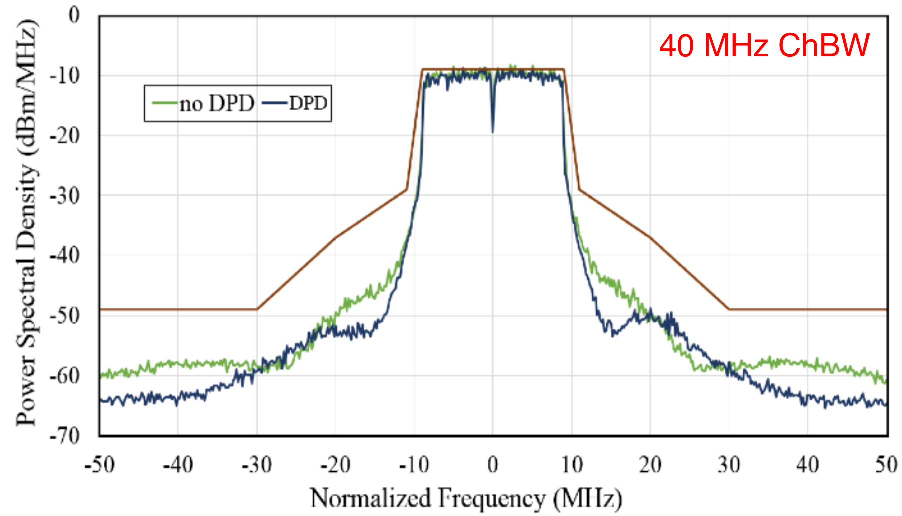


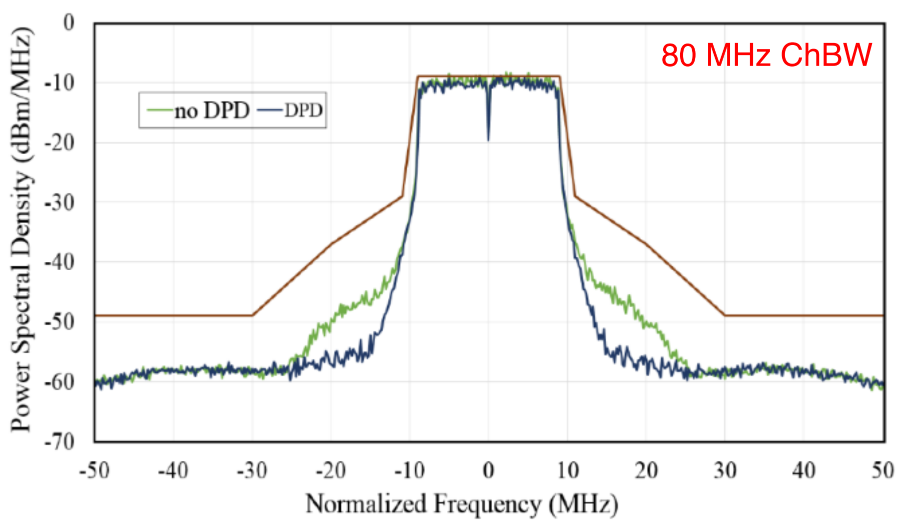
Tx Channel Bandwidth [MHz]	*Average Output Power [dBm]*	*Improvement compared to no DPD [dB]*
20	**12.30**	**1.1**
40	**12.56**	**1.4**
80	**12.75**	**1.6**

The linear output power limit is reduced by about 0.5 dB because of the bandwidth limitation.

RF spectrum for 20 MHz signal







Simulation Results

- We can do 80 MHz signal but only 80 MHz Tx bandwidth because of limitations in the existing design. What penalty will we pay for this limitation in bandwidth?
- Simulation: cadence/GoldenGate with the circuit model + SystemVue for EVM with DPD.
- Signal bandwidth = 80 MHz.

Tx Channel Bandwidth [MHz]	*Improvement compared to no DPD [dB]*	*Penalty [dB]*
80	**1.7**	**0**
160	**3.2**	**1.5**
320	**3.3**	**1.6**

- A reduction in EVM of 1.6 dB for the 80/80 MHz situation is estimated, compared to a case with 2-4 x ratio of signal-to-channel bandwidth.
- This is much larger than for the 20/20 MHz signal/BW (0.5 dB). Why?
- Simulation with 80 MHz signal and 90 MHz filter setting (same channel utilization as for the 20/20 case) gives 0.53 dB improvement of DPD, similar to the 20/20 MHz measurements.

Summary and conclusions

- The DPD performance analysis of an 802.11ac WLAN transmitter in 28 nm CMOS, to estimate the reduction in the output power for an EVM of -32 dB (2.5%) under band-limited conditions, has been presented.
- A measured reduction of about **0.5 dB** is obtained for a signal and transmitter chain bandwidth of **20/20 MHz**. Increasing the band to 2x * signal and 4x * signal improves the linear output power.
- For an **80/80 MHz** condition, the simulated output power reduction is about **1.6 dB**. This is partly due to extra channel utilization (7 % wider effective channel). Extra losses in the passband of the LPF also contribute to the reduction.

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