Baseband mitigation of nonlinear impairments in SOA based coherent optical OFDM systems: stochastic and experimental analyses

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ÉCOLE NATIONALE D'INGÉNIEURS DE BREST

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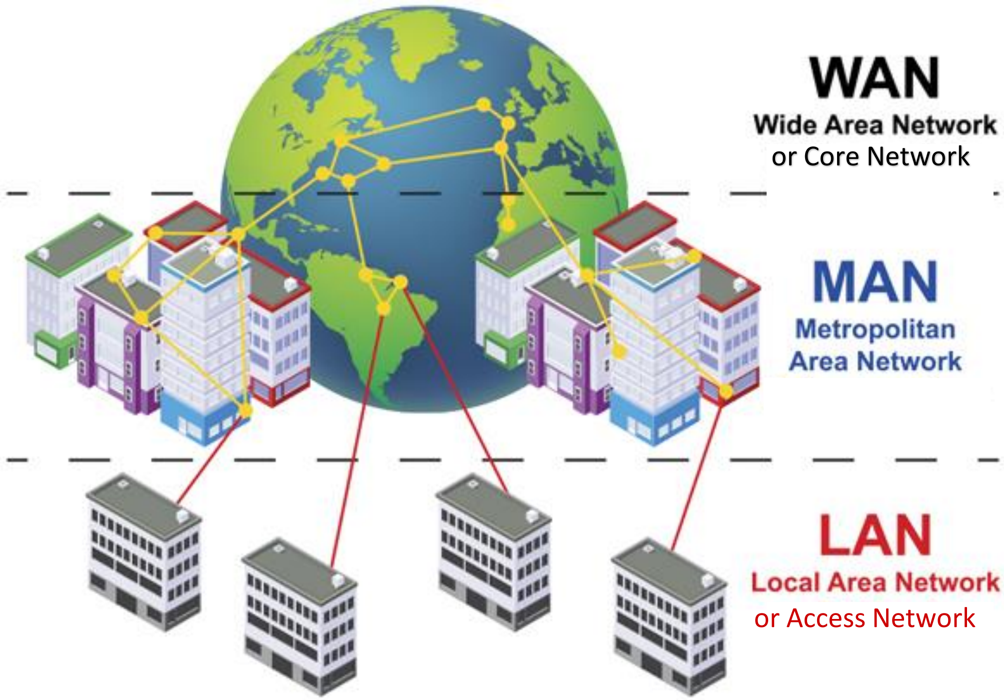
Outline

Context

- Demand for high data rates and spectral efficiency growing exponentially
  - Optical fiber
    - + Higher data rate
    - + Low attenuations
    - + High potential for capacity increase



Long distances, high cost

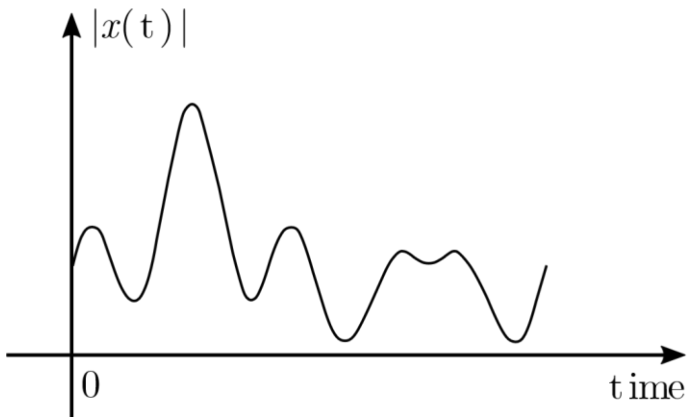
Medium distances, lower cost

Short distances, lowest cost

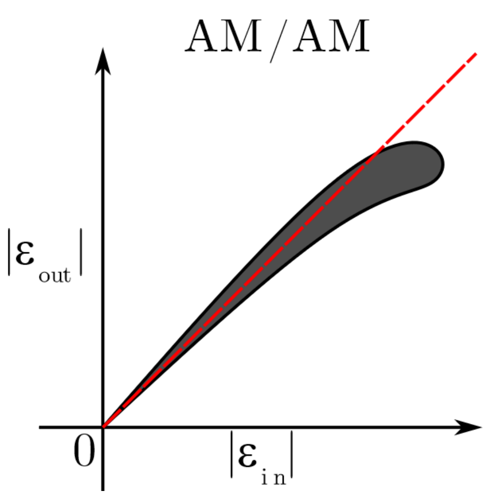
Context

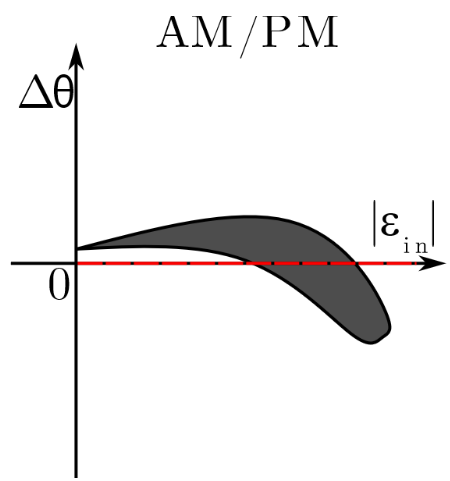
- Coherent optical communications
  - Orthogonal Frequency Division Multiplexing (OFDM) used in RF
    - \+ Uses Digital Signal Processing (DSP)
    - \+ High spectral efficiency
    - \+ Dynamic allocation of frequency bands
    - \- Non-constant envelope

- Access and metropolitan networks
  - Semiconductor Optical Amplifiers (SOAs) sparking interest
    - \+ Low cost
    - \+ Compact
    - \+ Large optical bandwidth
    - \- Nonlinear effects (Four Wave Mixing, phase-amplitude coupling)



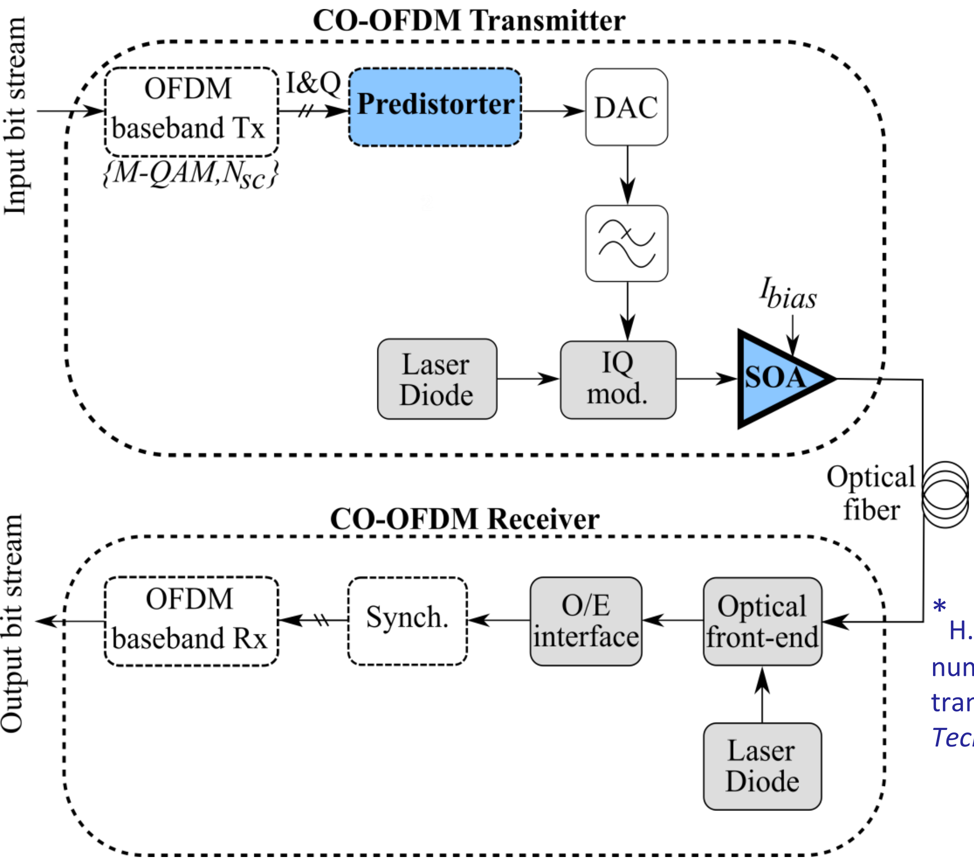
$$PAPR(x[n]) = \max_{0 \le n \le N-1} \frac{|x[n]|^2}{E[|x[n]|^2]}$$





Setup

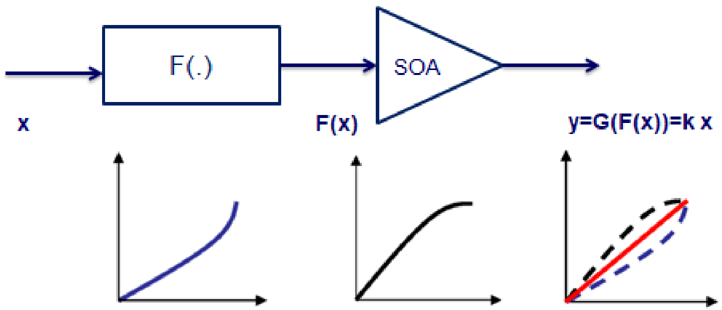
- Co-simulation MATLAB/ADS, SOA booster, optical Back-to-Back
- Physical model of a SOA (INPHENIX-IPSAD1501) has been implemented by *Khaleghi et al.*[*], using Agilent ADS software

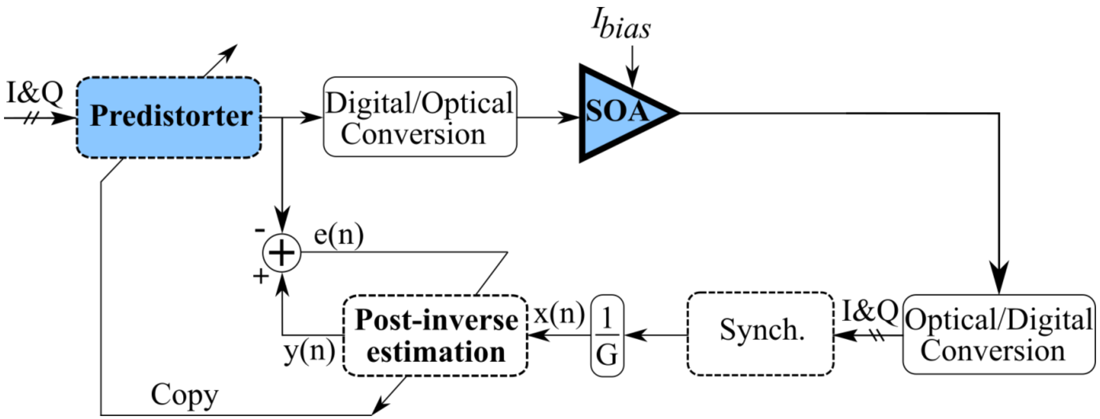


[*] H. Khaleghi, P. Morel, A. Sharaiha, and T. Rampone, "Experimental validation of numerical simulations and performance analysis of a coherent optical-OFDM transmission system employing semiconductor optical amplifier," *J. Lightw. Technol.*, vol. 31, no. 1, pp. 161–170, January 2013.

Predistortion principles

- Objective: Linearize SOA characteristics via digital baseband predistorters (DPD)





- Indirect Learning Approach
- Minimize Least Squares error

- Three criteria of interest:
  - Normalized Mean Square Error (NMSE)
  - Error Vector Magnitude (EVM)
  - Structural complexity

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Predistortion principles

- Simplified versions of the Volterra Series like the Memory Polynomials (MP) and Envelope Memory Polynomials (EMP):

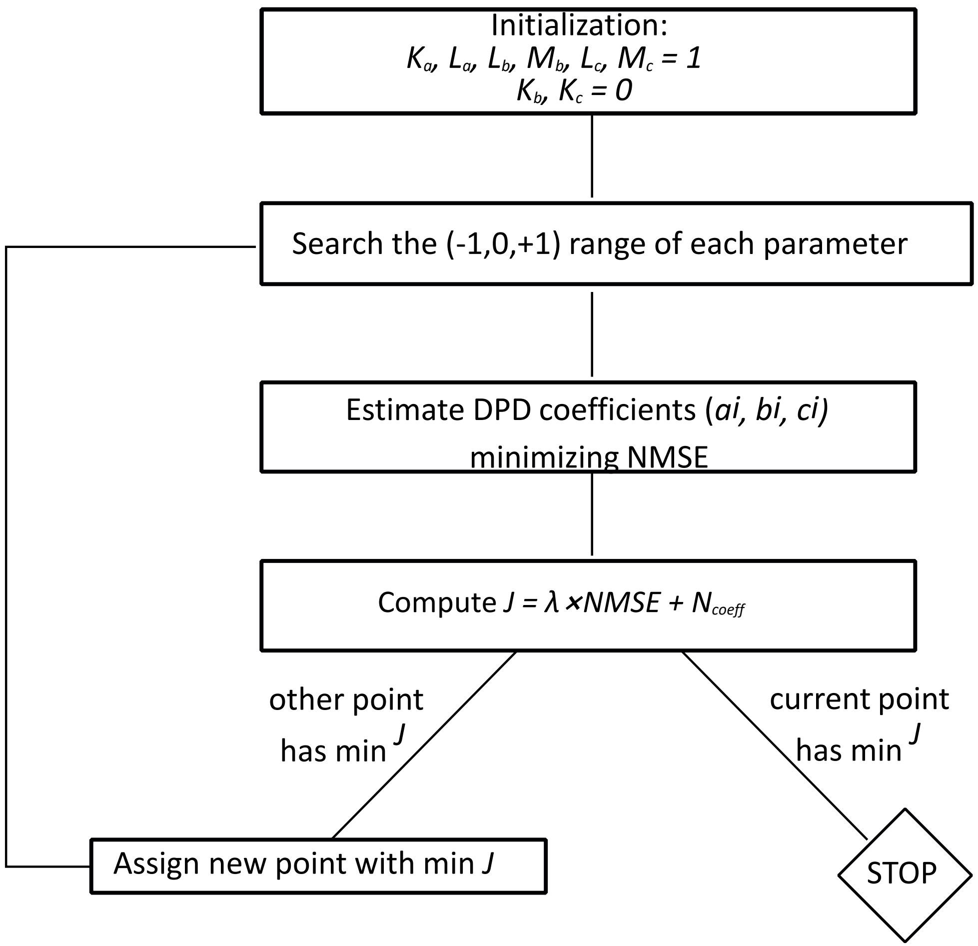
$$y_{MP}(n) = \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} a_{kl}\, x(n-l)|x(n-l)|^k \qquad y_{EMP}(n) = x(n)\left(c_0 + \sum_{k=1}^{K-1} \sum_{l=0}^{L-1} a_{kl}|x(n-l)|^k\right)$$

- The Generalized Memory Polynomials (GMP) encompasses other known predistorders such as MP and EMP

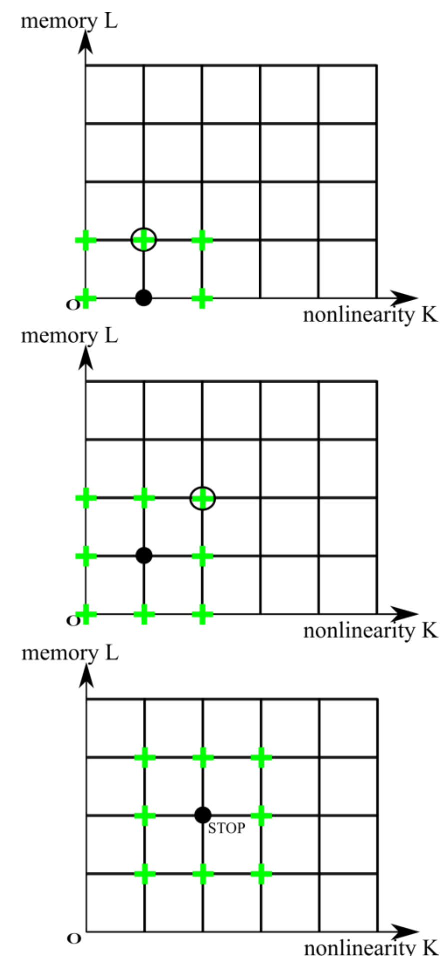
$$\begin{aligned} y_{GMP}(n) = & \sum_{k=0}^{K_a-1} \sum_{l=0}^{L_a-1} a_{kl} x(n-l)|x(n-l)|^k \\ & + \sum_{k=1}^{K_b} \sum_{l=0}^{L_b-1} \sum_{m=1}^{M_b} b_{klm}\, x(n-l)|x(n-l-m)|^k \\ & + \sum_{k=1}^{K_c} \sum_{l=0}^{L_c-1} \sum_{m=1}^{M_c} c_{klm}\, x(n-l)|x(n-l+m)|^k \end{aligned}$$

Hill-Climbing heuristic

- Finding structural parameters K_i, L_i, and M_i



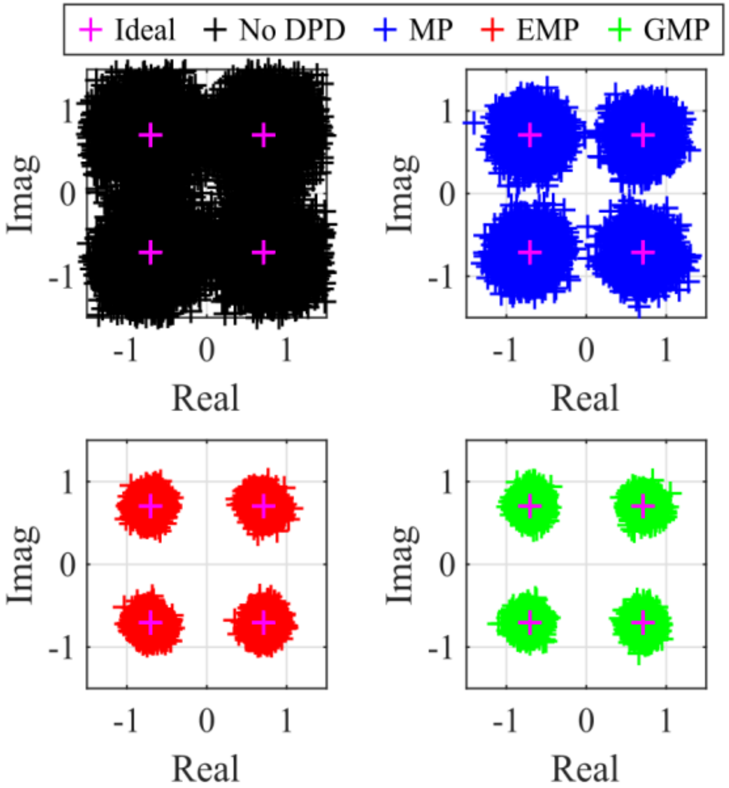
2-D example:

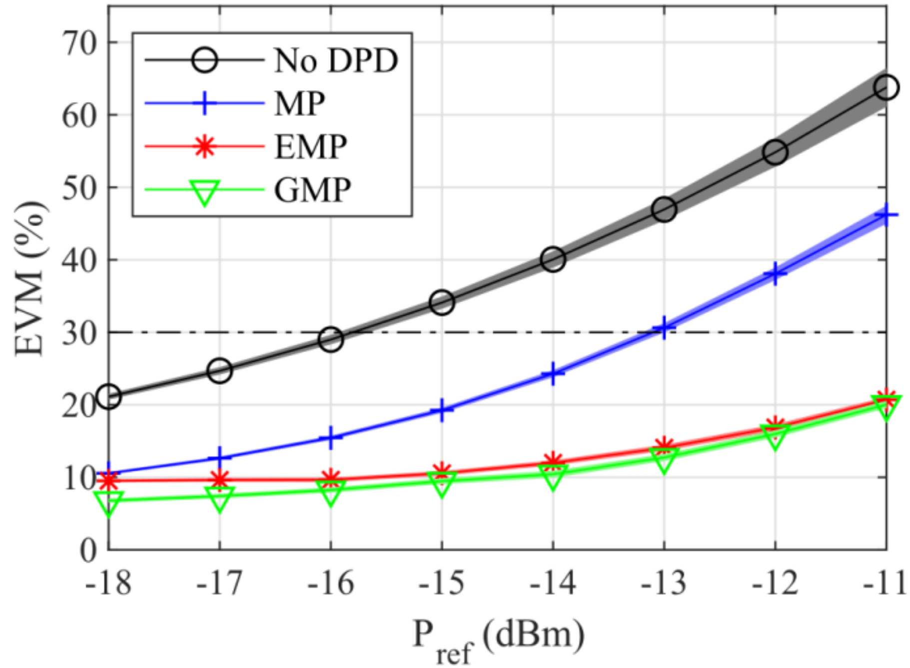


S. Wang, et al., “Optimal sizing of generalized memory polynomial model structure based on hill-climbing heuristic,” IEEE 46th European Microwave Conference (EuMC), pp. 190–193, October 2016.

Predistortion numerical results

- Digital predistortion (DPD) helps linearize the SOA



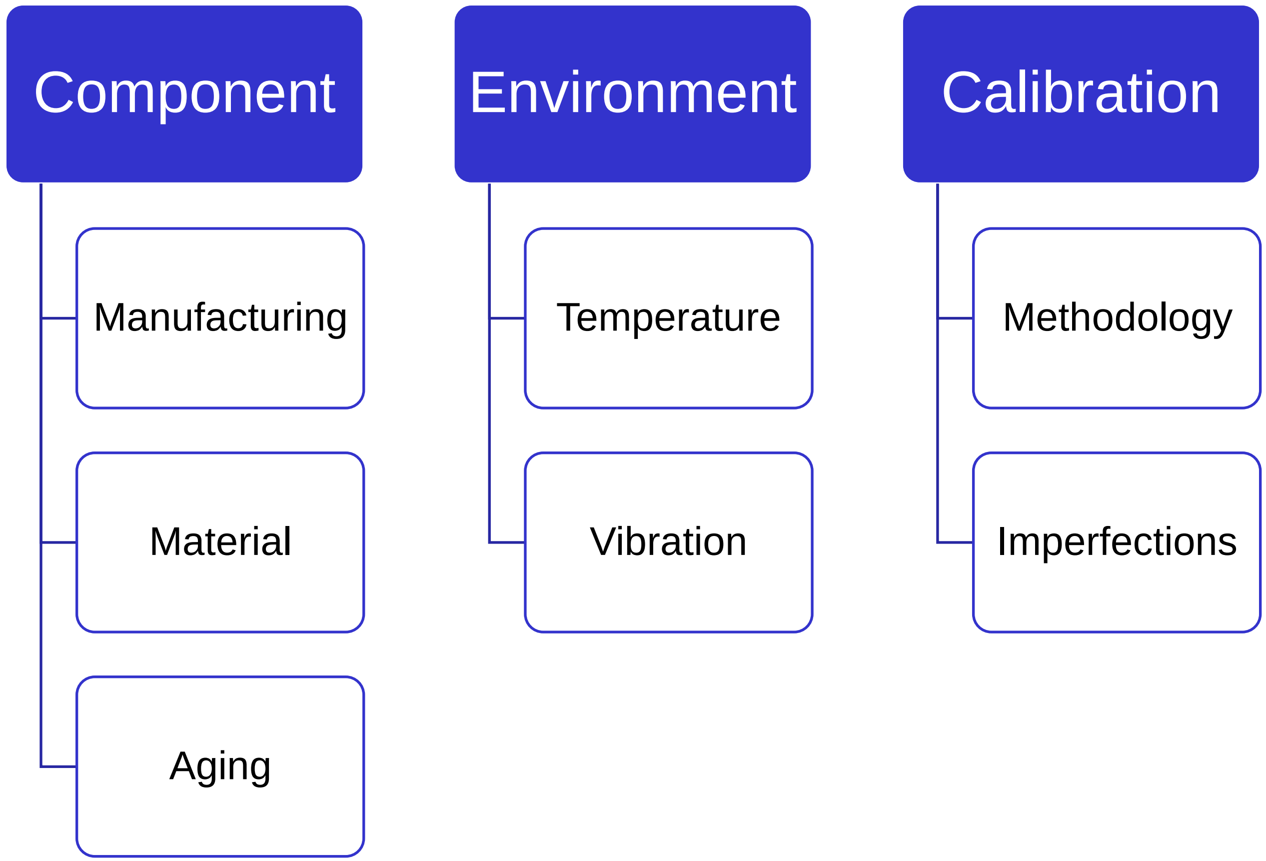


- 30% EVM corresponds to bit error rate (BER) of 10^{-3}
- We can increase input power from -16 dBm (no DPD) to -13 dBm (MP). And to more than -11 dBm for EMP/GMP

J. E. Sime, P. Morel, M. Telescu, N. Tanguy, S. Azou, "Digital Predistortion for CO-OFDM Systems Using Generalized Memory Polynomials," *8th IEEE Int. Conf. on Communications and Electronics (IEEE ICCE 2020)*, Phu Quoc Island, Vietnam, Jan. 13-15th 2021.

Stochastic analysis

- Uncertainty of communication systems



Polynomial Chaos Expansion

- Monte-Carlo constructs PDF by simulating each sample point
- PCE constructs metamodel by simulating a few sample points then computes the PDF using the metamodel

$$Y \approx \mathcal{M}(\boldsymbol{X}) = \sum_{\boldsymbol{\alpha} \in N^M} z_{\boldsymbol{\alpha}} \Psi_{\boldsymbol{\alpha}}(\boldsymbol{X})$$

Polynomial bases dependent on distribution of ***X***

$$\boldsymbol{z} = \underset{z \in \mathbb{R}^{card\,\mathcal{A}}}{\operatorname{argmin}} \mathbb{E}\left[\left(\boldsymbol{y} - \sum_{\boldsymbol{\alpha} \in \mathcal{A}} z_{\boldsymbol{\alpha}} \Psi_{\boldsymbol{\alpha}}(\boldsymbol{X})\right)^2\right]$$

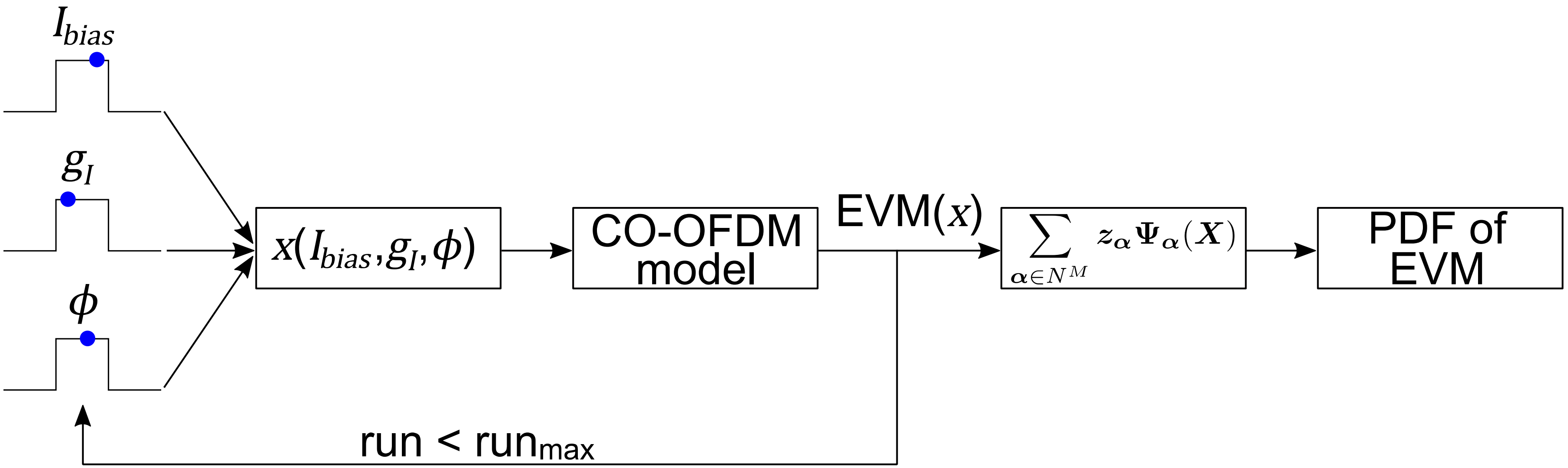
coefficients

Quantity of interest

Uncertain variables

PCE Setup

- PCE done through Marelli and Sudret's UQLab*



Distribution of input variables: Uniform
Uncertainty : ±5/10/15%
Sampling of uncertain variables : LHS
Quantity of Interest (QoI) : EVM
Runs to create model : 50
Error minimization method : LARS

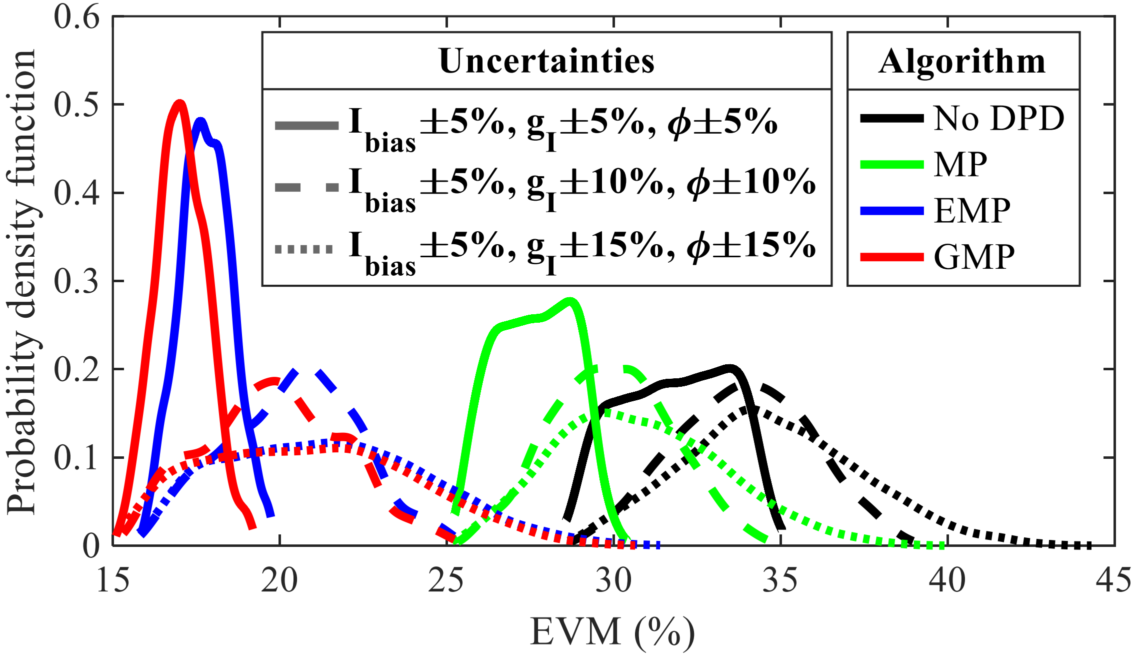
LHS: Latin Hypercube Sampling

LARS: Sparse least-angle regression

* S. Marelli, B. Sudret, "UQLab: A framework for uncertainty quantification in Matlab," *Proc. 2nd ICVRAM,* Liverpool, UK, 2014, pp. 2554-2563.

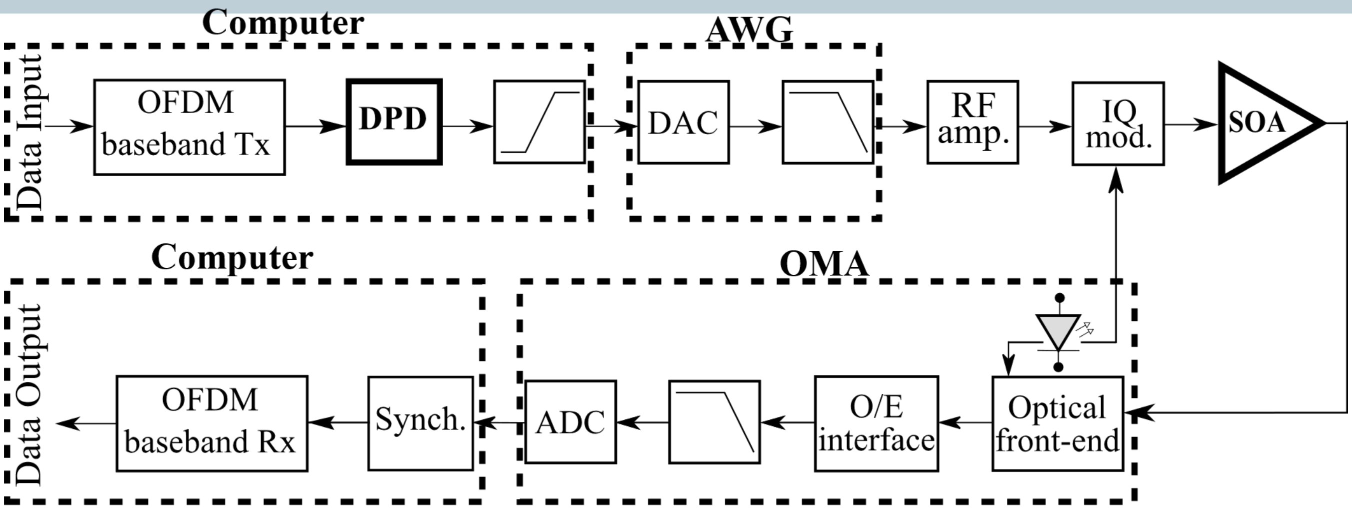
Numerical results

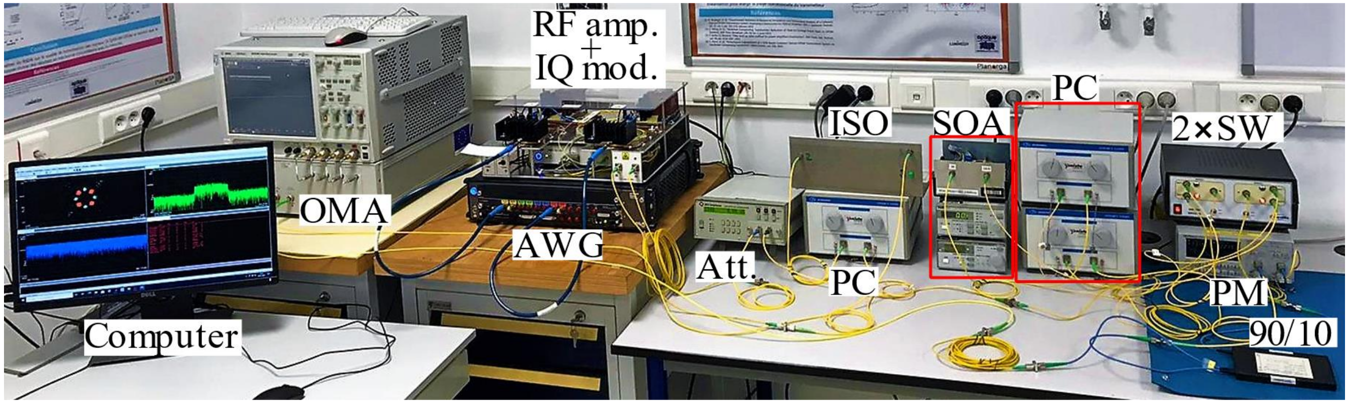
- 4-QAM configuration (27.8 Gbit/s) with a $P_{ref} = -14$ dBm into the SOA :

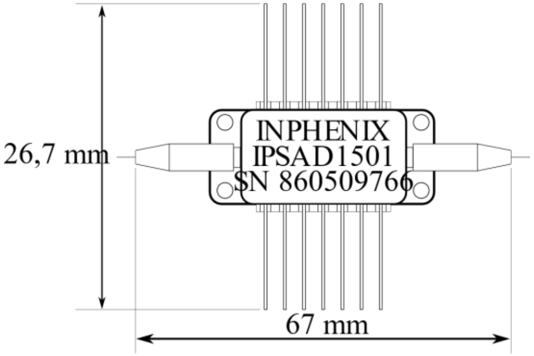


- # of coefficients: MP 9, EMP 33, GMP 69
- 30% EVM -> 10^{-3} BER (bit error rate)
- EMP and GMP meet requirements
- MP meets requirements for 5% uncertainty
- Improvement in robustness to uncertainties

Experimental setup







Concluding remarks

- Digital pre and postdistortion
- In-line SOA
- Effect of data rate on DPD efficiency
- GEMP more general structure like the GMP focusing on signal’s envelope

- For more details: PhD defense on November 30 at ENIB at 10:30 am

Thanks

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