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# SOAs and Digital Linearization in Optical Networks – A Stochastic Investigation

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**Abstract:** Digital predistortion has recently spurred interest in photonics. In this paper, the authors perform a sensitivity analysis of three digital predistortion algorithms and demonstrate an increase in performance and, in some cases, robustness to uncertainties. © 2020 The Author(s)

## 1. Introduction

The inclusion of Semiconductor Optical Amplifiers (SOAs) into optical communication systems has been suggested as they are easily integrable with other devices, cost-effective, and have a large optical bandwidth [1]. Coherent Optical Orthogonal Frequency Division Multiplexing (CO-OFDM) systems have been subjects of interest for their dynamic bandwidth allocation and the possibility for simple equalization implementation [2]. In this context of non-constant envelope, SOAs will bring nonlinearities. Fortunately, digital predistortion (DPD) was found capable of mitigating these effects by modifying the signal at the emitter according to an estimated inverse function of the SOA [3]. In addition, recent work using stochastic analysis showed DPD to be beneficial by reducing the impact of intrinsic uncertainties in the structure of the emitter [4]. The present paper brings new light on this topic by investigating DPDs subjected to the combined uncertainties of IQ imbalances (a current research focus [5]) in the presence of chromatic dispersion and digital-to-analog imperfections.

## 2. The SOA in a CO-OFDM system setup

This paper is based on the scenario depicted in Figure 1a. A bit stream undergoes M-QAM modulation before being coded into OFDM frames with a bandwidth of 20 GHz consisting of 512 subcarriers. After accounting for the null subcarriers and the cyclic prefix, the data rate is 27.8 Gbit/s or 55.6 Gbit/s for a 4-QAM and 16-QAM configuration respectively. Some hard-clipping at a 8 dB ratio is done on the constant length time signal which is sent through a digital-to-analog converter with an effective resolution of 6 bits. The electro-optic conversion includes an IQ modulator that has a peak-to-peak voltage of  $1.25 \times V_{\pi}$ . The channel configuration is 20 km of fiber followed by the SOA followed by 80 more km of fiber. At the receiver, the signal undergoes synchronization, equalization and demodulation. Figure 1b displays the parameters featuring the performance-limiting uncertainties in the system: the modulator's gains ( $g_I$  and  $g_Q$ ) and phase difference ( $\phi$ ), and the SOA's bias current ( $I_{bias}$ ). Their nominal values are 1 (where  $g_Q = 1 - (g_I - 1)$ ),  $\frac{\pi}{2}$ , and 150 mA respectively.

## 3. Uncertainty analysis via Polynomial Chaos Expansion

This paper deals with three predistortion algorithms known in the wireless radio literature: Memory Polynomials (MP), Envelope Memory Polynomials (EMP), and Generalized Memory Polynomials (GMP) [6]. Even though

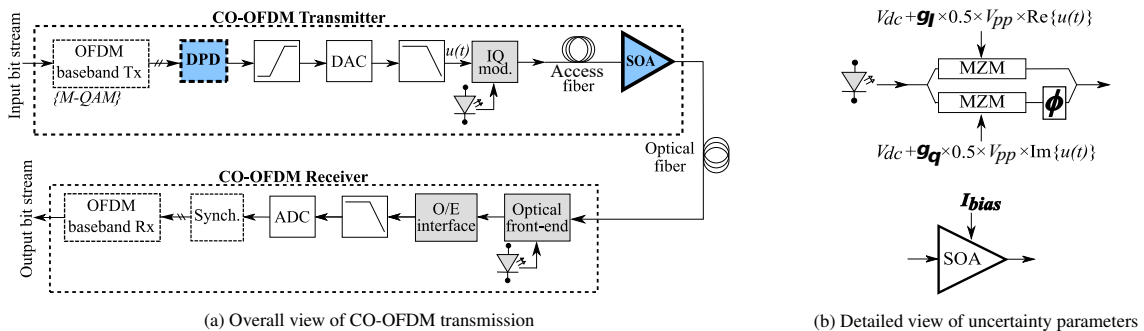


Fig. 1: CO-OFDM stochastic analysis setup

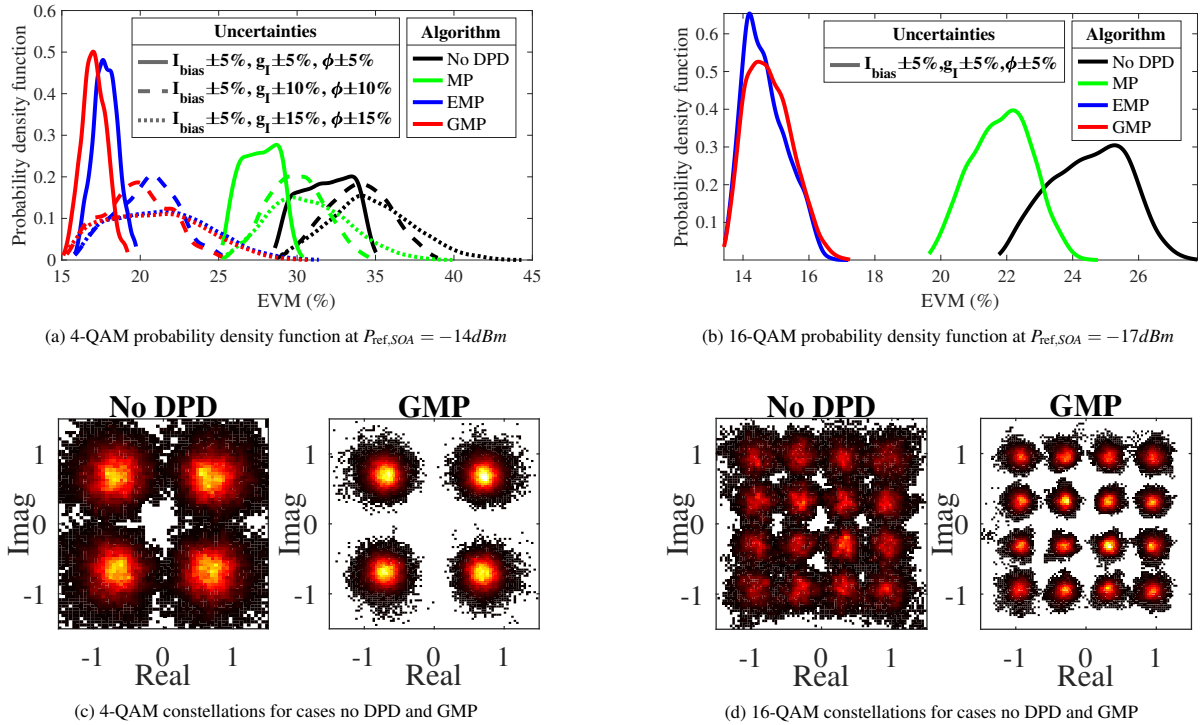


Fig. 2: Probability density functions and constellations

Monte Carlo (MC) simulations are usually used for uncertainty analyses, a macromodeling technique called the Polynomial Chaos Expansion (PCE) was demonstrated to be a viable alternative with an estimated speedup ratio of 200 for this scenario [4]. Thus, the PCE technique is used with the following parameters: Error Vector Magnitude (EVM) as the quantity of interest, Latin hypercube sampling as the sampling technique, 50 runs to create the model, and Sparse least-angle regression as the error minimization method.

#### 4. Results

The results are obtained through a MATLAB-ADS co-simulation where a  $750 \mu\text{m}$  INPHENIX-IPSAD1501 SOA with a gain of 18 dB and a noise figure of 9 dB is modeled through ADS [7]. The UQLab toolbox was used for the stochastic analysis [8]. Figures 2a and 2b demonstrate the estimated probability density functions (PDF) from the PCE models of four cases (no DPD, MP, EMP, GMP) at different levels of uncertainties. The reference input power to the SOA is  $-14 \text{ dBm}$  for 4-QAM and  $-17 \text{ dBm}$  for 16-QAM. A horizontal shift to the left signifies an improvement in EVM, hence a possibility for more reach. A vertical stretch upward entails a higher robustness to uncertainties. The EMP and GMP meet the EVM requirements in all cases: 30% for 4-QAM and 16% for 16-QAM [9]. The MP complies with that EVM objective for the 4-QAM, all parameters at 5% uncertainty scenario. Figures 2c and 2d portray 2D-histograms of the M-QAM symbols received. The constellation is color coded from dark to bright (lowest to highest density). The DPD shows brighter constellations with a tighter congregation.

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