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Robustness analysis of a parallel two-box digital polynomial predistorter for an SOA-based CO-OFDM system

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ABSTRACT

The linearization performance of various digital baseband pre-distortion schemes is evaluated in this paper for a coherent optical OFDM (CO-OFDM) transmitter employing a semiconductor optical amplifier (SOA). In particular, the benefits of using a parallel two-box (PTB) behavioral model, combining a static nonlinear function with a memory polynomial (MP) model, is investigated for mitigating the system nonlinearities and compared to the memoryless and MP models. Moreover, the robustness of the predistorters under different operating conditions and system uncertainties is assessed based on a precise SOA physical model. The PTB scheme proves to be the most effective linearization technique for the considered setup, with an excellent performance-complexity tradeoff over a wide range of conditions.

1. Introduction

Orthogonal frequency-division multiplexing (OFDM) has been recognized as one of the most promising techniques to support high data rate in next-gen optical communications networks, with some important advantages like simple compensation of linear channel impairments, dynamic bandwidth allocation capability in a multiuser context, and powerful digital signal processor (DSP)-based implementation [1–3]. However, a well-known drawback of multicarrier signaling is the high Peak-to-Average-Power Ratio (PAPR) [4], which makes OFDM very sensitive to nonlinear devices. Hence, PAPR reduction has been a subject of intense research in the past decade [5], with a wide variety of approaches originally developed for wireless and wireline communications and later investigated for optical OFDM systems [6]. Recently, Amiralizadeh et al. made an important contribution to the modeling and compensation of CO-OFDM transmitter nonlinearity [7] in presence of high PAPR, with a theoretical analysis of the impact of different nonlinear components (DAC, electrical power amplifier, optical modulator) in terms of bit-error-rate (BER) for different clipping ratios. It is also proposed to apply clipping along with digital predistortion to mitigate performance degradation. Some of the present authors have investigated similar problems by considering nonlinear effects originating from optical components, with a special focus on Semiconductor Optical Amplifiers (SOAs) [8,9]. Interesting features such as low cost, large optical bandwidth and small form factor [10] make SOAs an interesting alternative to the high-end EDFAs for some application scenarios [11]. However, as pointed out in our previous study, the use of the SOA as a booster amplifier may introduce strong nonlinear effects such as cross phase modulation (XPM) and four wave mixing (FWM) and degrade the overall system performance. PAPR reduction is required for shaping the envelope dynamics so as to limit the signal distortion but, as in [7], for a better performance improvement this may be combined with some linearization technique for compensating the nonlinear effects inherent to the SOA (which we consider as the main source of nonlinear distortion here). A broad variety of methods have been studied in literature for linearizing optical links or radio-over-fiber (RoF) links over the past few years, with a few approaches being specifically designed to cope with the nonlinear effects of SOA [12,13]. The various methods can be classified into three main groups: optical linearization, electrical analog linearization and electrical digital linearization [14]. A digital baseband predistortion (DPD) is considered throughout this study, which consists in pre-compensating the transmitter nonlinear characteristics based on a black-box behavioral model. Thus irregular characteristics of the transmitter can be counteracted in a flexible way, with a limited knowledge of physical link parameters and at a limited implementation effort. DPD has been the method of choice for power amplifier linearization in microwave wireless communication systems

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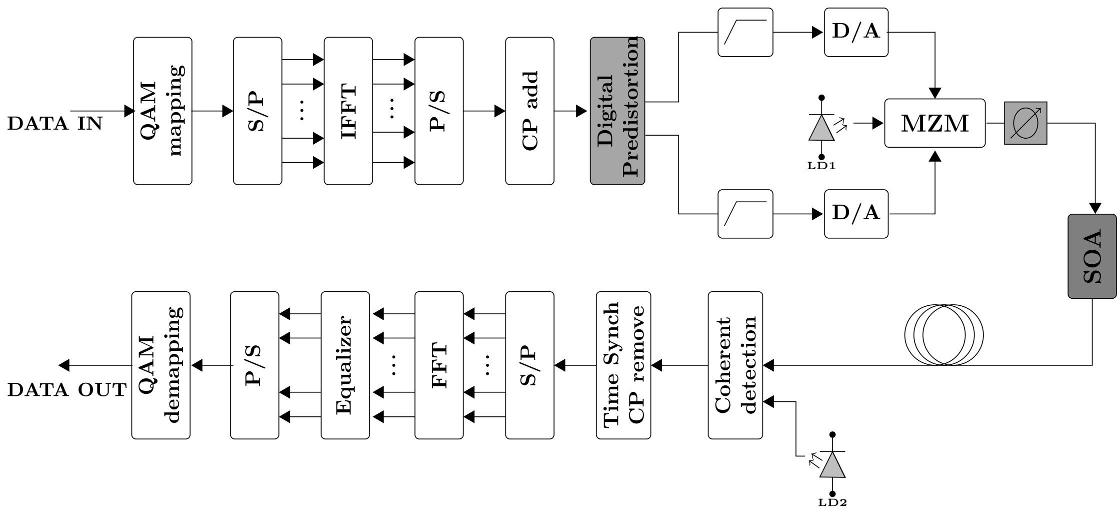

Fig. 1. CO-OFDM structure.

for a long time [15,16]. Numerous formulations exist featuring various block architectures either including or neglecting memory effects. The optical communications community has so far shown caution in importing such methods, but some proof-of-concept studies do exist and the effectiveness of DPD in optical fiber systems has been reported in a number of studies for different modulation formats (single carrier QAM, OFDM, CDMA) at various data rates and for different system setups/devices. The Memory Polynomial (MP) model [17–26], or its generalized formulation (GMP) [27,28], is extensively adopted for its good performance. The interest of using a simple look-up-table (LUT) scheme is mentioned in a few references [29–31] when the nonlinearity under test can be assumed as memoryless. It is also possible to use box-oriented models, which may be an attractive solution for lowering the implementation complexity while achieving good performance. In [32], it is proposed to combine the advantages of MP and Envelope Memory Polynomial (EMP) in a hybrid parallel structure whereas in [33] the authors study a Hammerstein model, which is composed of a memoryless nonlinearity function followed by a FIR filter. In our previous study [9], we investigated a Filter LUT scheme, which belongs to the augmented Hammerstein family, but with no special attempt to lower the complexity. The present paper tackles this issue which is crucial at optical data rates. A parallel two-box behavioral model is first examined for improving the same SOA-based transmitter, with a static nonlinear function and an MP model and with the objective of keeping the complexity as low as possible (low number of model parameters). It is proposed to design the static block by jointly considering the linearization and PAPR reduction objectives, via a simple constrained polynomial fitting. A second objective is to analyze the robustness of the predistorter in presence of parameter variations in the transmitter. Some of these parameters are physical such as the peak-to-peak voltage of the Mach–Zehnder modulator, optical power and wavelength of the optical signal or bias current for the SOA while others constitute changes in the modulation such as the number of subcarriers. To the best of the authors' knowledge this sort of analysis has not yet been conducted although it is extremely useful in the perspective of meeting future network demands, involving possibly adaptive transceiver parameters [34].

2. CO-OFDM system model

The following study is based on the coherent optical OFDM system model described in Fig. 1. The setup comprises a transmitter, a Semiconductor Optical Amplifier (SOA) device for boosting transmission reach and performance, and a receiver. Except the digital predistortion block, aiming at counteracting the SOA nonlinearities, the transmitter and receiver architectures are standard with common blocks such as QAM mapping/demapping, serial-to-parallel (S/P)/parallel-to-serial (P/S) conversion, FFT/IFFT transforms, Cyclic Prefix (CP) adding/removing, digital-to-analog (D/A)/analog-to-digital (A/D) conversion, time synchronization and equalization. At the transmitter side electro-optical (E/O) conversion is performed by an IQ modulator (Mach-Zehnder modulator, MZM) and linked to the main transmission laser (LD1). A second laser (LD2) is used to perform the coherent detection.

To carry out analyses in interest, the setup is implemented in a Matlab-ADS co-simulation environment. The CO-OFDM transmitter and receiver are modeled in Matlab while the SOA is modeled in ADS Ptolemy using the carrier density rate and optical signal field propagation equations [8]. Optical Amplifier parameters are tuned to realistically fit a 750 μm long commercial SOA (INPHENIX-IPSAD1501). Regarding the lasers, the study assumes perfect phase noise compensation and no frequency offset on the receiver side. A standard nonlinear model of the IQ optical modulator is implemented [1], with no imbalance impairment. For the D/A and A/D, a uniform quantization is considered, with a default resolution of 12 bits throughout the manuscript; the effect of the resolution will be investigated in Section 4 by decreasing its value to 4 bits. An ideal coherent detection is assumed (ideal photodetectors).

As presented in Fig. 1, input data stream is processed by the transmitter to obtain the initial OFDM electrical signal. Hard-clipping with a threshold of 12 dB is applied on the signal in front of DACs just before E/O conversion and the signal at SOA input has its power adjusted via an optical attenuator. Then, the equivalent OFDM optical signal with the SOA model are provided to the ADS environment for simulations relying on the field propagation equations. Once the simulation has been carried out, the Amplified Spontaneous Emission (ASE) noise sequence is calculated and added to the optical signal which is finally sent in the receiver which computes output data stream (back-to-back evaluation). Throughout the paper, we consider a 17 Gbps transmission with the default parameters presented in Table 1.

The structure and identification techniques of the predistortion systems in this study will be detailed in the following section.

3. Predistortion structures

The general concept behind predistortion is to precompensate amplification impairments by distorting the signal injected to the amplifier. The operation is carried out by a predistorter which basically corresponds to an inverse function of device under study. Four polynomial-based structures will be comparatively used to model the SOA inverse function: the static predistorter, the memory polynomial predistorter, the envelope memory polynomial predistorter and the parallel twin boxes predistorter. The memoryless digital predistorter