SOA Modeling for Advanced Optical Modulation Formats

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***Abstract*—The numerical modeling of semiconductor optical amplifiers (SOA) being able to simulate all of nonlinear effects of the SOA, particularly FWM effect, is presented. This model is integrated into a co-simulation platform to perform a simulation at a system level. A CO-OFDM transmission link and EVM measurement are used to study the impact of SOA and its relation to the number of subcarriers and phase-amplitude coupling.**

I. Introduction

With the dramatically increase of the data rates in optical telecommunication networks, some channel impairments like Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD) have become significant obstacles. Hence, the use of new techniques to overcome these impairments seems critical. One is the use of sophisticated modulation formats like Coherent Optical-Orthogonal Frequency Division Multiplexing (CO-OFDM) that can noticeably increase the tolerance to the linear impairments and improve spectral efficiency [1]. However, CO-OFDM presents a high sensibility to nonlinear behaviors of optical transmission link elements [2], which should be investigated accurately.

On the other hand, transmitting data over long distances needs the optical signals to be amplified. One valuable candidate is the Semiconductor Optical Amplifier (SOA) thanks to its large optical bandwidth vital for future WDM systems, its small size and its ability to be integrated with other optical devices. Moreover, it is a potentially low cost and low electric consumption component. One of its drawbacks when it is used as an optical amplifier is its fast dynamic gain, which introduces nonlinear effects such as Cross Gain Modulation (XGM), Cross Phase Modulation (XPM), Four Wave Mixing (FWM) and phase-amplitude coupling. Each of these nonlinear effects can have an impact on the data pattern quality.

In this paper, we study an SOA model based on [3] to examine its capability to simulate FWM. Subsequently, by using our system simulation platform, we investigate the impact of SOA on a CO-ODFM transmission link as functions of the number of subcarriers and phase-amplitude coupling.

II. Simulation Principle

The SOA model used in this study is a wideband time-domain transfer matrix model [3]. An advantage of time-domain modeling is the ability to use it inside the system simulations in the presence of time varying signals. This model simulates a bulk 750 µm long SOA having an optical gain of 20 dB at 1540 nm. It was modeled in Agilent Technology ADS™ software and designed to simulate nonlinearities such as XGM, XPM, FWM and phase-amplitude coupling. The modeling of a CO-OFDM optical system is performed using the VPItransmissionMaker™ software. Finally, we perform a co-simulation between ADS and VPI and study the performance of a CO-OFDM signal amplified by SOA, including nonlinear effects. Fig 1 shows the concept of this co-simulation.

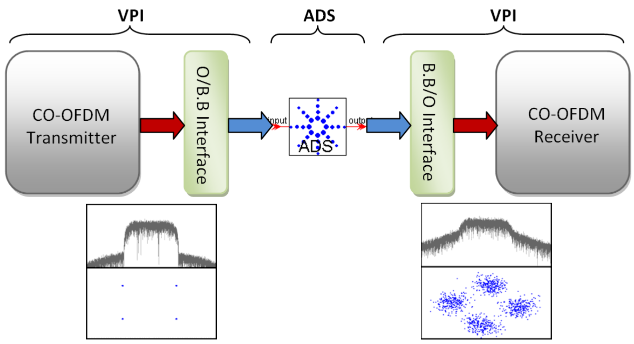

Fig 1 : Concept of co-simulation VPI-ADS and an example of a spectrum and a constellation of a QPSK CO-OFDM signal amplified with an SOA. O/B.B interface: Optical to Baseband signal conversion.

III. Simulation Results and Discussion

Firstly, we illustrate how our model simulates FWM effect in the SOA. An optical OFDM signal, including only two subcarriers with identical phases and amplitudes, is used. This optical OFDM signal corresponds to two optical signals injected into the SOA. The simulator calculates all the interaction between the two optical subcarriers.

The parameters that can affect on FWM products are the optical subcarriers power, their frequency interval and the phase-amplitude coupling (Henry's Alpha Factor or Linewidth Enhancement Factor). The Alpha Factor expresses the carrier-induced refractive-index change and consequently, the amplitude-phase coupling, which is responsible for a symmetric spectral broadening and also, causes asymmetry to the FWM spectrum. The latter is based on Bogatov effect [4] that describes the asymmetric gain saturation around a strong signal [5].

The FWM spectra at the output of the SOA are shown in Fig 2. We can see that the increase of the amplitude and the number of FWM products is related to an increase both in the power of the optical subcarriers and in the Alpha Factor of the SOA. It is also related to the decrease of the frequency

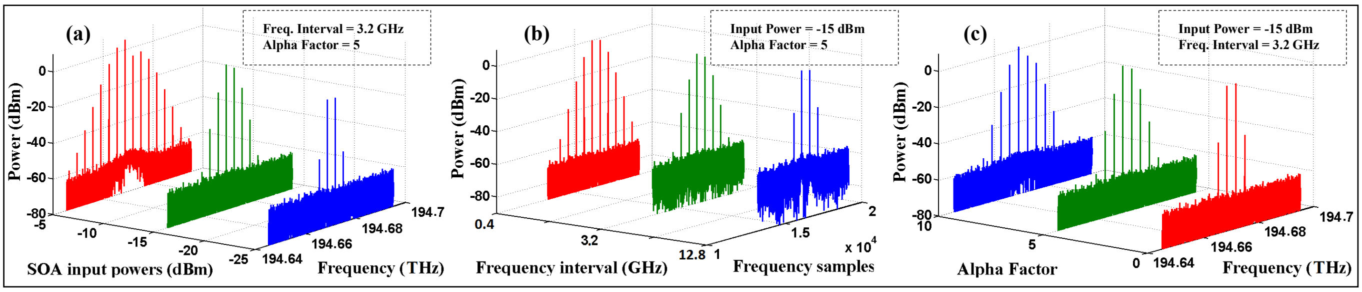

Fig 2 : FWM spectra at the output of the SOA as functions of (a) the input powers -25, -15 and -5 dBm, (b) the frequency interval 0.4, 3.2 and 12.8 GHz and (c) the Alpha Factor 0, 5 and 10. λ =1540 nm and f=c/ λ.

spacing of subcarriers. Decreasing the frequency interval is equivalent to increase the number of subcarriers of an OFDM with a constant data rate.

As deduced from Fig 2, the FWM can become a main source of degradation for multi-carrier signals. To study the influence of SOAs in a multi-carrier system, we use a CO-OFDM signal having a data rate of 100 Gb/s and 2^N subcarriers (N between 1 to 10), each subcarrier having a QPSK modulation format. We measure the Error Vector Magnitude (EVM) to evaluate the performance of the transmission link. In Fig 3, EVM results can be viewed as functions of the number of subcarriers and Alpha Factor values.

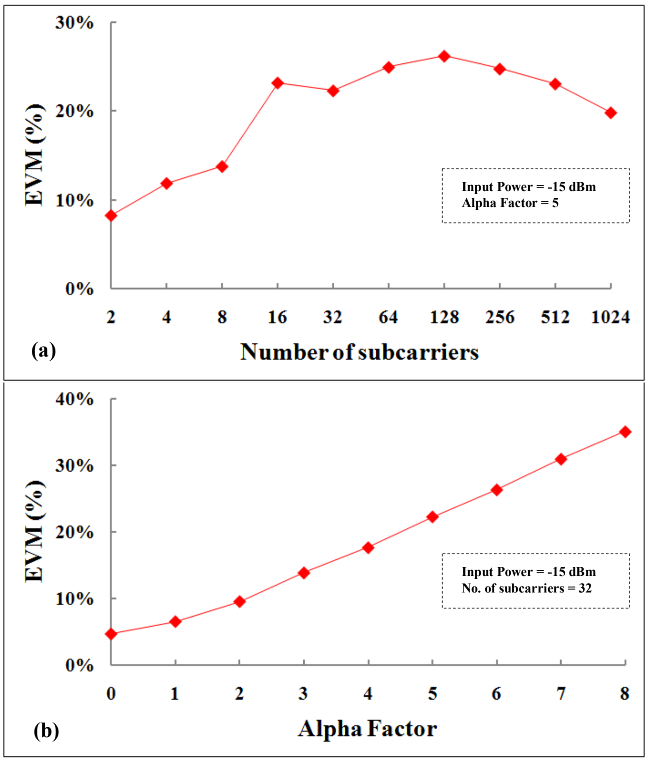

Fig 3 : EVM of a detected QPSK CO-OFDM signal as functions of (a) number of subcarriers and (b) Alpha Factor values. λ =1540 nm.

In Fig 3(a), with a small number of subcarriers, the effects of phase and amplitude modulations, like XGM, XPM and Alpha Factor, degrade the EVM. By adding new subcarriers, which is equivalent to decrease the frequency spacing, the FWM products are reinforced and consequently the EVM increases.

The EVM reaches its maximum value at 128 subcarriers and then reduces gradually. This can be explained by the fact that increasing the number of subcarriers causes a decrease in the power associated to each subcarrier. It reduces the FWM and consequently, improves EVM.

In Fig 3(b), we show that the EVM deteriorates with an increase of the Alpha Factor value. In fact, the Alpha Factor expresses a reciprocal change in the phase and amplitude of each subcarrier and between subcarriers. This distorts the data pattern in the time domain and also spreads the spectrum of each subcarrier in the frequency domain. The later causes an inter-subcarriers interference and accordingly amplifies the FWM products.

IV. CONCLUSIONS

In this paper, the validity of our SOA model in terms of its capability to simulate nonlinear effects including FWM was studied. We developed a co-simulation platform to study the effect of SOAs on CO-OFDM signals, and we evaluated the transmission link performance by measuring the EVM at the receiver. We have shown that the FWM effect combined with phase-amplitude coupling can significantly degrade multi-carrier signals transmission. According to this study, SOA-based multi-carrier signals amplification would benefit from using bulk SOAs with reduced Alpha Factor values or quantum SOA types.

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