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On the compensation of chirp induced from semiconductor optical amplifier on RZ data using optical delay interferometer

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ABSTRACT

The capability of an optical delay interferometer (ODI) to compensate the chirp induced on return-to-zero pulses amplified by a semiconductor optical amplifier (SOA) when operated under stressful conditions for its gain dynamics is investigated and demonstrated through extensive numerical simulation. The phase response of the ODI, which through its variation per time increment determines the chirp, is calculated at its crossed output port using an explicit expression. The theoretical analysis reveals that cascading the ODI after the SOA can reduce both the magnitude of the chirp and the variations of its peaks as well as those of the amplified pulses while ensuring error-free performance even for a tight combination of the critical parameters. In order for this goal to be successfully accomplished while not distorting the pulses acted on by the ODI the offset introduced by this passive element is computationally found that it must not exceed 10% of their repetition interval. Therefore the scheme can constitute a promising technological option for efficiently exploiting the chirp of an SOA and simultaneously using the SOA as gain block for direct amplification purposes.

1. Introduction

In last years the significant progress realized in the field of semiconductor optical amplifiers (SOAs) has made these active devices exhibit multi-functional capability, low power consumption, small footprint, wide gain bandwidth and integrability [1]. These attractive technological characteristics have spurred in turn intense research efforts for their deployment as power boosters [2,3], in-line amplifiers [4–6] and preamplifiers [7,8], with the ultimate goal to assist the implementation of lightwave communication systems and networks. However, their efficiency in these applications is constrained by the pattern effect that occurs due to the strong saturation and incomplete recovery of their gain in between excitation pulses of random binary content [9]. Among the various methods we have recently proposed [10–12] to resolve this problem and enable the unobstructed exploitation of a stand-alone conventional SOA in its classical role, the use of an optical delay interferometer (ODI) with its appealing features [13] is a very promising option. This potential has been demonstrated both theoretically [13] and experimentally [12] for the case of return-to-zero (RZ) data format. The ODI is serially placed after the SOA acting as a filter to properly suppress the spectral components of the unevenly amplified pulses that have been broadened under heavy saturation condition due to the manifestation of self-phase modulation (SPM), thus canceling the source of pattern-dependent distortion [14,15]. In this manner the amplitude wandering at the SOA exit, quantified by the amplitude modulation (AM), can be kept below an acceptable level [10–13]. This in turn allows the input power dynamic range of the SOA to be extended beyond the quasi-linear regime, where it should otherwise be operated for its gain to be unaffected by irregular variations at the expense of low output power and optical signal-to-noise ratio degradation [16,17]. On the other hand, the nonlinear phenomenon of SPM also imposes a chirp on a pulse whose intensity is relatively high with respect to the saturation level of a SOA via which it is propagated [18]. This quantity can be useful for mitigating the deleterious consequences of chromatic dispersion, hence extending the maximum reach of a fiber link [19]. Also it can enable pulse compression when its counterpart introduced in a suitable dispersive medium has the opposite sign [20]. However when the SOA is driven by a stream of pulses having alternating logical value and not by a train of continuous pulses or by just a single pulse then this potential is compromised. The reason is that due to the abnormal change of its gain dynamics that occurs in this case the physical mechanism leading to chirp is affected in a similar fashion. Accordingly the fluctuations in the peaks of the resultant pulses are also transferred to the chirp

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whose amplitude is thus not identical from pulse to pulse. Therefore in order to be able to take advantage of this induced instantaneous frequency deviation its uniformity in the bit slots containing a mark should definitely be enhanced. In this context it would also be desirable if its magnitude were simultaneously reduced. This for example would be necessary for avoiding degrading the performance of an all-optical switch [21] when an SOA is utilized as linear gain block to provide the necessary energy to the signal that determines switching [22]. For this purpose we propose in this paper to adopt the concept based on the ODI and theoretically investigate whether and to what degree it would be capable of compensating the chirp in the way mentioned before. The idea of using an optical filter, which the ODI essentially is, directly after an SOA to properly engineer the chirp imposed on the pulses passing through, has been undertaken before. However this has been done in various applications of SOA-based switches whose operation relies on the change of the SOA response incurred by one signal and suffered by another [23–29]. On the contrary in our case the modification of the SOA gain dynamics is provoked by a data-modulated signal onto itself, and so the approach required for removing patterning is different from a physical perspective. Compared also to previous works that deal with the complications of straightforward amplification using optical filtering [14,15,30–33], their primary concern has been to show the potential of the technique to alleviate the pattern effect only on the amplified pulses and not regarding the chirp as well. Thus in this paper our effort is focused on the chirp at the crossed output port of the cascaded ODI, aiming at thoroughly investigating its impact and optimally compensating its effect through its explicit treatment. This goal is methodically achieved by means of a numerical model validated through succinct comparison with available experimental evidence [12]. Furthermore, an analytical expression similar to that in [34] is used for the ODI phase response, whose variation per time increment determines chirp. In this manner it has been possible to assess the impact of the time delay inserted by the ODI on the chirp and specify the value that is appropriate for satisfying most the requirements defined for this parameter while simultaneously ensuring a tolerable AM. The outcome of this work can be helpful for allowing SOAs to better serve the needs of direct signal amplification for which they have been traditionally destined.

2. Principle of operation

The setup considered in this work is schematically shown in Fig. 1, and consists of a data-driven SOA and a concatenated ODI. In this configuration there are three points of interest, which are denoted by A, B and C and are located at the SOA input, SOA output and just after the ODI, respectively. At each one of them a set of traces is depicted both in the time (pulse waveform and eye diagram (ED)) and frequency (spectrum, including the ODI response, and chirp) domain. The information contained in them is available, experimentally from [12] and the details therein for the three first cases, and theoretically for the last one from the simulation conducted in this paper as described in the next section.

The data signal, which is characterized by high quality in terms of the aforementioned features, i.e. low AM [13], open ED with high extinction ratio (ER), symmetric spectrum and no chirp, is launched into the SOA from point A. If its power and temporal content are such that the SOA is highly saturated, then due to the SOA finite gain recovery time the SOA output depends on the logical values of the preceding input data bits instead of solely on the current input bit. The undesirable by-product of this situation is the severe performance deterioration at point B, which is directly reflected on the non-uniform profile of the amplified pulses. These are governed by intense amplitude excursions and a poor quality ED that is deformed to secondary envelopes. Furthermore, the strong gain saturation responsible for this pattern effect causes through the process of SPM the exit pulses to be spectrally broadened to the longer wavelength side and accordingly acquire a chirp. This is negative in the leading edge (red chirp) of the pulse, almost linear with increasing slope in its central part and positive in its trailing edge (blue chirp). The red chirp is related to carrier depletion and gain compression while the blue chirp is linked to carrier regeneration and gain recovery [24]. Since in

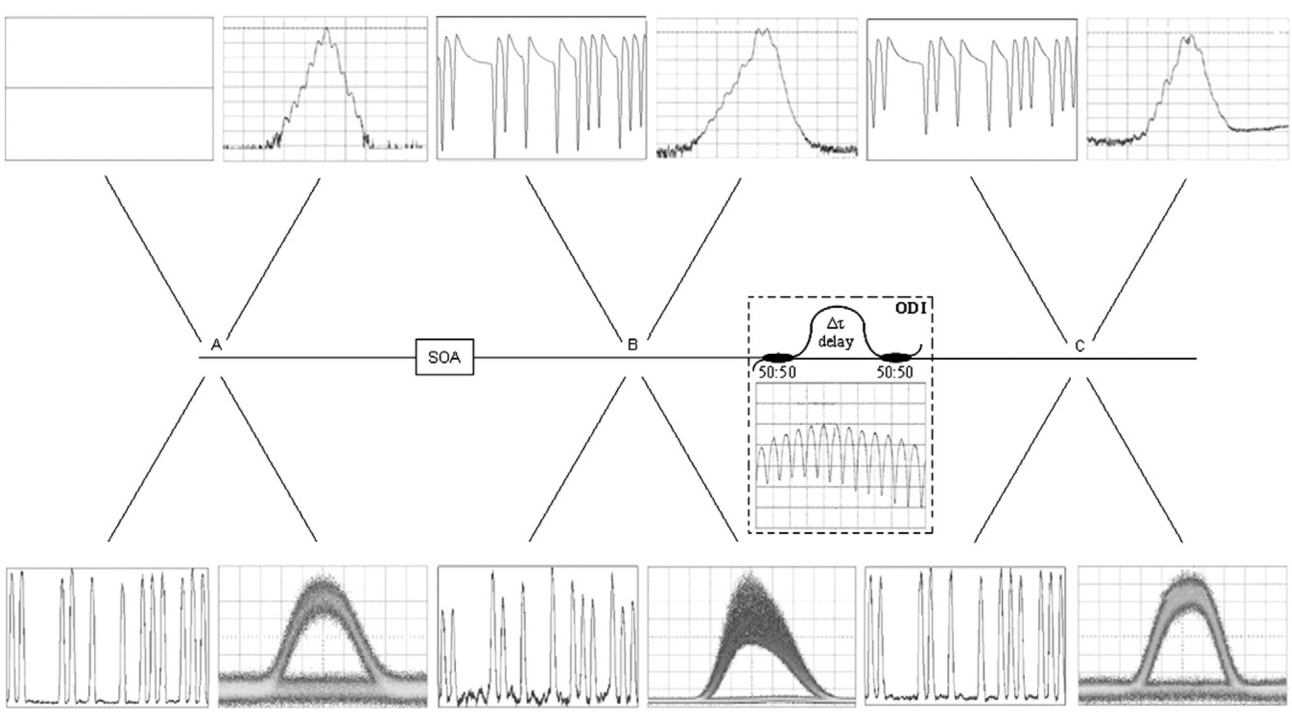

Fig. 1. Configuration of serially connected SOA and ODI considered in the simulation. The frames shown at different locations along the setup are representative for the data pulse train, the eye diagram, the spectrum and the chirp: before SOA (A), after SOA (B) and after ODI (C). The spectral response of the ODI is also shown below it.