Modelling of Semiconductor Optical Amplifier Chirp Compensation Using Optical Delay Interferometer

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***Abstract*—The feasibility of employing an optical delay interferometer (ODI) to compensate for the chirp imposed by a semiconductor optical amplifier (SOA) on its driving data pulses is demonstrated through the proper modelling of the joined setup of these elements. The simulation conducted for this purpose allows to specify the optimum temporal offset inserted by the cascaded ODI that effectively reduces the magnitude of the chirp and the variations of its peaks even when the SOA operational conditions are tight.**

I. INTRODUCTION

Semiconductor optical amplifiers (SOAs) have become key elements for the development of optical communications systems and networks [1]. In their classical amplification role the manifestation of the nonlinear effect of self-phase modulation broadens to longer wavelengths the spectrum of the incoming signal, which as a result acquires a (red) chirp [2]. Although this quantity can be exploited in optical communications [2], yet when the SOA is driven by pulses of random binary content that strongly saturate it then due to the concomitant irregular variation and incomplete recovery of the gain the chirp becomes pattern-dependent, and hence this potential is compromised. A possible technique to resolve this issue relies on placing an optical delay interferometer after the SOA. However so far it has been applied only to suppress the variations of the peak amplitudes of the amplified pulses [3] but not to properly engineer the SOA chirp as well. Thus in this paper we theoretically investigate whether this passive element is also capable of compensating this effect. For this purpose we formulate in Section II a model to describe the phase response of the SOA and ODI, which for the employed output port of the latter is done for the first time in an explicit manner. The conducted simulation enables to investigate the impact of the time delay inserted by the ODI on the chirp and find the value that is most suitable for satisfying the requirements for this parameter, according to the details in Section III.

II. MODELLING

Fig. 1 depicts the setup considered for simulation, which consists of the ODI with delay $\Delta\tau$ serially connected at the SOA exit. The objective is to model the chirp and obtain traces at the output of each one of these elements. For this reason the starting point is the general mathematical expression for the chirp, $\Delta\nu(t)$, which is given by [2] $\Delta\nu(t)=-\frac{1}{2\pi}\frac{dF(t)}{dt}$.

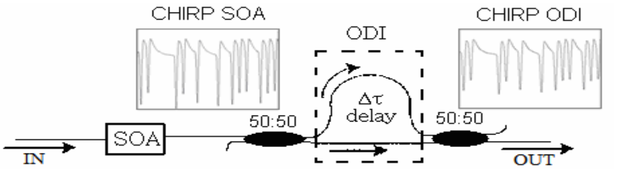

Figure 1. Simulated setup

Therefore in order to calculate the chirp at the points of interest it is necessary to know the corresponding phase transfer function, *F(t)*. For the SOA case this is mathematically described from [2]

$$F_{SOA}(t)=-\frac{1}{2}\alpha h(t) \tag{1}$$

where α is the SOA linewidth enhancement factor and *h(t)* its integrated gain that obeys the following first-order differential equation [2]

$$\frac{dh(t)}{dt}=\frac{\ln\left(G_{ss}\right)-h(t)}{T_{carrier}}-\frac{P_{data}(t)}{E_{sat}}\left\{\exp\left[h(t)\right]-1\right\} \tag{2}$$

where G_{ss}, $T_{carrier}$ and E_{sat} are the SOA small signal gain, carrier lifetime and saturation energy, respectively, while $P_{data}(t)$ is the power of the launched data pulses. On the other hand the phase response of the ODI at its crossed output port can be found by following a procedure similar to that in [4] but adapted to a passive element like the ODI. This involves working with the electric fields of the input signal and its delayed replica while properly handling the terms of the phase shift that these components experience as they traverse the ODI and recombine. The result after some cumbersome algebraic manipulations is

$$F_{ODI}(t)=F_{SOA}(t-\Delta\tau)-\arctan\left(A/B\right) \tag{3}$$

where $A=1+\sqrt{P_R(t)}\cos\left[\Delta F(t)\right]$, $B=\sqrt{P_R(t)}\sin\left[\Delta F(t)\right]$, and $P_R(t)=P_{SOA}(t)/P_{SOA}(t-\Delta\tau)$, $P_{SOA}(t)=P_{data}(t)\exp\left[h(t)\right]$, $\Delta F(t)=F_{SOA}(t)-F_{SOA}(t-\Delta\tau)$.

III. RESULTS

Equations (1) and (3) indicate that the calculation of the chirp after the SOA and ODI, respectively, requires the knowledge of *h(t)*. For this purpose (2) is numerically solved in a step-wise manner by sampling the optical pulse over its period at discrete temporal intervals, approximating the time derivative by a finite difference and applying the appropriate initial conditions [5]. This procedure is followed for the SOA parameters $G_{ss} = 23\ \text{dB}$, $T_{carrier} = 75\ \text{ps}$, $E_{sat} = 1.5\ \text{pJ}$, $\alpha = 8$, while the input data signal, $P_{data}(t)$, is a Gaussian-shaped 10 Gb/s unchirped return-to-zero pseudorandom binary sequence of word length 2^7-1 having peak power 4.6 mW and full-width at half-maximum pulsewidth 27 ps, which together cause a pronounced SOA pattern effect [4].

Figs. 2 and 3 illustrate the obtained simulation results.

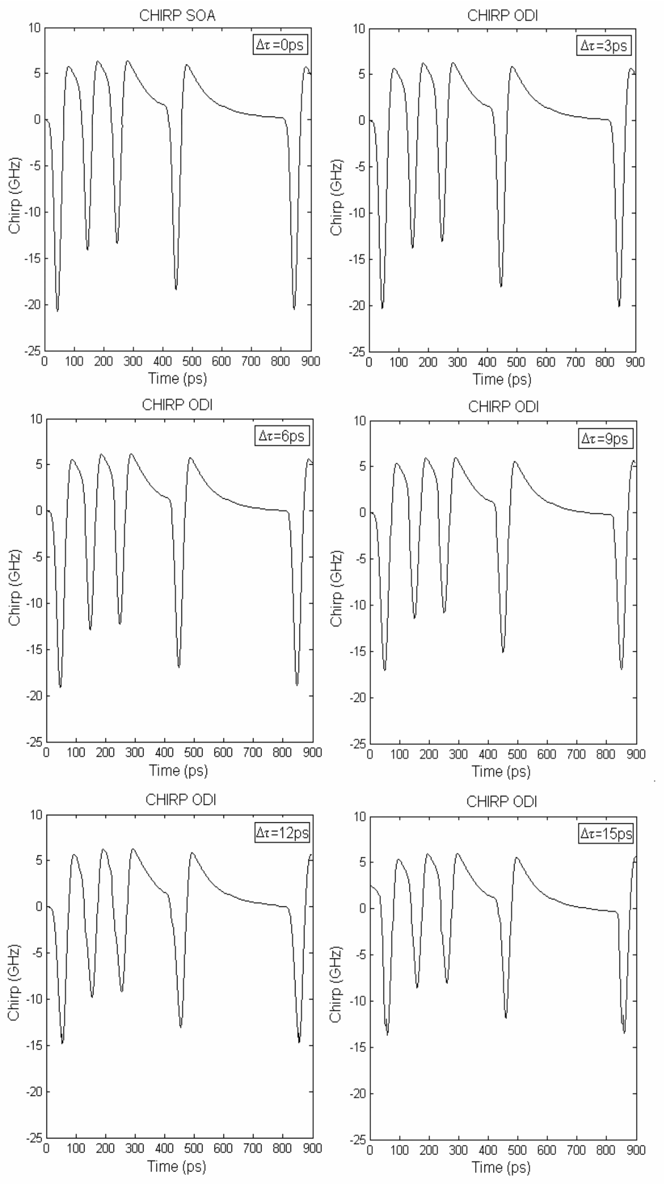

Figure 2. Simulated chirp profiles for different ODI time delays

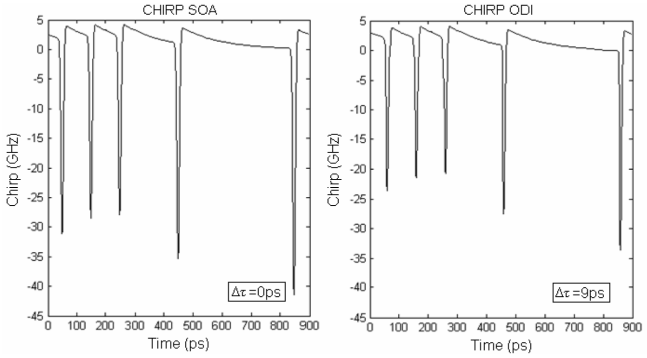

Figure 3. Comparison of chirp profiles for optimum ODI time delay

More specifically, for the SOA alone, i.e. Δτ = 0 ps, the severe pattern effect is deleterious for the form of the chirp. Nevertheless, owing to the ODI the situation is gradually improved as Δτ is increased in steps of 3 ps and up to 9 ps. This is apparent in Fig. 2, since compared to the case without the ODI the peak variations of the red chirp are compensated and its absolute magnitude is reduced. However, as the ODI temporal offset keeps augmenting at the same rate, the chirp becomes distorted at its peaks, as it begins to happen for 12 ps and then continues more strongly for 15 ps. Therefore from all this chirp evolution against Δτ it is realized that the latter should not exceed the critical limit of 10 ps. In fact, by running the model for Δτ = 9 ps, which constitutes the optimum value of the ODI time delay, it can be seen from Fig. 3 that it is possible to suppress the chirp even when the SOA operates under very tight conditions.

IV. CONCLUSION

The capability of an ODI to compensate for the chirp induced on data pulses amplified by an SOA has been investigated and verified by modelling and linking the phase response of these two elements. The simulation results have revealed that in order for the scheme to be efficient the ODI delay must correspond to, but not exceed, 10% of the allocated bit slot. The outcome of this study can be useful for enhancing the performance of applications that exploit the SOA chirp.

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