Data Rewriting After Carrier Erasing by Ultra-Long SOA

Napoleão S. Ribeiro [1*], André L. R. Cavalcante [1], Cristiano M. Gallep [2] and Evandro Conforti [1]
[1]Department of Microwaves and Optics - FEEC, University of Campinas (UNICAMP), C.P. 6101, 13083-970 Campinas, SP, Brazil;
[2]Division of Telecommunication Technology - FT, University of Campinas, 13484-370, Limeira/SP, Brazil
[*]Corresponding author: nribeiro@dmo.fee.unicamp.br

Abstract: Optical carrier erasing is demonstrated with evaluation of further remodulation up to 12.5Gbps. Small impairments achieved for all but the 7G-7G and 12.5G-12.5G cases, when spurious-pattern noise force higher penalties (respectively 2.3dB and 0.7dB).
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1. Introduction

The wavelength division multiplexing passive optical network (WDM-PON) with centralized light sources (CLS) has been considered an ultimate solution for the fiber-to-the-home (FTTH) structure implementation [1]. Many WDM-PON implementations use two wavelengths: one carrier for the upstream and another for the downstream signal [2]. However, the finite number of available channels may limit the system capacity, making the wavelength reuse approach an attractive candidate to provide power to the upstream channel - downstream carrier erasing and remodulation - with no additional wavelength required.

Some techniques were proposed to implement the optical data erasing/rewriting, based on use of two modulators [3], semiconductor optical amplifier (SOA) with feed-forward gain control technique and optical modulator [4], SOA as eraser/modulator [2], reflective SOAs (RSOAs) [5], interferometric filter & RSOAs [6]. However, the erasing capacity presented is not substantial in many cases, even more when considering PRBS, AM signal with input ER greater than 8 dB, and/or when trying high bit rates (above 2.5 Gbps). The use of gain-saturated SOA to erasure optical data was proposed first in [7] and implemented in [5] using cascaded SOAs. The new data rewriter scheme used here was presented previously in ref.[8], were some erasing characterization was presented. The scheme is based on deep gain saturation of an ultra-long SOA (L_Z = 8 mm), to erasure the downstream signal, and a local optical modulator, to rewrite data over the now upstream carrier.

Here we present the impact of the erased-carrier spurious oscillations over the quality of the upstream signal, with BERT curves for different downstream and upstream bit-rates (up to 12.5Gbps) and varying the modulation extinction ratio (ER_{in}, up to 12.4 dB) for the downstream channel. The rewritten carrier - the upstream - presented small BER penalties, lower than 1 dB when comparing with a clean (CW) original source and when varying the input bit-rates and negligible penalties when varying the ER_{in}. A error-floor appear just for operation using both up- and downstream at 12.5 Gbps, tending to BER = 10^{-9}; even so, the erased/rewritten channel presents equal performance to that of a clean (CW) input up to BER = 10^{-7}.

2. Experimental setup and results

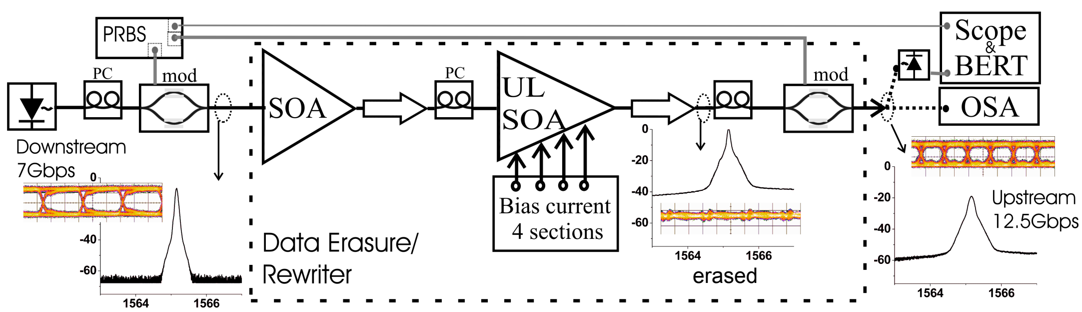

Fig. 1. Experimental setup - CW tunable laser; Mach-Zehnder amplitude modulator (mod); linear semiconductor optical amplifier (SOA); optical polarization controller (PC); Ultra-Long (UL)SOA; in detail, power spectra and eye-diagrams for the downstream (ex.7Gbps), the erased and the upstream (ex.12.5Gbps) carrier.

The experimental setup is shown in Fig.1 – the downstream source formed by signal generator, CW laser and optical amplitude modulator (2 to 12.5 Gbps) operating in non-return to zero (NRZ) PRBS with variable extinction ratio. The chosen carrier wavelength (1565nm) is the optimal in this case, coinciding with the peak of the UL-SOA amplified spontaneous emission (ASE) spectrum. After been modulated in amplitude, the downstream carrier is lead to the data-erasing/rewriter, composed by a linear SOA (pre-amplifier), optical isolators, an UL-SOA and an optical modulator. The quality of the up(down)stream signals are analyzed by optical oscilloscope and a BERT system (Agilent N4903A), simultaneously with the spectral behavior (OSA). Since the UL-SOA input optical power is a crucial parameter to operate in deep saturation, the linear SOA was used to provide a gain variation fro m 4.3 dB to 10 dB; this gain can also compensate the signal derivation needed to sense the downstream data at the local node. Although, the small BER variation with the UL-SOA input optical power (P_{in}), when between -1 to 4.5 dBm (not shown here) demonstrates that this parameter has no great influence on the data rewriting performance, at least for this moderate input levels. The UL-SOA has an active cavity 8-mm long, divided in four sections - two center ones with 3 mm and two edge ones with 1 mm [9]. The maximum total bias current is 2.7 A; in this work we report up to 450 mA in the center sections and up to 150 mA in the edge sections (Total 150+450+450+150 mA = 1,2A).

The eye-diagrams and power spectra presented in details of Fig.1 for the downstream (input), the erased and the remodulated (output) carriers, show that an amplitude-modulated optical carrier can be practically cleaned, with amplitude modulation reduced to small spikes around the former bit transitions, and that afterwards such a recycled optical carrier can be remodulated and used as the return channel, here demonstrated up to 12.5Gbps. The spectra of the rewritten carriers, however, present some self-phase modulation (SPM), intrinsic to the erasing nonlinear process in the UL-SOA. For high input levels (>6 dBm), SPM can lead to further impairment in fiber transmission (currently under tests).

The scheme operates with small penalties for different downstream bit-rates from CW (b-t-b) up to 7 Gbps, as shown in BERT curves in Fig.2(a) for the related (re)modulated 12.5Gbps upstream carriers– penalties of 0.8 dB when erasing 2 and 4 Gbps channels, and just 0.2 dB when erasing a 7Gbps channel, in comparison to the clean input. This bit-rate dependence is related to the remaining spikes over the erased carrier, affecting the sensed signal quality as much as can pass through the receiver bandwidth. Thus, as the downstream bit-rate decreases, the noise power that enters the receiver bandwidth increases, deteriorating the upstream signal [2].

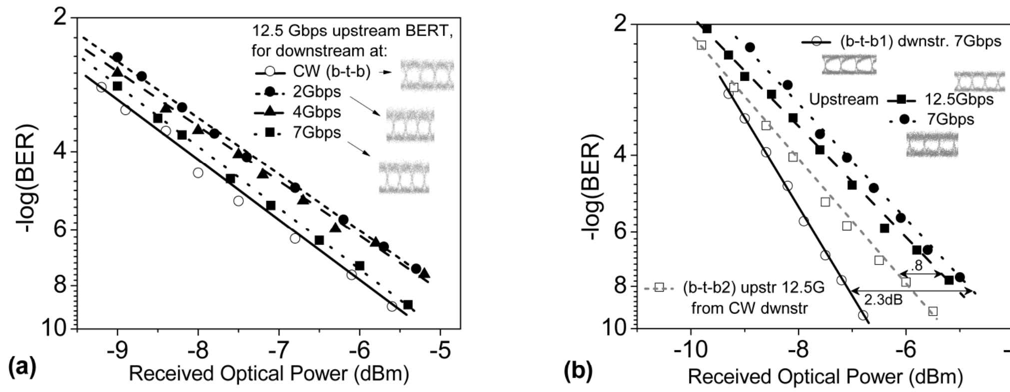

Fig. 2. BER curves and eye-diagrams of the (a) upstream signal at 12.5 Gbps, for diverse downstream - CW, 2, 4 and 7 Gbps; (b) 7 and 12.5Gbps upstr. for 7Gbps downstr. (included), 12.5Gbps upstr. for CW downstr.

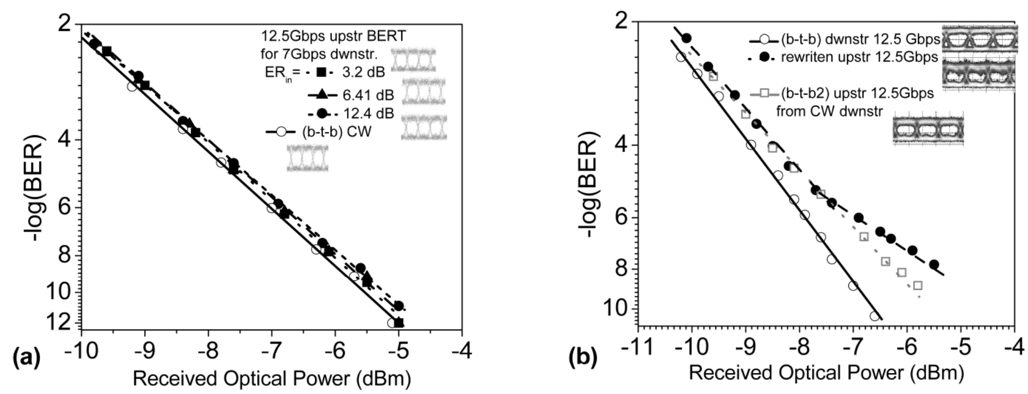

Fig. 3. BER curves and eye-diagrams of the (a) 12.5 Gbps upstream signal for diverse downstream (7Gbps) ER_{in} and CW; (b) 12.5Gbps upstr. for 12.5Gbps downstr. (included) and for CW downstr.

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Figure 2(b) shows penalty of 2.3 dB when erasing 7Gbps and remodulating at the same speed, but the recycled carrier remodulated at 12.5G has BER just 0.8 dB worse than the one using a clean (CW) optical carrier (b-t-b2). This indicates that the spurious amplitude noise over the upstream data is really small, and can be as deleterious as the ASE noise accumulated in the cascaded SOA amplification; also that the unsuppressed bit-pattern can induce more deterioration when over equal frequency remodulation, as confirmed next also for the 12.5G-up case. All data at Fig.2 (a) and (b) were acquired for (ULSOA) P_{in} = 3.3 dBm and ER_{in}=10.2 dB.

Figure 3 shows the performance of 12.5 Gbps upstream (a) when varying the ER_{in} of a 7Gbps downstream carrier (P_{in}=4.83 dB), and (b) the worst case – equal down-up frequency - when using a 12.5 Gbps downstream. The modulation deep does not interfere in the erasing process, at least up to ER_{in}=12.4 dB tested, with negligible BER penalties (Fig.3(a)). The erasing of a 12.5Gbps carrier and remodulation with same speed is presented in Fig.3(b), shows error floor tending to BER=10^{-9}. The b-t-b2 (12.5G-up from CW input) differs from the b-t-b1 (12.5G-downstr.) due ASE noise accumulated in SOA amplification, with 1 dB BER penalty at 10^{-10}. Although, the recycled 12.5 Gbps upstream fits the b-t-b2 up to 10^{-6}, deviating 0.7 dB at 10^{-9}, showing that even for the worst case of remodulation at equal rate the system can work with acceptable penalties.

In addition to the data here presented, the scheme was tested in a wavelength range of 15 nm with good results, been able to rewrite signals with high input extinction ratios (up to 12.4 dB).

3. Conclusion

We presented the performance of a data-erasing/rewriting scheme for variations in the downstream and the upstream bit-rates and in the downstream modulation deep (ER_{in}), with small power penalties in all cases but error floor at BER=10^{-9} when recycling a 12.5 Gbps optical carrier to an upstream at the same data-rate.

The system can successfully erasure an optical carrier and remodulate up to 12.5 Gbps with minor penalties, ex. 0.2 dB for 7 Gbps downstream recycled to a 12.5 Gbps upstream (Fig.2(a)). Major defects may occur when using the same bit-rate of the downstream carrier over the remodulated signal, leading to higher penalties (2.3 dB total for 7G-case) and even error floor (BER=10^{-9} for 12.5G-case, with 0.7dB penalty from b-t-b).

Although simple and effective, the scheme is still costly due the UL-SOA and has the above-cited limitations, including OSNR reduction due ASE accumulation; but the main drawback in the occurrence of SPM since the induced spectral broadening can, at high input powers (>6 dB), high ER_{in} and bit-rates (>7Gbps), have some deleterious impact over further fiber transmission, issue under test now. Nevertheless, with the BER performance achieved in the presented scheme we expect to realize efficient use of wavelength resources in WDM networks with CLS.

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4. References

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