BER Improvement Using Optical Gain Clamped Amplifier for Burst Transmission and Critical Cases Studies

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Abstract: This paper demonstrates significant BER improvement in burst traffic transmission using optical-gain clamped amplifiers. Critical chaotic cases are identified for peculiar burst sequences and their impact in transmission is assessed.

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1. Introduction

Strong signal power variations due to both signal add/drop or burst transmission are a main concern in amplified transmission systems due to gain saturation of optical amplifiers (OA). In particular this is a key issue for optical burst transmission [1], where potential degradation can be accumulated along the system [2]. Several techniques have been proposed to stabilize the amplifier gain and passive all-optical means is a very promising one [3]. In particular, all-optical gain clamping of Erbium-doped amplifiers in optimized condition have successfully proved to strongly reduce overshoot after add/drop transients [4], and allowed for the first time stable close-loop network operation [5]. Recent work has demonstrated that overshoot induced by burst transmission may also be significantly reduced by optical-gain-clamped (OGC) technique [6]. However, no direct bit-error-rate (BER) improvement has been assessed. In addition, the burst mode transmission may interplay with intrinsic chaotic dynamics of OGC-OA.

This paper reports BER improvement in WDM burst transmission and the BER performance in critical cases when burst duration and burst inter-arrival time interplay with OGC-OA dynamics. In addition, the paper investigates the burst traffic characteristics to evaluate the probability of critical case occurrence. The results demonstrate that OGC-OA brings **significant** BER improvement for burst traffic and critical case occurrence will not impact the BER performance.

2. Setup Description

The data used to simulate the WDM burst transmission was obtained from a pair of Full-Duplex Gigabit Ethernet links, which connects the Catalan R&D network (around 50 Universities and Research Centers) with the Spanish R&D RedIris network and to the internet [7,8]. An optical burst switching (OBS) node performs packets aggregation and burst generation [7]. A 14-s long trace with 95k burst is obtained from the testbed and used to build a 1-s long WDM burst stream by taking uncorrelated data from different time slots [7].
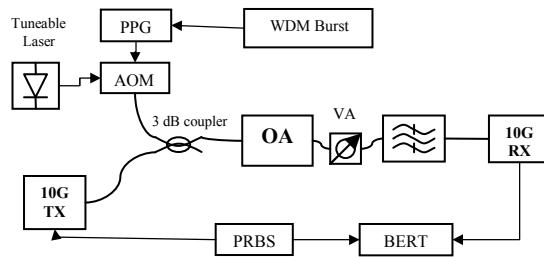

Fig. 1. Experimental setup for the multi-channel burst transmission

The experimental set-up is depicted in Fig.1. The signal obtained from 15 WDM burst traffic channels controls the pulse pattern generator (PPG) driving the acousto-optic modulator (AOM) to modulate a tunable laser source. The maximum power after the AOM entering the commercial erbium-doped fiber amplifier (EDFA) is -1 dBm and simulates 15 WDM channels at 1550 nm. A continuous wave probe signal simulating the 16th channel is used for BER measurement. This channel is implemented with a pseudo-random binary sequence generator (PRBS) and a 10 Gbit/s transmitter at 1556.5 nm with -15 dBm average power. The commercial EDFA used on these experiments is

configured for a 17-dB gain and has noise figure of 6.5 dB [6]. The amplifier is tested in clamped and unclamped conditions under same gain and input power conditions. To achieve optical feedback, for sake of simplicity and without affecting the test validation, a ring configuration with cavity length of about 7m is used. A variable attenuator (VA) simulates transmission losses and a tunable filter enables probe channel reception.

3. Amplifier dynamic characterization and critical case investigation

Before performing transmission experiments, the dynamic behavior of the amplifier is evaluated for specific burst sequences. As demonstrated in [8], the interplay of burst duration/inter-arrival time with OGC-OA relaxation oscillation frequency (i.e. with intrinsic frequency the OGC-OA relaxing to steady state after perturbation) may generate chaotic behavior, as shown in Fig. 2. The OGC-OA is tested using the -1 dBm signal on/off modulated.

First measurements evaluate the add/drop relaxation oscillation frequencies (ROF) [8], to be 13.5 and 23.5 kHz, respectively. Subsequently, the frequency f, which represents the simultaneous on/off of all the channels, is swept from 1 Hz to 200 kHz, 50% duty cycle, and backward. Fig. 2 shows the overshoot observed as a function of the burst inter-arrival time T ($T=1/2f$). During the forward sweep (with respect to time), when the burst duration and inter-arrival time are increased, it is possible to note a peak for burst of 21.3 μs, followed by a peak at 37 μs related to drop and add frequency, respectively. This is due to interplay between burst sequence and intrinsic OGC-OA gain recovery dynamic [9]. It may be inferred that sequences of bursts with duration and inter-arrival times between 10μs and 80μs may generate chaotic behavior with potential BER transmission performance penalty.
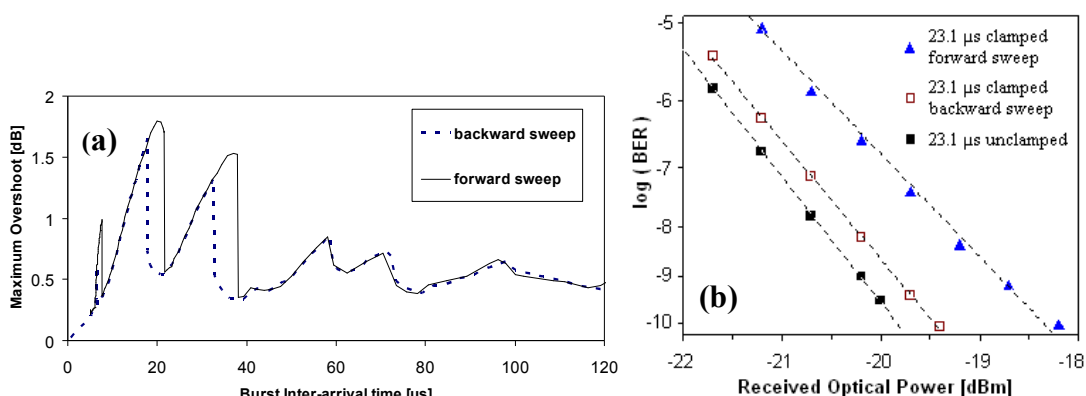

Fig. 2. (a) Maximum power overshoot for on/off modulation. Time scale refers to burst duration with 50% duty cycle: b) BER for on/off with burst of 23.1 microseconds (50% duty cycle) for clamped (forward and backward sweep) and unclamped condition.

BER measurements are performed in order to assess this issue, as shown in Fig. 2b. A BER penalty quite significant is observed for the forward sweep while very similar behavior for unclamped and backward sweep is also noted. For this worst case scenario with 15 simultaneous bursts with same duration and inter-arrival times, it is possible to observe that for the highest overshoot peak, the clamped amplifier introduces a transmission penalty of around 1.7 dB at BER = 10^{-10}. The good performance of unclamped OA is due to the fact that power variation due to short bursts is averaged by the ms-time scale dynamic of unclamped OA.

Next step is, therefore, the assessment of burst occurrence with duration and/or inter-arrival time between 20 μs and 80 μs. Fig. 3 shows the calculated statistic of the burst traffic data obtained from the OBS network and it is observed that most bursts and most of inter-arrival times fall in the potentially dangerous region 20μs-80μs.
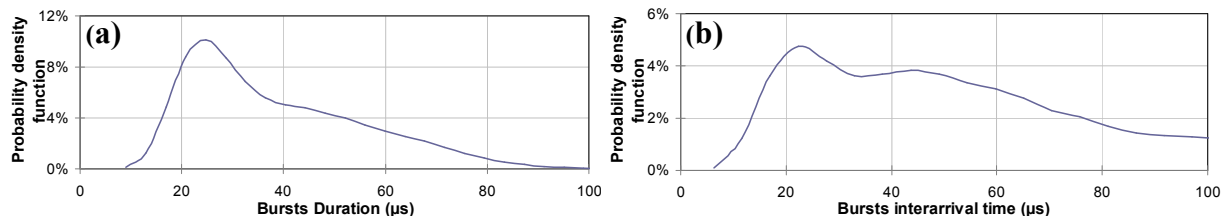

Fig. 3. Occurrence statistic of burst durations (a) and inter-arrival times (b).

4. Burst transmission experiment

The BER measurement is performed using the burst traffic data (see Fig. 4). The OGC-OA performs with no extra penalty with respect to the back-to-back BER measurement with traffic data, while unclamped OA exhibits a

penalty of 1 dB for BER = 10^{-10}. Figure 4 also shows BER values when the channels are simultaneously switched on/off at a 1 kHz repetition rate. In this case, the OGC-OA again shows no penalty while the unclamped OA shows a penalty of over 3 dB for BER = 10^{-10}. This last result is very indicative of the possibility of implementing synchronized WDM OBS transmission (all burst channels are aligned) using OGC-OA. The OGC-OA excellent performance with traffic data can be explained with the following considerations. Firstly, while it is true that burst falls in the dangerous region our simulations have shown that to initiate the chaotic behavior, 4 to 5 bursts in sequence are needed. The probability of having such a sequence is very low [10]. Furthermore, the chaotic behavior induced penalty grows nonlinearly with the amount of power switched on/off. In case of non aligned burst channels, as in burst traffic data, the power excursion is limited. In fact, the probability of having all bursts synchronized to generate add/drop like transient is almost zero. However, the chaotic behavior observed in the worst case scenario may be avoided by shifting the resonating frequency out of burst statistics. This can be done by adjusting the OGC-OA operating condition and/or the resonating cavity length.
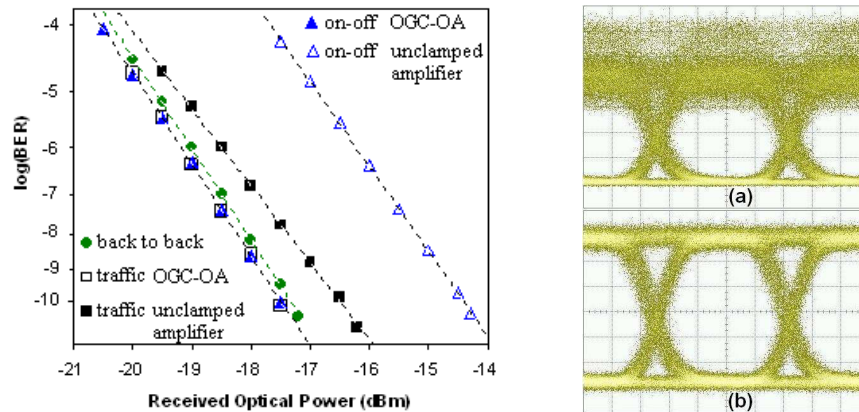

Fig. 4. Left: Bit Error Rate curves for the probe channel with burst traffic data and for 1 kHz simultaneous drop and addition of all channels. Right: Eye-diagrams for burst traffic scenario using (a) unclamped OA and (b) OGC-OA.

5. Conclusions

This paper demonstrates that OGC-OA has no penalty with respect to back-to-back burst transmission and also shows a 1dB improvement at BER of 10^{-10} with respect to unclamped OA. In addition, no penalty is shown for channels add/drop while 3 dB penalty at BER of 10^{-10} is measured for unclamped OA. Furthermore, the results show that while chaotic behavior may generate BER penalty in burst traffic condition, there is almost negligible probability of initiating such a chaotic behavior. The conclusion is that OGC-OA offers BER performance benefits versus unclamped OA for burst transmissions.

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