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# Assessment of an SOA for Burst Mode Pre-Amplification in Higher Speed PON reaching 30dB of Optical Budget

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burst of 50% duty cycle. This EML [6] is a single chip, showing two parts: a Distributed FeedBack laser (DFB) at 1310nm and an Electro-Absorption Modulator (EAM). As shown on Fig. 2.a), we use a micro-lensed fiber to couple the laser beam at the output of the chip associated with an isolator (ISO) to avoid back reflections. The EML is identified as the ONU 1 optical emitter. Before a Variable Optical Attenuator (VOA), zero or 25km of fiber is inserted to assess the optical budget measurement. A 2xN coupler aims at mixing the signal from the ONU 1 and from a continuous source (CW) emulating the cumulative off-levels of up to 63 other ONUs on the ODN. The continuous source is identified as “ONU 2-64”. With this coupler, we extract a part of the signal to measure the optical power and to visualize the input eye diagram. In this experimental setup, we use an SOA with a small signal gain of 19.2dB and a Polarization Dependent Gain (PDG) of 1dB when operating at a temperature of 20°C, controlled by a thermoelectric cooler (TEC) and 400mA of bias current. An optical isolator is inserted after the SOA in order to avoid back reflections. To reduce the amplified spontaneous emission (ASE), benefits of an optical filter (OF) are experimented at the SOA output, followed by a DC-30GHz PIN photodiode. Finally, to improve the amplitude of the electrical signal, a TransImpedance Amplifier (TIA) is inserted between the photodiode and the error detector (ED).

### 3. Results and discussion

First, we focus on the temporal aspect of the implementation of an SOA in PONs. The response time of the amplifier needs to be fast enough to adapt between consecutives bursts (Inter Burst Gap  $\geq 2 \times 10.24\text{ns}$ ). Fig. 3.a) and c) shows rising and falling edge of a square signal, b), corresponding to the burst envelop (without data). Enable and disable times (10-90%) were set to 10.24ns. For clearer observations, we used an optical filter to reduce ASE on the signal passing through the SOA. Comparing envelops before and after going through the SOA, we observe no overshoot and no latency on the signal at the output of the SOA. Thus, according to those results, the implementation of an SOA in upstream PON will not increase the time response of the system.

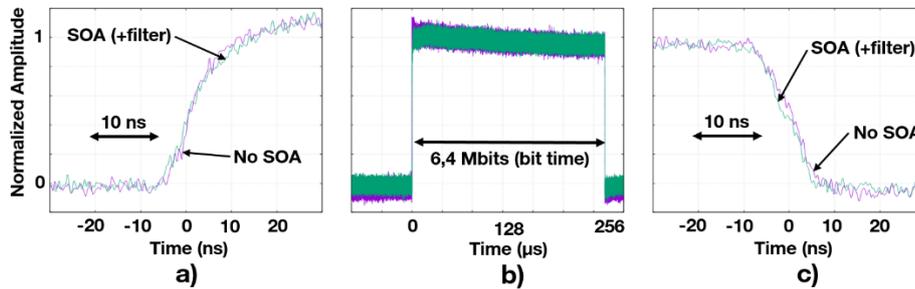


Fig. 3 : Rising edge a) of a square signal b) and falling edge c) for a burst, before and after SOA, with Tx On and Tx Off of 10.24ns.

Then, the impact of the Amplified Spontaneous Emission (ASE) on the quality of the transmission is assessed. The BER is measured without any optical filter and with two different optical filters: one thin filter (0.9nm 3dB-bandwidth (BW)) and a coarse filter (13nm BW). Fig. 4.a) presents the BER versus the Optical Budget (OB) in back-to-back. Optical eye diagrams (Fig. 4.b) and c)) were measured at the SOA input and output for transmissions with a  $\text{BER} < 10^{-9}$ , the extinction ratio (ER) reduction coming from the gain compression in presence of burst. We used a VOA (VOA 2 on Fig.2.c)) to maintain the same optical received power on the PIN despite the insertion losses of the filters and assess only the ASE noise filtering effect. A small improvement of 0.5dB on the OB at  $10^{-2}$  BER (HS-PON FEC limit) can be seen on Fig. 4.a) between the case without filter and with the 0.9nm width filter. We can then conclude that the ASE noise reduction impact is negligible in comparison to the filters insertion losses. Filter and VOA 2 will then be removed in the following discussions.

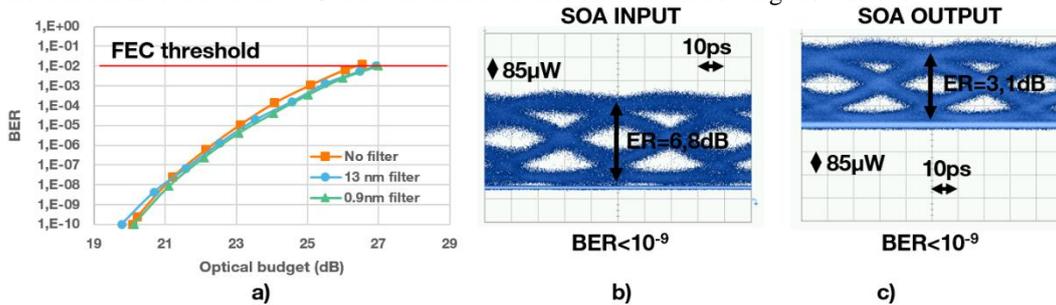


Fig. 4 : BER vs optical budget without filter, with coarse filter and thin filter a). Eye diagram for error free at input of the SOA b), and at the output c).

We now investigate the impact of the amplified off-levels of ONU 2-64 on ONU 1. The ONU off-level power (“launched optical power without input to the transmitter” in [2]) specifies that the burst off-level must not exceed -45dBm per ONU when the considered ONU is not supposed to send a signal between its bursts. In an upstream PON with 64 ONU to 1 OLT topology, amplified off-levels of ONU 2-64 will cumulate noise at the OLT receiver during ONU 1 time slot duration. The 2 to 64 ONUs total off-level power (defined as  $P_0$ ) can thus reach -27dBm when they all emit -45dBm at maximum. Taking into account the minimum propagation and splitting losses of the ODN (13dB losses), it would reach a maximum power of -40dBm in front of the SOA. Three different cases are considered in this work: a reference case transmitting the signal at 1310nm without continuous background power (no  $P_0$ ), a case with  $P_0 = -58\text{dBm}$  corresponding to the off-level of one ONU and a case with  $P_0 =$

40dBm corresponding to the sum of 63 ONU's off-levels.  $P_0$  is emitted at 1310.2nm so  $\Delta\lambda$  is equal to 0.2nm. Fig. 5.a) represents BER versus OB curves in these 3 cases. Also, we verify that 25km fiber propagation does not induce penalties at a BER= $10^{-2}$ . The results show that for any of the 3 cases, the off-levels power does not degrade the performances. The same OB is obtained in all considered cases of  $P_0$  indicating that off-levels of ONUs are not damaging the transmission. Also, an optical budget higher than 30dB was obtained at a BER of  $10^{-2}$  in all cases, demonstrating the possibility to use an SOA as a pre-amplifier for burst mode upstream transmissions of HS-PONs with at least the N1 budget class (14-29dB).

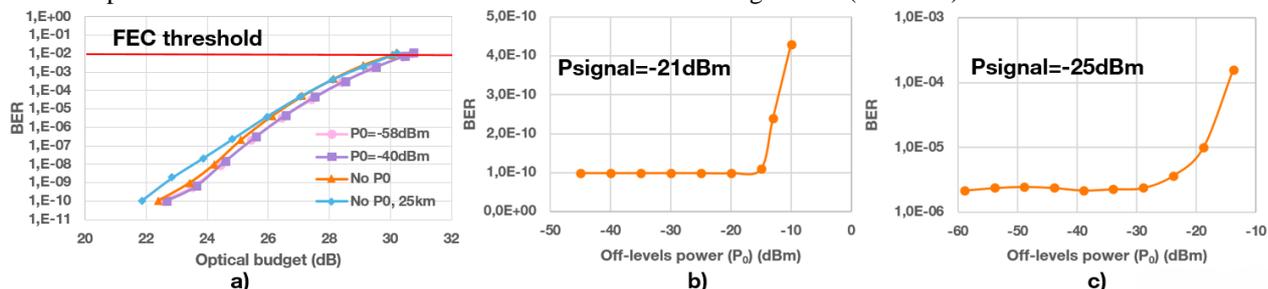


Fig. 5 : BER vs optical budget for off-levels power of -58dBm, -40dBm and without  $P_0$  in back-to-back and with 25km fiber propagation (a). BER vs Off-levels power in error free (b) and at BER start value of  $2 \cdot 10^{-6}$  (c).

For more discussions, on Fig. 5.b) and c), we present the BER versus the off-levels power  $P_0$  at two different received powers corresponding to different BER values: error free and  $2 \cdot 10^{-6}$ . The BER starts to deteriorate respectively at an off-levels power of respectively -13dBm and -27dBm which is a power more than 13dB higher than the worst case of a 64 ONUs ODN (13dB=-27dBm-(-40dBm)). Consequently, no impact will be expected on the quality of the link.

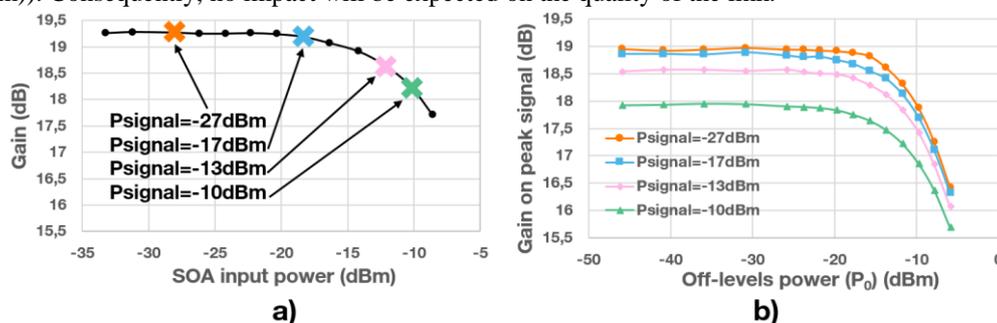


Fig. 6 : Reference gain curve of the SOA at 1310nm (a), and (b) gain on peak signal vs off-levels power for 4 different signal power: -27dBm, -17dBm, -13dBm and -10dBm.

On Fig. 6.a) and b), we measure the effect on the SOA gain of amplifying both the burst signal of ONU 1 and the burst off-levels of ONU 2-64 corresponding to  $P_0$ . Then Fig. 6.b), presents the gain of our amplifier versus off-levels power at 4 different signal input powers: -27dBm, -17dBm, -13dBm and -10dBm. Fig. 6.a) shows the reference gain at 1310nm. Whatever the input signal power, we observe a gain degradation when  $P_0$  reaches more than -20dBm, well above the cumulated off-levels power of 63 ONUs (-40dBm). Higher gain penalties are also noticed when the input signal power increases: up to 1dB of loss on the gain for an input signal power of -10dBm. This penalty is not reported on the quality of the transmission (Fig. 5.a) as the PIN receiver remains in its error free regime over a large input power variation.

#### 4. Conclusion

We performed a DSP free 25Gbit/s NRZ transmission in burst mode with 25km fiber propagation reaching more than 30dB of optical budget and thus reaching the targeted N1 class budget (14-29dB) for future HS-PONs. We have investigated different aspects of the insertion of an SOA in HS-PON, such as the impact of ASE on the BER and the uselessness of an optical filter in such transmission. Amplifying the off-levels power (" $P_0$ ") on the burst signals did not point out any blatant problem that can limit the use of SOAs for optical amplification of burst signals and this study is applicable for any PON technology.

#### 5. Acknowledgments

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