DSP-free and Shared SOA for HS-PON Transmissions with up to 30dB Optical Budget and 15dB dynamic range

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Abstract *We experimentally demonstrate a real time 50Gbit/s downstream and 25Gbit/s upstream HSP transmissions reaching 29.7dB of optical budget (45km reach) without DSP and using only a single SOA placed in the OLT.*

Introduction

With the recent approval of Higher Speed Passive Optical Networks current recommendations in ITU-T in April 2021 [1], the Higher Speed PON (HSP) is entering in an industrial development phase. Nevertheless, serious challenges remain, particularly on obtaining at such high bitrates (50Gbit/s downstream, 25Gbit/s upstream) optical budget classes that are high enough to ensure co-existence with legacy PONs (at least 29dB) [2,3] . Also, the use of Digital Signal Processing (DSP) with post-equalization techniques has been consented at the user side in the Optical Network Unit (ONU), which will add complexity, cost and power consumption. This led to the definition of a new metric in PONs, Transmission and Dispersion Eye Closure (TDEC). Moreover, interoperability between different equalizers, optics, ONU and Optical Line Terminal (OLT) vendors will become unreachable with so many varying parameters. HSP has also the particularity to transmit both downstream and upstream signals in the O-band to lower the chromatic dispersion penalties. The downstream wavelength range is 1342+/-2nm. For the upstream, multiple wavelength ranges can be chosen to ensure co-existence with previous PON technologies: “US1” 1300+/-10nm, “US2” 1270nm +/-10nm, “USnarrow” 1300+/-2nm.

In this paper, we propose to avoid using any DSP and to use a single Semi-conductor Optical Amplifier (SOA) shared and centralized at the OLT, to obtain optical budgets above 29dB for both downstream at 50Gbit/s and upstream at 25Gbit/s. This allows to maintain low cost and interoperable ONUs with simple PIN receivers and Distributed Feedback (DFB) emitters.

Experimental Setup and SOA static behavior

Fig. 1 presents the real time experimental setup of typical HSP bidirectional transmissions.

The upstream transmission is carried out at 1310nm, demonstrating real device implementations as we use commercial dual fiber pluggable transceivers (SFP28), initially made for 25Gbit/s Ethernet Point to Point links. The SFP28 emitter is a DFB laser emitting at -0.2dBm with an Extinction Ratio (ER) of 3dB and a typical -3dB Electro-Optical Band-Width (EO-BW) of 18GHz. At the OLT, a SFP28 with an Avalanche PhotoDiode (APD) of 17GHz EO-BW is used as the upstream receiver. These SFP28 and their drivers were not compatible with burst mode transmissions. Similar burst mode receivers at 25Gbit/s are now available for HSP [4,5] and our study will be focused on the behavior of the bidirectional SOA whose response will not be impacted by a burst transmission[6-8]. Therefore, the upstream SFP28 emitter was modulated by a Pulse Pattern Generator with a Non Return to Zero (NRZ) signal in continuous mode at 25Gbit/s with a Pseudo Random Binary Sequence length of 2^{31}-1. At the ONU, a commercial PIN-Trans-Impedence Amplifier (TIA) of 42GHz EO-BW at -3dB was used for the downstream reception.

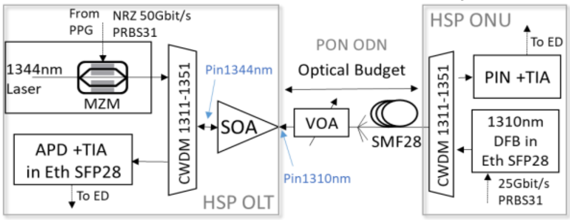

Fig. 1: Experimental Setup of a HSP with a bidirectional SOA at the OLT and simple ONU with PIN and DFB

The downstream link is realized with a continuous optical source emitting at 1344nm followed by a Mach-Zehnder Modulator (MZM) where a NRZ 50Gbit/s modulation is applied by a PPG with PRBS length of 2^{31}-1. For lower cost purposes, this emitter type could be replaced by a DFB with and Electro-Absorption Modulator (EAM) as demonstrated in our previous work[9]. However, no DFB-EAM emitting at 1342+/-2nm was available for these experiments. Here, the downstream wavelength is set to the maximum specified value in the standard (1342 +/- 2nm), which permit to use a simple Coarse Wavelength Division Multiplexer (CWDM MUX) filter, as a

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band-pass filter to multiplex both upstream and downstream signals into a single output fiber.

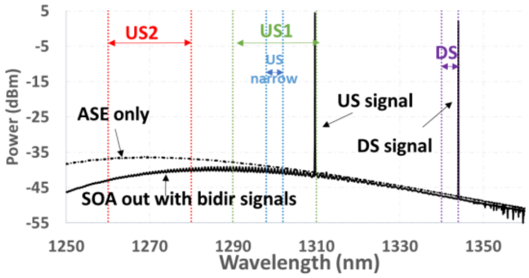

Fig. 2: SOA Output spectra w/ and w/o. 1344nm and 1310nm input signals; displayed HSP wavelength ranges

At that common output, a commercial SOA is inserted as a booster for the downstream signal and as a pre-amplifier for the upstream one. The SOA spectral characteristics over the different ranges of the HSP are presented in Fig.2 presenting a large -3dB spectral range of 80nm for a bias current of 450mA at 15°C. Its Polarization Dependent Gain remains low, below 0.5dB. Its Noise Figure is given at 6dB at 1310nm. The SOA gain for different input wavelengths and power levels are presented in Fig.3. The SOA small gain is measured at 21.6dB at the upstream wavelength of 1310nm. This gain could be higher (up to 27dB at 1260nm) considering other wavelengths options specified for the HSP upstream. At 1344nm, for the downstream signal, the SOA small signal gain is reduced to 16dB and decreases even more in its saturation regime, where the SOA will be used as a booster for the downstream transmission.

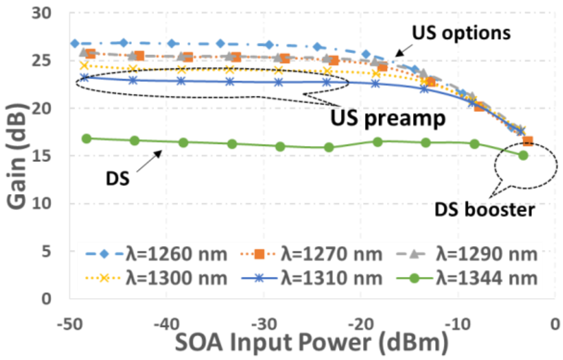

Fig. 3: SOA gain vs input power for different wavelength within the HSP wavelength ranges

The SOA being shared at the OLT side for bidirectional transmissions, it will encounters strong incoming signals in the downstream (>-5dBm input power) and weak input signals in the upstream (<-15dBm). Therefore, Fig. 4 presents the SOA gain measured for bidirectional transmissions at 1344nm and 1310nm and entering at different power levels in the SOA. Considering the upstream link, at 1310nm, we observe a high small-signal gain degradation of up to 15dB when the contra-propagating signal at 1344nm is as strong as 10dBm (booster mode). Considering a lower downstream power (-5dBm) the gain compression is reduced to 2.5dB. Also, for the gain at 1344nm on the downstream link (curves are not presented), a negligible gain penalty remaining below 0.7dB was measured when a small signal at 1310nm was injected (<-10dBm).

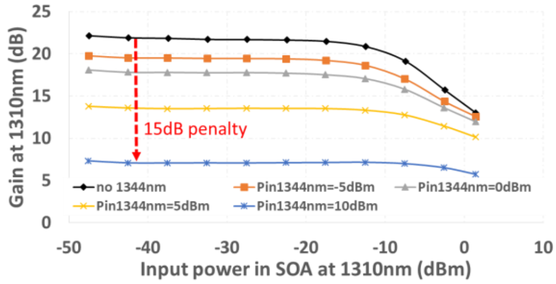

Fig. 4: SOA gain curves at 1310nm when 1344nm signal is injected at different power levels.

Therefore, in order to limit the gain degradation due to bidirectional amplification, we chose to inject the downstream signal at a -3dBm in the SOA. Also, reducing the output power of the OLT laser will release the constraints on producing in a replicable way, high output power levels with DFB-EAMs (>10dBm) while maintaining high output extinction ratios (>6dB) at 50Gbit/s, as expected for HSP.

Results and Discussions

Without SOA, the upstream receiver sensitivity at 25Gbit/s was measured at -27.3dBm at the HSP Forward Error Correction (FEC) limit of 1.10^{-2} Bit Error Rate (BER), giving an optical budget of 27dB. For the downstream, the optical budget without SOA is limited by the PIN receiver sensitivity at -18dBm at FEC limit, equivalent to an optical budget of 15dB when -3dBm of output power is considered at the OLT MUX output.

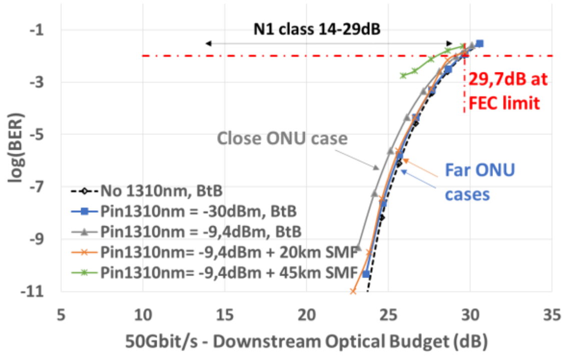

Fig. 5: BER results of the downstream transmission at 1344nm, 50Gbit/s for different upstream SOA input powers, in BtB, after 20km and 45km reach

The introduction of the bidirectional SOA permits to enhance the optical budget in both ways, as depicted in Fig.5 and Fig 6, showing BER results for the downstream transmissions at 1344nm, 50Gbit/s and upstream at 1310nm, 25Gbit/s respectively when different upstream powers are injected in the SOA in the opposite direction. The

SOA input power of the 1344nm signal was adjusted to -3dBm giving a +11.6dBm output power when a low upstream signal is injected.

On Fig. 5, an optical budget of 29.7dB was reached in Back to Back and with 20km of fiber for any configuration of the upstream signal: no penalty is induced when the SOA is in bidirectional amplification as long as the injected upstream power in the SOA remains low (<-15dBm). For an injected 1310nm power of -9.4dBm, which would correspond to a very low optical path loss, a penalty of 0,5dB is measured at the FEC limit. This is related to the SOA output power which is reduced by 0.5dB, owing to a lower gain with bidirectional amplification. In the case of 45km reach, we observe penalties that can be related to the cumulated chromatic dispersion which is not negligible at 1344nm (typically 2.35ps/km.nm).

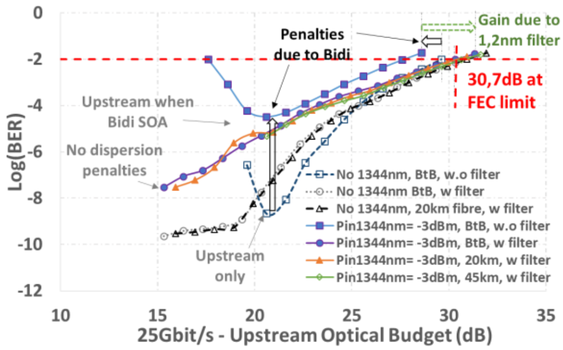

Fig. 6: BER results of the upstream transmission at 1310nm, 25Gbit/s w/ and w/o downstream signal injected in the SOA, w/ and w/o 1.2nm ASE filter, in BtB, after 20km and 45km reach

On Fig. 6, as expected from the gain penalties observed in Fig.4, we measured a penalty of 2dB at the FEC limit and degraded error floors when the downstream signal is injected at -3dBm and simultaneously amplified by the SOA. The optical budget is then limited to 27.6dB and we propose two solutions to enhance this up to 29dB to provide compatibility with current PON ODNs. The first solution would be to increase the emitted power of the DFB which is here very low (-0.2dBm) and being taken at the ONU MUX output (-1.3dBm) for the optical budget estimation. For further experiments, a new commercial DFB transceiver with an output power above 2dBm is then recommended to meet HSP requirements. A second solution is to insert an optical filter, here of 1.2nm width at -3dB, between the APD and the MUX in order to reduce the degradation due to the Amplified Spontaneous Emission (ASE) brought by the SOA. As shown in Fig. 6, when such filter is implemented, we obtained 3dB of extra optical budget thus reaching 30.7dB in BtB at the FEC limit. Then, we observed no penalty when inserting 20km and 45km of fibre since the chromatic dispersion is close to zero at 1310nm. However, a higher error floor is still persisting and can be related to Cross Gain Modulation (XGM) effects when the SOA is used in bidirectional mode. In Fig. 7, we measured the BER according to the received optical power at the APD in saturated and linear SOA regimes, when the downstream signal is injected at respectively -3dBm and -15dBm. We also varied the downstream modulation (no modulation, 50Gbit/s and 25Gbit/s) rate to highlight the effect of XGM on the upstream BER results. Indeed, we observed BER penalties (2dB at FEC limit and error floor) only when the SOA is saturated and when the downstream signal is modulated. Compared to a downstream modulation at 25Gbit/s, a lower XGM penalty is observed when the downstream is modulated at 50Gbit/s since the APD EO-BW of 18GHz is filtering part of this effect. Also, the use of a 1.2nm spectral filter of the SOA ASE helps to reduce those error floors by enhancing the Signal to Noise Ratio of the upstream signal.

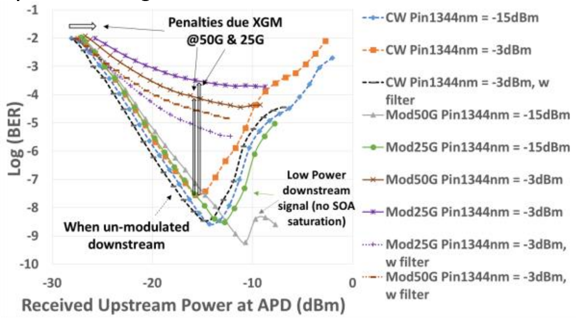

Fig. 7: BER results measured at the APD upstream receiver for different modulations on the downstream signal at 1344nm: CW, 25G and 50G, with and without ASE filtering

The use of an SOA in a PON topology could also affect the optical budget dynamic range of 15dB[8,10] which is required by the PON ODN configuration (Class N1: 14-29dB). Fig. 5 and Fig.6 demonstrated for both downstream and upstream signals, error free transmissions over at least 15dB of dynamic ranges, limited by the measurement setup not the receivers' overloads.

Conclusions

We demonstrated the feasibility to use a single and shared SOA located at the OLT side, to amplify both 50Gbit/s downstream and 25Gbit/s upstream signals of a HSP. The effects of gain degradation, ASE filtering and XGM are detailed with quantified impact on the BER of the real time transmissions. The mutualized SOA in this configuration will permit to maintain simple and low cost optics for HSP: PINs and DFBs at ONUs, a low power DFB-EAM at OLT.

Acknowledgements

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