Cross Gain Modulation Mitigation with Automatic Gain Control of Bidirectional SOA for DSP-free 50G-PON

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Abstract *We demonstrate how to mitigate cross gain modulation impairments induced when using a bidirectional SOA shared at OLT side in 50G-PON. Automatic gain control of the SOA reduces by 4 dB the XGM impairments induced by the upstream burst on the downstream signal. ©2022 The Author(s)*

Introduction

Telecom operators currently exploit gigabit capable-passive optical network (G-PON) generation and start to deploy 10 Gbit/s PON (as XGS-PON). The ever-growing bandwidth demands pushed the standardization bodies to standardize the next generation PON systems. The latest International Telecommunication Union (ITU-T) standard concerns the 50G-PON [1] (50 Gbit/s PON). Some points concerning the practical realization of such system remain undetermined for the industry. One of the difficulties is to reach a high link optical budget (up to 29 dB for N1 class) at such a bitrate. For that purpose, in [2], we proposed to use a Semiconductor Optical Amplifier (SOA) to increase the link budget and meet the requirements of the standard based on the legacy PON infrastructure. Locating the SOA at the OLT side reduces cost and complexity, as a single SOA is shared by all the users of the Optical Distribution Network (ODN) and operates in a controlled environment, the operator's central office. In terms of cost, the best solution seems to use an SOA for amplifying both the downstream (DS) and the upstream (US). It is known that operating an SOA in bidirectional amplification regime can bring some issues related mainly to the Cross Gain Modulation (XGM) associated to the upstream burst mode transmission: when a US reaches the OLT-side SOA (receiver side), the SOA gain available for the DS signal falls since the upstream burst consumes part of its gain [3]. Since the lifetime of the SOA's carriers is short (typically a few tens of ps or less) [4], the carrier's density and so the gain of the SOA imprints the gain fast fluctuations on the DS signal (the US burst envelope) and brings intensity noise on the US. XGM can then reduce the quality of the signal in both directions. In this paper, we propose a solution based on controlling the bias current of the SOA and synchronize it with the upcoming envelope of the burst, to compensate the fluctuations of the gain. Some other solutions were proposed to reduce XGM impairments such in [5-8] but these solutions require additional components or specific optical amplifiers.

Experimental setup

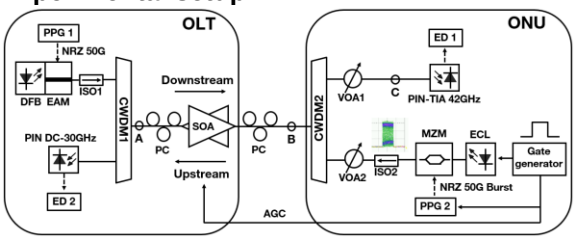


Fig. 1: Experimental setup

The experimental setup is presented on Fig. 1. In DS direction, we use an externally modulated laser (EML) composed of a distributed feedback laser and an electro-absorption modulator (DFB-EAM) integrated on a single chip from Almae Technologies. The EAM is modulated with a 50 Gbit/s Non-Return to Zero On-Off Keying Pseudo Random Bit Sequence signal of length 2^{31}-1 (NRZ-OOK PRBS31) generated by a pulse pattern generator (PPG1). The DFB biased at 100 mA emits light at 1310 nm, the EAM was biased at -1.1V with a Vpp of 800 mV leading to an extinction ratio (ER) of 6 dB. A Thermoelectric Cooler (TEC) is used to maintain the temperature of the EML at 20°C. The optical signal at the output of the chip is coupled into a micro-lensed fiber providing 4 dBm output power (with signal modulation). The optical signal passes through an optical isolator (ISO1) and a Coarse Wavelength Division Multiplexing filter (CWDM1) is employed to separate US and DS.

The DS signal is amplified by a booster SOA and is controlled at a room temperature of 20°C and at 280 mA when the automatic gain control (AGC) is turned OFF. As shown on Fig 2., the SOA presents a 17.7 dB small signal gain at 1310 nm (19.1 dB at 1270 nm), a saturation input power of -20 dBm and a low polarization dependent gain (PDG) of 0.5 dB. To ensure

optimal operation, two polarization controllers (PC) are used on each side of the SOA.

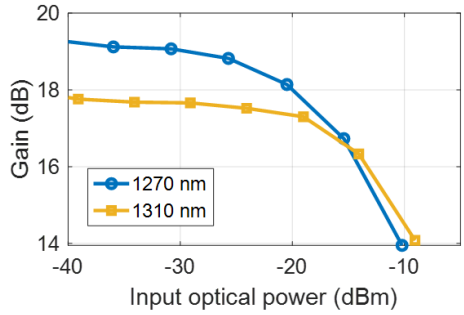


Fig. 2: Gain versus SOA input power at 280 mA and 20°C

After amplification, the DS signal crosses another CWDM filter (CWDM2) and reaches a variable optical attenuator (VOA1). The direct detection is realized by a photodiode (PD) PIN-TIA with 42 GHz 3 dB electro-optical bandwidth (EO-BW). The electrical signal is sent to the error detector (ED1) for bit error rate (BER) measurement. Concerning the US link, a gate generator sends the burst envelope (20 µs width and 125 µs periodicity) to both the second pulse pattern generator (PPG2) to trigger the data emission and an external cavity laser (ECL) which operates at 1270 nm. PPG2 generates the NRZ PRBS31 electrical signal for the 50 Gbit/s burst US link. The electrical signal modulates a lithium niobate Mach-Zehnder modulator (MZM) of 40 GHz EO-BW biased at 4 V leading to an ER of 7 dB. The optical signal is sent to ISO2, VOA2 and then reaches CWDM2. For the upstream link, the SOA works as a preamplifier in front of a PD PIN DC-30GHz. The detected signal finally reaches the ED2.

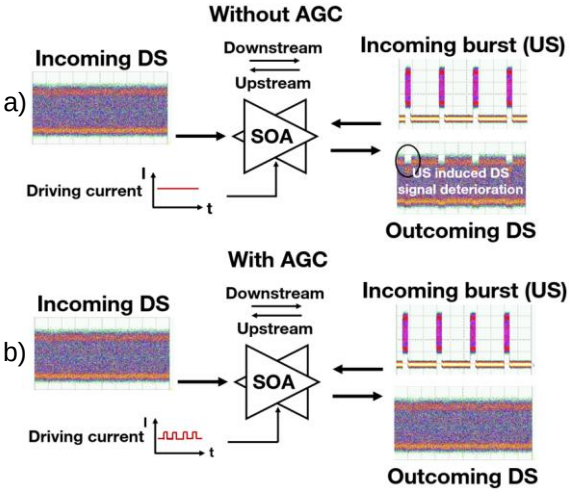


Fig. 3: Behavior of SOA in bidirectional amplification without (a)) and with (b)) AGC.

Fig. 3 a) presents the behavior of the SOA in bidirectional amplification in the context of PON (i.e. with an US link in burst mode), when the driving current is continuous and constant. When an US burst reaches the amplifier, the burst consumes some SOA's gain and the gain available for the signal on the DS direction falls temporarily. At the output of the SOA, the DS signal presents depletions. When such DS signal is detected, some errors are directly linked to cross gain modulation. To avoid this phenomenon, we propose to manage the SOA's gain by driving its bias current, to provide more gain to the system when an US burst crosses the SOA and decrease it when the SOA is only crossed by the DS signal, as shown in Fig. 3 b). Two conditions must be satisfied: the SOA gain variations and incoming bursts must be synchronized, and the SOA gain must be managed according to the burst magnitude, as a powerful incoming burst will consume more gain and imprints more on the DS signal than a less powerful burst. When it comes to the field exploitability of such solutions, it is worth noting that commercially available PON systems already manage the calendar (timing) of the US bursts to avoid collisions. The commercially available OLT also possesses information related to the optical power of the US bursts of the different ONUs through the Received Signal Strength Indication (RSSI). For our lab experiment, we employed a current gate signal synchronized with the burst envelope, which comes from the gate generator used to drive the SOA (Fig. 3 b)). By adjusting the amplitude and the time delay of the gate, we can compensate the depletion of the DS signal due to the burst in US direction.

Results and discussion

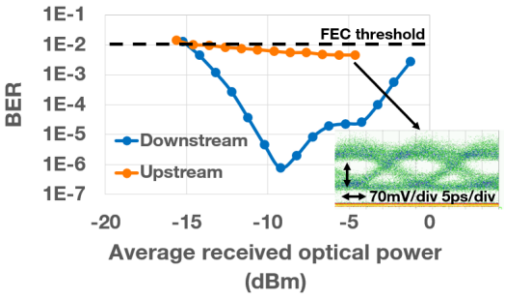


Fig. 4: BER versus average received optical power for DS (blue circle) and US (orange circle).

We first assess each link individually before testing the bi-directional case. Fig. 4 shows the performances of the 50 Gbit/s DS and of the US link alternately switched on. We reached 29.4 dB OB with a sensitivity of -15 dBm on the DS link, matching the N1 class (14-29 dB) budget requirement. In US (burst mode), a 13 dB OB and a sensitivity of -15 dBm are measured. The high error floor on US results (BER = 4.10^{-3}), is due to the very low conversion gain (19 V/W) of the available DC-30GHz photodiode (PD) which provides a low output amplitude. The use of a

receiver with higher sensitivity or with burst mode TIA [9, 10] should solve the problem and enable 50 Gbit/s burst mode transmission reaching 29 dB OB in US [11] as the eye diagram presents a good opening as seen on the insert on Fig. 4.

We now assess the bi-directional case and the effect of XGM. In this experiment, we drive the SOA with a constant current.

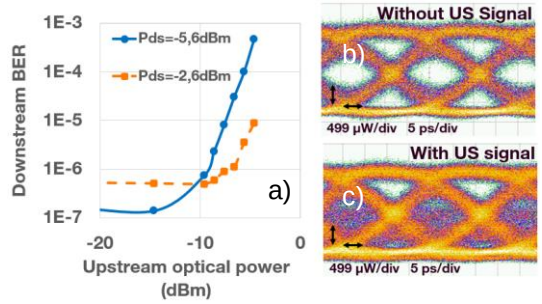


Fig. 5: BER measured on the DS for different US power injected in the SOA a), eye diagram without (b)) and with (c)) US signal in the SOA.

Fig. 5 presents the DS BER measurement at a fixed power of -7 dBm on the receiver when the US power P_{us} at point B varies. Cases with a DS power P_{ds} at point A of -5.6dBm (blue circles) and -2.6dBm (orange squares) are considered. First, with very low US signal (P_{us} < -15dBm), the error floor is slightly degraded for higher DS power (BER = $5.1.10^{-7}$ for P_{ds}= - 2.6dBm and $1.4.10^{-7}$ for P_{ds}= -5.6dBm); this is mainly due to the signal that slightly saturates the SOA gain leading to a lower extinction ratio in this case (the so-called self-gain modulation SGM).

Secondly, in each case we observe a BER degradation when the US increases (for P_{us} > -10 dBm when P_{ds}= -2.6 dBm and for P_{us} > -15dBm when P_{ds}= -5.6dBm) due to the XGM owing from the contra-propagating signal. Fig. 5 presents the optical eye diagram of the DS signal at the input of the PD (point C on Fig. 1), with (Fig. 5 b)) and without (Fig. 5 c)) US signal (for P_{us} = -4.6 dBm). This highlights the presence of XGM affecting the quality of the eye diagram as a second smaller eye seems to appear behind the first one on Fig. 5 c).

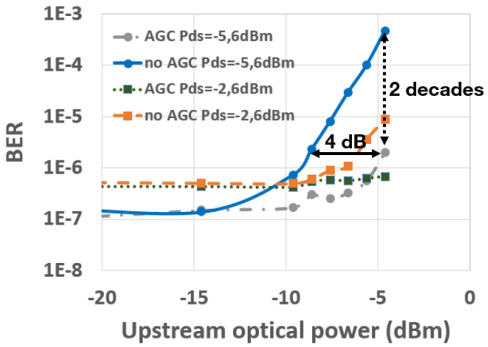


Fig. 6: BER versus US optical power for a DS power of -5.6 dBm (circle) and -2.6 dBm (square) at the input of the SOA with and without AGC.

We then studied the effect of SOA AGC on the DS signal BER. On Fig. 6, same experiments as in Fig. 5 are performed and results with or without the SOA AGC are compared.

The beneficial effect of dynamically controlling the gain of the SOA is clear on this result. The US power starting to degrade the DS signal is pushed to higher values (from P_{ds} > -15dBm to P_{us} > -10dBm when P_{ds}= -5.6dBm and from P_{us} > -10dBm to a value higher than -4.9 dBm when P_{ds}= -2.6dBm). Moreover, at a given US power of -4.6 dBm, it leads to a BER enhancement of up to 2 decades (for P_{ds}= -5.6 dBm). In terms of US power, the supported US power on the SOA at a same DS BER can be 4 dB higher as seen on Fig. 6. When P_{ds} is low, the US power at which a degradation happens is also lower and the XGM cannot be completely mitigated by the SOA AGC. Even if we can drive the SOA with higher current, the SOA will saturate and will not be able to compensate the XGM indefinitely.

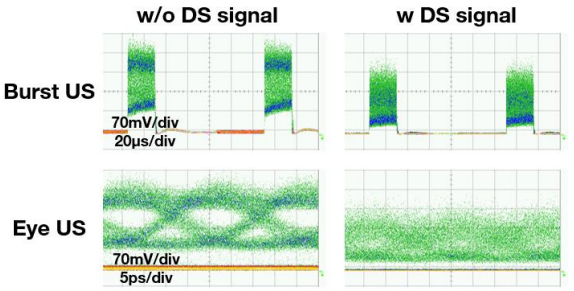


Fig. 7: US burst and eye diagram without and with DS signal.

The study of the BER degradation owing from XGM on the US signal was not possible given the low performance of our burst photodiode. However, we can observe its impact on Fig. 7, which presents the burst and the eye diagram from the US signal with and without DS signal in the SOA for P_{ds}=-5.6 dBm. We can observe less power on the burst and eye diagram closure with DS signal.

Conclusion

We demonstrate a technic for the mitigation of the effect of cross gain modulation in a 50G-PON system based on bidirectional semiconductor optical amplifier. By synchronizing the amplifier driving current gate with the upcoming burst, the cross gain modulation reduction leads to a BER improvement of up to 2 decades for the downstream signal and the upstream signal can be 4 dB higher on the SOA, to reach the same BER on the downstream signal.

Acknowledgements

The authors would like to thank Anritsu for the loan of the PPG 64G MP1900A.

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