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### ► To cite this version:

Fabienne Saliou, Mathilde Gay, Laurent Bramerie, Jeremy Potet, Hamza Hallak Elwan, et al.. 32dB of Optical Budget with DSP-free real time experimentation up to 50Gbit/s NRZ using O-band DFB-EAM and SOA-PIN for Higher Speed PONs. Optical Fiber Communication Conference (OFC 2021), Jun 2021, San Francisco, United States. hal-03327475

**HAL Id: hal-03327475**

**<https://hal.science/hal-03327475>**

Submitted on 27 Aug 2021

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# 32dB of Optical Budget with DSP-free real time experimentation up to 50Gbit/s NRZ using O-band DFB-EAM and SOA-PIN for Higher Speed PONs

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**Abstract:** We achieve 32.3dB of optical budget and 45km reach transmission in real time with an O-band EAM-DFB and SOA-PIN for 50Gbit/s NRZ standards. A DSP-free transmission was demonstrated with a semi-cooled transmitter.

## 1. Introduction

The International Telecom Union (ITU-T) is proposing a new Time Division Multiplexing Passive Optical Network (TDM PON) standard aiming at offering higher line bitrates for future optical access Networks. Higher Speed PON [1] (HSP) is being discussed and first recommendations of “G.9804” are expected in 2021. Some specifications have already been released: the downstream will be carried out at 1342nm+/-2nm with a line bitrate of 50Gbit/s. 12.5Gbit/s and 25Gbit/s upstream line rates are discussed and 3 wavelength range options are proposed to provide different co-existence strategies with current technologies, namely Gigabit capable PON (G-PON) and 10-Gigabit-capable symmetric PON (XGS-PON) [2]. O-band has been chosen in order to mitigate chromatic dispersion penalties. Nevertheless, many studies [3-6] pointed out the difficulties to increase the bitrates up to 50Gbit/s and reach high optical budgets. Indeed, in order to rely on legacy Optical Distribution Nodes deployed for GPON and XG(S)-PONs, the N1 class (14-29dB) will be the minimum targeted optical budget for future access networks. Reaching this target was not possible using simple and low cost optics without introducing Digital Signal Processing (DSP) [5,6]. However, using DSP in PONs will considerably increase the cost and complexity (cost of complex equalizers, added power consumption, Transmission Dispersion Eye Closure (TDEC) management) for physical layer interoperability in HSP [7,8]. It would also increase the processing and burst timing issues that should be avoided to maintain the maximum effective throughput and lowest latency. Moreover, DSP-free HSP will permit to reuse a regular Physical Layer Operation Administration and Maintenance (PLOAM similar to XGSPON), especially for the ranging phase (ONU discovery) which could be performed at the nominal line bitrate.

In this paper, we experimentally demonstrate a simple implementation of 50Gbit/s transmission for HSP without any DSP: up to 32.3dB at 50Gbit/s optical budget is obtained with an O-band semi-cooled Externally Modulated Laser (EML) transmitter and a Semiconductor Optical Amplifier (SOA) before a PIN receiver. We also present results at 25Gbit/s (the maximum HSP upstream bitrate) using the same experimental setup, in order to demonstrate compliance with upstream transmission where the SOA is shared at the Optical Line Terminal (OLT) side.

## 2. Experimental setup, results and discussions

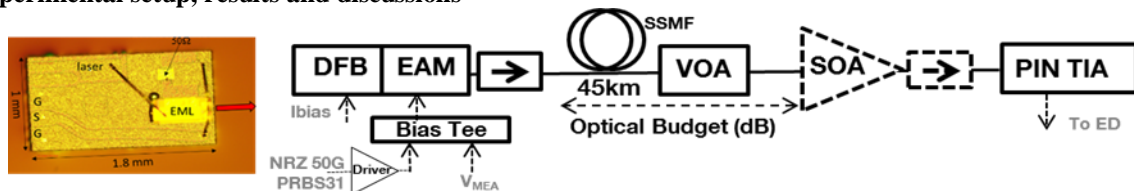


Fig. 1. Experimental setup of Higher Speed PON at 50Gbit/s (right) and EML chip picture (left)

Figure 1 presents our experimental setup of a physical layer transmission of HSP with a Non Return to Zero (NRZ) modulation at 50Gbit/s. An EML was used, as it presents a lower chirp than Directly Modulated Lasers (DML) commonly used in PONs. We also chose to avoid the complexity and extra cost of a Mach Zehnder Modulator and we designed an EML based on a single chip Distributed Feedback Laser integrated with an Electro-Absorption Modulator (DFB-EAM). The device, detailed in [9], is optimized to provide high output power and steep modulator

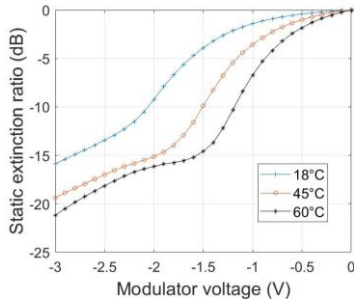


Fig.2 DFB-EAM static extinction

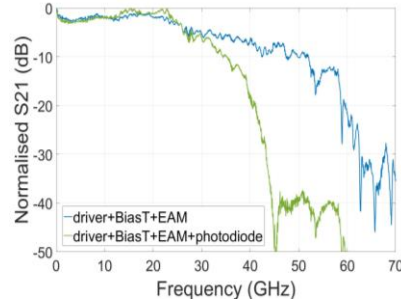


Fig.3: EO bandwidths measured at 18°C

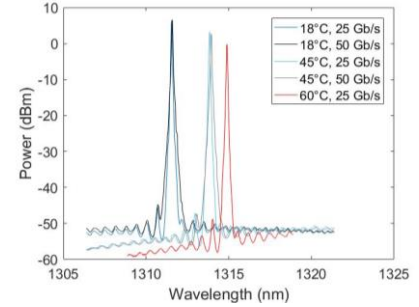


Fig.4: EML optical spectra

extinction curve as shown in Fig. 2, with 15dB extinction at -2V at 45°C. The EML is also designed for semi-cooled performances and the EAM length is optimized to limit the applied modulation voltage for easier integration. At the output of the chip (picture on Fig.1), a micro-lensed fibre [10] is used to couple the laser beam. As usual with PON transceivers, an isolator is placed at the output of this fiber to avoid back reflections. Measured electro-optical bandwidths of the modulator associated to its bias tee and linear driver are presented in Figure 3, presenting 25GHz bandwidth at -3dB and 48GHz at -10dB.

The affordable optical budget is measured in Back-to-Back (B2B) or by inserting 45Km of Standard Single Mode Fiber (SSMF) before a Variable Optical Attenuator (VOA). After this transmission span, we used a PIN photodiode associated with a TransImpedance Amplifier (TIA). The overall electro-optical bandwidth is represented in Figure 3, showing more bandwidth limitation when the photo receiver is added (35GHz at -10dB).

	$I_{bias}$ (mA)	$V_{EAM}$ (V)	$V_{mod}$ (Vpp)	$P_{out}$ (dBm)	$\lambda$ (nm)	$ER_{outEML}$ (dB)	$I_{SOA}$ (mA)	$ER_{outSOA}$ (dB)
25G 18°C	90	-1.4	1.5	7.3	1311.5	5.9	116	4
25G 45°C	102	-0.94	1.5	4.5	1314	7.8	116	5.28
25G 60°C	98	-0.63	1.5	1.5	1314.8	8.35	116	5.3
50G 18°C	90	-1.13	2.8	7.3	1311.5	7.9	110	4.35
50 45°C	102	-0.94	2.4	4.4	1314.1	8.4	102	5.23

Tab. 1: Optimized and measured parameters at 25Gbit/s and 50Gbit/s

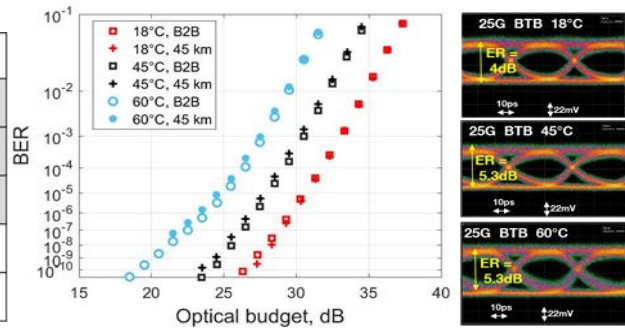


Fig.5: BER at 25Gbit/s vs Optical budget with SOA, for BTB (B2B) and 45Km reach, at 18°C, 45°C and 60°C, at 25Gbit/s and Corresponding Eye Diagrams in BTB

The EAM section is driven by a  $2^{31}-1$  Pseudo Random Bit Sequence at 25Gbit/s or 50Gbit/s. An Error Detector (ED) was placed after the reception to measure the Bit Error Rate (BER) of this transmission in real time. The optical spectra of the modulated laser are represented in Figure 4 for each tested cases. Table 1 summarizes the laser currents, EAM voltages and modulation amplitudes that were optimized to reach the lowest BER for 25Gbit/s and 50Gbit/s. This table also reports the measured EML output powers, peak wavelengths ( $\lambda$ ) and Extinction Ratios (ER). The EML is experimented at 18°C, 45°C and 60°C to show uncooled capabilities.

Since no commercial burst mode receiver at 25Gbit/s or 50Gbit/s are available yet [11-13], no impact of burst mode is presented in this paper. First, the BER versus the received optical power was measured for Back To Back (BTB) transmissions (0km) at 25Gbit/s and 50Gbit/s. The transmission is mainly limited by the sensitivity of the PIN receiver at -12dBm in BTB at 25Gbit/s for a targeted BER of  $10^{-2}$  which is the BER threshold defined in HSP before Forward Error Correction (FEC) [6]. At 50Gbit/s, a sensitivity of only -9dBm was reached, giving a maximum optical budget of 16.3dB at 18°C.

To improve the optical budgets, integrated SOA-PIN or Avalanche PhotoDiode are commonly used with ongoing competition on the market for ER40 and ZR4 transceivers. Thus, we inserted a commercial low polarization dependent gain SOA as a pre-amplifier to the PIN photodiode. The SOA's Amplified Spontaneous Emission (ASE) spectrum is centered at 1290nm and the SOA presented a small signal gain of 18dB and a Noise Figure of 5.9dB when biased at 110mA and at 20°C. We used an isolator between the SOA and the PIN to avoid amplification of back reflections due to optical connectors. Spectrally filtering the ASE noise is not possible in PON systems since the transmitted wavelength windows can be as large as 20nm. Therefore, no optical filter was present in our

experiments. A polarization controller is used at the SOA input to maximize the output power. Without polarization controller, a maximum power penalty of 1dB was measured to reach the same performances for a BER of  $10^{-2}$ . The optical budget is now measured according to the SOA input power and BER results are presented in Figure 5 and 6, for transmissions at 25Gbit/s and 50Gbit/s respectively. For each case, the ER is reduced at the output of the SOA due to the ASE which increases the zero level of the eye diagram. The SOA permits to reach error free transmissions at FEC threshold with fibre length up to 45km. Very negligible penalties were due to transmission over fiber since the EML wavelength is close to the zero dispersion. At 25Gbit/s, optical budgets of 29.3dB at 60°C, 32.1dB at 45°C and even 35dB at 18°C are demonstrated. This shows the feasibility to reach the N1 class (14-29dB), with 6dB of margin at 18°C which might be enough to overcome penalties due to burst mode, in the case of HSP upstream transmissions. At 50Gbit/s, optical budgets of 29.4dB at 45°C and 32.3dB at 18°C are obtained. This corresponds almost to the same Optical Modulation Amplitude (OMA) of -23.5dBm, because the temperature variation is affecting both the EML output power and the extinction ratios.

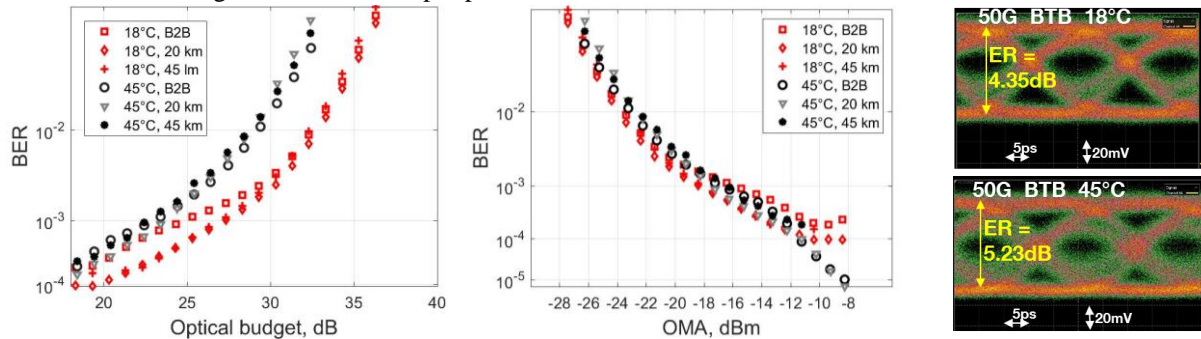


Fig. 6: BER at 50Gbit/s vs Optical budget with SOA, for BTB, 20km and 45Km reach, at 18°C, 45°C and 60°C, at 50Gbit/s (left) ; Same results vs OMA (middle) ; corresponding Eye Diagrams at 50Gb/s in BTB (right)

### 3. Conclusions

To the best of our knowledge, we experimentally demonstrated, for the first time a DSP-free NRZ transmission in real time at 50Gbit/s and 25Gbit/s using a semi-cooled O-band DFB-EAM transmitter and SOA-PIN receiver. At 50Gbit/s, optical budgets of 32.3dB (-23.5dBm OMA) were achieved for 0, 20 and even 45km. At 25Gbit/s, up to 36dB of optical budget was reached with 45km of fibre. All those results cope with the targets of HSP for co-existence with legacy PONs based on N1 classes (14-29dB) and with 0 to 40km reach. This experiment also shows the possibility to use simple NRZ transmissions for point to point long reach applications [14], offering a solution to avoid 4-level Pulse Amplitude Modulation (PAM4) and DSP for bitrates above 10Gbit/s.

**Acknowledgments:** The authors would like to thank Vectrawave for the design of the PIN-TIA, as well as “Region Bretagne” and “Lannion Tregor Communauté” for the founding of ASKIJ project.

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