Investigation of Real-Time 25 Gbps Burst Mode Transmission over 20 km fiber with Directly Modulated Laser, Ge/Si APD Receiver and BM-TIA Targeting 50G-PON

Dylan Chevalier(1,3,*), Cheng Wang(2,*), Jérémy Potet(1,3), Gaël Simon(1), Gertjan Coudyzer(2), Georges Gaillard(1), Fabienne Saliou(1), Sofiane Belahsene(5), Constant Libs(5), Laurent Bramerie(3), Xin Yin(2), Philippe Chanclou(1), Pascal Scalart(4), Monique Thual(3)

(1) Orange, 2 Avenue Pierre Marzin, 22307 Lannion, France, dylan.chevalier@orange.com
(2) IDLab, Ghent University - imec, 9052 Ghent, Belgium, cheng.wang@ugent.be
(3) Univ Rennes, CNRS, Institut FOTON - UMR 6082, 22305 Lannion, France,
(4) Univ Rennes, IRISA - UMR 6074, 22305 Lannion, France,
(5) Almae technologies, Site Data 4, Route de Nozay 91460 Marcoussis, France,
(*) Both authors contributed equally to the work

Abstract *We realize a Burst Mode (BM) transmission at 25 Gbps in a Passive Optical Network (PON), using a BM-TIA prototype. The sensitivity of -24.8 dBm B2B and -21.9dBm after 20km SMF is experimentally demonstrated in real-time in burst mode with a Directly Modulated Laser (DML). ©2023 The Author(s)*

Introduction

The 50G-PON standard [1] has recently been released by the ITU-T and proposes a downstream (DS) rate of 50 Gbps using a single wavelength on the 1342 ± 2 nm band. In the upstream (US), a single wavelength is also used, while several bitrates are proposed: 12.5, 25 and 50 Gbps as well as three wavelength options: 1270 ± 10 nm (US1), 1300 ± 10 nm (US2) and 1286 ± 2 nm (US3) [1].

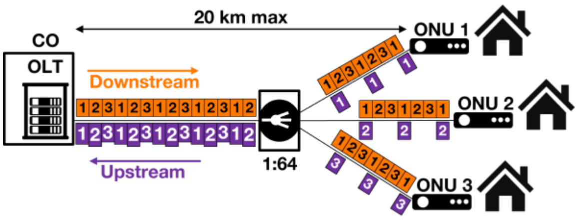

Fig. 1: Architecture of the PON.

Fig. 1 shows the general architecture of the PON for access network: an Optical Line Termination (OLT) located at the Central Office (CO) is connected to several Optical Network Units (ONUs) at client side, using a point-to-multipoint topology. The split can usually be as high as 64 and the reach does not exceed 20 km.

While for the DS, a signal is sent continuously, for the US, the Burst Mode (BM) is imposed, i.e. each ONU has a window allocated by the OLT over a period of up to 125 µs to transmit a slot of data to the OLT. As the ONU distance to OLT varies, the burst strength at the OLT also varies. For this reason, a BM TransImpedance Amplifier (BM-TIA) is needed regulating its output power for each burst. However, the design of TIAs for burst mode is not straightforward, as the BM-TIA needs to adapt its gain on a sub-microsecond scale, while having a limited impact on transmission at up to 50 Gbps, while achieving a high sensitivity.

In papers [2], a BM-TIA was demonstrated using a Mach-Zehnder Modulator (MZM) in a back-to-back experiment, achieving a sensitivity of -13.8 & -23.7 dBm for 25Gbps and 50Gbps respectively. In paper [3], a dual-rate, 12.5 & 25 Gbps BM receiver was designed and achieved Optical Modulation Amplitude (OMA) sensitivities of -27.8 & -26.5 dBm. Finally, in paper [4], an Electro-Absorption Modulator (EAM) is used for 25 Gbps BM and an OMA sensitivity of -27.7 dBm is obtained.

In this paper, we investigate upstream transmission using a BM-TIA prototype (described in [5]) in a PON-testbed targeting 50G-PON at 25Gbps. Moreover, we investigate the performance of both ECL-MZM as well as a 25G-class DML to resemble real-world operating conditions.

System Experiment

The experimental setup is shown in Fig. 2. The measurements are performed in two steps. First, using an External Cavity Laser (ECL) combined with a 40 GHz Electro-Optical Bandwidth (EO-BW) MZM having an Extinction Ration (ER) of 12.35 dB. With this laser, we were able to scan the different wavelength options offered by the US of the 50G-PON [1]. An electrical Pseudo Random Binary Sequence (PRBS) of length 2^{31}-1 is generated at 25 Gbps in Non-Return-to-Zero On-Off-Keying (NRZ-OOK) by a Pulse Pattern Generator (PPG) with a 140 mVpp amplitude. A 29 dB gain electrical

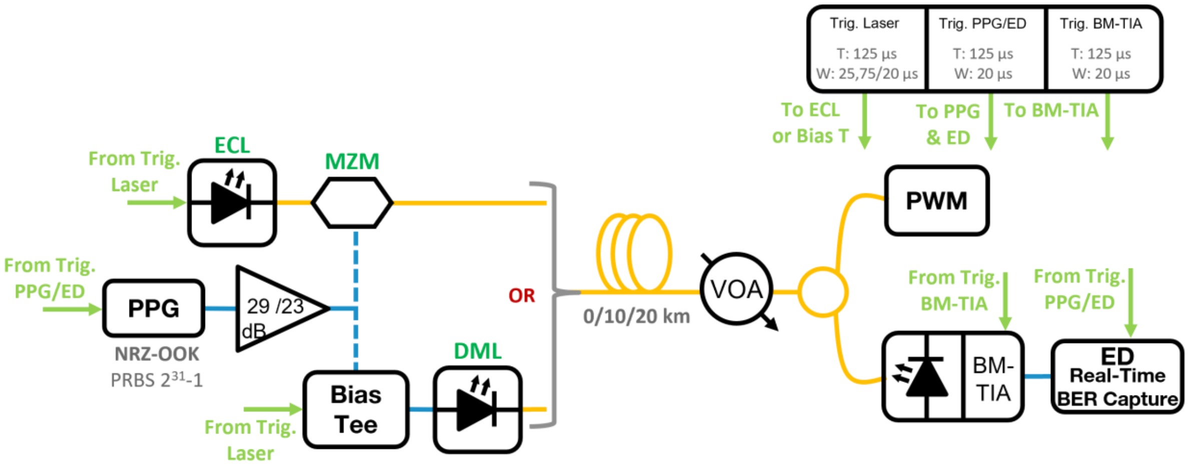

Fig. 2: General setup for the 25 Gbps burst mode from [5].

amplifier is used to drive the MZM having a 3-dB BW from 77 kHz to 55 GHz. 0, 10 or 20 km (maximum distance in the Fixed Access Network, FAN) of Single Mode Fiber (SMF) is added before a Variable Optical Attenuator (VOA).

A coupler is added with a branch connected to a powermeter ("PWM" Fig. 2) to measure the received power at the photodetector, while the other branch is connected to the BM-TIA with an EO-BW of 25 GHz. The BM-TIA's architecture and design is optimized for linear operation up to 25 Gbaud modulation rates. The linear BM receiver consists of a fixed gain TIA; followed by a three-stage post-amplifier and a 50 Ω output buffer. It is followed by an Error Detector (ED) that is used for computing the Bit Error Rate (BER). The BM-TIA was integrated with a 25 GHz Ge/Si Avalanche PhotoDiode (APD). The APD is performed in a standard CMOS commercial foundry [6] [7]. The integrated receiver shows a bandwidth of 25 GHz. The BM receiver is shown in Fig. 3d. The APD is biased with 20.6 V.

The second setup uses a DML with a wavelength of 1302 nm, shown on Fig. 3a. It is temperature controlled, at 20 °C and has an ER of 3.67 dB. The DML was chosen to resemble a typical transmitter used at the Optical Network Unit (ONU) side. Its technology is based on multiple Al-based Multi-Quantum Wells (MQW), ridge waveguide with an EO-BW of 18 GHz. The signal generated by the PPG, going through an amplifier of 23 dB of gain and a bandwidth from 77 kHz to 55 GHz, is sent to a bias tee before being received by the DML.

The burst envelope is generated by a gate generator with a period of up to 125 µs (the interval over which ONUs are allowed to transmit in PON technologies), called Trig. Laser in Fig. 2. It drives the ECL (or the DML) to generate 20 µs long bursts (see Fig. 3b), while another trigger from the same source is applied to the PPG to generate the data, see Fig. 3b. At the receiver side, the gate generator also provides a trigger to the ED to measure the BER, and another one for the BM-TIA, respectively named Trig. PPG/ED and Trig. BM-TIA in Fig. 2. In order to respect the activation of all different parts, the triggers' delays are adjusted, enabling the correct detection of the burst (see Fig. 3c). It is worth noting that no digital nor analog signal processing were used in the experiments.

Results and discussion

We start with an ECL-MZM for characterizing the BM-TIA with an "ideal" emitter. The ECL-MZM

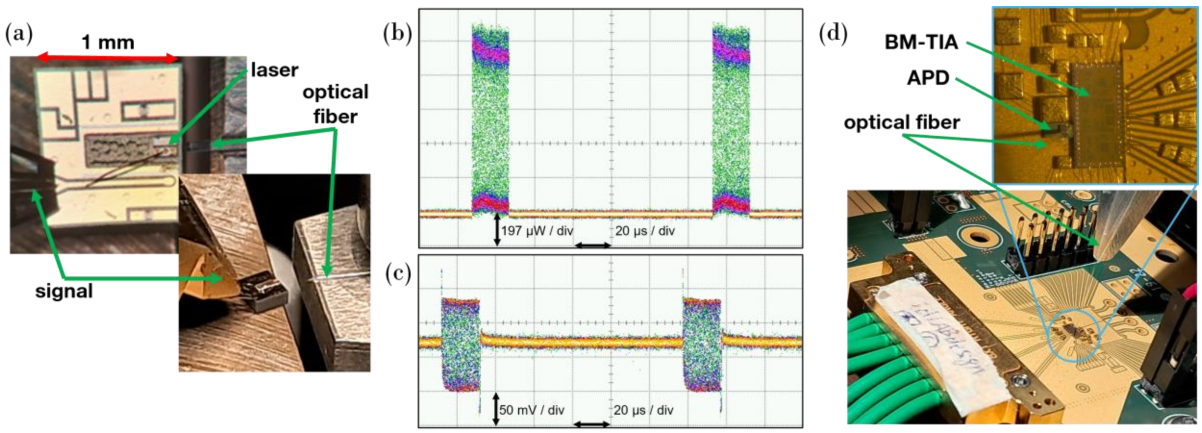

Fig. 3: (a) DML, **(b)** Optical burst at the transmitter side, **(c)** Electrical burst after the BM-TIA, **(d)** BM-TIA.

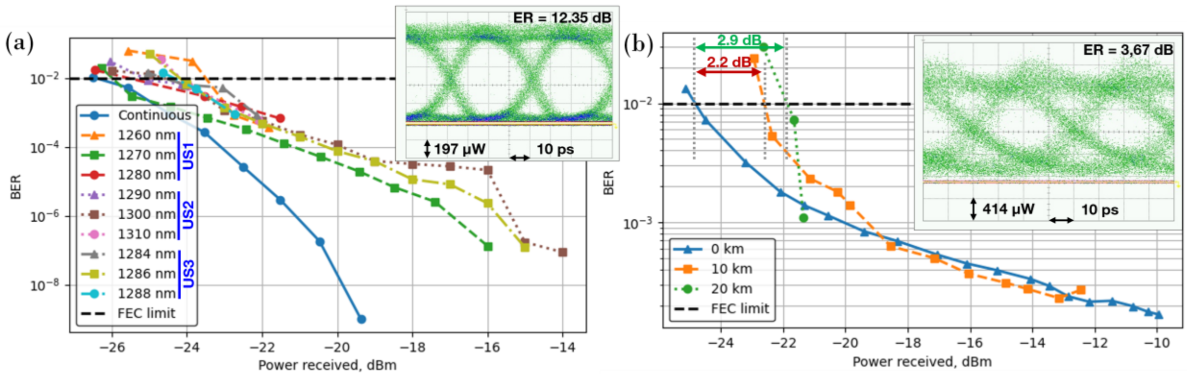

Fig. 4: (a) BER at 25 Gbps with the ECL-MZM, **(b)** BER at 25 Gbps with the DML.

system was used to measure the Bit Error Rate (BER) on the different US wavelength options proposed for the 50G-PON by the ITU-T to test the capacity of the receiver to handle the different wavelengths. Fig. 4a represents the BER as function of the power received at the APD with a laser output power of +4.7 dBm. In the standard, a maximum BER of 10^{-2} is defined as the sensitivity limit corresponding to the limit of the error correction code (FEC) chosen for this technology. The continuous curve presented on Fig. 4a reveals a sensitivity of -26.5 dBm at 10^{-2} for a wavelength of 1270 nm. We observe a BM penalty of 2.5 dB between the worst case (at 1260 nm) in burst mode and the continuous mode.

The sensitivity as function of the wavelength is shown on Fig. 5. However, a linear fit allows to extract a sensitivity of -26 dBm in US1 band, -25.2 dBm in US2 and -24.4 dBm in US3. Those results get compared to the standard, i.e. to the N1 optical class budget (14-29 dB). A difference of 0.3 dB is observed at 1310 nm in US2 between the N1 limit and the measured sensitivity.

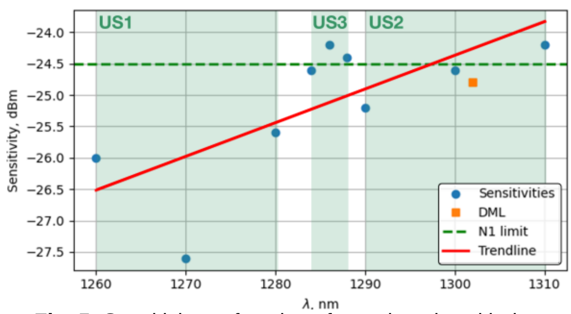

Fig. 5: Sensitivity as function of wavelengths with the ECL-MZM (25 Gbit/s)

Because ECL-MZM devices are not suited for use at the ONU side due to their high cost, we evaluated the performance penalty by using DML instead, to get closer to a real-life implementation, see Fig. 2. BER measurements were then made starting with 0 km of fiber (see the blue triangled curve in Fig. 4b) where a sensitivity of -24.8 dBm was reached. Then, we added 10 or 20 km of optical fiber. For high powers (> -18 dBm), the received signal is of sufficient quality to be easily detected and sticks to the 0 km curve because we work at the wavelength 1302 nm, close to the zero chromatic dispersion one. We observe a 10^{-2} BER sensitivity penalty of 2.2 dB for 10 km (orange squared curve) and 2.9 dB for 20 km (green circled curve), respectively. At higher powers, the BER performance converge for different fiber lengths. The sensitivity penalties in burst-mode and continuous-mode (Fig. 4a), as well as the difference in BER performance for lower powers (Fig. 4b) can be mainly attributed to the absence of a BM Clock and Data Recovery (BM-CDR), which quickly has to adapt the phase for each incoming burst in combination with residual transient effects after the BM-TIA. Nevertheless, at 0 km, the system is compliant with the N1 class and with a dynamic range of 15.17 dB.

Conclusion

In this paper, we tested and characterized a BM-TIA prototype in the context of the 50G-PON US. A 25 Gbps NRZ-OOK burst mode transmission reaching -24.8 dBm sensitivity with a DML is demonstrated. The experimental and real-time experiments in BM introduce considerable measurement imprecision. The measured impact is mainly attributed to the absence of a BM-CDR in combination with imperfect BM-TIA setting. We achieved an ECL-MZM transmission with the different options for the upstream proposed by the ITU-T (US1, US2 and US3) at 25 Gbps. In a second step, a DML emitter was used. Here, we obtained a sensitivity of -24.8 dBm, and reached an optical budget of 14.65 to 29.82 dB, compliant with the N1 class. For distances of 10 and 20 km, we achieved sensitivities of -22.6 and -21.9 dBm, respectively.

Acknowledgements

This work was carried out in OCTAPUS HORIZON-CL4-2021-DIGITAL-EMERGING-01-06 project (number: 101070009). We also thank Almae technologies for the realization of the DML.

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