

# Dispersion Tolerant 200 Gb/s Dual-Wavelength IM/DD Transmission with 33dB Link Budget for Next Generation PON

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**Abstract** *We demonstrate 2x100Gb/s 20km fibre transmission achieving -25dBm sensitivity around 1340nm resulting in 33dB link budget. This is achieved by two EML-SOAs with 13.5dBm output power and negative chirp parameter to overcome chromatic dispersion, enabling the use of unassigned wavelengths in the O-band for 200G-PON. ©2023 The Author(s)*

## Introduction

Increasing bandwidth (BW) demands in residential, business and wireless broadband services are driving the development of passive optical networks (PON) with higher capacities. In the IEEE and ITU-T, the next generation of PON are being defined based on NRZ 25Gb/s and 50Gb/s line rates, respectively. Since the standardisation of the 50Gb/s class PON is effectively completed and carrier lab trials of advanced prototypes are currently under way, research activities focus now on potential next generation PON beyond 50Gb/s. Previous 4- to 5-fold capacity increases in the PON evolution (2.5Gb/s to 10Gb/s and 10Gb/s to 50Gb/s) suggest 200Gb/s as the most likely rate after 50G-PON. It is still not clear whether intensity-modulated with direct detection (IM/DD) or coherent transmission will be the most suitable approach for 200G-PON. Although coherent systems allow for a higher sensitivity and robustness against channel penalties, global sales of much cheaper 100Gb/s transceivers should surpass sales of coherent modules in 2024 [1], benefiting the IM/DD ecosystem.

Up to 50G-PON, an increase of payload rates could be simply achieved by scaling up symbol rates of NRZ IM/DD. For 200Gb/s, however, enhanced limitations in optoelectronic (O/E) component BWs and reduced PON sensitivity motivates considerations of two further scaling possibilities: Multi-levels and multi-channels. Both options preserve to some extent the cost- and power-efficiency of IM/DD and both are well-known from the datacentre ecosystem, which moved to PAM-4 beyond 50 Gb/s and to two, four or more parallel lanes, where required. For 200Gb/s PON, a two wavelength scheme with 2x100Gb/s, similar to 50G-EPON [2], could provide a good trade-off of doubled data rate vs. cost and power penalties. Another doubling of data rate is possible by applying PAM-4 instead

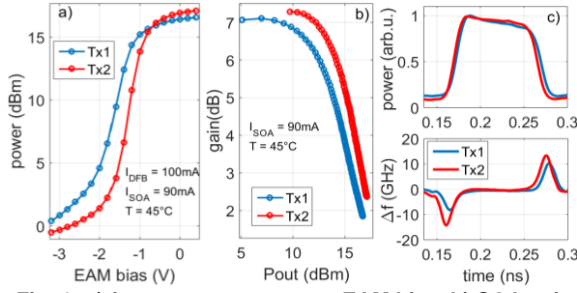
of NRZ at the cost of reduced sensitivity and less robustness to O/E component nonlinearities.

Although 100Gb/s PAM-4 has been reported before [3]–[8], most experiments address 1290-1310nm avoiding chromatic dispersion (CD) and preventing coexistence with legacy PON.

In this paper, we target the unassigned 1320-1340nm band to simultaneously transmit two 100Gb/s PAM-4 wavelengths, using two monolithically integrated EML-SOAs in a wavelength division multiplexing (WDM) approach to achieve 200Gb/s. Our EML-SOAs have been carefully designed for high saturation power of the SOA to allow for high output power and reduced nonlinearity. Further, the optimized devices provide a negative chirp parameter which allows fibre transmission under positive CD for coexistence with previous PON systems.

## The integrated EML-SOA Tx

We designed our EML-SOAs transmitters (Tx) to cost-effectively compensate for the main drawbacks in 100Gb/s IM/DD transmission, namely the limited receiver (Rx) sensitivity and the power fading effects due to CD. We target high modulated output powers of 14dBm, saturation powers of 15dBm and a negative chirp parameter at optimum operating conditions. Both chips are ~1mm long and consist of three monolithically integrated sections: a distributed-feedback laser (DFB), an electro-absorption modulator (EAM) and an SOA. All sections are based on the ridge waveguide technology due to its simplicity and well suitability for mass production. The two chips only differ in their emission wavelengths, given by the DFB Bragg grating, at 1343nm for Tx1 and 1337nm for Tx2. While Tx1 is outside the targeted unassigned spectrum, the effect of CD is higher, which demonstrates a worst case scenario. Both chips exhibit a 3dB modulation BW of 45GHz. Fig. 1(a) depicts the chip output



**Fig. 1: a) facet output power vs. EAM bias. b) SOA gain and c) instantaneous power vs. chirp at selected bias**

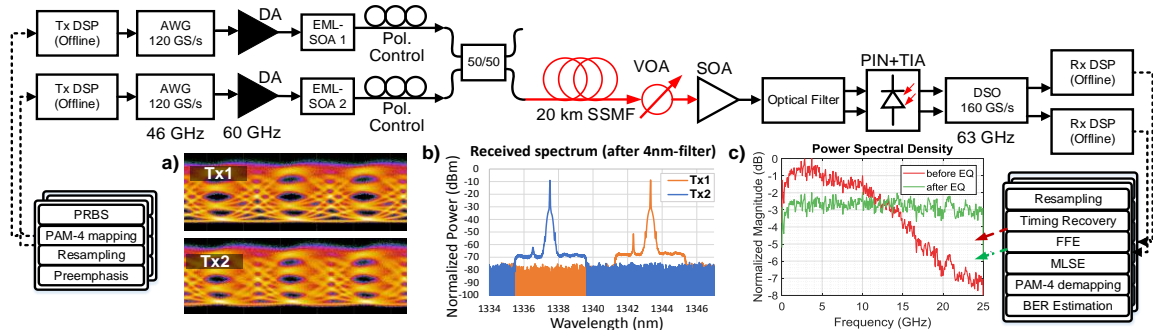
power as a function of EAM voltage at 45°C with applied currents of 100mA for the DFB and 90mA for the SOA sections. DFB operation at 100mA maximizes the output power without incurring EAM saturation and yields static extinction ratios (ER) over 15dB, as seen in Fig. 1(a). We bias the EAM of Tx1 and Tx2 at -1.3V and -1.0V, respectively, for an optimum ER of 6dB as well as evenly spaced levels of the PAM-4 signal. SOA operation at 90mA on both Tx maximizes the unsaturated gain of 7dB as shown in Fig. 1(b). At the selected operating conditions, an average facet output power of 13.5dBm is obtained for both Tx, at which the SOA is only saturated by 1.5dB in Tx1 and by 1dB in Tx2. To determine the chirp parameter at the chosen bias, we modulate the EAM section with a 150ps-pulse and measure the instantaneous frequency deviation ( $\Delta f$ ) of the modulated signal, as shown in Fig. 1(c). The chirp is clearly negative in both Tx, i.e. the frequency decreases at the pulse leading edge and increases at the trailing edge, from which we estimate the chirp parameter at -0.8 and -1.0 for Tx1 and Tx2, respectively.

### Transmission experiment at 200Gb/s

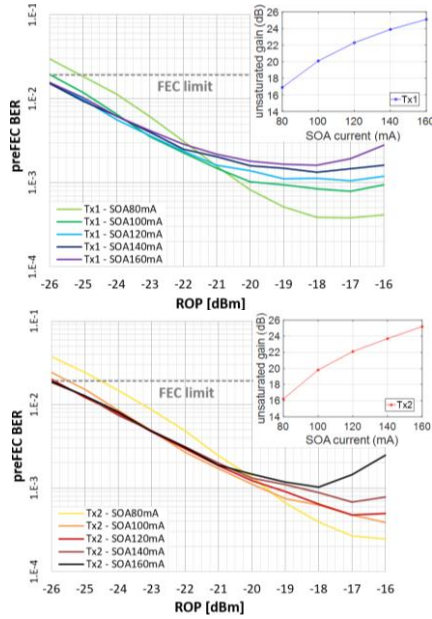
We perform BER measurements with the setup of Fig. 2. At both Tx, identical pseudorandom binary sequences (PRBS-14) are Gray-mapped to PAM-4 symbols. After resampling, the sequences match the 120GS/s arbitrary waveform generator (AWG), which converts the symbols to analogue signals. Before this conversion, a linear pre-emphasis filter boosts

the high frequency content of both signals to pre-distort against channel BW limitations. Although applied digitally here, such filters can be implemented in a single low-power analogue block with a small footprint. The AWG outputs are then amplified by 60 GHz driver amplifiers (DA) towards the EAM section of each Tx.

Fig. 2(a) shows the eye diagrams for output powers of 13.5dBm per channel after modulation. A power combiner (50/50 splitter) is used to multiplex the two wavelengths, as shown in Fig. 2. We measured the total power after the combiner at 8dBm per wavelength, which corresponds to the launch power per channel for link budget estimation. We carry out experiments in back to back (btb) and with 20km standard single mode fibre (SSMF) with an accumulated dispersion of 70ps/nm for Tx1 and 63ps/nm for Tx2 wavelength. A variable optical attenuator (VOA) is used to control the received optical power (ROP) by the Rx, which consists of an SOA and PIN-TIA. The SOA pre-amplifies the received signal with a gain of up to 25dB with a noise figure (NF) of 7dB and polarization dependent gain of 4dB. Hence, we optimize the polarization at each wavelength. We note that polarization insensitive SOAs with a similar gain and NF can be manufactured and would be preferred for this application [9]. The  $P_{\text{sat}}$  of the SOA is 12dBm, which ensures linear operation for the range of input powers in our experiments. We take advantage of the de-multiplexing optical filter to remove most of the SOA amplified spontaneous emission (ASE) noise for improved sensitivity. The optical filter has an insertion loss of 4dB. Its BW is fixed at 4nm, centered at each Tx wavelength as shown in the Rx spectra of Fig. 2(b). The PIN-TIA has a nominal BW of 35GHz. However, we observe a reduced BW in the end-to-end signal PSD in Fig. 2(c), which we compensate through offline DSP. The electrical signal is digitized by a real time oscilloscope, operating at 160GSa/s. Two million samples are captured for offline processing. After timing recovery, the signal is resampled to 1 sample per symbol and channel distortions are compensated



**Fig. 2: End-to-end transmission setup with inserts a) Tx eyes, b) received spectrum after filter and c) Power spectral density before and after equalization**



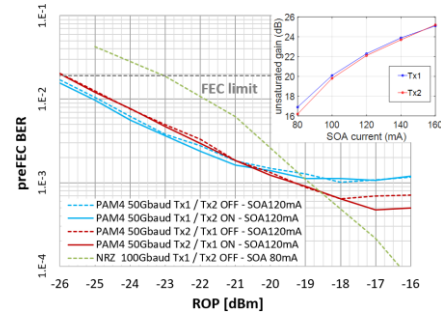
**Fig. 3: PAM-4 back to back SOA current sweeps: Tx1 (top) and Tx2 (bottom) with gain vs. current inserts**

with feed-forward equalization (FFE) of 21 taps. To overcome further fibre transmission penalties in the 20km configuration, we can add maximum likelihood sequence estimation (MLSE) of memory length 5 with a 1-tap noise whitening filter. We determine the optimum operating bias of the Rx SOA first by measuring its gain followed by offline bit error rate (BER) estimations in btb. We consider a forward error correction (FEC) limit of  $1.9 \times 10^{-2}$  as already suggested for beyond 50G-PON systems [10]. Fig. 3 plots btb PAM-4 100Gb/s results without the MLSE stage for Tx1 and Tx2 with the SOA gain as inset at the corresponding wavelength. We observe that increasing the SOA current beyond 120mA for more than 22dB gain yields no significant BER improvements at the FEC limit. In addition, there is a higher BER floor with increasing SOA gain that we attribute to input powers at the PIN-TIA approaching its overload level, which may call for a gain control circuit in the case of higher power levels and SOA gains beyond 22dB.

For the PAM-4 results of Fig. 4, we perform BER measurements in btb by turning on only one Tx at a time. Here, we operate the SOA at the optimum current of 120mA for a 22dB gain, which results in a BER of  $\sim -26$ dBm for both Tx in btb. The SOA gain is generally slightly higher at the Tx1 wavelength, which explains the somewhat better BER for Tx1.

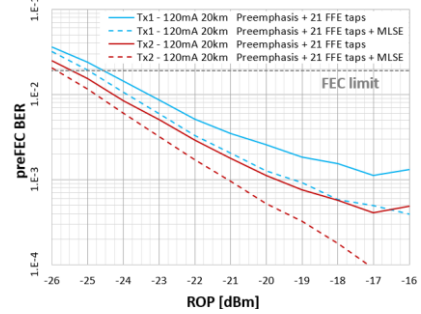
Almost matching curves, regardless if the neighbour channel is switched on or off, indicate insignificant crosstalk or nonlinear effects.

For comparisons, Fig. 4 includes 100Gb/s NRZ results for Tx1 alone with 80mA SOA current with a 21 tap FFE. Since 100G PIN TIAs are currently not commercially available, we used a 67GHz



**Fig. 4: Back to back PAM-4 50Gbaud with neighbour channel on or off, compared to NRZ 100Gbaud off**

PIN followed by a 67GHz RF amplifier, for which we obtained a BER of -23dBm. Theoretically, transmission in btb at 100Gb/s NRZ should achieve better sensitivity than 100Gb/s PAM-4 for a full BW system. However, the performance was most likely limited by the absence of the TIA, which results in decreased sensitivity for the 100G NRZ Rx. Unlike PAM-4 with an error floor at around  $1 \times 10^{-3}$  BER, NRZ shows no error floor.



**Fig. 5: PAM-4 50Gbaud 20km Tx1 and Tx2 with pre-emphasis, 21 FFE taps, with and without MLSE**

Fig. 5 shows results after transmission over 20km SSMF. Sensitivities are at -24.5dBm for Tx1 and -25.5dBm for Tx2, resulting in optical path penalties (OPP) of 1.5dB and 0.5dB. The higher OPP for Tx1 results from both, a higher CD at this wavelength and a less negative chirp of Tx1 compared to that of Tx2. We note that if we target the wavelength range of 1320nm to 1340nm the OPP of Tx1 can be seen as a worst case. To mitigate CD, we add an MLSE stage and achieve 20km sensitivities of -25.8dBm and -25dBm for Tx1 and Tx2. Considering the worst sensitivity of -25dBm and the launch power of 8dBm per channel, we attain a link budget of 33dB.

## Conclusions

We demonstrate the feasibility of dual-wavelength IM/DD WDM for next generation 200G-PON that could be potentially accommodated in the unassigned 1320-1340nm band for PON coexistence. We attain -25dBm sensitivity after 20km using relatively low-complex DSP techniques leading to 33dB link budget. The results are enabled by our EML-SOA devices, which can provide both very high power and negative chirp for combatting dispersion under positive CD.

## References

- [1] Lightcounting, "Emerging Market for PAM4 and Coherent DSPs," 5th ed., 2023.
- [2] C. Knittle, "IEEE 50 Gb/s EPON (50G-EPON)," in *2020 Optical Fiber Communications Conference and Exhibition (OFC)*, Mar. 2020, pp. 1–3.
- [3] J. Zhang *et al.*, "Demonstration of 100-Gb/s/λ PAM-4 TDM-PON Supporting 29-dB Power Budget with 50-km Reach using 10G-class O-Band DML Transmitters," in *2019 Optical Fiber Communications Conference and Exhibition (OFC)*, Mar. 2019, pp. 1–3.
- [4] K. Wang *et al.*, "100-Gbit/s/λ PAM-4 Signal Transmission over 80-km SSMF Based on an 18-GHz EML at O-Band," in *2020 Optical Fiber Communications Conference and Exhibition (OFC)*, Mar. 2020, pp. 1–3.
- [5] J. Potet *et al.*, "Real Time 100 Gbit/s/λ PAM-4 Experiments for Future Access Networks over 20 km with 29 dB Optical Budget," in *2021 European Conference on Optical Communication (ECOC)*, Sep. 2021, pp. 1–3. doi: 10.1109/ECOC52684.2021.9606149.
- [6] L. Xue, R. Lin, J. Van Kerrebrouck, L. Yi, J. Chen, and X. Yin, "100G PAM-4 PON with 34 dB Power Budget Using Joint Nonlinear Tomlinson-Harashima Precoding and Volterra Equalization," in *2021 European Conference on Optical Communication (ECOC)*, Sep. 2021, pp. 1–4. doi: 10.1109/ECOC52684.2021.9606041.
- [7] G. Caruso, I. Cano, D. Nasset, G. Talli, and R. Gaudino, "Real-Time 100Gb/s Downstream PAM4 PON Link With 34 dB Power Budget," *2022 European Conference on Optical Communications (ECOC)*.
- [8] J. Potet *et al.*, "Real-Time DSP-Free 100 Gbit/s/λ PAM-4 Fiber Access Link Using EML and Direct Detection," *IEEE Photonics Technology Letters*, vol. 34, no. 17, pp. 895–898, Sep. 2022, doi: 10.1109/LPT.2022.3191460.
- [9] R. Rosales *et al.*, "50G-PON Upstream With Over 36dB Link Budget Using an SOA-PIN Based Receiver," *IEEE Photonics Technology Letters*, vol. 34, no. 22, pp. 1222–1225, Nov. 2022, doi: 10.1109/LPT.2022.3207996.
- [10] P. Torres-Ferrera, F. Effenberger, M. S. Faruk, S. J. Savory, and R. Gaudino, "Overview of high-speed TDM-PON beyond 50 Gbps per wavelength using digital signal processing [Invited Tutorial]," *Journal of Optical Communications and Networking*, vol. 14, no. 12, pp. 982–996, Dec. 2022, doi: 10.1364/JOCN.468920.