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# Experimental Demonstration of a Large Dynamic Range Burst-Mode Receiver for 200G Upstream Coherent PON Based on Static Gain TIA

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**Abstract**: We experimentally demonstrate a net 200 Gb/s burst-mode coherent transmission using DP-QPSK and a commercial integrated coherent receiver with fixed-gain mode TIA, supporting 20 dB dynamic range for burst detection over a 40 km fiber link. 

## 1. Introduction

Passive optical networks (PON) are the core of modern access networks. The aggregated downstream (DS) / upstream (US) line rates have transitioned over the last 20 years from 2.5/1.25 Gbps (GPON), to 10 Gbps (XGS-PON), to 50 Gbps (50GPON), corresponding to a 4-5x increase in line rate every 5-7 years [1]. Following this trend, it can be projected that the next generation of PON will support 200 Gbps in DS and US [1]. ITU study group G.Sup.VHSP is currently exploring paths for realizing such challenging line rates by looking both into suitable IM/DD and coherent transceiver technologies. IM/DD has been the most effective choice for previous PON generations due to its low complexity and low cost. However, an IM/DD system supporting 200 Gbps in a point to multi-point (P2MP) topology with chromatic dispersion (CD) and polarization mode dispersion (PMD) remains challenging [2], even in the most desirable wavelength span around the minimum CD. On the other hand, coherent technology is known for supporting rates beyond 200 Gbps with high receiver (RX) sensitivity in continuous mode and its digital CD and PMD compensation capabilities give flexibility to the choice of the operating wavelength. However, today's cost of coherent technology and the current lack of coherent receivers with burst-mode transimpedance amplifiers (TIA) remain a challenge for the deployment of the technology in access networks, where burst-mode operation is typically used in US. Transmitter (TX) power pre-leveling at the optical network unit (ONU) using SOAs may reduce the dynamic range (DR) requirements of the RX as suggested in [3]. In this paper, we explore the potential use of a commercially available integrated coherent receiver (ICR) with static gain setting for large DR burst-mode reception. We choose DP-QPSK as modulation format and tolerate the clipping of the TIA output amplitude by up to 60%. This approach leads to supporting > 30 dB of DR in simulations and > 20 dB DR in our 200 Gbps US experiments.

## 2. Burst-mode receiver dynamic range for coherent reception

The 50GPON standard [4], allows for 5 dB of ONU transmission power uncertainty and up to 15 dB of differential optical path loss from the optical distribution network (ODN). This means that the optical line terminal (OLT) RX must support up to 20 dB of optical burst power imbalance. In a direct detection receiver, an optical burst power ratio $\kappa_{\mathrm{dB}}$ at the RX leads to the same root mean square (RMS) current ratio $\eta_{\mathrm{APD,dB}}$ at the avalanche photo-diode (APD) output, see Eqs. 1 and 2. For handling such a large DR, direct-detection PON receivers utilize burst-mode TIAs and burst mode post-amplifiers (PA) with ~50 ns gain control time constant [5], to have high sensitivity for low-power (soft) bursts, and avoid clipping or distortion of high-power (loud) bursts. In a commercial coherent receiver, burst detection is challenging, because its TIA gain control time constant, developed for continuous point-to-point operation, is ≥ 1 µs, which is longer than the maximum permitted burst preamble duration of 611ns [4]. Coherent reception, however, can greatly relax TIA gain control requirements. As illustrated in Eq. 3, the output RMS current $i_{\mathrm{BPD,rms}}$ of a balanced photo diode (BPD) pair does not scale linearly with the power of the optical signal $P_{\mathrm{sig}}$, but with its square root. Consequently, for a given optical burst power ratio $\kappa_{\mathrm{dB}}$, the RMS current ratio $\eta_{\mathrm{BPD,dB}}$ at the BPD output equals $\kappa_{\mathrm{dB}}/2$, see Eq. 4. Hence, it is expected that without gain control, the DR supported by a coherent receiver is inherently larger than the one achievable through direct detection.

$$i_{\mathrm{APD,rms}} \propto P_{\mathrm{sig}} \quad (1) \qquad \eta_{APD,dB} = 10 \cdot \log_{10} \frac{i_{\mathrm{APD,loud,rms}}}{i_{\mathrm{APD,soft,rms}}} = 10 \cdot \log_{10} \frac{P_{\mathrm{sig,loud}}}{P_{\mathrm{sig,soft}}} = \kappa_{\mathrm{dB}} \quad (2)$$

$$i_{\mathrm{BPD,rms}} \propto \sqrt{P_{\mathrm{sig}} P_{\mathrm{LO}}} \quad (3) \qquad \eta_{BPD,dB} = 10 \cdot \log_{10} \frac{i_{\mathrm{BPD,loud,rms}}}{i_{\mathrm{BPD,soft,rms}}} = 10 \cdot \log_{10} \sqrt{\frac{P_{\mathrm{sig,loud}}}{P_{\mathrm{sig,soft}}}} = \frac{1}{2} \cdot \kappa_{\mathrm{dB}} \quad (4)$$

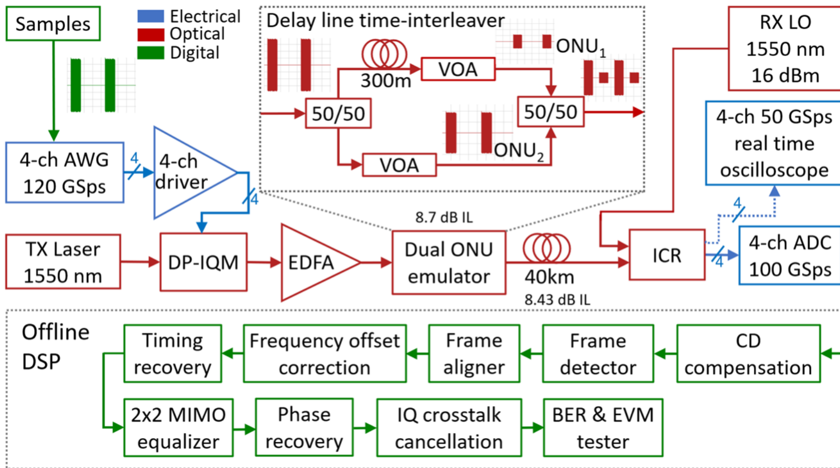


**Fig. 1.** Experimental setup for 64 GBaud burst-mode DP-QPSK. A delay line time-interleaver with variable attenuators is used to interleave soft and loud bursts. DSP is performed offline and depicted in green, where frame detection and alignment, and MIMO equalization are based on constant amplitude zero auto-correlation (CAZAC) sequences present in the preamble.

## 3. Burst-Mode Experiments

The experimental setup for generating alternating bursts of loud/soft power ratios exceeding 30 dB is depicted in Fig. 1. The transmitter consists of a 120 GSps 4-channel arbitrary waveform generator (AWG), a 4-channel driver amplifier, a class-40 lithium niobate DP-IQM, and an external cavity laser with 100 kHz linewidth, operated at 1550 nm. For capturing at least one loud-burst and one soft-burst within the limited analog-to-digital converter (ADC) memory, the AWG is configured to send a burst of 0.93 µs duration, including 0.27 µs of constant amplitude zero auto-correlation (CAZAC) preamble, followed by 2.2 µs of zeros. The burst is fed into the dual ONU emulator with a 300 m delay line, which interleaves two copies of the original burst, emulating 2 distinct ONUs in the ODN. Individual VOAs are used to set the power of the soft and loud bursts independently. The interleaved bursts then propagate over 40 km of SMF28 before being received by the ICR. To compensate for the ~17 dB of loss from the ONU emulator and fiber an EDFA is added, allowing for loud-burst powers up to -2 dBm at the coherent receiver input. A second 100 kHz laser is used as LO for the ICR. A 4-channel differential ADC with a sampling rate of 100 GSps and detection range of 500 $mV_{pp,diff}$ is used for acquiring the ICR output. Additionally, a 4-channel 50 GSps real-time oscilloscope with 5.5 ENOB is used to measure the signal's full-swing prior to capturing the clipped signal. This allows us to determine the clipping percentage of the received signal. The captured traces, containing both types of bursts, are processed burst-by-burst through offline digital signal processing (DSP) as indicated in Fig. 1. The DSP stores the RMS voltage of each burst to distinguish between loud-bursts and soft-bursts.

The dynamic range of the ICR in manual gain control mode is studied both through simulations and experiments at 32 and 64 GBaud. In simulation, the channel is modelled in Python as a digital twin of our experimental setup, with the TIA transimpedance and input referred noise density set to 1400 Ohm and 20pA/$\sqrt{Hz}$ and input referred PD responsivity set to 85mA/W. The simulation and experiment share identical DSP blocks for sample generation and signal reception. In all studies, we keep the received power of the $ONU_1$ burst constant, utilizing around 40% of the ADC range, see Fig. 2c), while the received power of the $ONU_2$ burst is varied from -34 dBm to -2 dBm. The simulation results are displayed by the solid black lines in Fig. 2b) and 2d), showing an achievable dynamic range of 32 dB and 30 dB, for 32 and 64 GBaud, respectively. The experimental results are illustrated by the box plots in the same figures where each box displays the BER distribution of ~25 bursts. Fig. 2a) illustrates the experimental data of three operating regimes of the burst mode receiver. At $\kappa_{dB} = 0$ dB, the signal quality is limited by electrical noise as the received burst power is close to the RX sensitivity. At $\kappa_{dB} = 10$ dB, the loud $ONU_2$ burst SNR improves and the ADC is not clipping yet. At $\kappa_{dB} = 24$ dB, the $ONU_2$ burst gets clipped by ~60%, leading to signal distortions. In Fig. 2b), we limit the symbol rate to 32 GBaud to be compatible with our 50 GSps real time oscilloscope. This allows us to sense the output swing from the TIA before clipping occurs. However, for data reception we limit the oscilloscope range to 250 $mV_{pp}$ (single-ended) to clip TIA outputs exceeding 500 $mV_{pp,diff}$, making the reception consistent with the finite range of a differential ADC. Despite the heavy clipping at high input powers, we measure a BER below the FEC threshold of $2x10^{-2}$ (compatible with O-FEC [6] or SD-LDPC [7]) for $ONU_2$ bursts in the range of -34 dBm to -4 dBm. Thus, the experimentally assessed reception range (RR) is 30 dB, agreeing well with the simulations.

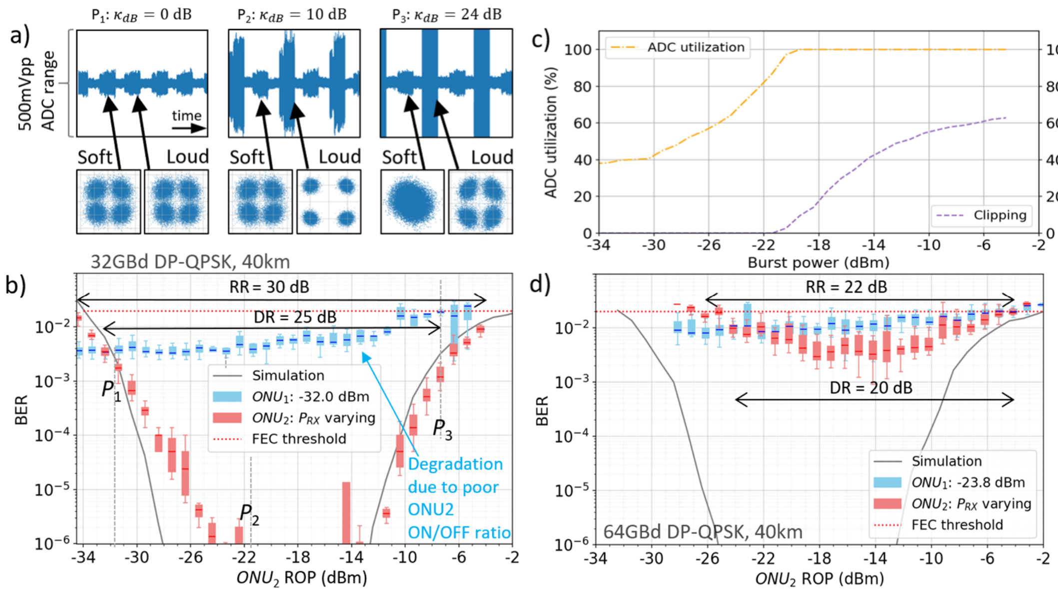


**Fig. 2.** (a) Experimentally received ADC traces and constellations for different loud/soft ratios. $P_1$: $ONU_2$ at -31.4 dBm, 0 dB loud/soft ratio $\kappa_{dB}$ (40% ADC utilization), $P_2$: $ONU_2$ at -21.4 dBm, 10 dB loud/soft ratio (100% ADC utilization), $P_3$: $ONU_2$ at -7.4 dBm, 24 dB loud/soft ratio (60% clipping) (b) Burst dynamic range characterization at 32 GBaud DP-QPSK. Each box plot displays the BER distribution of 25 bursts. (c) ADC range utilization and clipping percentage as a function of received burst power extracted from oscilloscope measurements. (d) Burst dynamic range characterization at 64 GBaud DP-QPSK.

Being kept at a constant power, it is expected that the performance of the $ONU_1$ bursts remain constant throughout the $ONU_2$ burst power sweep, hence the supported DR should match the RR. However, in our experiment, we find a degradation of the soft-burst BER as the loud-burst power increases due to a low TX ON/OFF ratio of 18 dB achieved through the simple muting of the electrical signal by the AWG. Consequently, the demonstrated DR at 100G is limited by the soft-burst performance to 25 dB. The poor TX ON/OFF ratio is a result of residual carrier (25 dB to 30 dB MZM ER) and electrical noise of the driver and of the AWG. This is a pure limitation of our shutter-less burst generation method. In a practical implementation, an ONU would be expected to achieve > 50 dB ON/OFF ratio e.g. by means of a TX shutter as shown in [3], leading to a constant $ONU_1$ BER and causing the supported DR to equal the RR. In Fig. 2d), we replace the real time oscilloscope by a 100 GSps differential ADC and transmit a 64 GBaud DP-QPSK signal. While the simulated performance shows the potential for a 30 dB dynamic range for 200G bursts, the measurements show a RR >22 dB and an overall DR of 20 dB, due to a high error floor in our experimental setup. Furthermore, clipping-induced non-linearities might lead to additional penalties when linear distortions like CD and PMD are present. However, the short propagation distances ≤40 km in access networks keep those penalties low, thus supporting a large dynamic range during burst-mode reception.

## 3. Conclusions

We have demonstrated that the use of a commercial coherent RX with DP-QPSK and static gain setting TIA potentially allows for an US burst-mode dynamic range of 30 dB by working with clipped signals. The measured supported DR at 200G is 20 dB (due to limitations of our experimental setup), which is compliant with the requirement for today's direct detection burst mode receivers (15 dB + 5 dB margin for ONU TX power uncertainty [4]). While the development of a burst-mode TIA can further extend the US coherent receiver DR, these measurements show the feasibility of using existing commercial ICRs for US coherent PON without the need for power leveling, by exploiting the clipping regime, which can potentially reduce the complexity and cost of such networks.

## 4. References


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