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25Gb/s PAM4 Burst-Mode System for Upstream Transmission in Passive Optical Networks

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Abstract: A 25Gb/s PAM4 burst-mode upstream transmission is demonstrated over 25km of fiber using 10G components and a linear burst-mode TIA with a 14.7dB dynamic range and with differential chromatic dispersion equivalent to 25km of fiber.

OCIS codes: (060.2330) Fiber optics communications; (060.4080) Modulation

1. Introduction

In order to meet the continuous global growth in bandwidth demand, research and standardization activities are now moving towards 100G passive optical network (PON) systems. Given the cost sensitivity of optical access solutions, it will be particularly important to leverage existing 10G components, more mature and lower cost compared to 25G electro-optical devices, even when increasing the line rate beyond 10Gb/s. Multilevel modulation formats are being proposed, in particular electrical duo-binary and multi-level pulse amplitude modulation (PAM) are promising solutions thanks to their higher spectral efficiency that can support 25Gb/s or 40Gb/s transmission with 10G devices [1–5]. In these previous demonstrations digital signal processing (DSP) was employed at the optical network unit (ONU) or at optical line terminal (OLT) in order to improve the link performance [1–6]. Interestingly PAM-4 could potentially leverage the high-volume market of data center interconnect thus driving down transceiver cost.

The performance of time division multiplexed (TDM) PONs is usually determined by the upstream channel which aggregates bursts from the different ONUs to the OLT. Successive bursts originating from different ONUs located at different distances from the OLT will have large differences in amplitude (>20dB optical dynamic range), phase (unknown phase relative to the local OLT clock) and signal impairment due to chromatic dispersion (CD). In order to be able to compensate these impairments on a burst by burst scale a linear burst-mode receiver (LBMRx) is required in the OLT to support adaptive electronic dispersion compensation (EDC) [7]. In a previous study we have analyzed the electronic equalization requirements for a 25Gb/s PAM4 burst-mode upstream link showing that linear adaptive feed-forward and decision-feedback equalizers (FFE, DFE) are suitable for use in burst-mode links [5]. Here we propose an extension of our previous work where system performances are investigated in burst-mode operation using the first stage of a LBMRx. The burst-mode transimpedance amplifier (TIA) implements fast DC alignment for consecutive burst allowing simple AC-coupling with the following components without compromising guard time and preamble lengths. In the architecture proposed in this work the ONU transmitter is using 10G devices and not adopting pre-processing to reduce complexity and cost, concentrating all the DSP at the OLT which is shared between all the users. Optical amplification is also introduced at the OLT to increase the power budget of the network while preserving the cost-effectiveness, as the cost of this amplifier is shared amongst all connected ONUs. Burst-mode transmission is performed with a dynamic range (DR) up to 14.7dB in back-to-back (B2B) and 13dB after 25km of standard single mode fiber (SSMF) with the use of adaptive EDC. The system is also tested with differential (burst-by-burst) chromatic dispersion equivalent to 25km of fiber.

2. Experimental Setup

The experimental setup implements two ONUs with distributed feedback (DFB) lasers tuned on different channels of the 50GHz ITU grid with wavelength 1538.186nm and 1539.766nm within the NG-PON2 upstream band [8]. Each laser is followed by a semiconductor optical amplifier (SOA) that is switched off during the burst-off state to carve bursts from the optical signals. The two signals are merged with an arrayed waveguide grating (AWG) to suppress the SOAs amplified spontaneous emission (ASE) and sent to an electro-absorption modulator (EAM) driven with a Gray coded PAM4 12.5GBd burst signal. A 25km SSMF is used as optical trunk line (OTL) and an optical waveshaper (WS) is used to introduce arbitrary attenuation and CD between the two channels creating a power DR between the packets and emulating differential fiber reach. At the receiver a linear BM-TIA integrated with a PIN photodiode is used in conjunction with an erbium-doped fiber amplifier (EDFA) with fast transient control to enhance its sensitivity. The LBMRx front-end was fabricated using a 130nm SiGe BiCMOS technology. The EDFA is followed by a 4nm wide optical bandpass filter to suppress the out of band ASE while allowing both channels to be detected. The burst-mode TIA has a 3dB bandwidth of 12GHz and it includes a mechanism for fast baseline alignment of consecutive bursts and partial amplitude equalization. Full amplitude equalization would then be performed by the next stage of the LBMRx, the variable gain post-amplifier stage. Post-equalization of the signal and error counting were done with offline processing on the differential signal captured by a 50GS/s, 12GHz digital storage oscilloscope (DSO). In this work a fractionally spaced, 2-taps per symbol, adaptive FFE with 14 taps is used.

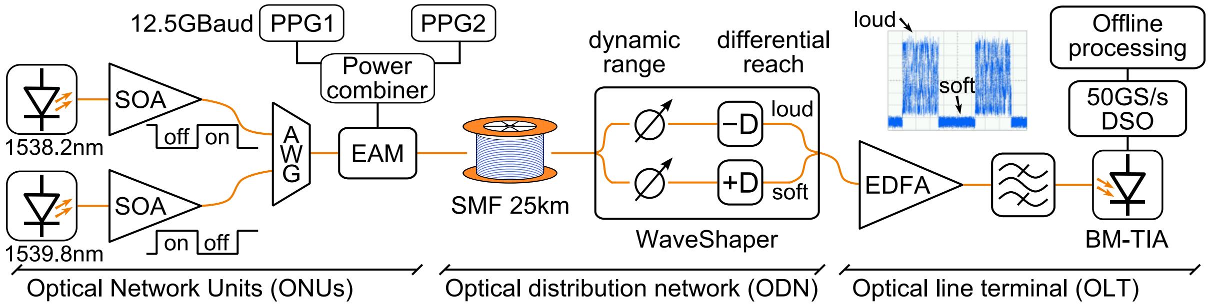

Fig. 1: Experimental setup with two ONUs showing dynamic range and differential reach at the OLT.

3. Results and Discussion

As mentioned, the linear BM-TIA includes a mechanism for fast restoration of the baseline of successive bursts, allowing AC-coupling in the BMRx chipset. The mechanism operates by quickly extracting the baseline of the burst during the preamble using a suitable low-pass filter and adding it to the incoming burst. The time constant introduced by this low-pass filter is subject to a trade-off between settling time and baseline wander. While in principle this trade-off can be broken by switching time constants, this would require a reset signal, either auto detected or provisioned from the higher layer, which should be preferably avoided to simplify system design. This trade-off was studied by changing a programmable time constant on the realized LBMRx front-end. For different filter settings the settling times are reported in Fig.2 measured under increasing DR. Also reported is the required optical power to obtain a pre-forward error correction (FEC) bit error ratio (BER) of 10^{-3} for different types of pseudo-random quaternary sequences (PRQSs). Increasing the loud/soft ratio results in longer settling times of the soft bursts, due to the larger transient of the loud burst. In some cases the burst envelope also shows an overshoot increasing the necessary preamble time. On the other hand, when the settling time is faster, baseline wander during long sequences of consecutive identical digits (CIDs) increases resulting in a sensitivity penalty. PRQS15 shows higher penalty than PRQS7 due to the occurrence of longer CIDs in the former. However, in burst-mode operation even in the worst case a settling time within 100ns and with a sensitivity penalty of less than 0.5dB can be achieved by choosing an intermediate setting. The settling times were found to be independent of the contents of the preamble, either PRQS or binary. This means a single PRQS sequence can be used for both the BMRx adjustment and the successive EDC training, simplifying system design.

The receiver BER is then measured in B2B comparing continuous mode and burst-mode operation (Fig. 2b). The maximum DR when no equalization schemes are employed is 12.8dB, determined by −11.5dBm sensitivity on one side and by the receiver overload of +1.3dBm on the other, for a pre-FEC BER of 10^{-3} (Fig. 2b). It should be noted that the variable gain stage of the burst-mode TIA is not active for these measurements and over 20dB dynamic range is expected when fully implemented with an improvement in the overload power. The use of an FFE extends the DR up to 15.6dB while still operating below pre-FEC threshold. Operation in burst-mode without FFE using a 160ns long preamble does not add a penalty compared to continuous mode, meaning there is no waveform distortion caused by the neighboring bursts even for high power mismatch. When the FFE is used a 0.5dB penalty is observed for the soft-packet due to the fact that the higher power loud-packet is now driving the amplifier in saturation.

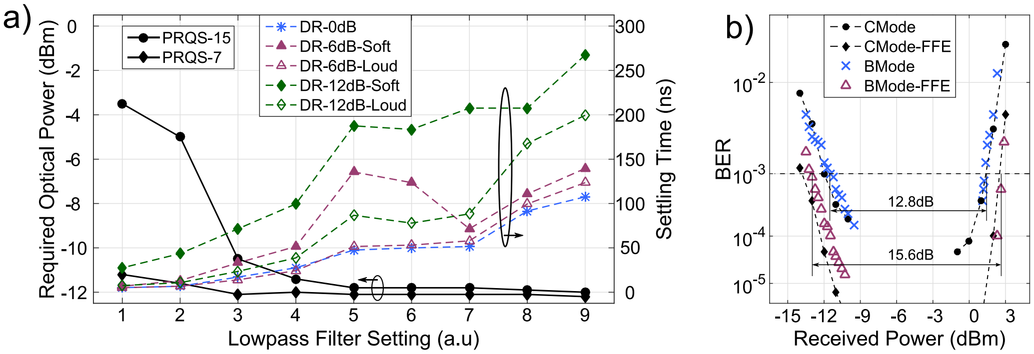

Fig. 2: a) Settling time and sensitivity penalty for different low pass filter settings of the BMRx. b) BER performance in B2B in continuous mode and burst-mode with maximum DR of 15.5dB when an FFE is used.

The BM-TIA is then used as part of an optically pre-amplified OLT receiver as in Fig. 1. Continuous mode and burst-mode operation are compared and no performance degradation is observed up to the maximum loud/soft ratio supported. The measurements in Fig. 3 are obtained in burst-mode where the loud-packet power is fixed at the BER 10^{-3} overload threshold and the soft-packet power is reduced thereby increasing the DR. In B2B the soft-packet sensitivity observed at the input of the pre-amplified receiver is −24dBm, or −25.5dBm with the use of FFE, and the overload input powers are −11.6dBm and −10.8dBm respectively, resulting in supported DRs of 12.4dB and 14.7dB. The allowable DR is reduced by 0.9dB compared to the one observed for the receiver on its own because of the OSNR degradation introduced by the EDFA at low input power. The lowest soft-packet power at the OLT interface of −25.5dBm translates to a maximum 34.5dB power budget when considering a launched power of +9dBm at the ONU [8]. The system is then tested with 25km of SSMF which makes it necessary to compensate for CD in order to obtain a BER below 10^{-3} for any input power. The loud-packet overload power is measured to be −10.7dBm, similar to the B2B case, while the soft packet sensitivity is −23.7dBm, showing 1.8dB penalty caused by the not fully compensated CD. The system is hence supporting 13dB DR after 25km of fiber with the use of a 14-taps fractionally spaced FFE. Adaptation of the filter is observed within 500 training symbols corresponding to 40ns, after a 160ns long preamble.

Adaptation capability of the EDC for successive bursts was confirmed by introducing a different amount of CD between the loud and soft packets with the WS. After a 25km long fiber +195ps/nm dispersion was applied to the soft packet, for an equivalent CD of 37.5km of fiber, and either +195ps/nm or −195ps/nm to the loud, emulating respectively 37.5km and 12.5km of SSMF at the operating wavelength for a differential reach of 25km. The loud-packets presents overload powers at BER 10^{-3} of −11.3dBm and −12.3dBm respectively for 37.5km and 12.5km. Power of the loud-packet is then fixed at the receiver overload and BER performance of the soft packets are compared in burst-mode with the same DR (Fig. 3c). No penalty is introduced by the 25km differential reach and the measured sensitivity is here −22.6dBm, having a 2.9dB penalty with respect to the B2B case due to residual CD.

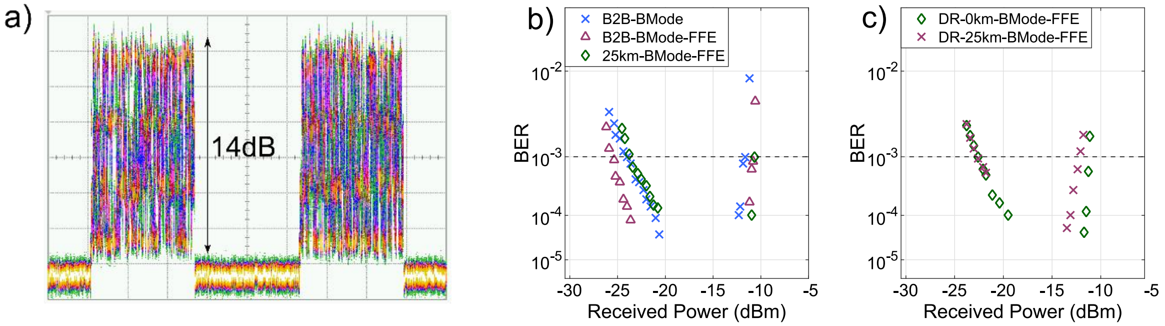

Fig. 3: a) 25Gb/s PAM4 burst-packets with 14dB optical dynamic range. b) BER performance of the pre-amplified receiver in B2B and with 25km of SMF. c) BER for 25km differential chromatic dispersion between loud and soft packets (loud 12.5km, soft 37.5km).

4. Conclusion

We demonstrated burst-mode PAM4 25Gb/s upstream transmission using an optically pre-amplified BM-TIA receiver. The BM-TIA features fast automatic baseline restoration requiring a short preamble of only 100ns, while still allowing AC coupling to the following parts in the receiver chain. No reset signal is required and the technique does not require any specific symbol pattern in the preamble. A sensitivity of −23.7dBm at the OLT and dynamic range up to 14.7dB are demonstrated over 25km of fiber using 10G components and FFE at the receiver. The system in burst-mode is not impaired by optical dynamic range and 25km fiber differential reach between packets.

5. Acknowledgements

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6. References

[1] R. van der Linden et al., “Demonstration of Upstream Flexible 2-/4-PAM Formats for Practical PON Deployments,” Proc. ECOC 2016.

[2] C. Ye et al., “Demonstration and Analysis on PAM-4/8, DB-PAM-2/4 and DMT Formatted TDM-PON with 25Gbps, 40Gbps, 50Gbps Capacity per Lane using Economical 10Gbps Transceivers,” Proc. ECOC 2016.

[3] S. Yin et al., “Investigation of Symmetrical Optical Amplified 40 Gbps PAM-4/Duobinary TDM-PON using 10G Optics and DSP,” Proc. OFC 2016.

[4] J. Wei et al., "Demonstration of the First Real-Time End-to-End 40-Gb/s PAM-4 for Next-Generation Access Applications Using 10-Gb/s Transmitter." Journal of Lightwave Technology, vol. 34, no7, p. 1628-1635 (2016).

[5] M. Dalla Santa et al., “25Gb/s PAM4 Adaptive Receiver Equalisation Requirements for Burst-Mode Transmission Systems,” Proc. ECOC 2016.

[6] J. Wei et al., “40 Gb/s Lane Rate NG-PON using Electrical/Optical Duobinary, PAM-4 and Low Complex Equalizations,” Proc. OFC 2016.

[7] S. Porto et al., "Demonstration of 10 Gbit/s burst-mode transmission using a linear burst-mode receiver and burst-mode electronic equalization," Journal of Optical Communications and Networking, vol. 7, no1, p. A118-A125 (2015).

[8] ITU-T G.989.2, “40-Gigabit-capable passive optical networks 2 (NG-PON2): Physical media dependent (PMD) layer specification,” (2014).