A Novel Line Coding Pair for Fully Passive Long Reach WDM-PONs

M. Presi (1), R. Proietti (1), K. Prince (1,2), G. Contestabile (1), E. Ciaramella (1)
1 : Scuola Superiore Sant'Anna, via Moruzzi, 1 – 56124 – Pisa (ITALY); marco.presi@sssup.it
2 : Department of Photonics Engineering, Technical University of Denmark, DK-2800, Kgs. Lyngby, Denmark

Abstract

A novel line coding pair allows to use unsaturated Reflective-SOAs as upstream remodulator in long-reach WDM-PONs. Full-duplex and symmetric 80 km reach is demonstrated without in-line amplification at 1.25 Gb/s.

Introduction

WDM-PONs are envisioned as a natural evolution of currently deployed TDMA technologies to face the traffic growth in the local access networks [1]. The availability of Reflective SOAs and athermal AWGs opened the way to the deployment of fully passive infrastructures with colourless and amplified ONUs. However, in order to perform full downstream erasure, RSOA should be operated in saturation regime [2], thus introducing power budget issues. At the same time, industry is currently looking to the so called long reach WDM-PONs, which should provide a viable solution to merge local access and metro networks. Usually, the reach extension is achieved by adding in-line amplifiers (also known as extenders) in already installed infrastructures [3]. However, optical amplification would change the passive nature of such networks and increase the operational expenses.

Here we introduce a novel line coding pair that allows for such extension in R-SOA based WDM-PONs without asking for in-line amplification, and infrastructure changes. The proposed line coding pair allows R-SOAs operation far from the saturation regime thus relaxing power losses constraint but still achieving remodulation with full downstream erasure.

Operating Principle

The proposed architecture is shown in Fig. 1: it is a common WDM-PON in which an AWG acts as a remote passive splitter. The downstream signal is coded 50% Inverse-RZ (IRZ), (Fig. 1, inset). Instead of using lower bit-rate NRZ remodulation as in [4], we propose to remodulate the upstream with RZ coding, half-bit interleaved in respect to the incoming IRZ pattern. When the ONU receives a logical "1", a dark pulse, it might suppress the dark pulse tail (if a "0" has to be transmitted) or amplify it (if a "1" must be transmitted); otherwise, if a logical "0" (a CW bit) is received, the R-SOA will carve a pulse by suppressing half of the bit (if a "1" has to be transmitted) or will suppress the whole bit (if a "0" has to be transmitted). All the possible 2-bit combinations are illustrated in inset of Fig. 1. We highlight that this does not require the R-SOA to be saturated, nor does it impose any extinction ratio limitation on the downstream signal, as the remodulation is performed always over the downstream half-bit that contains a constant energy. As the only drawback, the upstream signal must be properly synchronized with the downstream at the ONU; however this should not be a significant issue since a local clock signal is always available at the ONU receiver.

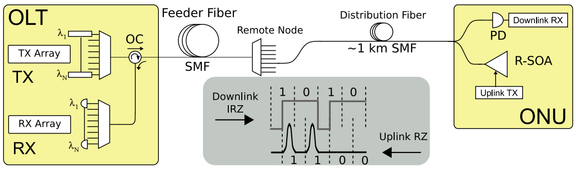

Figure 1: Scheme of the proposed Line Coding Pair and architecture

Experiment and Results

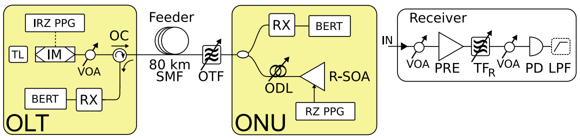

Figure 2: Experimental Setup

The experimental setup is illustrated in Fig. 2. The experimental evaluation was performed at a single wavelength. At the OLT, the downstream IRZ pattern was obtained by externally modulating a DFB laser operating at 1542 nm with a Mach-Zehnder modulator; it was driven by an electrical PRBS (2^7-1 bits long, encoded in an IRZ pattern at 1.25 Gb/s). The OLT transmitter comprised a Variable Optical Attenuator (VOA) used to set power received at the ONU. After passing through an optical circulator (OC), having 1 dB insertion loss (IL), the signal was launched over 80 km of Single Mode Fibre (SMF) of 20 dB total IL. The AWG was emulated by means of a 0.8 nm tunable optical filter (3 dB IL). Although the single wavelength experiment, the filter was needed to reject the ASE noise from the R-SOA. The ONU comprised a 3 dB coupler, a receiver and an R-SOA. The R-SOA was a commercially available device, providing 21 dB of small signal gain at 70 mA bias current, 2 dBm output saturation power, 1 dB polarization dependent gain, 8 dB noise figure and 1.5 GHz modulation bandwidth. The R-SOA was driven with a 7 V peak-to-peak RZ encoded signal (a

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1.25 Gb/s 2^7-1 long PRBS as for the downstream). While in a real deployment the required synchronization between downstream and upstream traffic should be performed by the ONU modem, here, it was obtained by means of an Optical Delay Line (ODL). The ONU receiver was optically pre-amplified (see inset of Fig. 2) by means a double stage Erbium Doped Fiber Amplifier (EDFA). It was followed by an optical tunable filter (0.2 nm FWHM, TF_R in Fig. 2) for ASE noise rejection. BER measurements were carried out by keeping a constant optical power to the photodiode (-6 dBm), which was followed by a post-detection low-pass filter (Bessel, 4th-order, 1.87 GHz bandwidth). The same preamplified receiver was used at the OLT to characterize the upstream performance. In a real environment, an avalanche photodiode (APD) would be preferred, at least at the ONU side.

The PON performance was assessed with BER measurements, reported in Fig. 3. The downstream signal showed about 1.5 dB of power penalty after the 80 km SMF transmission (Fig. 3-a). We attribute this power penalty partially to the lack of a clock recovery circuit at the receiver and chromatic dispersion. Another source of penalty was the Rayleigh scattering generated inside the feeder by the upstream signal: indeed, as the upstream signal was disconnected, the downlink power penalty was reduced by about 0.5 dB. This additional power penalty was observed only when the R-SOA was saturated (i.e. when it was fed with optical power exceeding -15 dBm) thus providing around 0 dBm of remodulated power; The backscattering effect is also apparent in the upper level of eye-diagram (right inset in Fig. 3-a).

The upstream BER performance is reported in Fig. 3—b. The transmission power penalty of the upstream signal is essentially determined by the RSOA seeding power. We report here three cases: -25, -30, and -35 dBm seeding power levels, where the RSOA was operating more than 10 dB below the saturation. The eye-diagrams reported in insets of Fig. 3-b are measured back-to-back at the RSOA output, for -25 (bottom left) and -35 dBm (top right). In both cases, there was a discrete amount of patterning, due mainly to the limited electro-optic modulation bandwidth of the RSOA: indeed, due to RZ coding the signal bandwidth is about twice the electro-optic modulation bandwidth. Despite of this, both the eye diagrams resulted quite open. For -35 dBm seeding power level, the eye- diagram showed additional noise. The upstream transmission power penalty was been found to be 4.5 and 5.5 dB for -25 and -30 dBm seeding power, respectively. In those two cases, the power penalty was mostly due to the Rayleigh back scattering, which limited the Optical Signal to Noise Ratio (OSNR) to 15 dB at the Optical Line Terminal. For RSOA ultralow seeding power levels (lower than -30 dBm) we found a significant degradation performance. Indeed, in these conditions the total R-SOA ASE noise over the OTF bandwidth became not negligible in respect of the remodulated signal power. This out-band ASE noise slightly affected the back-to-back upstream sensitivity (1 dB power penalty for -35 dBm seeding power level with respect to the case of -25 and -30 dBm). On the contrary, the interplay of chromatic dispersion and ASE noise introduced a transmission power penalty of about 7 dB and a tendency to BER floor (white and black circles in Fig. 3-b). However, also in this extreme cases, this impairment might be reduced by using narrower AWGs or lower dispersion feeder fibers.

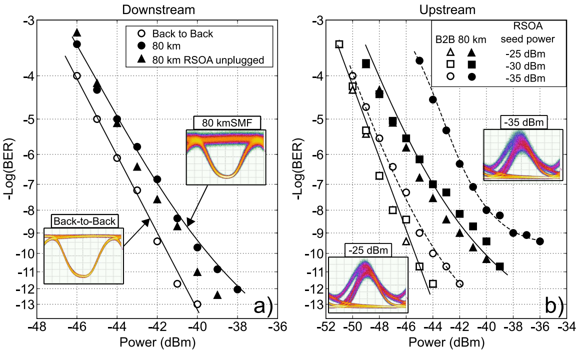

Figure 3 BER measurements for downstream (a) and, upstream (b). Eye diagrams timescale is 100 ps/div

Conclusions

We reported a fully passive 80 km long reach PON based on reflective SOAs which is full-duplex and bidirectional and operated at 1.25 Gb/s. This result extends of about 50 km the reach of R-SOAs based PONs. This result has been achieved by the use of a novel line coding pair, Inverse RZ in downstream and RZ in upstream, which allowed to strongly relax the power constraints in the PON. When using this particular line coding pair, R-SOAs can be unsaturated. In this configuration, system reach is mainly limited by R-SOA noise figure (which imposed a lower limit on the R-SOA seeding power) and gain (which imposed a limit on the upstream launch power). The enhanced power budget might be exploited both to implement long reach PONs (as demonstrated here), or to increase the power splitting ratio in shorter reach hybrid WDM/TDMA PONs.

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