Real-Time 400 Gbit/s PAM-4 Optical Link over 30 km for Future Access Network

Jeremy Potet [1,2], Mathilde Gay [2], Laurent Bramerie [2], Fabienne Saliou [1], Gaël Simon [1], Philippe Chanclou [1], and Monique Thual [2]

[1] Orange, 2 Avenue Pierre Marzin, 22300 Lannion, France
[2] Univ Rennes, CNRS, Institut FOTON-UMR 6082, F-22305 Lannion, France
jeremy.potet@orange.com

Abstract: We experimentally demonstrate a 4λ WDM real-time 100 Gbit/s/λ PAM-4 fiber link supporting 30 km of fiber propagation and 23.5 dB supported channel insertion losses using analog pre-equalization and common semiconductor based optical pre-amplification.© 2022 The Author(s)

1. Introduction

With the commercial deployment of 5G networks and the foreseen of bandwidth hungry application such as metaverse, augmented reality and cloud gaming. The latest research efforts have moved to the preparation of high speed access network supporting optical links for 6G networks with point to point links [1]. The actual standards for intensity modulation and direct detection point to point link provide up to 50 Gbit/s (50 GBaud) per wavelength [2]. But for example, 6G X-haul will require optical interfaces supporting up to several hundred of Gbit/s. Such optical interfaces are already commercially available for data center market, but the specificity of the access networks imposes strong requirements such as high link budget and medium reach transmission (20 km). Due to the number of optical terminations, low complexity optical components are also required. The Institute of Electrical and Electronic Engineer (IEEE) has provided a specification for four wavelengths modulated at 25 Gbit/s optical link, leading to a total bitrate of 100 Gbit/s with 30 km fiber reach [3]. In this specification, the targeted optical budget is equal to 21.5 dB and the channel insertion loss are equal to 15 dB for 30 km and 18 dB for 40 km.

In this paper, we demonstrate a 400 Gbit/s wavelength division multiplexing (WDM) PAM-4 link using low complexity analog 6-tap pre-equalization and a common semiconductor optical amplifier (SOA) at the receiver (Rx) side. We based our experimental setup on the IEEE specifications for 100G-ER4-30 and the multi-source agreements (MSA) 400G-ER4-30 [4]. We use the local access network wavelength division multiplexing (LAN-WDM) grid (1304.6 nm, 1306.9 nm, 1309.1 nm, and 1311 nm). Each wavelength is modulated using 4-levels pulse amplitude modulation (PAM-4) at 50 GBaud, leading to a total bitrate of 400 Gbit/s [5]. We experimentally demonstrate an optical link supporting channel insertion loss of 23.5 dB and 30 km fiber reach, in real time.

2. Experimental setup

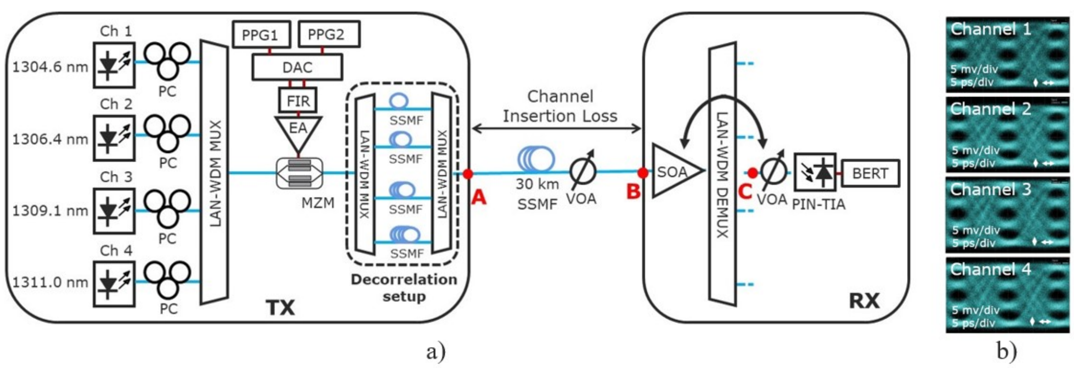
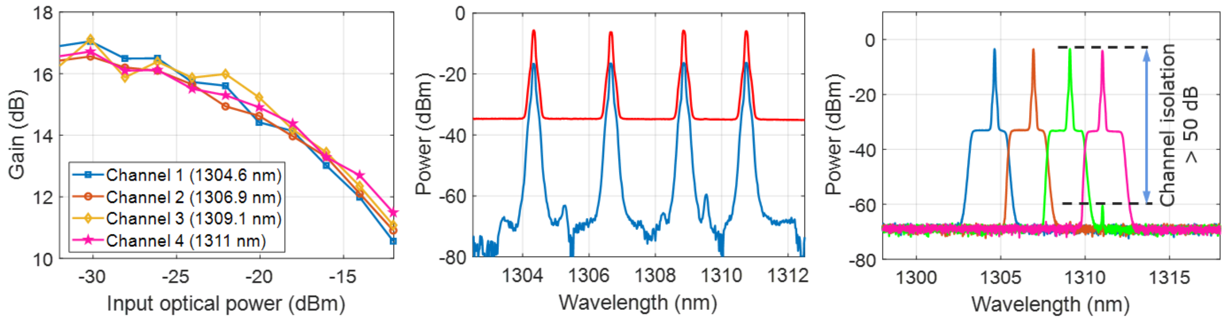


Fig. 1. a) Experimental setup. b) Transmitter eye diagrams.

Fig. 1 a) presents the experimental setup. At the transmitter side, we use four continuous wave (CW) sources (wavelengths as indicated on Fig.1 a). Polarization controllers are used to co-polarize all channels in the main polarization state of the modulator. The optical signals are then multiplexed using a LAN-WDM multiplexer (MUX) and launched to a Mach-Zehnder modulator (MZM) with 40 GHz electro-optical bandwidth (EO-BW). The MZM is driven with a 50 GBaud pseudo random bit sequence of length 15 (PRBS15) 4-levels pulse amplitude modulation (PAM-4) signal. The electrical modulation PAM-4 signal is generated using two 50 Gbit/s non-return to zero (NRZ) signals coming from two pulse pattern generators (PPG) and mixed in a digital-to-analog converter (DAC). The PAM-4 signal is equalized with the help of an analog 6-tap finite impulse response (FIR) filter mainly to compensate for the impairments of the RF chain. The signal is then amplified by an electrical amplifier (EA) before being applied to the MZM. As observed on Fig. 1 b), the optical eye diagrams measured at point A on Fig. 1 for each single channel show a good opening on the 4 channels. As only one MZM was available for our experiment, we first ensured that we do not observe any penalty linked to cross gain modulation in the preamplifier SOA using the decorrelation setup with optical delay lines (ins. Fig. 1 a)). The Rx output power at point A when the four channels are turned ON, is equal to 6.5 dBm. The optical signal is sent through 0 or 30 km of standard single mode fiber (SSMF) and crosses a variable optical attenuator (VOA) which emulates the optical losses of the link. The four channels are then demultiplexed by a LAN-WDM demultiplexer (DEMUX). For the receiver, two options for placing the SOA are explored. One with the SOA placed between the DEMUX and the photodiode (PD) at point C on Fig. 1 a) and one with the SOA in front of the DEMUX at point B. The optical-electrical conversion is performed by a 42 GHz EO-BW PIN PD coupled with an integrated trans-impedance amplifier (TIA). A VOA is placed in front of the PD to work at constant power on the receiver. The electrical signal finally reaches a bit error rate tester (BERT) for bit error rate (BER) calculation.

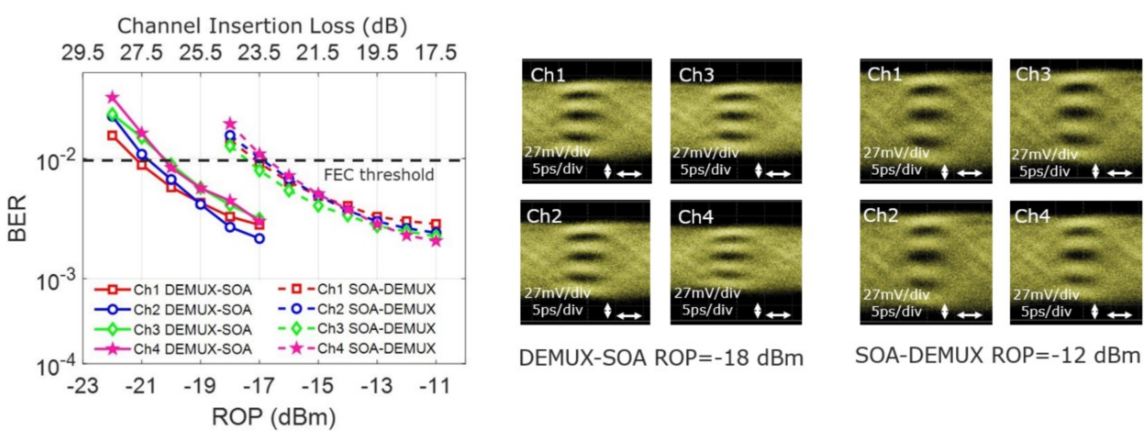
3. Experimental results and discussion



a) b) c)

Fig. 2. a) SOA gain versus input optical power for the four channels. b) Optical spectrum at the input (blue) and at the SOA output (red). c) DEMUX output signal of the four channels.

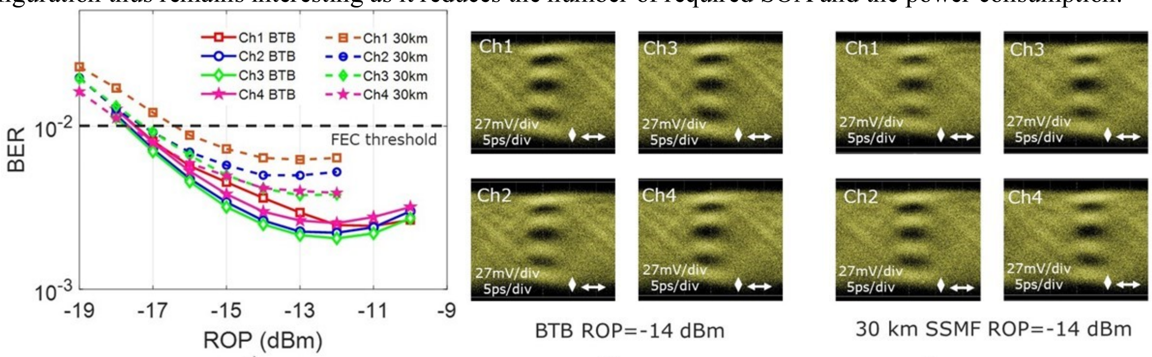
We first assess the behavior of the pre-amplifier SOA in a WDM operation. The low polarization dependent gain SOA has a small signal gain of 16.5 dB for all the four channels of our WDM grid as shown on Fig. 2 a). Fig. 2 b) represents the optical spectrum at the SOA input (blue curve) and output (red curve). The flatness of the WDM grid is better than 0.5 dB and it is preserved after pre-amplification. The optical spectra at the DEMUX output for each of the four channels are presented on Fig. 2 c) showing an adjacent channel isolation ratio higher than 50 dB.



a) b) c)

Fig. 3. a) BER versus average received power in the two configurations: DEMUX-SOA (full curves) and SOA-DEMUX (dash curves). Electrical eye diagram in the two configurations b) and c) at BER = 2.10^{-3}.

We then compared the BER with or without the decorrelation setup and we observed no penalty. These results are not shown in this paper in order not to overload the paper. Consequently, as this transmitter configuration presents extra losses, the decorrelation setup was removed in the following study. We now compare two positions of the pre-amplifier. The first one with the SOA placed after the DEMUX (one SOA per channel) and the 2nd one with a shared SOA in front of the DEMUX (one SOA for all channels). BER measurements as a function of the received optical power (ROP), which is the total power measured at point B, is performed in each case. Fig. 3 a) shows the BER evolution as a function of ROP and channel insertion loss for all channels in both configurations. The sensitivity (at BER=10^{-2} [7]) of the receiver is stacked around -20 dBm in the configuration DEMUX-SOA, and -17 dBm when the SOA is placed before the DEMUX. We observe a receiver sensitivity degradation of 3 dB in the SOA-DEMUX case because of a slight SOA gain saturation and the multi-wavelength amplification which degrades the optical signal-to-noise ratio. The eye diagram (ED) of Fig. 3 b) and c) are measured at the same BER of 2.10^{-3}. Although the power on the PD is the same (-9 dBm), in the case of SOA-DEMUX, the ED presents more peak to peak amplitude which confirms the signal degradation in this case. Despite this degradation, the targeted channel insertion loss of 15 dB is still reached with a single SOA placed in front of the DEMUX and with a Tx launched power of 6.5 dBm. This configuration thus remains interesting as it reduces the number of required SOA and the power consumption.



a) b) c)

Fig. 4. a) BER versus average received power for the 4 channels in back-to-back (full curves) and after 30 km SSMF propagation (dash curves). Electrical eye diagram at ROP of-14 dBm b) in BTB and c) after 30 km.

We finally assess the link transmission performance with the SOA placed before the DEMUX. We insert 30 km of SSMF between the Tx and the Rx. The BER measurement is reported on Fig. 4 a) showing a small degradation of the sensitivity of the receiver (about 1dB for the worst channel) and of the error floor after 30 km transmission compared to the BTB. This is mainly due to the impact of the chromatic dispersion (CD) as we observe a larger degradation on channels presenting more CD. The dispersion of our SSMF is indeed null at 1314 nm, and Channel 4 presents the lower cumulated CD with no penalty. We can also observe a slight degradation of the crossing point after propagation on ED of Fig. 4 c) probably owing from an inter-symbol interference.

4. Conclusion

We have experimentally demonstrated a real time WDM 400 Gbit/s PAM-4 link using four wavelengths on the local access network-wavelength division multiplexing grid. A sensitivity better than -17 dBm is achieved using a PIN photodiode and a shared SOA preamplifier in front of the demultiplexer. Only low complexity analog equalization is used at transmitter side. We reached 23.5 dB of channel insertion loss and 30 km on all the O-band channels.

5. Acknowledgment

We would like to thank *EXFO Optics* for the loan of the LAN-WDM sources.

6. References

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