Bidirectional 100G-PAM4 transceiver for 60-km O-band transmission

Fabio Bottoni[1], Alessandro Cavaciuti[1], Dirk Lutz[2]

[1] *Cisco Photonics, via Santa Maria Molgora 48/C, 20871 Vimercate (MB), Italy*
[2] *Eoptolink Technology Inc., Ltd., 127 West Wulian Street, Chengdu, 610213, China*
[*] *fbottoni@cisco.com*

Abstract: We experimentally demonstrate a real-time 100G PAM4 bidirectional optical transceiver suitable for 60km links (ER+). The transceiver design is based on a O-Band EML, commercial DSP and do not use any kind of optical amplifiers.

1. Introduction

Optical transceivers are the basic component of 5G fronthaul, midhaul and backhaul. In 5G terminology, fronthaul is the link between the Remote Unit (RU) and the Distribution Unit (DU), midhaul is the link between DU and the Central Unit (CU) and backhaul is the link connecting the CU to the core network.

Optical transceivers used in the fronthaul segment typically have specific requirements in terms of extended or industrial temperature ranges (i.e. -40/85 °C) and are often produced as bidirectional (BiDi) modules to minimize fiber usage. While currently 10G/25G optics dominate the fronthaul transceivers shipment, 50G/100G optics are expected to grow significantly in the near future [1].

Both IEEE and ITU completed BiDi Point-to-Point (PtP) specifications in the previous years. More specifically IEEE 8023.cp specified 10G / 25G / 50G rates for 10km / 20km / 40km distances while ITU Q2/SG15 specified 10G / 25G / 50G rates for 20km / 40km distances.

As a next step, the 100G-BiDi standardization is currently being discussed by both the IEEE (802.3dk) and the ITU-T (G.9806Am3). Within the IEEE, specifications for distances shorter than 20 km are discussed based on a single wavelength channel approach (@ 1304.58 / 1309.14 nm $\pm$ 1nm). On the other hand, for the 40km specification, the feasibility of a single wavelength channel is still under investigation.

Recently, several 100G O-band links suitable for the access networks have been demonstrated [2–4]. In [2] a 60km $100G/\lambda$ transmission was demonstrated at 1306.7 nm, in [3] a 20km link at 1310.5 nm with 34dB power budget was presented for passive optical network (PON) scenarios and finally in [4] a $100G/\lambda$ signal at 1298.5nm was successfully transmitted over 80km. In all the previous cases an SOA (semiconductor optical amplifier) has been used and no Bidirectional functionalities has been proved.

In this paper we present a bidirectional 100G PAM4 optical transceiver not employing any kind of optical amplifiers, neither O-band SOAs nor doped fiber optical amplifiers (e.g. praseodymium-doped fiber amplifiers) and leveraging on a DSP (digital signal processing) suitable for a realistic 100G BiDi PtP scenario. To the best of our knowledge, this is the longest reach reported for 100G bidirectional link with a realtime set-up and without using optical amplification.

2. Experimental setup

Fig. 1 shows the experimental setup. We used a 100G transceiver with the following characteristics:

- Tx: Externally Modulated Lasers (EMLs) @ 1304.58 nm upstream (US) / 1309.14 nm downstream (DS)
- Rx: Ge/Si Avalanche PhotoDiode (APD)
- Optical Interface: 1x53.125 GBaud PAM4
- DSP: commercial off the shelf PAM4 DSP, 24-tap FFE (Feed-Forward Equalizer)

The 100G BiDi module is equipped with on-chip PRBS generation and error detector capabilities, as per CMIS (Common Management Interface Specification) [5] and each optical lane was encoded with a SSPRQ (Short Stress Pattern Random Quaternary) pattern for the TDECQ measurement and with the PRBS31Q for the BER test. SSPRQ pattern has been specifically proposed for TDECQ measurement because shows similar statistical

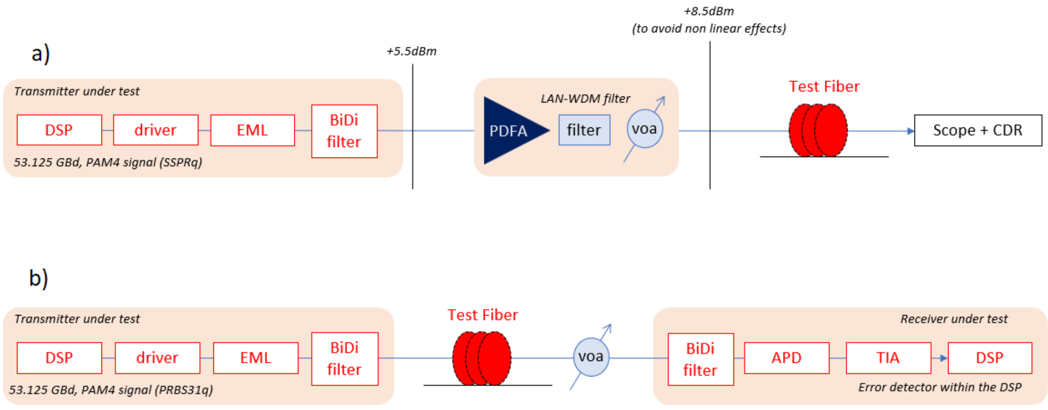

Fig. 1. a) setup used to acquire TDECQ measurements. b) setup to acquire BER measurements. DSP: digital signal processing, EML: external modulated laser, VOA: variable optical attenuator, CDR: Clock and Data recovery, TDECQ: Transmitter and Dispersion Eye Closure Quaternary, TECQ: Transmitter Eye Closure Quaternary

properties as PRBS31Q but is short enough to allow pattern lock on sampling scope (less than 2^{16} symbols), and practical to implement in Serdes. The average transmitted optical power for both downstream/upstream channels was around +5.5 dBm.

For the TDECQ measurement, the optical lane under test was amplified a PDFA, filtered by a LAN-WDM optical filter to suppress the ASE (amplified spontaneous emission) noise outside of the wavelength under test and attenuated by a VOA (variable optical attenuator) t0 +8.5dBm; up to this power level, non linear effects has not been reported. The amplified signal was then transmitted along 40km and 60km G.652 fiber spools: where the 40km shows 4ps/nm @1304.5nm and 25ps/nm @1309.1nm and the 60km spool exhibits 7ps/nm @1304.5nm and 28ps/nm @1309.1nm. Insertion loss of the spools was 15dB and 19dB, respectively. The signal output from the spool was fed into the CDR (Clock Data Recovery) and finally into the scope, where the TDECQ was calculated according to the IEEE 802.3bs standard [6].

For the BER measurement (Fig. 1b), the setup is similar, with the following differences: no PDFA has been used before the test fiber, and instead of the CDR/scope chain, a counterpart BiDi receiver has been used (to evaluate two scenarios, DS Tx vs. US Rx and US Tx vs. DS Rx).

3. Results

Finally we evaluated the 100G PAM4 transmission in terms of TDECQ (Fig. 2) and BER (Fig. 3) results.

Transmitter dispersion and eye closure for PAM4 (TDECQ) is the optical power penalty of the measured optical transmitter compared to an ideal transmitter. More specifically TDECQ (measured with the fiber under test) takes into account the noise introduced by both the non-ideal transmitter and by the fiber propagation, while TECQ (measured BtB, without the fiber spool in the middle) considers only the transmitter non-idealities. TDECQ-TECQ represents the fiber propagation penalty in dB.

Fig. 2 shows the TDECQ versus the chromatic dispersion (ps/nm). At the bottom of Fig. 2 the TDECQ (left) and TDECQ-TECQ (right) values vs can be observed. Different chromatic dispersion (CD) values has been obtained by using different G.652 spools available in the lab and two samples for each wavelengths have been used: "$DS_{01/02}$" for the downstream (1309.1nm) and "$US_{01/02}$" for the upstream (1304.5nm). As mentioned before the 60km spool exhibits 7ps/nm @1304.5nm and 28ps/nm @1309.1nm; while the 40km shows 4ps/nm @1304.5nm and 25ps/nm @1309.1nm. At those CD values both TDECQ and TECQ are well below the pass/fail criteria.

At the top of Fig. 2, the TDECQ equalized eyes are shown; namely a) and b) represent the eyes after 60km for the "$DS_{01/02}$" transmitters while c) and d) represent the eyes after 60km for the "$US_{01/02}$" transmitters.

Then we measured the BER vs the received optical power (Fig. 3), in three scenarios: BtB, 40km and 60km. On the left and right side are respectively shown the performance at 1309.1nm and 1304.5nm.

For the 60 km transmission @ 1309.1nm (left side), the receiver sensitivity was -14.2 dBm, which was calculated when BER was at the KP4-FEC limit of 2.4×10^{-4}. The power penalty for 60 km transmission against the BtB condition was around 0.8 dB. For the 60 km transmission @ 1304.5nm (right side), the receiver sensitivity was -15.2 dBm and the power penalty for 60 km transmission against the BtB condition was negligible. This was probably caused by the negative chromatic dispersion of the SMF and the positive chirp parameters of the EML.

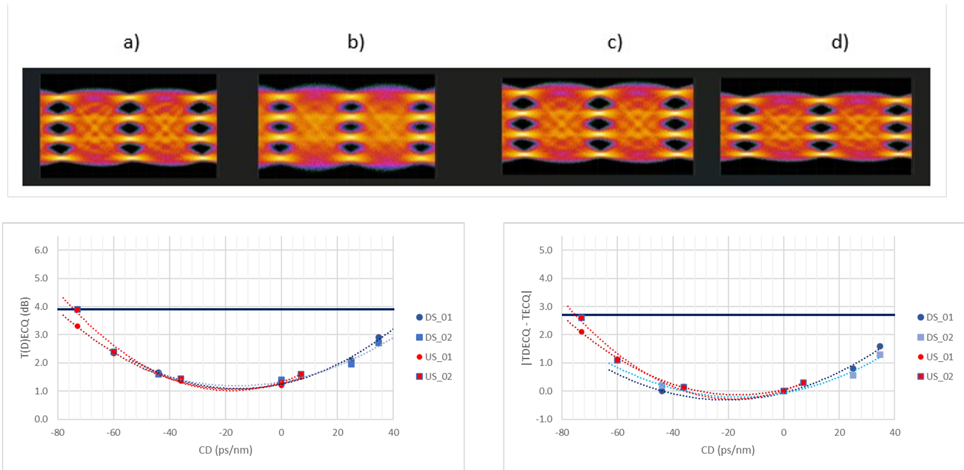

Fig. 2. TDECQ (left) and TDCEQ-TECQ (right) measurements along with the eyes (top). a) and b): eyes after 60km for the "$DS_{01/02}$" transmitters. c) and d): eyes after 60km for the "$US_{01/02}$" transmitters.

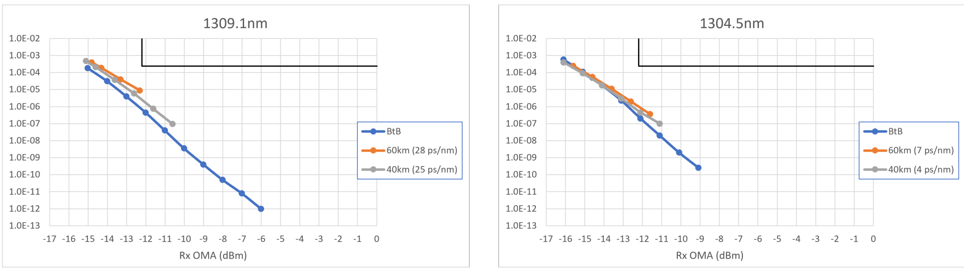

Fig. 3. Sample figure with preferred style for labeling parts.

In addition, it is important to understand that the transmission distance for this condition is limited by the optical loss of the SMF, and not by the chromatic dispersion.

The BER and sensitivity pass/fail levels shown in Fig. 3 are taken from the 100G-Lambda (ER1-40) MSA specifications [7].

4. Conclusions

We demonstrated a real-time 100G PAM4 bidirectional optical transceiver suitable for 60km links (ER+). The transceiver uses simple O-Band components, low-complexity real-time 24-tap T-spaced FFE at the Rx and do not require any optical amplification. At a KP4-FEC limit of 10^{-4}, we achieved 60km sensitivities close to -14 dBm at 1309.1nm and around -15 dBm at 1309.1nm. To the best of our knowledge, this is the longest reach reported for a bidirectional 100G link with a real-time setup and without optical amplification.

These results show a simple approach to realizing 100G bidirectional access links for the PtP applications being discussed in IEEE and ITU-T standardization bodies.

References

1. Lightcounting, "Optical Communications Market Forecast" (April 2023), https://www.lightcounting.com.
2. T. Shindo et al., "106 Gbit/s PAM4 60-km fibre-amplifierless transmission using SOA assisted extended reach EML (AXEL) with average output power of over 9 dBm" , in *European Conference on Optical Communication (ECOC 2019)*.
3. T. Shindo et al., "Real-Time 100Gb/s Downstream PAM4 PON Link with 34 dB Power Budget" , in *European Conference on Optical Communication (ECOC 2022)*.
4. T. Shindo et al., "100-Gbit/s PAM-4 signal transmission over 80-km SSMF based on an 18-GHz EML at O-band" , in *Optical Fiber Communication Conference (OFC 2020)*.
5. CMIS specification http://www.qsfp-dd.com/specification/.
6. IEEE Std 802.3bs-2017, https://standards.ieee.org/ieee/802.3bs/6748/.
7. 100G Lambda MSA, https://https://100glambda.com/specifications.