50Gb/s Real-Time Transmissions with Upstream Burst-Mode for 50G-PON using a Common SOA Pre-amplifier/Booster at the OLT

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Abstract: We perform real-time 50Gb/s transmission targeting the HS-PON standard. An SOA shared at OLT enables 30dB optical budget and 50km upstream burst-mode transmission. The SOA's XGM impact from upstream to downstream is studied. © 2022 The Author(s)

1. Introduction

Fiber access systems utilizing passive optical network (PON) technologies have been widely deployed worldwide to meet the demand for reliable, high-bandwidth broadband services. From 2021, it is expected that the number of shipped PON ports at 10Gb/s will overtake those of GPON (Gigabit PON). As we enter the 10 Gigabit PON era, the research and standards communities have been considering what should come next in PONs. In the ITU-T, this is manifested as the Higher-Speed PON (HSP) [1] project focused on defining PON systems with a line-rate of 50Gb/s. Recently, the ITU-T completed the first HSP recommendations (G.9804.x Series) i.e. the 50G-PON which is a single wavelength channel per direction TDMA PON (time-division multiple access). In the first published version of this standard, the downstream (DS) rate is 50Gb/s and there are two upstream (US) rates specified – 12.5Gb/s and 25Gb/s. It is planned to address a 50Gb/s US rate in a future amendment.

So far, there is no clear consensus in the ITU on how the 50Gb/s US rate channel should be implemented. 50Gb/s in US is expected to tighten the cost constraints on the components. To some extent, the optimal technical solution and associated cost will need to consider the primary applications for ONUs with 50Gb/s US capability. In some applications, the balance of tolerable OLT and ONU costs may permit higher complexity in ONUs to facilitate this capability. Furthermore, the technically achievable link budget considering the use of practical components is another key study topic. To date, there have been papers addressing aspects of the 25Gb/s burst-mode US channel [2-4]. There has also been a partial study on the 50Gb/s burst-mode US channel for HSP [5].

In this paper we focus on a first real-time demonstration of the 50Gb/s burst-mode US channel for HSP. To realize this, we employ a shared Semiconductor Optical Amplifier (SOA) at the OLT for the downstream (booster) and upstream (pre-amplifier) as in [6], without the use of an electrical domain equalization. We employ Externally Modulated Laser (EML) based transmitters in both the US and DS with SOAs used to boost the power. A link budget of more than 29dB (beyond N1 class [1]) is demonstrated for the 50Gb/s US channel at 1308nm with 50km standard fiber (G.652). To our knowledge, this is the first real-time experimental demonstration of the 50Gb/s US channel for 50G-PON.

2. Experimental setup: real-time 50Gb/s upstream burst-mode and 50Gb/s downstream

The experimental setup emulating a real-time bidirectional 50Gb/s transmission for 50G-PON is presented on Fig. 1. In the US, we use an EML based on a single chip Distributed Feedback Laser emitting at 1308nm (50G-PON US option 2 standard wavelength), integrated with an Electro-Absorption Modulator (DFB-EAM) with 25GHz bandwidth at -3dB, previously used in [7]. The burst mode optical signal is created by applying a bias current to the laser during 18.5µs every 125µs. The EAM section of the chip is modulated by a 2.6Vpp 2^{31}-1 Pseudo Random Binary Sequence (PRBS) burst mode data sequence synchronized with the laser electrical signal. The EAM reverse bias was set to 1.2V. The ONU US optical power reaches +12dBm, thanks to a low Polarization Dependence Gain (PDG) SOA used as booster, SOA1 on Fig. 1. An isolator protects the EML from potential Amplified Spontaneous

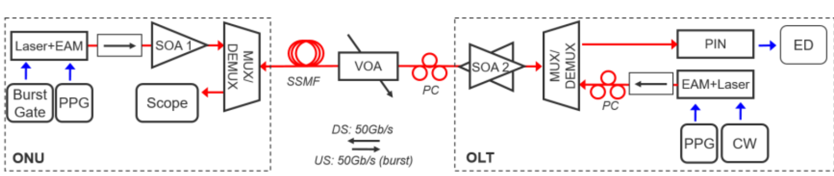

Fig. 1. Experimental setup

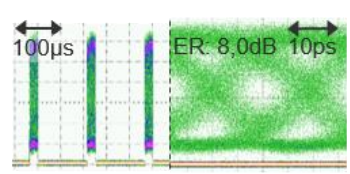

Fig. 2. Optical upstream burst at SOA1 output. *µs* scale (left) and *ps* scale (right)

Emission (ASE) back-propagation. The resulting optical burst, showing 8.0dB extinction ratio (ER), is depicted in Fig. 2. The 19nm width filter for MUX/DMUX on Fig. 1 is used to insert the optical burst in a spool of Standard Single Mode Fiber (SSMF) and a Variable Optical Attenuator (VOA). A second SOA, SOA2 in Fig. 1, is used as an US preamplifier shared at the OLT between the US and DS. We operate SOA2 at 200 mA to obtain a small signal gain of ~ 18 dB @ 1310 nm and the gain is optimized by the use of a Polarization Controller (PC). After a second MUX/DMUX, which separates the US and DS signals at OLT side, the US optical bursts are sent to a PIN receiver (bandwidth: DC-30GHz) and the Bit Error Ratio (BER) is measured with an Error detector (ED) synchronized with the emission part (clock and burst gate).

In the DS, another single-chip DFB-EAM with 35 GHz bandwidth is used to generate a continuous optical signal at 1341nm (50G-PON DS standard wavelength) at the same time as the US. The laser is biased at 50mA, and the electrical signal applied to the EAM is set to 2.0Vpp with a reverse bias of 1.0V and a 2^{31}-1 PRBS. As previously stated, SOA2 boosts also the DS signal, providing a gain of ~ 13 dB @ 1341 nm. An isolator protects the DS emitter from ASE back-propagation. A PC optimizes the SOA2 DS gain, and OADM2 manages the DS/US multiplexing. The resulting continuous DS signal reaches up to +11dBm at the SOA2 output. It is injected in the VOA and the SSMF, before being demultiplexed and detected by a scope.

3. Results and discussions

We first evaluate the US performance while the DS is disconnected. The results are determined at BER=10^{-2} (50G-PON FEC threshold), and the burst power is the mean power for the burst duration (independent from duty cycle), unless specifically mentioned otherwise. Fig. 3 shows the Optical Budget (OB) performance in back-to-back (blue dashed curve), with 25km (yellow dotted) and 50km of SSMF (purple). The sensitivity in BtB was measured to be -19.8dBm, giving 30.8dB optical budget in US, with a dynamic OB range wider than 15dB. The corresponding electrical eye diagram (see Fig. 4 top) shows an extinction ratio of 5.1dB. The detected electrical burst is also depicted in Fig. 4.

As the Chromatic dispersion (CD) is low at the working wavelength, the transmission did not suffered from major penalties when inserting SSMF. The absence of Clock Data Recovery (CDR) to manage the phase variations introduced uncertainties in the BER measurements, explaining error floors on the 50km curve of Fig. 3. Still, we showed 29.0dB and 30.1dB OB with 25km and 50km, respectively.

In order to assess the impact on US transmission of an SOA shared among DS and US, we then inserted the DS signal previously described. We varied the SOA2 input power to get different SOA2 (OLT) output configurations, since we expect Cross-Gain Modulation (XGM) to impair the transmission. The results, presented in Fig. 5, showed a 2.0dB penalty between the case without DS (blue dashed curve) and with a DS output power of 11.5dBm, 9.7dBm and 6dBm (green, light blue, and red curves on Fig. 5., respectively). These power levels covered the range of the standardized 50G-PON DS output power at OLT side. The 15dB OB dynamic range was achieved in all cases. We also demonstrated the US performance with an SOA2 output power of 6dBm and 25km (orange solid line on Fig. 5).

Finally, we analyzed the impact of XGM induced between US burst mode and DS at SOA2 (OLT-side shared SOA). When an US burst reaches SOA2, the SOA gain is temporarily shared among US and DS, before being fully dedicated to DS when no burst is received. It then imprints the burst envelope to the DS signal, by decreasing the SOA2 gain on the DS output power for the US burst duration (for 18.5µs every 125µs here). This effect is observable in Fig. 6, which represents the received 50Gb/s DS optical signal at ONU side. The corresponding DS eye diagram is presented in Fig. 7: the bottom eye, less visible because of the short burst duration compared to the

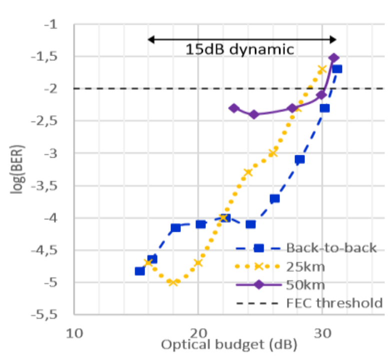

Fig. 3. Upstream optical budget vs. BER at 50Gb/s mode burst for BtB, 25km and 50km (downstream off).

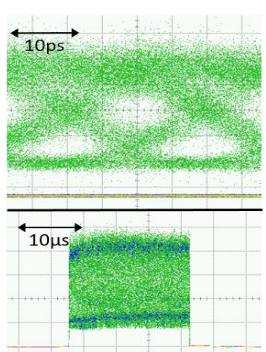

Fig. 4. Upstream received electrical signals (PIN output). Top: eye diagram (electrical ER: 5.1dB). Bottom: 18.5µs burst

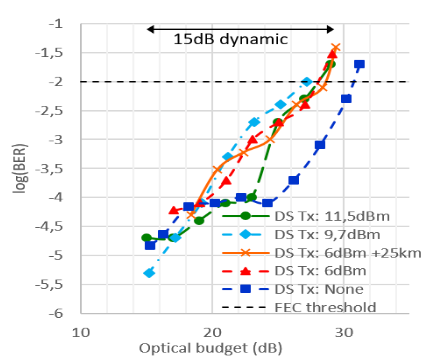

Fig. 5. Upstream optical budget vs. BER at 50Gb/s mode burst for several downstream configurations (11.5dBm, 9.7dBm and 6dBm at SOA2 DS output)

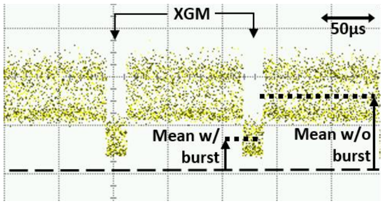

Fig. 6. Received downstream signal subject to strong US/DS XGM

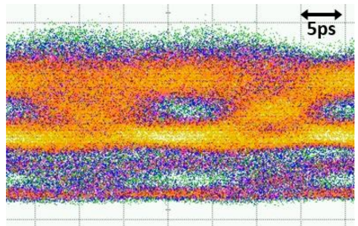

Fig. 7. Eye diagram of downstream signal subject to strong US/DS XGM

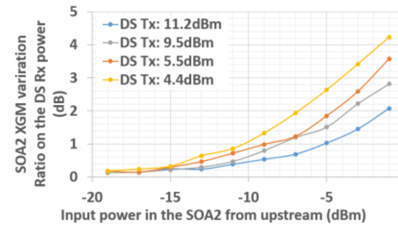

Fig. 8. XGM variation ratio on DS signal, depending on mean US burst input and DS SOA2 optical output

repeat cycle, corresponds to the DS signal generated when the burst arrives at SOA2, while the top eye corresponds to the DS signal for the remaining part of the cycle. We analyze the phenomenon by measuring the ratio between the mean DS received power when the gain is shared or not among US and DS (see marks in Fig. 6). This was done for different DS output powers, depending on the SOA2 US input power (the US power reaching the OLT), and we present the results in Fig. 8. First, it can be observed that the ratio increases with the US input power, eventually reaching 4.2dB when the US power at SOA2 is -1dBm and the DS output power is 4dBm. Secondly, the ratio increases when the DS output power decreases: it is assumed that the DS requires less gain in less saturated configuration, thus leaving more gain to the US, and thus intensifying the XGM phenomenon.

The XGM challenges the use of a SOA shared among US and DS in 50G-PON. According to the current specifications, the ONU output power should be between 4dBm and 9dBm for N1 class, depending on the US bitrate, while the OLT DS launch power (SOA2 output) should remain between 5.5dBm and 11dBm. Considering the worst case, i.e. the highest US output power (9dBm), a 1:32 topology (15dB losses, neglecting the insertion losses), and considering a short reach (no fiber losses), the OLT US received power at shared SOA could be as high as -6dBm. According to Fig. 8 results, the XGM ratio would be as high as 1.5dB in the 1:32 topology worst case. A 1:64 topology (with 3dB losses more) would lead to 1dB XGM ratio also in the worst case. Now, considering a more plausible case, when the SOA2 received power (OLT received power) is as low as -15dBm or below, the XGM ratio is reduced below 0.3dB (~7%) and considered negligible. A way to mitigate the XGM could be to improve the detectors' sensitivity, using for example uni-travelling carrier receivers [8], to relax the ONU transmitted power constraints.

4. Conclusions

We demonstrated, to the best of our knowledge, the first real-time bidirectional 50Gb/s transmission for HS-PON applications, without the use of digital signal processing (equalizer-free), but with a shared upstream/downstream SOA at OLT side. The upstream alone burst mode transmission showed more than 30dB optical budget with 15dB dynamic range, and up to 50km transmission. The downstream affected the upstream performance by introducing up to 2dB penalty due to the shared SOA, while the upstream still achieved 25km transmission with an optical budget matching N1 class requirements. We also showed that the upstream burst affects the downstream signal because of XGM in the shared SOA. The resulting modulation ratio was measured to be as high as 1.5dB in the worst case, but below 0.3dB in a more realistic case. High sensitivity receivers could mitigate the XGM in relaxing the transmitted power constraints.

5. Acknowledgments

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