The Impact of Transmitter Chirp Parameter on the Power Penalty and Design of 50 Gbit/s TDM-PON

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Abstract: We study the impact of transmitter chirp parameter (effective α-factor) on the chromatic-dispersion-induced power penalty in 50-Gbit/s TDM-PON. We experimentally show interplay of chirp and dispersion using 50G-class integrated EML-SOA driven in distinct operating points.

1. The chirp challenges of 50 Gbit/s TDM-PON transmitters

Transmitter (Tx) chirp is an important parameter that determines the power penalty (PP) observable after signal propagation over a dispersive fiber. In ITU-T G.hsp discussions about the wavelength plan for the 50 Gbit/s TDM-PON (time-division-multiplexed passive optical network) are ongoing. Like IEEE 802.3ca, O-band operation is considered, and the wavelength bands of 1260-1280 nm and 1290-1310 nm are of interest for the upstream (US) operation, while (1342±2) nm is adopted for downstream (DS) operation [1]. The increase in TDM-PON line rate demands for high Tx output power, e.g., around +8 dBm…+10 dBm, to enable a 29-dB optical power budget class [2]. Such output power requirements favor the use of electro-absorption-modulated laser (EML) augmented with a semiconductor optical amplifier (SOA) as a Tx source [3]. Here, the EML-SOA must be designed and operated that its effective (accumulated) chirp allows for a reasonable dispersion penalty for fiber transmission over distances of up to 20 km.

In this paper, we investigate unanswered research question about the influence of effective EML-SOA chirp parameters on the power penalty of 50 Gbit/s TDM-PON as well as how different the effective chirp parameters must be chosen for the US and the DS directions, respectively. Experimental investigations of an EML-SOA O-band chip-on-carrier support the extensive simulation runs performed in the wavelength region of 1260 nm to 1360 nm considering different fiber dispersion models. It is shown that chirp parameter of an EML-SOA, depending on the wavelength window of operation, should be carefully chosen by design to keep the induced transmission penalty low. Fine-tuning of the designed effective chirp parameter by adjusting operating point of EML-SOA offers an option to mitigate manufacturing uncertainties or enabling slight on-demand chirp adjustment, which may help to avoid sensitivity degradations from Tx extinction ratio (ER) reduction or output power degradations.

2. Chirp parameters of an EML-SOA

The mentioned candidate Tx for 50 Gbit/s TDM-PON is an integrated EML-SOA, where EML is further composed of two sections: a distributed feedback laser (DFB) followed by an electro-absorption modulator (EML) [4]. Each of these sections can potentially introduce adiabatic and/or transient chirp to the transmitted signal, and hence result in an elaborate chirp pattern, here described by an effective chirp parameter. The same holds true if wavelength drift under burst-mode operation has to be considered in the US direction. In general, EML-SOA structure possesses multiple degrees of freedom which can be used to change the effective chirp parameter, e.g.: DFB laser current, EAM bias voltage, SOA current, device temperature as well as using manufacturing design rules of detuning DFB emission wavelength from the absorbing material. However, the freedom of device tailoring is limited towards achieving optimized PON system parameters like high output power, high extinction ratio (ER) and good giber transmission properties. It has been observed that in such operating points typically the opposite sign of the chirp parameter for

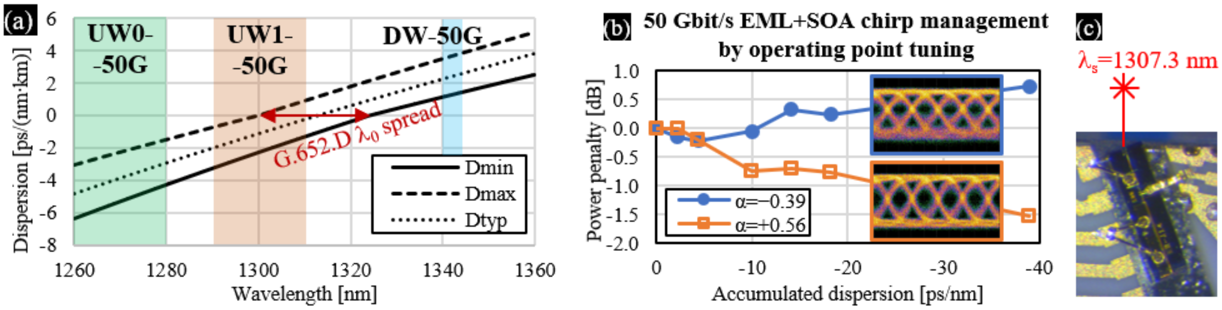

Fig. 1. (a) Provisional 50 Gbit/s TDM-PON wavelength plan overlaid with G.652.D dispersion bounds (D_{min}/D_{max}) and a datasheet fiber dispersion. (b) Experimental power penalty of a chirped 50 Gbit/s signal after transmission in negative dispersion regime. Different chirp was obtained by adjustment of the EML-SOA operating point. (c) Microphotograph of the 50G-class EML-SOA chip.

transient chirp in an SOA compared to the typical EAM chirp parameter allows tailoring of the effective chirp parameter of an EML-SOA [5]. By adapting the SOA bias current and EAM bias points, different effective chirp parameters for an EML-SOA have been reported at 10 Gbit/s reaching from –2 to +2 [3,6]. Performance improvement via chirp management for 25 Gbit/s TDM-PON was also demonstrated in [7]. However, extensive chirp or experimental investigations on 50 Gbit/s EML-SOA integrated chips are not reported for TDM-PON yet. After interaction with fiber dispersion, this effective chirp may lead to signal degradation (pulse spreading) or improvement (pulse compression), depending on the chirp as well as fiber distance. Moreover, a commonly used SMF fiber (specified according to ITU-T G.652.D) may exhibit a large variation of the zero dispersion wavelength (1300–1324 nm) and dispersion slope 0.078–0.092 ps/(nm^2·km), yielding minimum and maximum dispersion parameter bounds, as shown in Fig. 1(a). Thus, the resulting PP in actual operation cannot be exactly determined, however bounds may be established.

3. Experimental demonstration

To show the effect of interaction between positive/negative chirp and fiber dispersion, we use a state-of-the art integrated EML-SOA chip (Fig. 1(c)) from III-V Lab with approximately 30 GHz of electrical bandwidth emitting at λ_s=1307.3 nm. We modulate the EAM section with a 50 Gbit/s non-return-to-zero (NRZ) on-off keyed (OOK) signal. The optical signal is then launched into a multi-span SMF link with lengths up to 51 km, and dispersion parameter of −0.78 ps/(nm·km) at the emission wavelength (corresponding to zero-dispersion wavelength of approximately λ_0=1316 nm). The signal is then attenuated in front of the receiver in order to find reference sensitivity for roughly 10^{-2} bit error ratio, and a corresponding penalty after fiber transmission. The receiver is composed of SOA preamplifier with 15 dB of gain, 2 nm optical amplified spontaneous emission noise filter and a 35 GHz p-i-n photoreceiver including a transimpedance amplifier (TIA).

A small-signal chirp characterization using method described in [8] has been performed for various operating points of the EML-SOA (DML bias current, EML bias voltage, SOA bias current). Two operating points with chirp parameters of opposite signs were chosen: α_1=−0.39 corresponding to EML bias voltage of −1.0 V and α_2=+0.56 (−0.4 V). DML and SOA bias currents were fixed at 100 mA and 30 mA respectively. The resulting dynamic ER for the operating point α_1 was 4 dB, while for α_2 only 2.8 dB. These operating points were chosen as to experimentally demonstrate interaction of the effective chirp with dispersion, and not to optimize the absolute receiver sensitivity. The measured PP as a function of accumulated dispersion is shown in Fig. 1(b), along with back-to-back optical eye diagrams as insets. It can be observed that after negative dispersion of the fiber ($\lambda_s<\lambda_0$), the effective negative chirp parameter leads to degradation of the receiver sensitivity, while an improvement of the signal quality is observed for the positive chirp parameter.

Since in a physical system (our device), multiple parameters are interdependent (e.g., ER varies with EAM bias), we resort to simulations to demonstrate the influence of an effective chirp parameter of the transmitter on a 50 Gbit/s signal transmission in the O-band. However, these interdependencies and their relation to chirp are for further study.

4. Simulation environment

A 50 Gbit/s NRZ-OOK transmission system is modeled in a simulation environment. The extinction ratio of the transmitter is set to 6 dB and the average optical output power is +8 dBm, accounting for system-relevant future EML-SOA performance expectations. Effective chirp parameters ranging −2.0 to +2.0 are tested. The receiver model is based on a 35 GHz Si-Ge avalanche photodiode (APD) with a multiplication gain M=5, followed by a TIA, to account

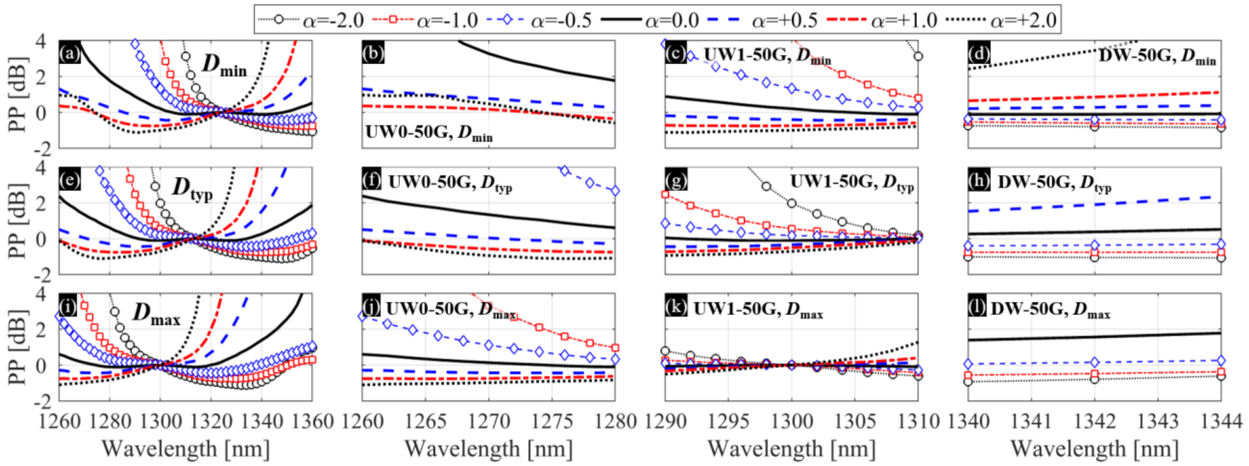

Fig. 2. Power penalty evaluated at a BER threshold of 10^{-2} after 20 km of SMF as a function of wavelength for different effective chirp parameter, and three different dispersion models (rows). Second and further columns show zoom into the figure from the first column, focusing over wavelength ranges corresponding to upstream and downstream windows of a potential 50G TDM-PON wavelength plan.

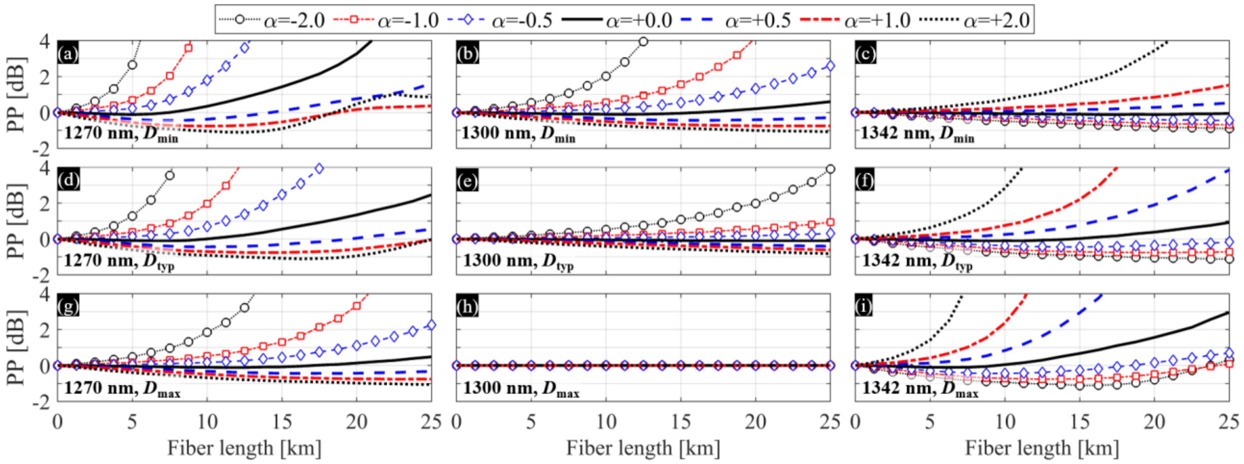

Fig. 3. Power penalty as a function of fiber length for different effective chirp parameter for dispersion model D_{min} (a-c), D_{typ} (d-f), and D_{max} (g-i) and wavelengths corresponding to centers of UW0-50G (a,d,g), UW1-50G (b,e,h) and DW-50G (c,f,i) windows.

for expected future device performance. Neither analog nor digital equalization is applied to the received signal. The bit error ratio (BER) is estimated from χ^2 distribution fitted at the receiver. The effective chirp parameter α describing the resulting transmitter (i.e., EML-SOA) transient chirp, is modeled as a bias-voltage- and time-independent quantity. The output field E_{out} of the transmitter is modeled as $E_{\mathrm{out}} = E_{\mathrm{in}} \cdot \sqrt{V} \cdot \exp\left[\frac{j}{2}\alpha \ln V\right]$, where $V = (1-m) + m \cdot d(t)$, with E_{in} being the input optical field, m the modulation index (related to extinction ratio) and $d(t)$ represents the zero-mean electrical modulation signal normalized to a power of 1, including limited rise and fall times. The chirped 50 Gbit/s NRZ-OOK signals from the transmitter is launched into one span of a single-mode fiber (SMF) with length varying between 0 (back to back) and 25 km in steps of 1.25 km. Three dispersion models are investigated as shown in Fig. 1(a): D_{min}: lower boundary of ITU-T G.652.D dispersion [9] (zero-dispersion wavelength λ_0=1324 nm with dispersion slope S=0.092 ps/(nm^2·km) for $\lambda<\lambda_0$ and S=0.073 ps/(nm^2·km) for $\lambda\geq\lambda_0$); D_{max} – upper boundary (λ_0=1300 nm; S=0.073 ps/(nm^2·km) for $\lambda<\lambda_0$ and S=0.092 ps/(nm^2·km) for $\lambda\geq\lambda_0$) , and a datasheet dispersion link D_{typ}, in between of both extremes (λ_0=1313 nm, S=0.086 ps/(nm^2·km)).

5. Results and discussion

Fig. 2 provides insights into the possible variations of the PP referred to BER of 1.0×10^{-2} across effective chirp parameters at 20 km SMF for investigated dispersion models. In the negative dispersion region (upstream windows), a positive effective transmitter chirp can mitigate the dispersion penalty over 20 km of transmission. Specifically, for UW0-50G, selecting α ≥+0.5 allows to limit the PP to below 2 dB over any G.652.D-compliant fiber. On the other hand, in UW1-50G, α≥0 will allow to limit the penalty in the D_{min} link. This case is supported by our experimental demonstration, where α=−0.39 produced close to 1 dB penalty after 40 ps/(nm·km) of dispersion, while α=+0.56 exhibited negative penalty (improvement). For the DW-50G window, operation with less than 2 dB penalty is ensured for α≤0.

Fig. 3 shows PP as a function of fiber distance for each considered dispersion model (rows) as well as a wavelength corresponding to center of windows UW0-50G, UW1-50G and DW-50G. Obviously, a design target for the effective chirp parameter is to achieve 0 penalty for EML-SOA. Tuning the operating point in the individual US and DS cases towards slightly larger/lower effective chirp parameters could be employed to optimize the transmission performance for a particular case. However, the influence of these operating point adaptations on other system parameters like ER and output power needs further experimental investigations, especially under burst-mode operation.

6. Conclusion

It can be concluded that to meet satisfactory power penalty target, effective chirp parameter needs to be tailored to a specific operating window. By a proper design choice of effective alpha parameter, it is possible to mitigate the PP within UW0-50G, UW1-50G, and DW-50G windows. An alternative approach is to apply chirp management by adjusting operating point of the device to improve transmission properties. This however, may be applied only in a limited set of operating conditions.

7. References

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