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# Input power dynamic range analysis of SOA and EDFA link extenders on TDM–PON systems without burst effect control

Bo-Hun Choi [a,*], Sang Soo Lee [b]

[a] Department of Materials Physics, Dong-A University, Hadan2-dong, Saha-gu, Busan 604-714, South Korea
[b] Optical Internet Research Department, ETRI, Daejeon 305-350, South Korea

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ABSTRACT

SOA and EDFA were compared as an upstream link extender on the bidirectional TDM–PON system for 256 ONUs of 2.5 Gb/s and 50 km transmission. The total power budget of this uplink was 58 dB with an extender gain of 25 dB. As the input power to the extender was changed from −30 dBm to 0 dBm, burst signals with and without preamble bits were compared. This gave quantitative analysis of the signal aggravation that was caused by the burst effect. The comparison experiment showed that the links using SOA and EDFA extenders had input power dynamic ranges of 15 dB and 10 dB respectively from −30 dBm without burst effect control. So, it presents a practical possibility for the usage of link extenders on the extended PON link without burst effect control.



## 1. Introduction

Gigabit optical access networks are accelerating high bandwidth services to end customers. They will play a leading role in the future FTTx networks because their cost effective user-shared facilities accommodate many subscribers per single feeder fiber [1–3]. In these systems to allow time-sharing of the available upstream bandwidth between customers using time division multiple access, the splitting ratio has been recently intensified beyond 128 and the physical reach has been increased significantly from today's usual 20 km to longer than 50 km [4]. The requirement needs large link power budget and gives rise to the use of optical line amplifiers in conventional PON systems as a link extender. So, a single system will serve several hundred optical network units (ONUs) rather than the typical 32 of today's deployed optical access systems. These new types of networks could greatly improve the cost effectiveness of deploying fiber access by integrating metro and optical access networks into a single all-optical system, thus drastically reducing the number of network elements, interfaces, and electro-optical conversions required to serve a given customer base [2].

Several methods that use optical link amplifiers in these PON systems have been suggested by using semiconductor optical amplifiers (SOA) [3], praseodymium-doped fiber amplifiers (PDFA) [5], or erbium-doped fiber amplifiers (EDFA) [6]. One of the major research challenges posed by these next generation PONs is related to the upstream burst power variation that results from the differences in the optical distribution network loss and ONU transmitter output power. The distribution network loss differences arise from the port-to-port non-uniformity of passive optical splitters and the variation in the fiber distance to each subscriber. The differences cause input power variation in the optical amplifiers in PON links and these amplifiers experience gain transients [3]. The effects of gain transients on signal distortion are different according to the optical amplifier types and bursty nature of the TDMA upstream traffic tends to require the use of gain control techniques with these amplifiers. In order to prevent this signal distortion, gain stabilization electrical circuits have been applied to EDFA [2] or SOA [7]. Also gain clamped SOAs that use gain saturation [3,8] or ultra past quantum dot SOAs with a life time of less than 1 ps [9] have been studied. In other words, input power into an EDFA has been electrically controlled to have a constant value [10].

However, it is very clear that the link amplifiers that operate without burst effect control are simpler and can be expected to be less expensive compared to other approaches if the amplifier is feasible [11]. In fact the burst effect can be greatly mitigated when the input power into the amplifier is low enough, but the power level often goes out of this low value in the commercial PON link. So, in order to access the necessity of the burst effect control, it is required to investigate quantitatively the performance aggravation caused by the burst effect. In this paper pulse distortions and power penalties caused by a link extender of SOA or EDFA were analyzed in the suggested bidirectional TDM–PON

* Corresponding author. Tel.: +82 51 200 7223; fax: +82 51 200 7232.
*E-mail address:* adamchoi@dau.ac.kr (B.-H. Choi).

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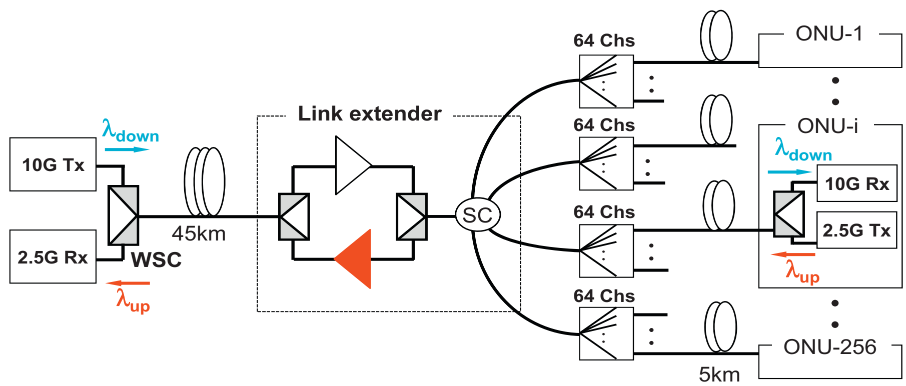


**Fig. 1.** A schematic of the bidirectional TDM–PON system with a link extender. OLT: optical line terminal, ONU: optical network unit, WSC: wavelength selective coupler, and SC: star coupler.

system to support 256 ONUs and 50 km transmission. The influence of the input power variation was investigated and the burst effects at these input powers were accessed using the technique to add preamble bits. Thus, dynamic ranges of input power without the performance aggravation were obtained for both EDFA and SOA as a link extender. This experiment was based on computer simulation due to the hardware experiment limitations such as generating various burst signal bit streams and selecting a part of them on measurement. However, for simulation, practical data that was extracted from our hardware experiment were used [12,13].

## 2. Experiment and result

Fig. 1 shows a schematic of the bidirectional TDM–PON system which is composed of one optical line terminal (OLT), total 50 km single mode fiber (SMF), and 256 optical network units (ONUs) with a link extender of two unidirectional inline amplifiers. Each upstream (US) signal was generated using a 2.5 Gbit/s directly modulated DFB laser with a non-return-to-zero (NRZ) format and duration of 64 bits. Relative intensity noise of the laser was −130 dB/Hz. The signal-on-and-off ratio called as extinction ratio was 30 dB. A laser wavelength of 1270 nm or 1540 nm was used for comparison. After +3 dBm power from an ONU experienced a 5 km transmission and 256 TDM signal multiplexing, the signal was launched into a link extender as −30 dBm power. 25 dB gain was achieved in the extender which used a SOA for 1270 nm input or an EDFA for 1540 nm because these combinations of the amplifier and the wavelength are the most popular in the field. The signal was again transmitted through 45 km SMF which had 9 dB loss at 1550 nm and 18 dB loss at 1270 nm, respectively. The dispersion coefficient of this fiber was 16 ps/nm/km at 1550 nm and dispersion compensation was not used because of the short transmission distance [14]. Nonlinear effects in SMF were considered by using a nonlinear coefficient of $26 \times 10^{-21}$ m$^2$/w and a Rayleigh scattering coefficient of −80 dB. The signal was input to a receiving module in OLT as −25 dBm power after a wavelength selective couple (WSC) which combines and also divides US and downstream (DS) signals. It was converted by a PIN photodiode (PD) and was electrically demultiplexed as each TDM US signal. Finally, its bit error rate (BER) was measured by using a clock recovery and a bit error rate tester (BERT). On the other hand, a DS signal of 1555 nm wavelength was modulated by 10 Gbit/s NRZ format using a Mach–Zehnder modulator. The US signal of +0 dBm after a WSC served as a −10 dBm input to an EDFA link extender of 23 dB gain. After a 1:64 ratio split and 5 km transmission, the signal was launched into each ONU comprising of receiving and

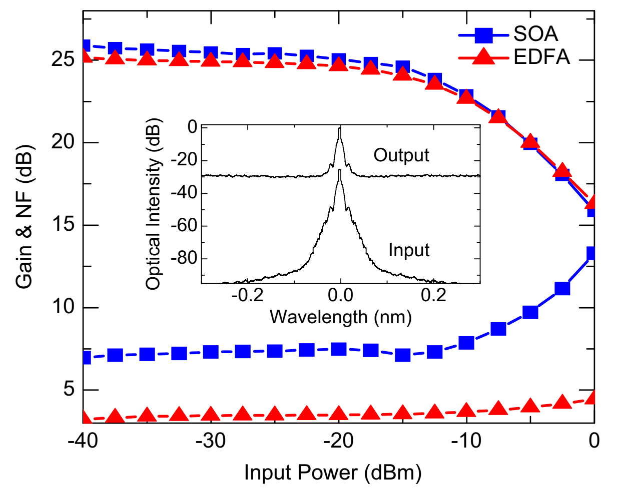


**Fig. 2.** Gains, noise figures, and input and output optical spectra (inset) of SOA and EDFA as a link extender.

transmitting modules. Finally, a signal of −20 dBm was received at a PD in the ONU. The total power budget of this link was approximately 55 dB for the DS direction and 58 dB for the US direction. From our hardware experiment [13], the figures including optical power values at each link point were carefully chosen. In this simulation, 16 calculation points were taken per each data bit. At least 256 bits were simultaneously treated as a time window together with the WDM wavelength bandwidth.

The gain and noise figure (NF) of a SOA and an EDFA used in the link extender are given for comparison in Fig. 2. The SOA chip was designed in the simulation as a bulk structure in which its active region had thickness of 100 nm, width of 2.5 um, length of 350 um, and facet reflectivity of $1 \times 10^{-4}$. The confinement factor is about 0.2. Erbium concentration and the numerical aperture of the EDF in EDFA were $7 \times 10^{24}$ m$^{-3}$ and 0.28 respectively. EDF length and life time of $Er^{3+}$ were chosen as 10 m and 10 ms respectively. Wavelength-dependent cross section values were applied to the EDFA simulation. The EDFA used a forward pumping structure with a 980 nm pump and its pump power was 95 mW. These two amplifiers were designed to have an identical gain of 25 dB for the link budget and the results of Fig. 2 meet the target value in the small signal regions. 2. Input and output optical spectra that are used in the measurement are given in the inset of this figure. Noise figures (NFs) are different for the two amplifiers. NF of the SOA is around 7 dB and this is 3.5 dB worse compared to that of the EDFA, which are conventional and consistent values with hardware experiment.