1G / 10G coexistence long-reach PON system using ALC burst-mode SOAs

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Abstract: This paper evaluates the allowable loss ranges of 1G / 10G dual-rate symmetric long-reach 10 gigabit Ethernet passive optical networks (10G-EPONs) that employ cascaded semiconductor optical amplifiers with fast automatic level controlled circuit (ALC-SOAs) for upstream transmission and a single SOA for downstream transmission. Experiments show that our optical amplifiers have the ability to achieve the maximum loss budget of 61 dB with very wide loss ranges for both access and trunk spans; they support up to 80 km transmission (60 km trunk span and 20 km access span).

Keywords: PON, access system, 1G / 10G coexistence, SOA, ALC

References

1 Introduction

Gigabit Ethernet passive optical networks (G-EPONs) and Gigabit-capable PONs (G-PONs) can provide users with cost-effective Gb/s class broadband services and have been commercialized in several countries. In addition, many papers have intensively investigated the application of optical amplifiers to these PONs to offer PON-based services more effectively [1, 2, 3, 4]. 10G-EPON and XG-PON were standardized in IEEE and ITU-T, respectively, as the most promising candidate for the next generation optical access systems. In response to this movement, some research groups have started to study 10 Gb/s-class long-reach PONs [5, 6, 7]. To achieve smooth migration from 1 Gb/s to 10 Gb/s-class PONs, the specifications pursue the coexistence of both systems on a single optical line terminal (OLT), however, the possibilities of 1G / 10G dual-rate PONs using optical amplifiers are less well-studied [8, 9].

In this paper, we study, for the first time, the feasibility of dual-rate symmetric long-reach 10G-EPONs where different wavelengths are assigned to upstream transmission in G-EPON (1310 nm) and 10G-EPON (1270 nm). Unlike downstream transmission, the losses in upstream transmission are very large due to the wavelength dependence of optical fibers. Moreover, upstream signal amplification must offer a very wide input dynamic range due to the different transmission distances of the optical network units (ONUs). To resolve these issues, we employ cascaded semiconductor optical amplifiers with fast automatic level controlled circuit (ALC-SOAs) for upstream transmission. Downstream signals are amplified by a single SOA. System performances are evaluated from the viewpoint of allowable losses in upstream and downstream transmission.

2 ALC burst-mode SOAs

Fig. 1 (a) shows the configuration of the proposed ALC-SOAs for upstream transmission; it consists of two SOAs, optical filters, and a fast ALC circuit for burst-mode operation. The first SOA boosts the input optical powers to meet the input power ranges of the fast ALC circuit. The optical filters consist of two CWDM filters with center wavelengths of 1270 nm / 1310 nm. The two optical band-pass filters have the flat pass-band of 3 nm, and eliminate the amplified spontaneous emission (ASE) light from the first SOA. The fast ALC circuit proposed in [6] is placed after the optical filters to keep the input optical powers to the second SOA constant regardless of the input powers to the first SOA. The time constant of the ALC circuit is around 50 ns. This function prevents the second SOA from inducing the pattern effect and con-
tributes to the realization of wide input dynamic range. The second SOA is used as a booster amplifier. Fig. 1 (b) and (c) show the gains and the noise figures (NFs) of the first SOA at the wavelengths of 1270 nm and 1310 nm, respectively. The driving current is 400 mA. As shown in the figure, the gains at 1270 nm and 1310 nm are 20.5 dB and 19.5 dB, respectively. The polarization dependent gains (PDGs) and the NFs for both wavelengths are within 0.8 dB and within 7.8 dB, respectively. These figures also show that the 3-dB saturation input powers to the SOA at 1270 nm and 1310 nm are about $-9$ dBm and $-4$ dBm, respectively, which suggests that the output signal qualities at 1270 nm will be degraded more than those at 1310 nm due to the pattern effect in the first SOA.

![Fig. 1. Configuration of ALC-SOAs (a) and gains and NFs of first SOA at 1270 nm (b) and 1310 nm (c).](image)

### 3 Experiments

#### 3.1 Upstream transmission

Fig. 2 (a) shows the experimental setup used to evaluate the allowable loss ranges of upstream transmission. It consists of our ALC-SOAs and a dual-rate 10G-EPON system. Our 10G-EPON system supports the maximum transmission distance of 100 km and the ONU differential transmission range of 20 km. Here, we adjust the transmission distance range from 0 to 20 km. The 10G-EPON OLT supports 1G / 10G dual-rate operation and can also accommodate commercial G-EPON ONUs. The wavelengths from 1G and 10G ONUs are 1313.7 nm and 1275.2 nm, respectively. The receiver sensitivities of the OLT receiver for 1G and 10G signals are $-33.8$ dBm and $-28.0$ dBm, respectively. Here, forward error correction (FEC), RS (255,223), is applied
Fig. 2. Experimental setup to evaluate allowable loss ranges in upstream transmission (a), signal traces for our ALC-SOAs input and output (b), and allowable loss of Link B against that of Link A (c).

to achieve error free operation for 10G signals. The downstream signals are dropped by three WDM filters and an optical splitter to evaluate only upstream transmission. The loss value of access span (Link A) is adjusted by VOA1 and VOA2. The loss value of trunk span (Link B) is also adjusted by VOA3. We measured BERs by varying the loss values of Link A and Link B.

Fig. 2 (b) shows the measured signal traces for the ALC-SOAs input and output. Here, we set the input power of the weak burst signals (10G-ONU) to $-27.0 \text{ dBm}$ and those of the strong burst signals (1G-ONU) to $-10.0 \text{ dBm}$. As shown in the figure, the output burst signal powers of 10G-ONU and 1G-ONU are 5.0 dBm and 3.6 dBm, respectively, and the ALC function suppresses the power difference to 1.4 dB. Here, the input power of $-27.0 \text{ dBm}$ is the lower limit that our ALC circuit works properly.

Fig. 2 (c) shows the allowable loss of Link B against that of Link A. Here, we assume the output powers from both ONUs are the same value of 5.0 dBm, which is typical for a 10G-EPON ONU. Moreover, the input power ($P_{\text{in}}$) of the dummy strong burst signals in weak burst signal measurements is set
to −10.0 dBm and \( P_m \) of dummy weak burst signals in strong burst signal measurements is set to −27.0 dBm. As shown in the figure, the losses of Link B are constant regardless of \( P_m \) values due to the ALC function of our burst-mode optical amplifier. Degradation in loss of Link B for strong burst signals from 10G-ONU is caused by the pattern effect in the first SOA. On the other hand, those for weak burst signals from both 1G-ONU and 10G-ONU are caused by the ASE noise accumulation of the cascaded SOAs. Very wide input dynamic ranges are required for optical amplifiers used in upstream transmission because PON systems must accommodate many ONUs with different distances. To meet this demand, a large loss budget must be firstly ensured in Link A. Actually, our ALC-SOAs can accept the Link A loss of up to 32 dB, which is derived from the ONU output power (5.0 dBm) and the lower input power limit for ALC operation (−27.0 dBm). The square delineated area [5] shows the admissible operating ranges obtained with reference to this maximum Link A loss. As shown, Link B achieves the large allowable loss budget of 29 dB against a wide range of Link A losses, from 13 dB to 32 dB. The allowable loss of Link B can be reduced to 12 dB against the same range of Link A losses. The loss budget of this system is expected to reach 61 dB.

### 3.2 Downstream transmission

In long-reach PONs, the downstream signals of a 10G-EPON are severely degraded due to chromatic dispersion of standard single mode fibers (SMFs). Therefore, the ONU receiver must employ a chromatic dispersion compensation technique. Fig. 3(a) shows the experimental setup used to evaluate the allowable loss budget of downstream transmission for a signal bit rate of 10.3125 Gb/s. The output power and the wavelength from the transmitter (10G-Tx) are 2.3 dBm and 1577.3 nm, respectively. Downstream signals are transmitted over 80 km SMFs which include Link A of 20 km (SMF #1) and Link B of 60 km (SMF #2). An SOA is placed between these two SMFs. Its gain and NF are 17.9 dB and 8.7 dB, respectively. To hold the output powers from the SOA to those from the 10G-OLT regardless input powers, the SOA uses an ALC circuit. Note that this circuit does not work in burst-mode. Even though the losses of Link A and Link B are small, this function helps to keep input powers to the ONUs within the input power range of their receivers. As an ONU receiver, we use an avalanche photodiode with a trans-impedance amplifier (APD-TIA) followed by a commercial electronic dispersion compensation (EDC) circuit. The received power for error free operation, which corresponds to the bit error rate (BER) of \( 10^{-3} \) for a pseudo random bit sequence (PRBS) pattern of \( 2^{31} - 1 \), is −31.4 dBm. Here, we assume that RS (255,223) is utilized to achieve the BER of \( 10^{-12} \). The losses of Link A and Link B are adjusted by variable optical attenuators (VOA4 and VOA5). Of particular note, VOA5 is utilized to evaluate the loss margin in Link B. We measured receiver sensitivities by changing the attenuation value of VOA4 with a fixed attenuation value of VOA5.

Fig. 3(b) shows the output signal powers from the SOA and the receiver.
Fig. 3. Experimental setup to evaluate allowable loss budget of downstream transmission (a) output signal powers from SOA and receiver sensitivities against loss of Link B (b).

sensitivities against different loss values of Link B. Although the wavelength of the downstream signals is 1577.3 nm, we define the loss of Link B at 1270 nm to ensure its consistency with the previous section (upstream transmission). Differences between these two powers show the allowable loss budgets of Link A. As shown, Link A exhibits a loss budget of 32 dB against Link B loss of 29 dB, which means that the downstream transmission does not reduce the operating ranges obtained for the upstream transmission. The loss of SMF #2 at 1270 nm is 23.9 dB, therefore, the loss margin in Link B for the span distance of 60 km can be estimated by 5 dB.

4 Conclusion

We presented an SOA-based PON repeater configuration consisting of cascaded SOAs with a fast ALC circuit for upstream transmission and a single SOA for downstream transmission. The key points in upstream signal amplification are that the cascaded SOAs achieve high gain without inducing the pattern effect in the second SOA through the help of the ALC function and the wide gain bandwidths of the SOAs provide simultaneous amplification of the wavelengths assigned to 1G-ONU (1310 nm) and 10G-ONU (1270 nm). We also evaluated the allowable loss ranges of a 1G / 10G dual-rate symmetric long-reach 10G-EPON system where the maximum access span loss allowable for upstream transmission using our ALC-SOAs of 32 dB was assumed. Experiments confirmed a large operating range with the dynamic range of 17 dB for trunk span loss and 19 dB for access span loss. The max-
imum allowable loss budget was 61 dB for the total transmission distance of 80 km consisting of a 60 km trunk span and a 20 km access span.

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