

# Loss budget in single-fiber loopback access networks with ASE light source considering gain compression effect of GS-SOA

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**Abstract:** This paper estimates the loss budget of wavelength division multiplexing (WDM) single-fiber loopback access networks that employ a broadband amplified spontaneous emission (ASE) light source at the central office (CO) and an optical modulator with optical amplification function in each optical network unit (ONU). This study considers the backreflection lights from two sources, a broadband ASE light from the CO (Reflection-I) and a modulated signal from the ONU (Reflection-II). A gain-saturated semiconductor optical amplifier (GS-SOA) is placed at the ONU to reduce the excess intensity noise of sliced ASE and the spontaneous-spontaneous beat noise caused by Reflection-II; this technique increases the loss budget of the transmission line and removes an optical pre-amplifier from the optical receiver. Experiments clarify that with the gain compression effect of the GS-SOA the loss budget is 22.7 dB.

**Keywords:** optical access network, bidirectional transmission, backreflection, semiconductor optical amplifier, WDM

**Classification:** Fiber-optic communication

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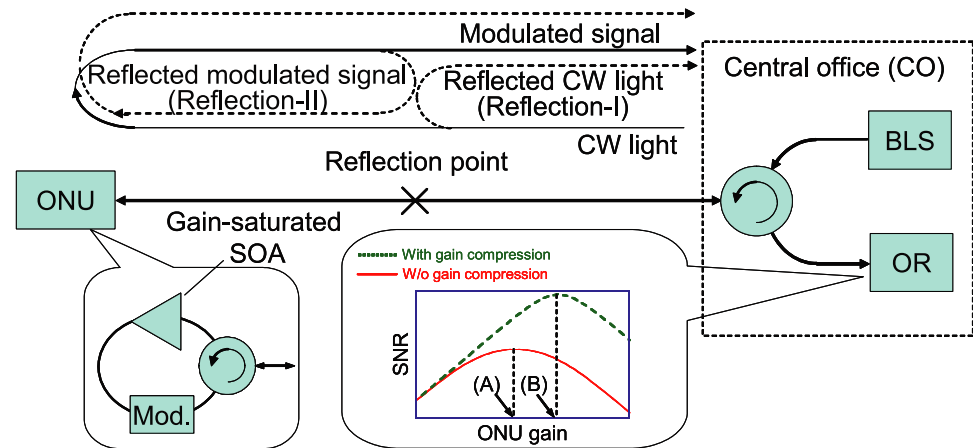
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## 1 Introduction

Passive optical networks (PONs) such as the Broadband PON (B-PON), Gigabit Ethernet PON (GE-PON), and Gigabit-capable PON (G-PON) are being deployed in some countries. To provide a wider bandwidth, wavelength division multiplexing (WDM)-PON is a promising approach. For WDM-PONs, a colorless optical network unit (ONU) is important in terms of usability and reducing the inventory cost. Loopback techniques can realize the colorless ONU; a WDM light source is located at the central office (CO) and each ONU includes an optical modulator [1, 2]. For upstream transmission, a continuous wave (CW) light is distributed from the CO to each ONU, modulated, and sent back to the CO. When this loopback transmission is conducted by using single-fiber, the signal-to-noise ratio (SNR) of the upstream signal is severely degraded by the coherent beat noises caused by two backreflection paths: one is the backreflection of the CW light (Reflection-I), and the other is the backreflection of the upstream modulated signal (Reflection-II) [2, 3]. The received SNR can be improved by employing the spectrum slicing technique with a broadband amplified spontaneous emission (ASE) light source at the CO [3, 4, 5]. We have already reported the loss budget of a transmission line that employed this technique [3]. Although our previous work was the first study considering the two backreflection paths against a sliced ASE light source, an optical pre-amplifier was required to achieve error free operation. This is because the semiconductor optical amplifier (SOA) placed in the ONU was not driven at the gain saturation condition. Utilizing the gain compression effect of a gain-saturated SOA (GS-SOA) is expected to reduce the excess intensity noise of sliced ASE and the spontaneous-spontaneous beat noise between the CW light distributed from the CO and the Reflection-II [2, 5] such that error free operation is achieved without any optical pre-amplifiers.

This paper estimates the loss budget in single-fiber loopback access networks considering the gain compression effect of GS-SOA against a sliced ASE light source. We conduct a single-fiber bidirectional transmission experiment and clarify the loss budget achieved by using an avalanche photo diode (APD) receiver.

## 2 Gain compression effect of GS-SOA



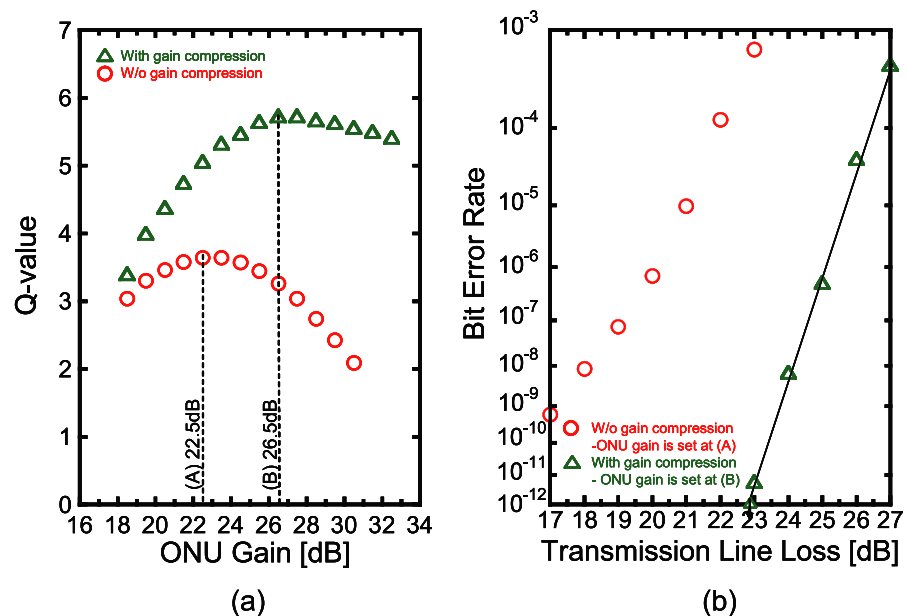
**Fig. 1.** Configuration of single-fiber loopback access networks employing an ASE light source and two paths of backreflection (Reflection-I and Reflection-II). The inset shows the SNR improvement by placing a GS-SOA at the ONU.

Fig. 1 illustrates the configuration of single-fiber loopback access networks employing an ASE-based broadband light source (BLS). Here, the wavelength-splitter located outside the CO is not shown. In these networks, we have to consider the impact of two types of backreflections, i.e. Reflection-I and Reflection-II shown in the figure. The impact of Reflection-II was considered in previous works for the first time [2, 3]. After reflection, Reflection-II proceeds toward the ONU together with the CW light distributed from the CO causing spontaneous-spontaneous beat noise. The inset of Fig. 1 shows the SNR improvement achieved by placing a GS-SOA in the ONU. As studied in the previous works, ONU gain optimization is required to maximize the received SNR [2, 3]. Position (A) shown in the inset is the optimum ONU gain without gain compression. On the other hand, placing a GS-SOA at the ONU reduces the excess intensity noise of the sliced ASE [5]. If we take only this effect into consideration, the received SNR is increased at the same optimum ONU gain position (A). However, the GS-SOA also suppresses the beat noise caused by Reflection-II. This beat noise suppression effect is expected to further improve the SNR by increasing the ONU gain at a new position, position (B) [2].

## 3 Experiments and discussions

ITU-T G.983.3 and G.984.2 define the maximum optical return loss (ORL) as  $-32$  dB [6, 7]. To investigate the loss budget of upstream transmission, we measured the bit error rate (BER) under this condition. The experimental setup is described below. The CO included an ASE-based BLS, an optical circulator, a thin film filter (TFF) as a demultiplexer, and an optical receiver

(OR) including an APD. The optical bandwidth of BLS was limited by an optical band pass filter (BPF) and the output optical power was amplified by an optical amplifier. The ASE light was launched into the transmission line through the optical circulator and distributed to the ONU. The transmission line included two 1:1 couplers, two variable attenuators, 7 km of single mode fiber (SMF), and a TFF as a multiplexer/demultiplexer. The transmission line loss was adjusted by the variable attenuators. The ONU consisted of an optical circulator, an electro-absorption (EA) modulator, two erbium doped fiber amplifiers (EDFAs), and a variable attenuator. A GS-SOA was inserted between the first variable attenuator and the EA modulator when required. The input power to the SOA was increased by the first EDFA. The distributed ASE light was sliced by the TFF and sent to the EA modulator through the optical circulator, and modulated. The signal bit rate was 1.25 Gbps using a  $2^7 - 1$  non-return to zero (NRZ) pseudo random bit-sequence because we assumed gigabit Ethernet (GbE) frame transmission. The modulated signal was gain-controlled by the second optical amplifier and the variable attenuator and launched into the transmission line again through the optical circulator. The transmitted signal to the CO was sent to the TFF through the circulator and received. The transmission line also included two sets of optical circulators and variable attenuators to create Reflection-I and Reflection-II. The ORL was set to  $-32$  dB by the variable attenuator. The TFFs used had a flat pass band with 0.5 dB-bandwidth of 0.9 nm, therefore, the coherent length of the sliced ASE light was estimated to be of the order of 100  $\mu$ m. This



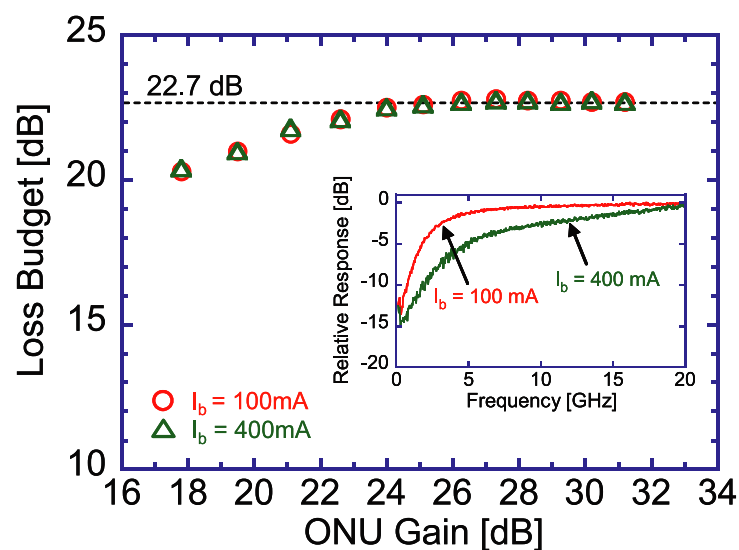
**Fig. 2.** (b) Measured BER versus transmission line loss without and with gain compression effect of SOA when ONU gains are optimized at positions (A) and (B) for each case. (a) Measured Q-value versus ONU gain without and with gain compression effect of SOA.

value is exceedingly short and it is reasonable to assume that the signal light interferes with backreflection lights without phase correlation in actual access fibers. Therefore, although this experimental setup has only one reflection point for each path of Reflection-I and Reflection-II, we can consider that this setup is valid in simulating the backreflection lights of actual access fibers.

Fig. 2 (a) shows the measured Q-value against the ONU gain. Both cases, ONUs without and with the GS-SOA gain compression effect, are shown. The transmission line loss, the fiber launch power at the CO per channel, and the noise figure of each EDFA were 24 dB, 0 dBm, and 7 dB, respectively. The input power into GS-SOA ( $P_{in}$ ) and the SOA bias current ( $I_b$ ) were 0 dBm and 100 mA, respectively. As shown, the measured Q-value for the ONU without gain compression reached its maximum value at the ONU gain of 22.5 dB (A). Furthermore, this improvement is enhanced by increasing the ONU gain to 26.5 dB (B). Therefore, these results confirm the SNR improvement shown in the inset of Fig. 1.

Fig. 2 (b) shows the measured BER characteristics against the transmission line loss. Two BER curves are shown in the figure. For measured data without and with gain compression, the ONU gains are set at position (A) and position (B), respectively. As shown, compared to the error floor observed for the ONU without gain compression, error free operation is obtained for the ONU with gain compression. This figure also shows that the transmission line loss that yields error free operation for the ONU with gain compression is 22.7 dB.

The gain compression effect of the GS-SOA can be enhanced by increasing  $I_b$ . To investigate the possibility of increasing the loss budget beyond 22.7 dB, we increased  $I_b$  from 100 mA to 400 mA. Fig. 3 shows the measured loss budget versus the ONU gain. The inset of Fig. 3 also shows the measured relative response of the GS-SOA used in this experiment. As shown, although



**Fig. 3.** Loss budget versus ONU gain when driving bias current of SOA is increased from 100 mA to 400 mA.

the gain compression effect is enhanced by increasing  $I_b$ , the loss budget could not be increased. This is because the ASE noise generated by the optical amplifiers in the ONU reduces the gain compression effect of the GS-SOA. Therefore, this result indicates that it is difficult to increase the loss budget beyond 22.7 dB.

#### 4 Conclusion

We estimated the loss budget of single-fiber loopback access networks that place an ASE light source at the CO. Two paths of backreflection lights were taken into consideration: one is for the broadband ASE light (Reflection-I) and the other is for the modulated signal (Reflection-II). A GS-SOA was placed at the ONU to reduce the excess intensity noise of sliced ASE and the spontaneous-spontaneous beat noise caused by the interference between sliced ASE light and Reflection-II. We used an experimental configuration with two reflection points to create the two backreflection lights and showed that the loss budget of 22.7 dB was achieved under the ORL of  $-32$  dB at the signal bit rate of 1.25 Gbps with an APD receiver. This loss budget value meets the requirement of the Class A optical distribution network (20 dB) defined in ITU-T G.983.3 and G.984.2. We also found that the ASE noise output from the optical amplifiers in the ONU reduced the gain compression effect of the GS-SOA and limited the loss budget increase to 22.7 dB.