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Reflection Tolerance of RSOA-based WDM PON

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Abstract

We investigate the effects of back-reflection in RSOA-based WDM passive optical networks. The results show that the upstream signal can tolerate the back-reflection in the range of up to -27 ~ -25 dB, depending on the data rate of the downstream signal.

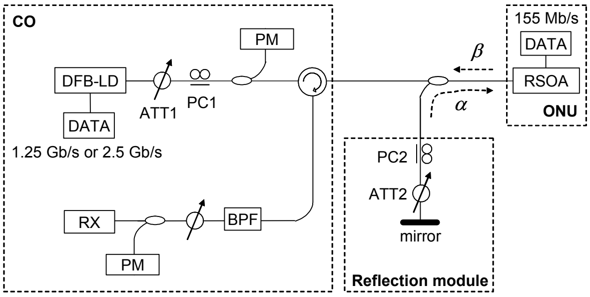
I. Introduction

For the realization of the practical WDM passive optical network (PON), the wavelength-independent operation of the optical network unit (ONU) is indispensable. Various types of colorless light sources have been proposed to achieve this objective, including the spectrum-sliced light sources, ASE-injected Fabry-Perot lasers, and reflective semiconductor optical amplifiers (RSOA's) [1]-[4]. In particular, the use of RSOA's is attractive since the received downstream signal can be reused for the upstream transmission [3]-[4]. However, in such a network, the back-reflections from splices and connectors can severely degrade the performances of the upstream signals. This is because the upstream signal reflected back to the ONU is re-amplified by the RSOA, and induces a large intensity noise. Recently, this effect of back-reflection on the upstream performance has been studied in WDM single-fiber loopback networks [5]. However, in this study, it is assumed that additional WDM light sources are used at the central office (CO) to inject the cw seed light into each ONU (implemented by using an optical amplifier and an optical modulator). Thus, each ONU in this network amplifies and modulates the injected cw light from the CO for the upstream transmission.

In this paper, we investigate the effect of the back-reflection on the upstream transmission performance in the RSOA-based WDM PON. Unlike the previous report [5], we assume that the modulated downstream signal is injected to the RSOA instead of the cw seed light. The results show that the upstream signal can tolerate the back-reflection up to -27 ~ -25 dB, depending on the data rate of the downstream signal.

II. Experiment setup

Fig. 1 shows the experimental setup. We assumed a bidirectional WDM PON system, and evaluated the impact of a discrete reflection occurred near the ONU. At the CO, we used a DFB laser operating at 1551 nm for the downstream transmission. We directly modulated this laser with 1.25-Gb/s or 2.5-Gb/s non-return-to-zero (NRZ) signals. The extinction ratio of the downstream signal was set to be 2 dB to ensure the saturated operation of the RSOA even at '0'-level [4]. The downstream signal was sent to the ONU and reused for the upstream transmission. At the ONU, an RSOA was used as an upstream light source. The small signal gain was 17 dB (@ bias current = 80 mA), and its polarization dependence was 0.4 dB. We directly modulated the gain of the RSOA with a 155-Mb/s NRZ signal. In order to improve the upstream performance by compressing the downstream signal, we set the optical power of the downstream signal incident on the RSOA to be –11 dBm (at which the RSOA gain was compressed by 3 dB) [4]. The upstream signal was then sent to the upstream receiver at the CO. To evaluate the effect of the back-reflected light into the RSOA, we used the reflection module composed of a mirror and a variable optical attenuator. The fiber length between the mirror and RSOA was about 15 m. The effect of back-reflection was highly dependent on the state-of-polarization of the reflected light. Thus, we used a polarization controller, PC2, for the worst case analysis (i.e., worst BER).



* Reflectivity = α / β, PM : Optical power meter

Fig. 1: Experimental setup.

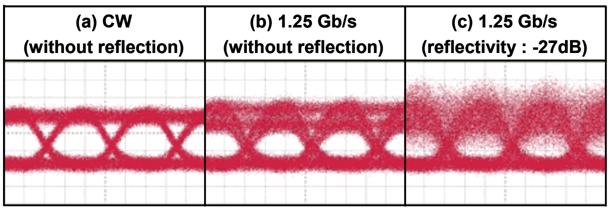

(a) CW (without reflection) **(b) 1.25 Gb/s (without reflection)** **(c) 1.25 Gb/s (reflectivity : -27dB)**

Fig. 2: Eye diagrams of the upstream signal.

III. Results and Discussions

We first evaluated the impact of the back-reflection by observing the eye diagram of the upstream signal using a 2.5-GHz photodetector. Fig. 2 shows the eye diagrams of the upstream signal measured with and without applying the back-reflection. In this figure, the downstream signal was modulated at 1.25 Gb/s except in the case of Fig. 2(a), which was measured without modulating the downstream signal for a reference. Fig. 2(b) shows the eye diagram measured without back-reflection. In this diagram, the

'1'-level of the upstream signal was split into two levels due to the residual downstream signal. This thick '1'-level is one of the major impairment factors for the upstream signal in the loopback network utilizing re-modulation [3]-[4]. When we applied the back-reflection (reflectivity = -27 dB), the eye diagram was further degraded (i.e., the thickness of '1'-level increased) as shown in Fig. 2(c).

To evaluate the impact of these noises (induced by the back-reflection) quantitatively, we measured the BER of the upstream signal by using a 155-Mb/s optical receiver. Fig. 3 shows the measured receiver sensitivity (@ BER = 10^{-9}) as a function the reflectivity. No significant degradation was observed in the receiver sensitivity when the reflectivity was smaller than -35 dB. However, as we increased the reflectivity, the sensitivity was drastically degraded. For example, when the downstream data rate was 1.25 Gb/s, it was not possible to achieve the error-free transmission of the upstream signal if the reflectivity exceeded -27 dB. On the other hand, the same result was observed for the 2.5-Gb/s signal at the reflectivity of -25 dB. These results indicate that the reflection tolerance of the upstream signal increases with the downstream data rate due to its broadened spectral width.

Previously, it has been reported that the back-reflected light in a single-fiber loopback system could generate extra intensity noises due to the optical beat interference (OBI) between the upstream and reflected signals [5]. In this report, the bandwidth of the generated intensity noise was assumed to be identical to the signal's bandwidth (since cw light from the CO was used as a seed for the RSOA at the ONU), and estimated the degradation of the signal-to-noise ratio (SNR) caused by the back-reflection. However, in our case (i.e., the downstream signal is not cw but directly modulated), the downstream signal has much broader bandwidth than that of the upstream receiver. Thus, the intensity noise (induced by the OBI) is spread over a wide spectral range, and, consequently the SNR degradation caused by the back-reflection is alleviated.

To estimate the SNR degradation caused by the back-reflection, we evaluated the intensity noise parameter r_i by using $\delta_I = -10\log(1 - r_i^2 Q^2)$, where Q is the Q-factor (=6) and δ_I is the power penalty in dB [6]. The error-free transmission (i.e., BER<10^{-9}) cannot be achieved if r_i exceeds 0.167. Fig. 4 shows the intensity noise parameter obtained by using this equation and the measured receiver sensitivities in Fig. 3. This parameter, r_i, was nearly constant at the low reflectivity. However, r_i increased with the reflectivity, when it was higher than -35 dB. These results suggested that the intensity noise parameter could be expressed in the following form:

$$r_i^2 = r_{\text{remod}}^2 + r_{\text{ref}}^2 = r_{\text{remod}}^2 + \alpha R^2 \qquad (1)$$

where R is the reflectivity, r_{remod} and $r_{\text{ref}}(\equiv \sqrt{\alpha} R)$ are the intensity noise parameters resulting from the residual downstream components and the OBI caused by the back-reflection, respectively. The constant α is a fitting parameter originating from the spectral distribution of the upstream signal. The dashed curves in Fig. 4 are the calculated values by using equation (1). The results show that these curves agree well with the measured values. In comparison, the solid line in Fig. 4 represents the intensity noise parameter calculated by using the theory in [5]. It is clearly shown that this simple theory overestimates the SNR degradation (caused by back-reflection) when the modulated downstream signal is injected to the RSOA.

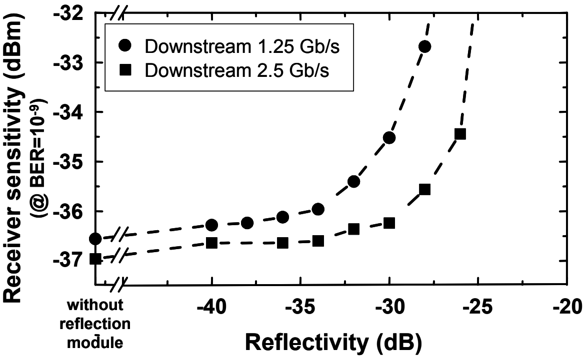


Fig. 3: Measured upstream receiver sensitivity.

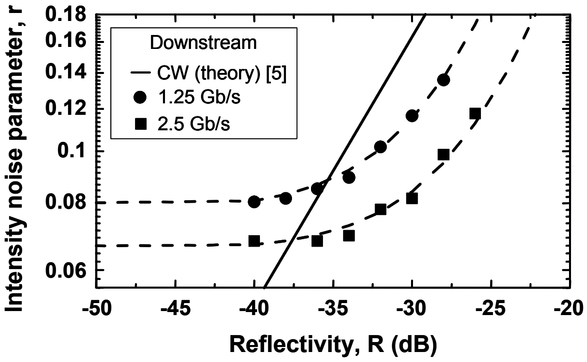


Fig. 4: Intensity noise parameter obtained by using the results in Fig. 3 and equation (1).

IV. Summary

We investigated the effects of the back-reflection on the upstream signal in a RSOA-based WDM PON. The results showed that this network could tolerate the back-reflection up to -27 ~ -25 dB (when the RSOA gain is 14 dB), depending on the data rate of the downstream signal injected to the RSOA.

References

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