An ASE-Injected FP-LD-Based Return-to-Zero Transmitter for Long-Reach WDM-PONs

Hoon Kim
Dept. of Electrical & Computer Engineering, National University of Singapore, 4 Engineering Drive 3, Singapore 117576
E-mail: hoonkim@ieee.org

Abstract: We propose and demonstrate a simple RZ transmitter based on incoherent-light-injected FP-LD which improves the dispersion tolerance by a factor of 1.5. Thanks to wide timing margin between adjacent bits, we successfully transmit incoherent 1.25-Gb/s signals over 45 km of SSMF.
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1. Introduction

Recently, long-reach (LR) passive optical networks (PONs) have received a great deal of attention for wavelength-division-multiplexed (WDM) PONs [1]. By increasing the transmission distance between optical line terminals (OLTs) at the central office (CO) and optical network units (ONUs) at customers' premises, LR PONs can reduce the number of COs and place numerous OLT equipment at a centralized location. Thus, these networks not only save the lease and operation fees for the COs but they also greatly simplify the operation and maintenance of the networks. For the cost-effective implementation of these networks, it is desired to place wavelength-selective upstream light sources at the CO and to employ low-cost optical modulators at the ONUs. This configuration makes the ONUs color-less, greatly relieving initial installation of the optical transmitter as well as the inventory problem. However, this system is susceptible to intra-band crosstalk caused by Rayleigh backscattering and optical reflection on the transmission line, especially when a single strand of fiber is employed for upstream transmission. One way of suppressing the deleterious effects of the intra-band crosstalk is to utilize incoherent light sources [2]. The crosstalk effects decrease with the ratio of the data rate to the source linewidth. Thus, an incoherent light source which has a much wider linewidth than coherent light can efficiently suppress the crosstalk. For example, the crosstalk suppression is as high as 25 dB if 155-Mb/s signals are carried over 0.4-nm incoherent light. Wide linewidth of incoherent light is also beneficial for suppressing excess intensity noise (EIN) caused by spontaneous-spontaneous beating. In this regard, an incoherent-light-injected Fabry-Perot laser diode (FP-LD) is a promising candidate for WDM-PON optical sources [3]. It utilizes low-cost semiconductor devices with simple structure and high yield. However, when a wide line-width incoherent light is employed to suppress the crosstalk and EIN, the system can be vulnerable to fiber dispersion [4]. This could be a major stumbling block to increasing the data rate and transmission distance in LR PONs.

In this paper, we propose and demonstrate a return-to-zero (RZ) transmitter for LR WDM-PONs using incoherent light-injected FP-LDs. The RZ format is known to be more sensitive to fiber dispersion than non-return-to-zero (NRZ) for coherent light signals. This is simply because the RZ signals have wider spectral bandwidth than NRZ.

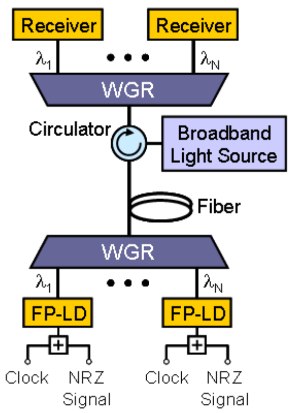

Fig. 1 A WDM-PON system using the proposed RZ transmitter based on incoherent-light injected FP-LDs. Only uplink system is depicted.

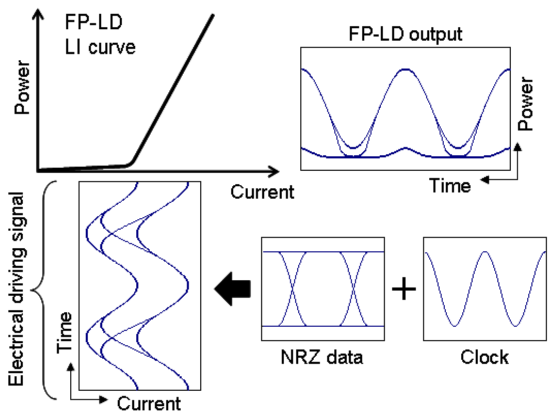

Fig. 2. The generation of optical RZ signals using the nonlinearity of the FP-LD LI curve. The FP-LD driving signals are obtained by adding the NRZ data to the clock signal.

For spectrum-sliced incoherent light, on the other hand, the spectral width is determined by the slicing bandwidth. Thus, the RZ format, which offers a large timing margin between adjacent bits, can be more tolerant to dispersion-induced pulse broadening than the NRZ format for incoherent light. For the generation of RZ signals in cost-sensitive WDM-PON systems, we simply add electrical NRZ signals to a clock signal and then apply them to the FP-LD for direct modulation. The nonlinear light-output versus current (LI) curve of the FP-LD converts the applied electrical signals into optical RZ signals. Our experimental demonstration for 1.25-Gb/s upstream transmission shows ~50% improvement of dispersion tolerance compared to NRZ signals. To the best of our knowledge, it is the first time the RZ modulation format is employed for incoherent-light-based optical access networks.

2. Proposed Scheme and Experimental Demonstration

Fig. 1 shows a WDM-PON system utilizing the proposed transmitter. It depicts the uplink only. The amplified spontaneous emission (ASE) from a broadband light source is fed to the transmission fiber to be spectrum-sliced by a waveguide grating router (WGR) at the remote node. The spectrum-sliced incoherent light is then injected into FP-LDs for data modulation. The FP-LDs are driven with NRZ plus clock signals. Fig. 2 illustrates how the driving signals of the FP-LDs are generated. The driving signals are obtained simply by adding NRZ data to a clock signal [5]. This can be readily done with a passive power combiner. The added signals have a sinusoidal oscillation both on the marks and the spaces. When these signals are applied to an FP-LD biased near the threshold current, the oscillation on the spaces are clipped and significantly suppressed. The nonlinear response of the LI curve eliminates the oscillation on the spaces but retains the oscillation on the marks, and consequently generates optical RZ signals, as illustrated in Fig. 2. It should be noted that the driving signals (i.e., the NRZ plus clock signals) have a narrower bandwidth than the signals generated with an electrical NRZ-to-RZ converter. Thus, the proposed scheme would be suitable for RZ generation with low-bandwidth FP-LDs.

Fig. 3 shows the experimental setup. A wideband ASE was generated from an Erbium-doped fiber amplifier (EDFA), and sent to an optical filter (BPF1) for spectral slicing. The 3-dB bandwidth of the filter is 0.58 nm (Note that the bandwidth is selected to ensure the color-less operation of the FP-LD). The sliced ASE at 1532 nm was sent to the transmission fiber via a circulator. Before the ASE was injected into an FP-LD, it passed though another optical filter (BPF2) with a 3-dB bandwidth of 1.5 nm. This is to reject small side-modes of the FP-LD output spreading over 30 nm. The transistor outlook (TO)-packaged and uncooled FP-LD has a mode spacing of 0.55 nm and the threshold current of 14.5 mA. To facilitate the ASE injection, the front-facet reflectivity is reduced to 1% with anti-reflection coating. The driving signals of the FP-LD were obtained by adding 1.25-Gb/s NRZ signals to a 1.25-GHz sinusoidal clock signal with a passive power divider. A variable electrical delay line was used to align the clock signal to the NRZ data. The pseudo-random bit sequence length of the NRZ signals was 2^{23}-1. The driving signals were amplified to 1.87 V_{pp} with an RF amplifier before applied to the FP-LD biased at 16.9 mA, as shown in Fig. 3(a). Due to the nonlinear phase response of the FP-LD outside its modulation bandwidth, the clock signal was delayed by ~0.1 ns with respect to the NRZ signals. Fig. 3(b) shows the optical eye diagram of the FP-LD output measured with an oscilloscope when the optical powers of the injected ASE and the output signals were -3.7 and -0.7 dBm, respectively. The measurement bandwidth was 2.0 GHz. It shows the FP-LD produces optical RZ signals with a 50% duty ratio and 13-dB extinction ratio. The optical eye diagram for the NRZ signal is plotted in Fig. 3(c) for comparison. In this case, we just turned off the clock signal to the FP-LD and other operating conditions are identical with those for the RZ signals. After transmission, the signals were detected with a PIN receiver (bandwidth=938 MHz). In the setup, it should be noted that we utilized two band-pass filters, one for spectrum

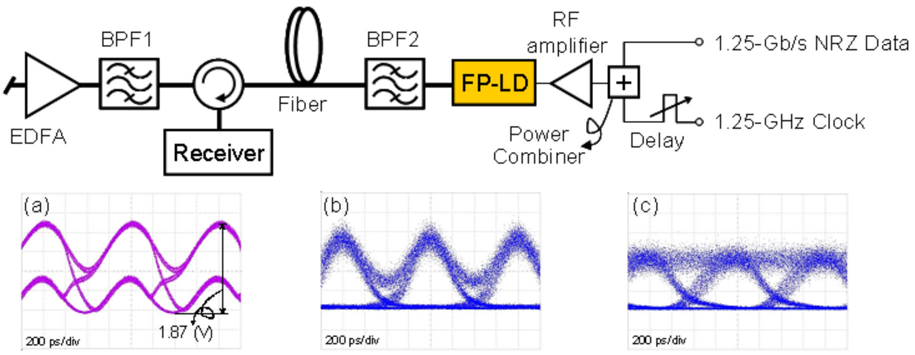

Fig. 3 Experimental setup. (a) Eye diagram of the electrical driving signals to the FP-LD. (b) Measured optical eye diagram for the RZ signals. (c) Measured optical eye diagram for the NRZ signals obtained when the clock signal is turned off.

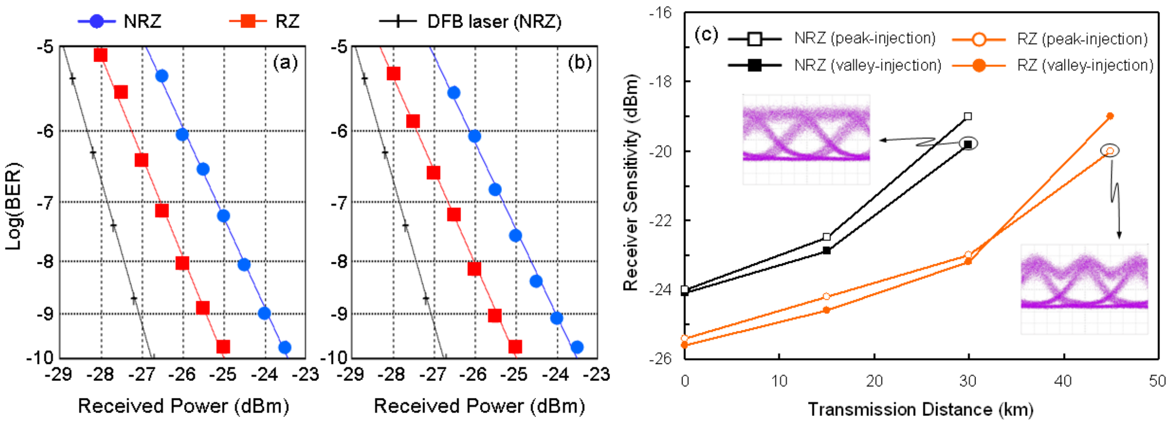

Fig. 4 Back-to-back BER curves measured with the NRZ and RZ signals (a) when the ASE is injected at the peak of one of the FP-LD modes and (b) when the ASE is injected between the modes. (c) Measured receiver sensitivity as a function of transmission distance over SSMF.

slicing (BPF1) and the other for side-mode rejection (BPF2). This was because BPF1 was not reciprocal, but in real systems the two filters can be replaced with a single filter (e.g., WGR in Fig. 1).

Fig. 4(a) and (b) shows the measured bit-error ratio curves when the spectrum-sliced ASE is injected either at the peak of one of the FP-LD modes (hereafter referred to as peak injection) or between the modes (hereinafter referred to as valley injection). The optical power of the injected ASE was -3.7 dBm. The receiver sensitivities of the RZ signals at a BER of 10^{-9} are -25.4 and -25.5 dBm for the peak- and valley-injections, respectively, which are 1.7 or 1.6 dB poorer than the sensitivity measured with a directly modulated distributed-feedback laser. However, the measured receiver sensitivities of the NRZ signals are -24.0 and -24.1 dBm for the peak- and valley-injections, respectively. Thus, the proposed transmitter shows 1.4-dB better receiver sensitivity than the NRZ signals.

The dispersion tolerance of the signals is measured with standard single-mode fiber (SSMF). Fig. 4(c) shows the measured receiver sensitivity as a function of the transmission distance. With the NRZ signals, we have sensitivity penalties of 4.3~5.0 dB after 30-km transmission and we cannot achieve a BER of 10^{-9} after 45-km transmission. BER error floors were observed at around 10^{-8}. Obviously, this should be ascribed to inter-symbol interference and EIN increase by dispersion [6]. With the RZ signals, however, we can successfully transmit the 1.25-Gb/s signals over 45-km SSMF. The transmission penalties are measured to be 5.4~6.6 dB, depending upon the injection wavelength. Thus, the dispersion-limited transmission distance is increased by nearly 50% with the use of RZ format. The eye diagrams in the inset show wider eye opening for the RZ signals than the NRZ signals. Since there is no difference in the linewidth between the RZ and NRZ signals, the improvement of dispersion tolerance should be attributed to wide timing margin between bits.

It is worth noting that the 1.25-Gb/s transmission over 45-km SSMF is achieved at low signal-to-Rayleigh-scattering ratio of 13.8 dB. The incoherence and wide spectral linewidth of the output light allow us to have a low penalty even in the presence of high in-band crosstalk. We expect that a sensitivity penalty of 0.4 dB is incurred by the Rayleigh scattering for 45-km transmission experiment.

3. Summary

We have proposed and demonstrated a simple and cost-effective optical RZ transmitter based on incoherent-light-injected FP-LDs for cost-sensitive long-reach WDM-PON applications. The use of the RZ format does not change the spectral characteristics of incoherent-light-injected FP-LD outputs. Thus, we improve the dispersion-limited transmission distance by ~50%, compared to the use of the NRZ format.

Reference

[1] S-M. Lee *et al.*, "Demonstration of a long-reach DWDM-PON for consolidation of metro and access networks," *JLT* **25**, 271-276 (2007).
[2] Y. S. Jang *et al.*, "Effects of crosstalk in WDM systems using spectrum-sliced light source," *IEEE PTL* **11**, 715-717 (1999)
[3] H. D. Kim *et al.*, "A low-cost WDM source with an ASE injected Fabry-Perot semiconductor laser," *IEEE PTL* **12**, 1067-1069 (2000).
[4] C. H. Kim *et al.*, "Performance comparison of directly-modulated, wavelength-locked Fabry-Perot laser diode and EAM-modulated spectrum-sliced ASE source for 1.25 Gb/s WDM-PON," OFC, paper JWA82 (2007).
[5] A. Sano *et al.*, "20 Gbit/s chirped RZ transmitter with simplified configuration using electro-absorption modulator," *EL* **36**, 1858-1860 (2000).
[6] H. Kim *et al.*, "Impact of dispersion, PMD, and PDL on the performance of spectrum-sliced incoherent light sources using gain-saturated semiconductor optical amplifiers," *JLT* **24,** 775-785 (2006).