All-Optical RZ-to-NRZ Converted Data Transmission at 10 Gb/s

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Abstract. This paper proposes and demonstrates a novel all-optical return-to-zero (RZ) to nonreturn-to-zero (NRZ) data format conversion using a semiconductor optical amplifier (SOA) loop mirror. The format conversion has been performed between the most widely used data formats—NRZ and RZ formats. The format conversion scheme is based on gain variation by an intensity-dependent phase change in an SOA-loop mirror. 10 Gb/s error-free fiber transmission up to 78 km for the converted NRZ format data is achieved. Further, the proposed method shows improved transmission performance than the conventional Mach-Zehnder modulation technique.

Keywords: All-optical RZ-to-NRZ, SOA(semiconductor optical amplifier), optical loop mirror, data format conversion.

1 Introduction

Future all-optical networks are likely to employ both wavelength division multiplexing (WDM) and optical time division multiplexing (OTDM) and there will be a need for all-optical data format conversion between WDM and OTDM signals [l]. Non-return-to-zero (NRZ) and return-to-zero (RZ) formats are both widely used data formats. While the RZ format is preferred in ultra-fast OTDM networks to make use of bit-interleaving technique, the NRZ format has a lower bandwidth requirement and a higher timing jitter tolerance than RZ format. Therefore, RZ-to-NRZ format converter is essential in linking and interfacing the ultra-fast OTDM networks and the lower speed WDM networks [1]. Previous reports included all-optical RZ-to-NRZ conversion using a Mach-Zehnder PIC [2], SOA/fiber grating filter [3], SOA-XGM [l], and NOLM [4]. None except for Ref. [2] reported optical fiber transmission of the converted NRZ data. Also we propose and demonstrate, for the first time to the best of our knowledge, 10 Gb/s optical fiber transmission of the RZ-to-NRZ converted data using SOA-loop mirror.

2 RZ-to-NRZ Conversion Using SOA-Loop-Mirror

Fig. 1 shows an experimental setup for the proposed RZ-to-NRZ converter scheme. A nonlinear optical loop mirror using an SOA (SOA- loop-mirror) is often used for

T.-h. Kim et al. (Eds.): FGIT 2010, LNCS 6485, pp. 601–605, 2010.

all-optical switching in OTDM networks [5]. The switching principle is based on the optically induced phase difference (that is controlled by external control pulses) between a clockwise (*cw*) and a counter-clockwise (*ccw*) pulse in a fiber loop mirror.

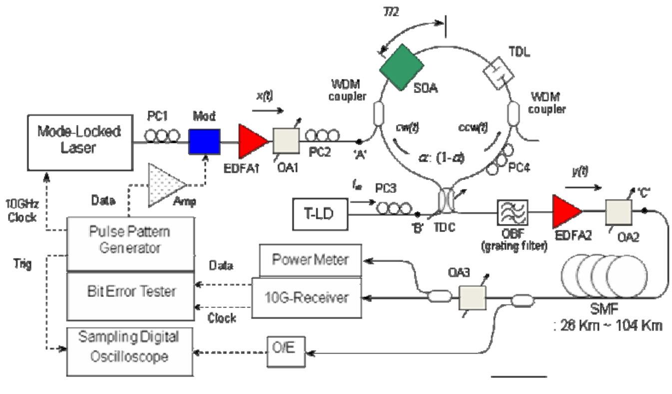

Fig. 1. Experimental Setup

Due to the displacement, it executes an exclusive OR (XOR) function for the input RZ signal and its *T* delayed signal, and finally generates NRZ signal. From the SOA-loop-mirror of Fig.1, the transmitted intensity is given by [6]

$$y = I_{in}(a^2 G_{cw} + (1-a)^2 G_{ccw} - 2a(1-a)\sqrt{G_{cw}G_{ccw}}\cos\theta_{diff}) \tag{1}$$

where, I_{in} is the input intensity, a is the coupling coefficient of the TDC, G_{cw} and G_{ccw} are the gains of an SOA for *cw* and *ccw* beams, respectively, and θ_{diff} $(=\theta_{cw} - \theta_{ccw})$ is the phase difference between *cw* and *ccw* beams. For the simplicity, we set a TDC coupling coefficient a to 0.5. The operational timing diagram is illustrated in Fig. 2. In fact, the gain and the phase of *cw* and *ccw* beams depend on the intensity of the input signal $x(t)$, simultaneously. Here, we assume that when the input signal $x(t)$ is 'on', the gain of the *cw* beam is the same as that of the *ccw* beam due to cross-gain modulation (XGM) of the SOA, i.e., $G_{cw,on} = G_{ccw,on}$, and when the input is 'off', $G_{cw,off} = G_{ccw,off}$. Cross-phase modulation (XPM) of the SOA also induces the phase difference between $I_{in}G_{cw,on}$ (or $I_{in}G_{cw,off}$) and $I_{in}G_{ccw,off}$ (or $I_{in}G_{ccw,on}$), which is assumed to be 'π' (or '-π') as shown in Fig. 2.

If we consider only the XPM effect (the gain is constant (=G)) alone, the output of the SOA-loop-mirror can be expressed as

$$\begin{aligned} y(t) &= 0.5 I_{in} G(1-\cos(\theta_{cw}(t) - \theta_{ccw}(t))) \\ &= 0.5 I_{in} G(1-\cos(\theta_{cw}(t) - \theta_{cw}(t+T))) \end{aligned} \tag{2}$$

On the contrary, with only the XGM effect (that is, the phase is constant ($\theta_{cw} = \theta_{ccw} = \theta$)), Eq. (1) is reduced to

$$y(t) = 0.5I_{in}(G_{cw}(t) + G_{ccw}(t) - 2\sqrt{G_{cw}(t)G_{ccw}(t)})$$
$$= 0.5I_{in}(G_{cw}(t) + G_{cw}(t+T) - 2\sqrt{G_{cw}(t)G_{cw}(t+T)}) \quad (3)$$

From (2) and (3), if $\theta_{cw}(t) = \theta_{ccw}(t)$ $(\theta_{cw}(t+T))$ and/or $G_{cw}(t) = G_{ccw}(t)$ $(=G_{cw}(t+T))$, $y(t)=0$. Otherwise, $y(t)$ has a certain value. Therefore, we can obtain the relation of $y(t) = x(t) \oplus x(t+T)$, where $\oplus$ denotes XOR logic. In fact, because the phase and/or the gain is not able to be abruptly changed, the output $y(t)$ shows a NRZ data format rather than an RZ data format like the doted output in Fig. 2.

The operation principle of the proposed RZ-to-NRZ conversion is topologically identical to that of Ref. [2] except for the use of a grating filter to obtain good chirping characteristics as shown in fig. 1. Ref. [2] employs a scheme using a Mach-Zehnder (MZ) interferometer while the proposed scheme is based on a Sagnac interferometer. In Fig. 1, the incoming RZ signal $x(t)$ enters into the fiber loop mirror through the WDM coupler. Because the SOA is located at the displacement of $\tau/2$ ($\tau \leq T$, T is a signal period) from the mid point of the fiber loop, the *ccw* beam takes a phase changing effect τ later than the *cw* beam from the incoming RZ signal as shown in Fig. **2.** Due to the phase change difference in both *cw* beam and the τ-delayed *ccw* beam, the τ gating window can be made. This operational principle is topologically identical to Ref. [2], but the proposed scheme has more simple and stable architecture.

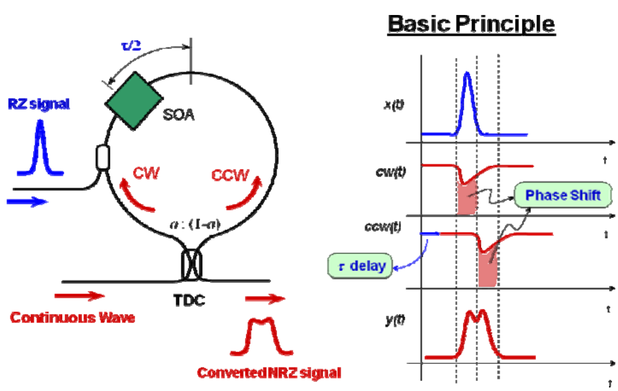

Fig. 2. Principle of the proposed RZ-to-NRZ conversion

3 Experiments and Results

In the experimental setup of Fig. 1, the SOA-loop-mirror consists of TDC, TDL, PC4, and SOA, which are connected by the WDM coupler for the RZ input signal $x(t)$. A $LiNbO_3$ electro-optic modulator and a mode-locked laser (~6 psec FWHM, 10 GHz) driven by a pulse pattern generator (PPG), generates a 10 Gb/s 2^{31}-1 RZ data sequence at 1557.13 nm. The RZ input signal enters into the SOA-loop-mirror through the WDM coupler. For NRZ data generation, the continuous wave beam I_{th} at 1550 nm is generated from Tunable-LD. The SOA used in this experiment was 1000 μm-long and nearly polarization insensitive (~0.6 dB). The SOA current is set to 190 mA, coupling coefficient α of TDC was adjusted to 0.41. The SOA-arrival time difference τ was set to ~70 psec. The optical power at points 'A', 'B' and 'C' in Fig. 1 was set to 8.7 dBm, 5.0 dBm, and 8.5 dBm , respectively.

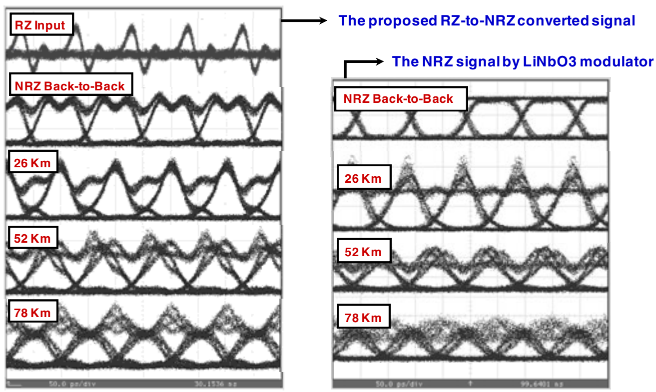

Fig. 3. Principle Eye diagrams of the optical transmission for of the proposed RZ-to-NRZ conversion (a) the proposed RZ-to-NRZ converted signal and (b) the conventional NRZ signal generated by $LiNbO_3$ MZ-modulator

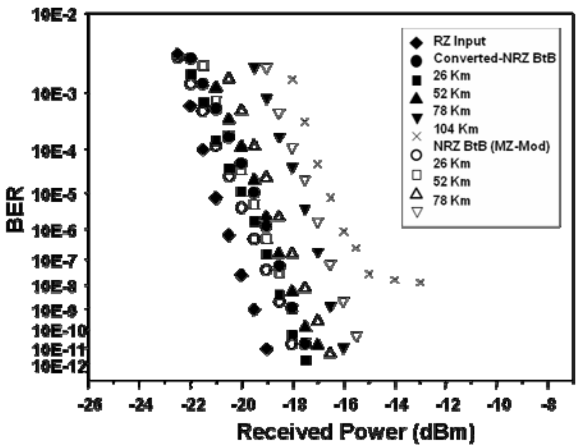

Fig. 4. Comparison of the measured BERs for the proposed RZ-to-NRZ signal and the conventional NRZ signal according to fiber transmission lengths

Fig. 3(a) shows eye diagrams for 10Gb/s RZ-to-NRZ converted signal and its optical transmissions over 26 km to 78 km dispersive standard single mode fiber. For comparison, the eye diagrams for the conventional NRZ signal generated by $LiNbO_3$ MZ-modulator are also shown in Fig. 3(b). Note that in Fig. 3, the propagation eyes for the proposed method are better than those for the conventional NRZ modulation method even though the original RZ-to-NRZ converted signal is distorted. BERs for

26, 52, 78, and 104 km fiber transmissions are shown in Fig. 4 and the proposed RZ-to-NRZ converted signal show improved transmission performances compared to the conventional NRZ signal.

4 Summary

We have proposed and demonstrated a novel all-optical RZ-to-NRZ data format conversion using SOA-loop-mirror. 10 Gb/s error-free transmission up to 78 km for the converted NRZ format data is achieved. Also, the proposed RZ-to-NRZ conversion method shows improved fiber transmission performance than the conventional Mach-Zehnder modulation method, and will serve as a key block in linking and interfacing for all-optical OTDM and WDM networks.

Acknowledgments. This work was supported by Kyungnam University Foundation Grant, 2010.

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