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40 Gbit/s signal format conversion from NRZ to RZ using a Mach-Zehnder delay interferometer

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Abstract

40 Gbit/s signal format conversion from NRZ to RZ using a Mach-Zehnder delay interferometer has been demonstrated for the first time. The converted RZ signal has high receiver sensitivity and shows significantly improved transmission performance.

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Keywords: Format conversion; Optical network; Mach-Zehnder delay interferometer; Optical communication system

1. Introduction

Format conversions are likely to be used for future all-optical networks in order to add the optical network flexibility [1,2]. Especially all-optical format conversion between NRZ and RZ data formats is an essential function in linking and interfacing metro/access and core optical networks. Fig. 1 shows an optical network including metro/access network and core network. In the metro and access network with a transmission distance from a few meters to a few hundred kilometers, the preferred format for the transmission signal is low-cost NRZ signal. In the core network, we can transmit very high-speed OTDM signals, such as 40 and 160 Gbit/s. Therefore, we need a low-cost format conversion to convert the NRZ signals to RZ signals or RZ signals to NRZ signals. Different techniques are used to realize NRZ to RZ conversion [1–8]. However, up to now, no 40 Gbit/s all-optical format conversion from NRZ to RZ has been reported. In this paper, we experimentally demonstrate 40 Gbit/s format conversion from NRZ to RZ using a Mach-Zehnder delay interferometer (MZ-DI) over 200 km transmission distance.

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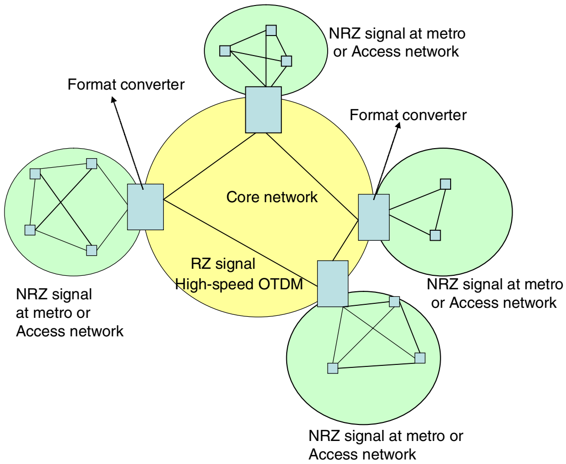

Fig. 1. Signal format conversion at the interfaces between metro/access and long haul high-speed OTDM core networks.

2. Principle

Fig. 2 shows the operation principle for format conversion from NRZ to RZ based on a MZ-DI, the principle is similar to modified duo-binary RZ signal generation by using a dual-arm LN-modulator [9–11]. A MZ-DI is used to realize format conversion. We can see that NRZ signal is converted to RZ signal. In principle, any duty cycle RZ signals can be obtained by choosing proper time delay between the two arms in MZ-DI; however the smallest duty cycle is limited to the rise and fall time of the NRZ signal. Since the consecutive ones in the symbol sequence alternate between the two opposite-phase levels, the converted RZ is modified duobinary signal or alternate mark inversion (AMI) signal; therefore a decoder is necessary in the real system. The decoder technique can be found in [12]. In this experiment, both the rise and fall time of the NRZ signals are ≈12 ps, therefore the minimal duty cycle of RZ signal is ≈0.5.

3. Experimental setup and results

Fig. 3 shows the experimental setup. The DFB-LD wavelength is 1554.8 nm. A binary 40 Gbit/s NRZ electrical signal is generated by a commercial 4:1 electrical multiplexer. The word length of the PRBS of the electrical signal is $2^{31} - 1$. The data from the multiplexer is amplified to 6.4Vp-p by using a wideband electrical amplifier; then it is used to drive the LN-MOD. The optical eye diagram measured by an oscilloscope with a bandwidth of 50 GHz is inserted in Fig. 3 as inset (i). The generated 40 Gbit/s NRZ signals are amplified to 7.5 dBm before they are transmitted over 100 km SMF-28 and matching DCF. The input power into the DCF is set to be 0 dBm. Then we use a MZ-DI to realize format conversion. The MZ-DI is based on the fiber delay using two 50/50 couplers as shown at Fig. 2. The time delay is set to be 12.5 ps, therefore a RZ signal with duty

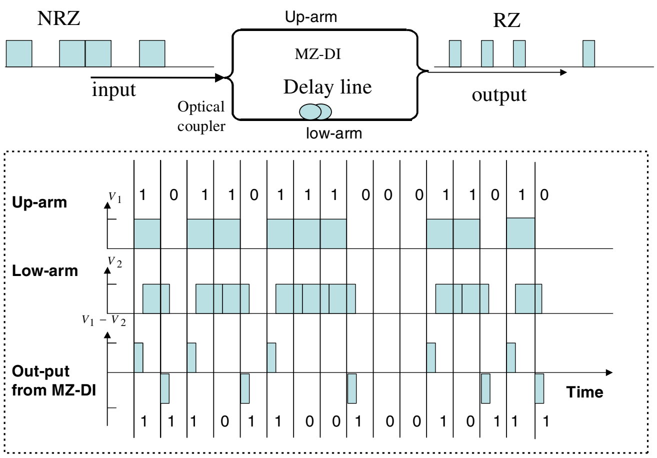

Fig. 2. The principle for format conversion from NRZ to RZ based on a MZ-DI.

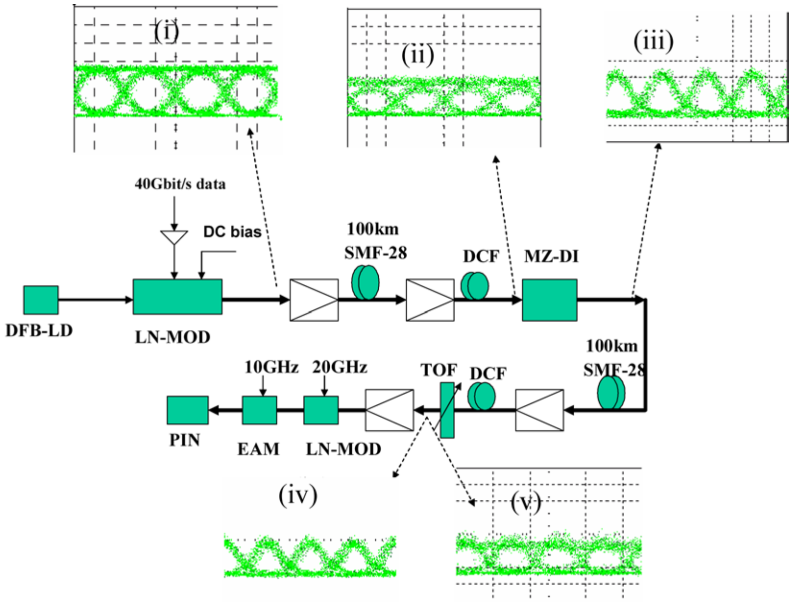

Fig. 3. Experimental setup and typical eye diagrams at different nodes (10 ps/div).

cycle of 0.5 is obtained. Since the fiber delay can be affected by the temperature, we put the MZ-DI in an isolated box covered by some heat insulator to make the MZ-DI demodulator more stable. The eye diagrams before and after format conversion is inserted in Fig. 3 as inset (ii) and (iii). The corresponding optical spectra are shown in Fig. 4. Fig. 4 illustrates that the converted RZ signals are modified duobinary signals. Then the RZ signals are amplified to 7.5 dBm and it is transmitted another 100 km SMF-28 and matching DCF. The first 100 km fiber is used to emulate the metro or access network, and the second 100 km fiber is used to emulate the core network. The 40 Gbit/s NRZ original signal and transmitted signals are optical time-division de-multiplexed by using a cascaded LN-MOD and EAM. The LN-MOD and EAM are driven by 20 and 10 GHz clock signals, respectively. At the receiver, a tunable optical filter (TOF) with a 3 dB bandwidth of 1.4 nm is used to suppress the ASE noise of EDFAs. The 10 Gbit/s de-multiplexed signal is detected by a PIN receiver with a 3-dB bandwidth of 7 GHz. Clock recovery circuit is also realized in the PIN receiver. The BER of the de-multiplexed 10 Gbit/s signal is measured and shown in Fig. 5. First we measure the BER performance after we remove the transmission fiber, it is shown that the RZ signals have 0.8 dB improvement of receiver sensitivity at a BER of 10^{-9}. Then we connect the 200 km transmission fibers and their matching DCFs, it is shown that the power penalties for NRZ and RZ signals after transmission are 1.3 and 0.8 dB. When the BER for NRZ signal transmission over 200 km SMF-28 is measured, we remove the MZ-DI. RZ signals can tolerant high nonlinear effects and PMD, therefore, the

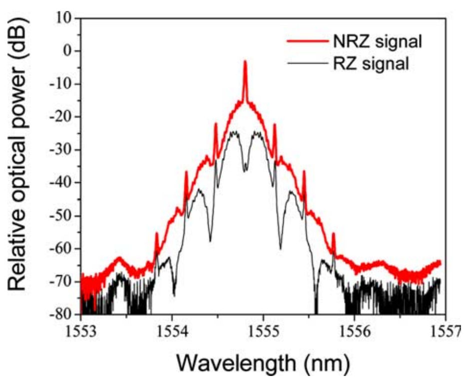

Fig. 4. Measured optical spectra. BW: 0.01 nm.

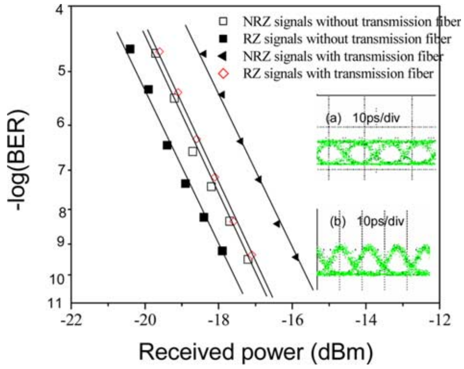

Fig. 5. Measured BER performance: (i) 40 Gbit/s NRZ eye diagram without transmission fiber; (ii) 40 Gbit/s converted RZ signal without transmission fiber.

RZ signals have a small power penalty after transmission.

We investigate the nonlinear tolerance of the RZ signals. We remove the 100 km SMF-28 and DCF before the MZ-DI and keep the fiber after the MZ-DI. In this situation, a NRZ signals are directly converted into RZ signals after the MZ-DI. We change the input powers into the SMF-28 and keep the input power into the DCF to be 0 dBm. Fig. 6 shows the power penalty as a function of the input power. For comparison, we also measure the NRZ nonlinear tolerance performance; in this case the MZ-DI is removed from the experiment setup. Fig. 6 shows that the RZ signals can tolerant higher input power. At a power penalty of 2 dB, RZ signals can tolerant over 3.5 dB launch power more than NRZ signals.

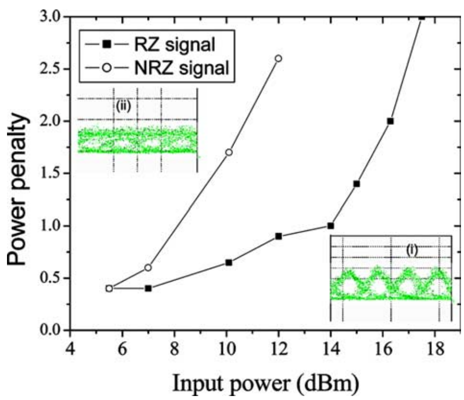

Fig. 6. Power penalty as a function of input power. Inset eye diagrams: (i) RZ; (ii) NRZ with input power into SMF-28 of 15 dBm.

4. Conclusions

40 Gbit/s signal format conversion from NRZ to RZ has been proposed and successfully demonstrated for the first time. The converted signal has a minimal duty cycle of 0.5 and the receiver sensitivity of the demultiplexed RZ signal is 0.8 dB better than that of the NRZ signal. The format converter as a network element has been implemented successfully in a 200 km transmission system. Our results show that the converted signals improve transmission performance significantly. Furthermore, through simple design and operation, the cost of future network elements that interface the metro/access and high-speed, long-haul OTDM core networks can be reduced.

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