Multi-channel all-optical format conversions from RZ signals with different duty-cycle to NRZ signals

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Abstract

We propose and theoretically demonstrate multi-channel all-optical non-return-to-zero (NRZ) format to return-to-zero (RZ) format conversions for wavelength division multiplexing (WDM) network. By using two fiber based delay interferometers (DIs) with free spectral range (FSR) of 20GHz and 40GHz, 8*10Gb/s (200GHz spacing on ITU grid) RZ signals can be converted to corresponding NRZ signals with small penalty. The principle and simulation are analyzed in both time and frequency domains. Format conversions are demonstrated for multi-channel RZ signals with duty cycle of 33%, 50% and 66% respectively. Q factors before and after the multi-channel RZ-to-NRZ conversions show a good performance and thus the practicability of the proposed format converter.

Keywords: Format conversion**,** Non-return-to-zero (NRZ), Return-to-zero (RZ), Multi-channel, Different duty cycles

Introduction

All-optical networks are likely to be a hybrid of wavelength division multiplexing (WDM) and optical time division multiplexing (OTDM) networks, adopting the advantages of both technologies [1]. The return-to-zero (RZ) format is widely used in OTDM networks due to its tolerance to fiber nonlinearities in spite of dispersion-induced effects, while the non-return-to-zero (NRZ) is preferred in WDM networks for its ease of implementation, relatively high spectral efficiency and timing-jitter tolerance. Therefore, format conversion between NRZ and RZ is a desirable function at the nodes of OTDM and WDM networks. Several papers have demonstrated all-optical format conversions from NRZ-to-RZ [2-6]. These approaches, though achieving the format conversions based on various techniques, remain inherently single-channel operation and thus cannot offer the advantage of parallel optical processing. Multi-wavelength all-optical conversions between NRZ and RZ modulation formats with tunable duty cycle are highly desirable for WDM network and all-optical parallel signal processing.

Photonics and Optoelectronics Meetings (POEM) 2009: Optoelectronic Devices and Integration,
edited by Zishen Zhao, Ray Chen, Yong Chen, Jinzhong Yu, Junqiang Sun, Proc. of SPIE
Vol. 7516, 75160X · © 2009 SPIE · CCC code: 0277-786X/09/$18 · doi: 10.1117/12.840746

In this paper, we therefore propose and demonstrate simultaneous and regenerative WDM RZ to NRZ format conversions, using two fiber based delay interferometer (DI) with specific free spectral range (FSR). As we know, the main difference for RZ and NRZ spectra is the sidebands, and from the spectral domain, the two DIs act as comb-like filters, which can perform selectively filtering for the spikes in the multi-channel RZ spectra at the same time. By using two DIs with FSR of 20GHz and 40GHz, 8*10Gb/s (200GHz spacing on ITU grid) RZ signals can be converted to corresponding NRZ signals with small penalty. The principle and simulation are analyzed in both time and frequency domains. Format conversions are demonstrated for multi-channel RZ signals with duty cycle of 33%, 50% and 66% respectively. Q factors before and after the multi-channel RZ-to-NRZ conversions show a good performance and thus the practicability of the proposed format converter.

Operation principle and simulation results

The schematic setup is shown in Fig. 1, 8 continuous wave (CW) channels from a DWDM laser array, at wavelengths from 1547.79 to 1559.79 nm with 200GHz spacing, are coupled via an array waveguide grating (AWG) into two Mach-Zender modulators (MZMs). The first MZM is driven by a 10 Gb/s 2^{31}-1 PRBS pattern to generate NRZ signals, and the second one is driven by a synchronized RF clock signal to form multi-channel RZ signals. The polarisation of the signals input to the MZM is optimised with a polarisation controller (PC). The output power can be controlled by the subsequent EDFA and attenuator (ATT). The RZ signals are then input a multi-channel format converter consisting of two fiber based DIs to perform the RZ to NRZ signal conversions with different input duty cycles. The output NRZ signals are de-multiplexed by another AWG.

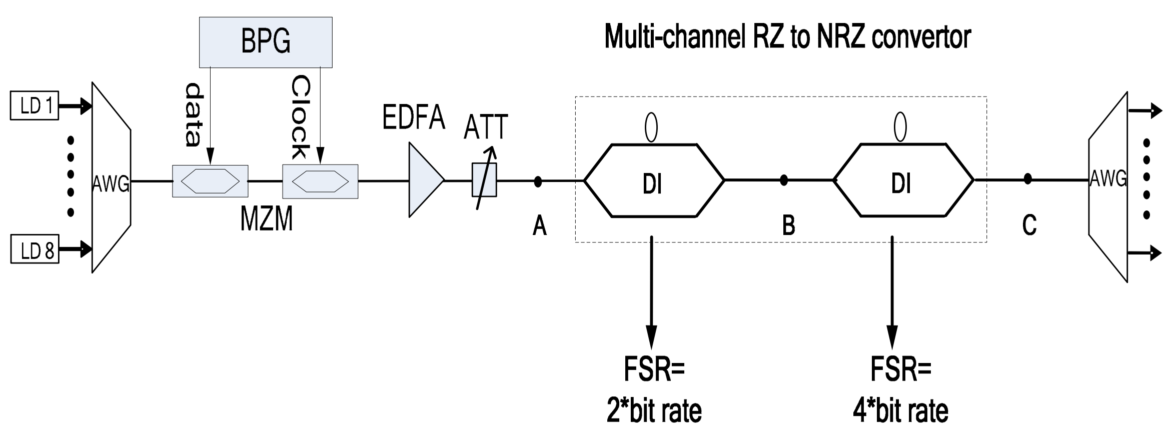
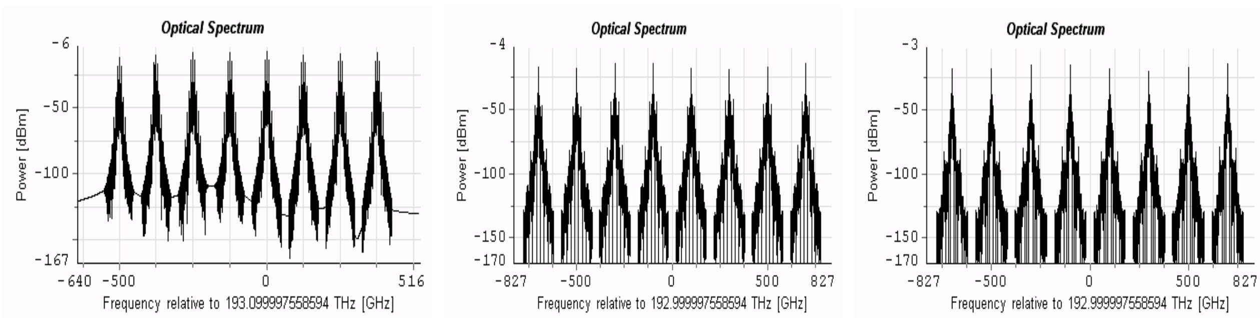


Fig. 1 The schematic setup

From the point of view of optical spectra domain, the DIs act as the comb filters which select the carrier and eliminate the sidebands in the RZ spectrum. For RZ signal with large duty cycle, the high order sidebands in the spectrum are very weak, and thus one DI is enough to perform the RZ to NRZ conversion. However, for RZ signal with small duty cycle, the high order sidebands in the spectrum are much stronger, and thus single DI fails to eliminate all of them. In this case, one DI with FSR as twice as signal modulation bandwidth is used to preprocess the RZ signal, and another subsequent DI with FSR as fourfold as signal modulation bandwidth is added to filter the remaining sidebands and thus complete the format conversion.

Firstly, we use 8*10 Gb/s channel RZ signals with 33% duty cycle to demonstrate the feasibility of the format converter. The channel spacing of the input RZ signals is 200 GHz, and the FSR for the two DIs are 20 and and 40 GHz respectively. The simulated optical spectra corresponding to points A, B and C are shown in Fig. 2 (a) to (c), showing the RZ spectra before the format converter, the preprocessed spectra after the first DI and the converted NRZ spectra after the second DI respectively. In order to illustrate the principle of the proposed format conversion, we show details for one of the 8 channels, as the spectra and eye diagrams shown in Fig. 3 and Fig. 4.

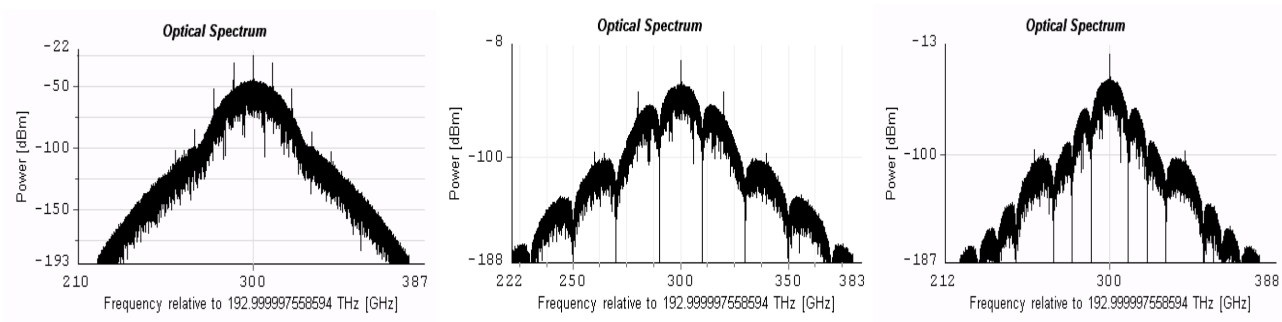


(a) (b) (c)

Fig. 2 Optical spectra corresponding to points A, B and C in Fig. 1

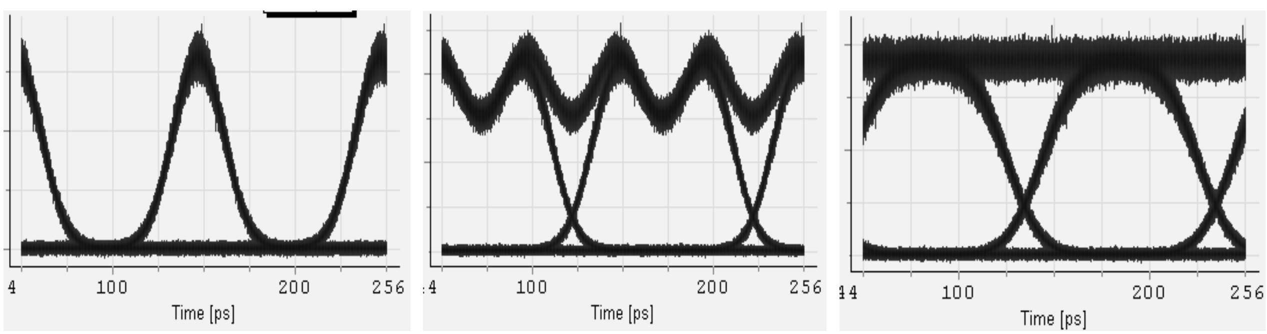
(a) Spectra for multi-channel RZ signals (b) spectra after the first DI (c) spectra after the second DI

Fig. 3(a) is the original spectrum of input RZ signal. It is clear that the sidebands are obvious and their spacing equals to the signal modulation bandwidth (10 Gb/s). The sidebands are strong and exist at ±10, ±20, ±30, ±40 GHz, and so on. Fig. 3(b) shows the spectrum after the first DI. We can see that the carrier can pass through the comb-like DI, and some of its spectral spikes (such as ±10, ±30 and so on) are first suppressed by the DI. Meanwhile, some other spikes (such as ±20, ±40 and so on) can also pass through the DI, leading ripples on the top of the pre-processed signal [7], as the eye diagrams shown in Fig. 4(b). At the second DI, the remaining spikes, which corresponding to the ripples, are filtered and only the carrier can pass through, resulting in NRZ signals with no ripples, as shown in Fig. 4(c). Please note that, due to the periodical transmission profile of the comb-like DI, the multi-channel input RZ signals can experience the same filtering and be converted to NRZ signals at the same time.



(a) (b) (c)

Fig. 3 Spectral evolutions for one of the multi-channel signals (a) RZ signal (b) Preprocessed signal after the first DI (c) converted NRZ signal

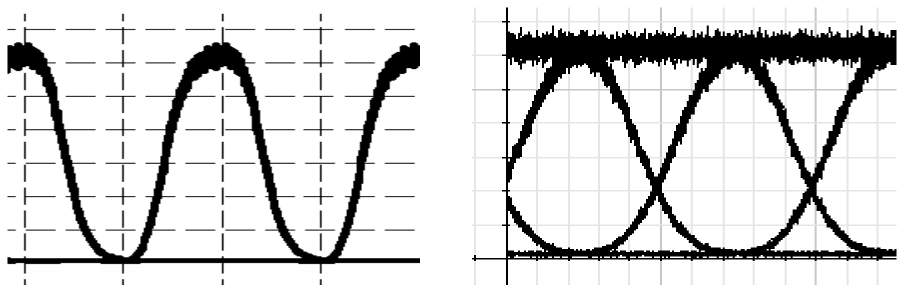


(a) (b) (c)

Fig. 4 Eye diagrams for the RZ to NRZ conversion (a) original RZ signal (b) preprocessed signal (c) converted NRZ signal

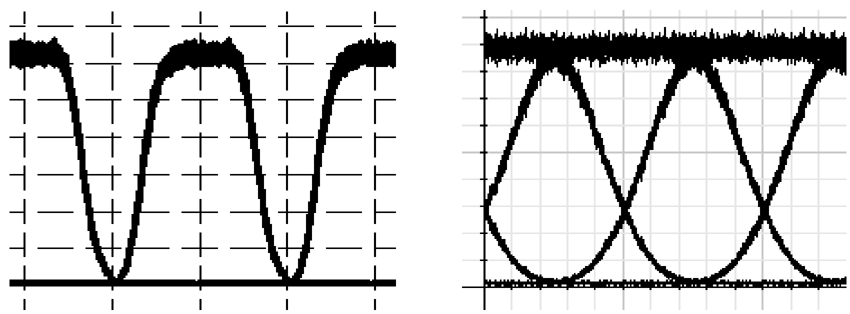
In order to evaluate the performance of the multi-channel format converter, we calculate and compare the BER equivalent Q factors before and after the conversions. Taking one of the 8 channels for example, the Q factors are 25.9 and 21.2 dB for input RZ signal and output NRZ signal respectively. Considering the receiver sensitively for RZ and NRZ signals, the Q penalty is very small, showing the good performance for the proposed format converter.

We also investigate the format conversions with RZ duty cycles of 50% and 66%, as the eye diagrams in Fig. 5 and Fig. 6 shown. Results indicate that RZ signals with 50% and 66% duty cycles can also converted to corresponding NRZ signals with small Q penalty. The proposed format converter can also work well for input RZ signals with other duty cycles at 10 Gb/s. The sidebands at 10 GHz and its odd harmonics can be suppressed by the first DI, while the other spikes can be filtered by the followed second DI.



(a) (b)

Fig. 5 Eye diagrams for the RZ to NRZ conversion with 50% duty cycle (a) original RZ signal (b) converted NRZ signal



(a) (b)

Fig. 6 Eye diagrams for the RZ to NRZ conversion with 66% duty cycle (a) original RZ signal (b) converted NRZ signal

Conclusions

We have proposed and demonstrated multi-channel all-optical NRZ format to RZ format conversions for WDM network, using two fiber based DI with specific FSR of 20GHz and 40GHz. 8*10Gb/s (200GHz spacing on ITU grid) RZ signals with different duty cycles can be converted to corresponding NRZ signals with small penalty. The principle and simulation are analyzed in both time and frequency domains. Format conversions are demonstrated for multi-channel RZ signals with duty cycle of 33%, 50% and 66% respectively. Q factors before and after the multi-channel RZ-to-NRZ conversions show a good performance and thus the practicability of the proposed format converter.

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