JThB32.pdf

Novel NRZ-to-RZ format conversion with tunable pulsewidth using phase modulator and interleaver

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Abstract: We experimentally demonstrate a 10-Gb/s NRZ-to-RZ format conversion with tunable pulsewidth using phase modulation followed by interleaver. RZ signals with pulsewidth of 34~84 ps are obtained with extinction ratio over 15 dB and negative power penalty. ©2005 Optical Society of America

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1. Introduction

Future all-optical networks are likely to employ and support a variety of modulation and data formats, such as nonreturn-to-zero (NRZ) and return-to-zero (RZ) formats. RZ data format is widely employed in optical time-division multiplexing (OTDM) systems, owing to its tolerance to polarization mode dispersion and superior performance in terms of receiver sensitivity and transmission performance. Whereas NRZ format is preferred in optical wavelengthdivision multiplexing (WDM) networks for its high spectral efficiency and timing-jitter tolerance. Therefore, format conversion between NRZ and RZ is desirable in linking and interfacing ultra-fast OTDM and WDM networks. Different approaches based on nonlinear optics technique have been proposed to realize the format conversion from NRZ to RZ including the use of nonlinear optical loop mirror (NOLM) [1], semiconductor optical amplifier (SOA) [2], or SOA-based interferometric devices [3]. But these nonlinear techniques are sensitive to the input power of optical signal. Recently, several passive and simple methods using delay-interferometer have been utilized to implement the NRZ to RZ format conversion [4,5], however, the input NRZ signal should be pre-coded by using a differential encoder to achieve the conversion function exactly.

In this paper, we propose and experimentally demonstrate a 10-Gb/s NRZ to RZ format conversion with tunable pulsewidth using a clock-driven phase modulator followed by a 50-GHz interleaver. The proposed scheme offers the following advantages: i) the pulsewidth of the generated RZ signal can be changed by tuning the relative offset between the input signal and the interleaver, which is different from the conventional pulse carver such as a clock-driven Mach Zehnder (MZ) modulator [5]; ii) no additional differential encoder is needed, and iii) the conversion is not sensitive to the input power. In conjunction with an NRZ transmitter, the proposed converter can be used as an RZ transmitter, which is attractive for the upgrade of existing NRZ transmitters into RZ transmitters [6]. In addition, the proposed conversion scheme could also serve as an optical pulse generator with tunable pulsewidth once the input signal is a CW light, instead of an NRZ optical signal [7].

2. Operation Principle



Fig. 1. Operation principle of the proposed NRZ-to-RZ converter.

Fig. 1(a) shows the proposed NRZ-to-RZ format conversion module using phase modulation followed by an interleaver. An input NRZ light is first phase-modulated by an RF square-wave clock signal with the same repetition

JThB32.pdf

rate as the input NRZ signal. Due to the induced phase modulation, the mark levels of the input NRZ signal experience blue shift (up chirp) at the rising edge of the clock, and red shift (down chirp) at the falling edge. This linear phase modulation leads to frequency chirp and power reallocation, hence resulting in a spectral broadening. As shown in Fig. 1(b), the different shadow patterns in the mark levels represent different wavelength shifts. The pattern at the rising edge corresponds to the blue-shift part of the optical spectrum, while that at the falling edge represents the red-shift part. By filtering out the blue or red shift spectral component using an interleaver, an RZ signal is obtained as shown in Fig. 1(b). The pulsewidth and chirp of RZ signal can be changed by finely tuning the relative spacing between input signal and interleaver. Therefore, the format conversion from NRZ to RZ with tunable pulsewidth is achieved using the phase modulation followed by an optical interleaver.

3. Experiment and Results



signal before/after phase modulation, as well as the interleaver's spectral response.

To evaluate the performance of the proposed format converter, a 10-Gb/s NRZ-to-RZ format conversion is experimentally demonstrated using the proposed technique. As shown in Fig. 2, light from a tunable laser is externally modulated by a LiNbO₃ intensity modulator with 2^{31} -1 PRBS to generate a 10-Gb/s NRZ signal. The NRZ signal is then fed into a phase modulator driven by a 10-GHz square-wave clock. A time delay component is used to make sure that the clock signal is temporally aligned with the input NRZ pattern. Due to the induced phase modulation, as shown in Fig. 3, the signal spectrum is noticeably broadened after the phase modulation. The output of phase modulator then passes through an interleaver with 50-GHz channel spacing, which spectral response is shown in Fig. 3. To filter out the red-chirped or blue-chirped spectral component, one of the maximum transmission peaks of the interleaver should be aligned with the upper or lower band of the phase modulated signal. We define the wavelength offset as the wavelength spacing between the central wavelength of the input NRZ signal and the nearest transmission peak of the interleaver. The positive wavelength offset indicates the upper-band filtering of the input NRZ signal, while the negative value represents the lower-band filtering. As shown in Fig. 3, the interleaver extracts the upper-band component of the phase-modulated input NRZ signal with wavelength offset of 0.16 nm. In this case, the RZ signal with pulsewidth of 49 ps and extinction ratio (ER) of 16.45 dB can be obtained at the output of the interleaver. Fig. 2 shows the corresponding eye diagram and data pattern of the converted RZ signal in comparison with the input NRZ signal.

By tuning the wavelength offset between the input signal and interleaver, the pulsewidth of the converted RZ signal can be finely changed. To evaluate the pulsewidth tunability of the format converter, the pulsewidth and ER of the converted RZ signal are investigated with respect to the change of wavelength offset. As shown in Fig. 4, with the increase of wavelength spacing between input signal and interleaver, pulsewidth of the converted RZ signal increases while ER decreases for both the upper-band and lower-band filtering. The RZ signal with pulsewidth from 34 ps to 84 ps can be obtained, and the ER is maintained above 15 dB, and up to 20 dB.

To further assess the performance of the proposed converter, the receiver sensitivities of the converted RZ signals with different pulsewidth were measured, and the measured BER curves were plotted in Fig. 5, in comparison with that of the input NRZ signal. It clearly shows that negative power penalty can be obtained for the converted RZ signals compared with the input NRZ signal, which is mainly due to the change of the data format. At BER of 10⁻⁹, receiver sensitivities from -21 dBm to -19.2 dBm could be obtained for the RZ signals with pulsewidth varying from 36.4 ps to 69.6 ps, showing 2.35 dB to 0.51 dB sensitivity gains over the input NRZ signal with -

JThB32.pdf

18.65-dBm receiver sensitivity. The sensitivity gain is reduced with the increase of the pulsewidth, which should be attributed to the increased duty cycle and the decreased ER. The corresponding eye diagrams are shown in Fig. 6. The results clearly demonstrate that a 10-Gb/s NRZ signal has been successfully converted to a RZ signal with a tunable pulsewidth.



Fig. 4. The pulsewidth and ER of converted RZ signals with tuning of the wavelength offset.

Fig. 5. Measured BER curves for the input NRZ signal and converted RZ signal with different pulsewidth.



Fig. 6. The eye diagrams of converted RZ signals with pulsewidth of (a) 36.4ps, (b) 40.6ps, (c) 49ps, and (d) 53.4 ps; time scale: 50 ps/div.

4. Conclusion

In this paper, we proposed and experimentally demonstrated a 10-Gb/s NRZ to RZ format conversion with tunable pulsewidth using a phase modulation followed by an interleaver. Without any nonlinear process involved, the format conversion is simply achieved using the optical filtering from a broadened spectrum resulting from clock-driven phase modulation. The experimental results show that, by tuning the wavelength offset between the input signal and the interleaver, an RZ signal with pulsewidth from 34 to 84ps could be obtained with an extinction ratio over 15 dB, and up to 20 dB. In addition, a negative power penalty is achieved. The device facilitates the cross-connection between optical transmission networks employing different modulation formats, and would be helpful for the timing-jitter suppression. Moreover, it can serve as a tunable pulse source with a CW light input instead of an NRZ signal.

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