Pulse-carver-free RZ-64 QAM transmitter using RZ drive signal with electronic CD pre-compensation

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Abstract: We propose a novel technique that can generate an optical return to zero quadrature amplitude modulation (RZ-QAM) signal without using a pulse carver. This technique permits electronic pre-compensation of the chromatic dispersion (CD) because the envelope of the optical waveform is not restricted by pulse carver performance. We successfully generate polarization multiplexed RZ-64 QAM signals (72 Gbit/s) with and without electronic CD pre-compensation. By utilizing 50% CD pre-compensation, the Q-factor is improved by 0.4 dB after 240 km (+4900 ps/nm) transmission.

Keywords: optical RZ-QAM, chromatic dispersion, pre-compensation

Classification: Fiber-Optic Transmission for Communications

References


1 Introduction

To handle the ever-increasing data traffic, high order optical QAM schemes and their variants have been widely investigated [1]. To achieve longer reach, RZ-QAM is one of the more attractive variations of optical QAM [2], though its spectral efficiency is lower than that of non-return-to-zero QAM (NRZ-QAM). The conventional RZ-QAM transmitter, constructed with IQ-modulator and pulse carver, requires two sets of driver circuits and skew controller. Moreover, it makes electronic pre-compensation of dispersion [3] quite difficult, because the strongly predistorted RZ-QAM signal envelope cannot be generated by an RZ-QAM transmitter with pulse carver.

In this letter, we propose a novel technique to generate an optical RZ-QAM signal without using a pulse carver. Using this technique, we successfully generate polarization multiplexed RZ-64 QAM signals (72 Gbit/s) with and without electronic CD pre-compensation. After 240 km (+4900 ps/nm) transmission, both the power tolerance and the Q-factor are improved by CD pre-compensation. This technique easily supports other RZ-QAM formats such as RZ-QPSK or RZ-16 QAM. Moreover, the proposed transmitter can also generate NRZ-QAM signals by changing the setting of the digital signal processor (DSP). Thus high spectral efficiency can be achieved by selecting NRZ-QAM without changing the hardware. It means that the proposed technique offers elastic optical networking.

2 Construction of conventional and proposed RZ-QAM transmitter

Fig. 1 (a) shows the construction of the conventional RZ-64 QAM transmitter. CW light is launched into an IQ-modulator, which is driven by two 8-level drive signals (denoted D_I and D_Q), corresponding to In-phase data and Quadrature-phase data. D_I and D_Q are generated by a digital analogue converter (DAC) using 6 bit streams, denoted D_1∼D_6. The phase shifter (PS) and phase modulators (PM) inside the IQ-modulator are biased at the π/2 and null point, respectively. The generated NRZ-64 QAM is launched to a pulse carver, which is driven by a clock signal. The optical delay between the pulse carver and IQ-modulator is cancelled by a skew controller.

Fig. 1 (b) shows the construction of the proposed RZ-64 QAM transmitter. In this technique, the DSP inserts a 0 level between the symbol to create a multilevel RZ drive signal. Output of the DSP is launched into the DAC, and D_I and D_Q are generated. Between the symbols, D_I and D_Q fall to 0 level simultaneously. Because PM inside the IQ-modulator is biased at the null point, optical power is often minimized and RZ-pulse shaping can be achieved without a pulse carver and skew controller. When CD in the trans-
mission line is significant, electronic CD pre-compensation can be added to the multilevel RZ drive signal by a DSP, using the inverse transfer function of the transmission line [3]. Note that, if the proposed transmitter shown in Fig. 1 (b) skips the procedure of 0 level insertion, it generates NRZ-64 QAM instead of RZ-64 QAM. Switching between these formats can be achieved by changing DSP setting.

Fig. 1 also shows the examples of D_I (or D_Q). For ease of understanding, these examples do not use CD pre-compensation or reshaping filters. In the conventional transmitter, D_I and D_Q are 8-level signals, and 64 = 8^2 traces appear at cross points (see Fig. 1 (a)). In the proposed transmitter, D_I and D_Q are multilevel RZ signals, and only 8 traces appear in the eye diagram (see Fig. 1 (b)). Because of the simple waveform, clear eye-opening can be achieved without reshaping filters.

![Fig. 1. Construction of transmitter for optical RZ-64 QAM, and drive signal for IQ-modulator (without CD pre-compensation or reshaping filters). (a) Conventional construction and waveform of 8-level drive signal. (b) Proposed construction and waveform of multilevel RZ drive signal.](image)

### 3 Experimental setup

We measured the Q-factors of a polarization multiplexed RZ-64 QAM signal (6 G baud, 72 Gbit/s) generated by the proposed technique, shown in Fig. 1 (b). Because of the restriction of the experimental setup, multilevel RZ drive signals D_I and D_Q were generated by an offline computer and arbitrary waveform generator (AWG), instead of a DSP and DAC. Data sequences for D_I and D_Q were generated by an offline computer, using six 2^{15}-1 PRBS patterns. After zero insertion and electronic CD pre-compensation, generated data sequences were uploaded to the AWG, and drive signals D_I and D_Q were generated. Baud rate was 6 G baud, and sampling rate was 2 samples per symbol (one sampling point was used to make 0 level). The
CW light source generated the 1550 nm signal light, and its linewidth was less than 100 KHz. Examples of the generated optical signal are shown in Fig. 2. Fig. 2 (a) shows the waveform without pre-compensation. It shows RZ-QAM was successfully generated. Fig. 2 (b) shows the waveform with pre-compensation of $-4900 \text{ ps/nm}$. The optical pulse was spread and peak to average power ratio was decreased. Fig. 2 (c) shows the experimental setup of the 240 km transmission line and digital coherent receiver. Before transmission, polarization multiplexing (PolMUX) was achieved by a few meter delay line and polarization beam combiner. The optical power of the test signals before transmission was set to $-29 \text{ dBm}$ by a variable optical attenuator (VOA), to normalize the optical signal to noise ratio (OSNR) before transmission. The generated signals were launched into three consecutive spans, each 80 km single mode fiber (SMF) and a repeater amplifier. Fiber launched power $P_{in}$ was controlled by the VOA after the repeater amplifier. Total chromatic dispersion of the 240 km transmission line was $+4900 \text{ ps/nm}$ at the signal wavelength, and no optical dispersion compensator was used in this experiment. Linewidth of local light used for homodyne detection was less than 100 KHz. The transmitted signal light and local light were launched into a coherent receiver based on a dual polarization optical hybrid and balanced photodetector. The detected signals were stored in a digital storage oscilloscope, and the Q-factor was calculated by offline processing.

Before the transmission experiment, we measured the Q-factor in back to back operation. Transmission line and repeater amplifier inside the bracket shown in Fig. 2 (c) were skipped, and CD pre-compensation was not used. Measured Q factor was 9.8 dB at OSNR = 25 dB /0.1 nm. For comparison, we also measured the Q-factor with the conventional transmitter shown in Fig. 1 (a). Measured Q factor was 9.4 dB at OSNR = 25 dB /0.1 nm, which means that no penalty was induced by the proposed technique.
4 Result and discussion

We measured the Q-factor after 240 km (+4900 ps/nm) transmission, with the proposed transmitter shown in Fig. 1 (b). The fiber launched power $P_{in}$ was $-3$ dBm $\sim +1$ dBm. Fig. 3 shows the result. Hollow symbol shows Q-factor without pre-compensation. Maximum Q-factor, 8.6 dB, was achieved with $P_{in} = -0.5$ dBm. Filled symbol in Fig. 3 shows Q-factor with 50% ($-2450$ ps/nm) CD pre-compensation. Maximum Q-factor 9.0 dB was achieved with $P_{in} = 0.1$ dBm. It means both the Q-factor and maximum fiber launch power were increased with 50% CD pre-compensation. Fig. 3 also shows constellations measured at $P_{in} = -0.5$ dBm and 1.0 dBm. Without pre-compensation, the constellation was degraded compared to that with 50% CD pre-compensation, especially in high $P_{in}$. Without pre-compensation, stars at four corners which means high optical electric field, exhibited interference. The 50% CD pre-compensation suppressed the optical nonlinear phenomena in the transmission line and thus the phase noise [4], which improved the transmitted signal quality.

![Fig. 3. Measured Q-factor and constellation after 240 km transmission. filled symbol: with 50% ($-2450$ ps/nm) pre-compensation of CD. hollow symbol: without pre-compensation of CD.](image)

5 Conclusion

We proposed a pulse-carver-free RZ-QAM transmitter that enables electronic CD pre-compensation. We used the proposed technique to successfully generate a polarization multiplexed RZ-64 QAM (72 Gbit/s) signal with and without electronic CD pre-compensation. We also showed that 50% pre-compensation prevented the phase noise caused by optical nonlinear phenomena. After 240 km transmission (+4900 ps/nm), measured maximum Q-factor was 9.0 dB with 50% CD pre-compensation, but 8.6 dB without CD pre-compensation.

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