Improved Margin in Long-Haul 40 Gb/s Systems Using Bit-Synchronously Modulated RZ-DQPSK

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Abstract: We demonstrated a substantial improvement in FEC margin at 40 Gb/s using bit-synchronously modulated RZ-DQPSK. We transmitted 28×40 Gb/s CRZ-DQPSK channels over 6,550 km with ~2 dB of actual FEC margin, without any PMD compensation.

OCIS codes: (060.2330) fiber optics communications; (060.5060) phase modulation

1. Introduction

Recent 40 Gb/s research efforts have been focused on improving the average transmission performance by using advanced modulation formats such as RZ-DBPSK [1, 2], or alternate polarization (AP)RZ-DBPSK [3]. Less emphasis has been placed on Q-factor fluctuations, which are just as important as average performance for the design of 40 Gb/s transmission systems. PMD induced fluctuations greatly limit the performance of transoceanic length systems. For example in a 6,500 km path with PMD of $0.06\,ps/\sqrt{km}$, there is ~1.2% probability that the accumulated DGD will exceed 10 ps, or 43% of the bit time for OC-768 with 7% FEC overhead. The resulting margin requirements could render 40 Gb/s transoceanic transmission impractical. Thus, a modulation format with much better PMD tolerance would be required. DQPSK, with the reduced symbol rate, is much less affected by PMD than DBPSK. However, the worse nonlinear tolerance of DQPSK has prevented its transmission over transoceanic distances [4-5].

In this paper, we report on the first 40 Gb/s transmission over transoceanic distance using synchronously modulated DQPSK formats. We show improved nonlinear tolerance using RZ pulses bit-synchronously modulated with either phase modulation (CRZ) or polarization modulation (PRZ). We demonstrate ~2 dB actual FEC margin for the transmission of twenty-eight 40 Gb/s CRZ-DQPSK channels (with 133 GHz channel spacing) over 6,550 km using only single-stage C-band EDFAs, no in-line regeneration, and without PMD compensation. Furthermore, for the first time, we quantify the long-term Q-factor distributions for 40 Gb/s transoceanic length transmission and demonstrate a substantial fluctuation advantage for CRZ-DQPSK over both RZ-DBPSK and APRZ-DBPSK.

2. Experimental setup

The transmitter and receiver block diagrams are shown in Fig. 1. Twenty-eight channels with 133 GHz channel spacing at a bit rate of 42.7 Gb/s were transmitted using the DQPSK or DBPSK modulation formats. The bit synchronously modulated RZ-DQPSK transmitter (Fig. 1a) consisted of a DQPSK modulator, an RZ modulator, and either a polarization or phase modulator. Odd channels were modulated by a common serial DQPSK modulator and even channels by a parallel modulator. The DQPSK modulators were driven by two 21.4 Gb/s pre-coded 2^{15}-1 PRBS (note: word length limited by BERTs memory). Adjacent channels were randomly polarized (PRZ) or orthogonally polarized (CRZ) and modulated with inverted and delayed data patterns. The RZ-DBPSK and APRZ-DBPSK transmitters (Fig. 1b) consisted of a DBPSK modulator, an RZ modulator, and an alternate polarization modulator (bypassed for RZ-DBPSK). The DBPSK modulators were driven by 42.7 Gb/s 2^{23}-1 PRBS. Adjacent channels were randomly polarized and modulated with inverted and delayed data patterns.

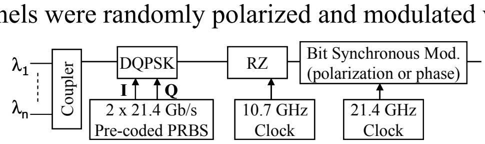

Fig. 1a. Bit synchronous RZ-DQPSK transmitter (one rail).

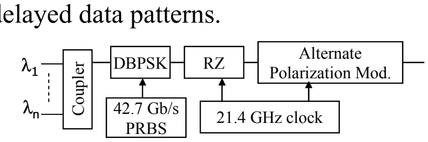

Fig. 1b. RZ-DBPSK and APRZ-DBPSK transmitter (one rail).

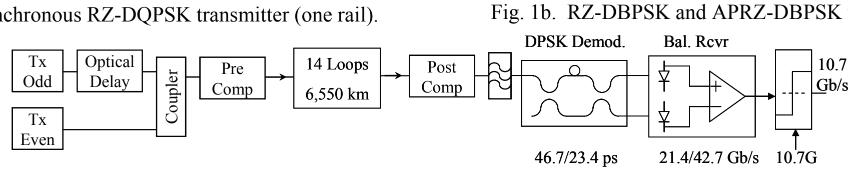

Fig. 1c. Schematics of 40 Gb/s bit synchronous RZ-DQPSK, RZ-DBPSK, and APRZ-DBPSK transmitters and receivers.