Optical differential binary phase shift keying of return-to-zero pulses for long-haul DWDM transmission systems

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Abstract

Transmission of 12.5 Gb/s return-to-zero differential binary phase shift keyed (RZ-DBPSK) DWDM signals with 25 GHz channel spacing in a circulating loop was performed. Test results show that transmission distance of 3000 km over SMF-28 fiber is feasible without Raman amplification and without special dispersion management. Direct comparison of the DBPSK and OOK formats had shown at least 4-dB signal-to-noise ratio advantage of the DBPSK due to better resistance to nonlinearities and balanced detection.

Introduction

It had been demonstrated experimentally and by simulation [1-3] that the RZ-DBPSK format offers better resistance to fiber nonlinearities than RZ-OOK. In this paper we report results on transmission tests of 12.5 Gb/s RZ-DBPSK and RZ-OOK DWDM signals with 25 GHz spacing in a SMF-28 fiber based circulating loop without distributed Raman amplification or dedicated dispersion map such as pre-or-post-compensation. Test results show that transmission over a distance of 3000 km is feasible when SuperFEC (25% overhead) is employed. Comparison of the two formats show that DBPSK has at least 4 dB SNR advantage over OOK.

Experimental setup and results

The experimental setup is shown in Fig. 1. Seven or nine DFB lasers (25-GHz spaced) are combined using a fiber coupler before launching into a lithium niobate Mach-Zehnder modulator (MZM) driven by a 12.5 GHz sine wave producing an RZ optical pulse train. The RZ optical pulse (approx. 50% duty cycle) is encoded with a DBPSK (or OOK) signal using a push-pull MZM biased at null (or quadrature) driven by a 12.5 Gb/s NRZ data (PRBS: 2^7-1) with peak-to-peak voltage of $2V_\pi$ (or V_π).

The DWDM signals are amplified and launched into a circulating loop through an acousto-optic switch. All the channels in the same polarization state are launched into the loop that consists of 82.4 km of SMF-28 fiber followed by 10.9 km of Corning dispersion compensating fiber. One EDFA is used to boost the launch optical power into the SMF-28 span and another one to compensate for the loss in the switch and coupler. Due to the short loop length, a polarization controller is inserted in the bop for long-haul transmission tests in order to compensate for the polarization-dependent losses. The output signal is filtered, polarization controlled and split to ensure a proper polarization state at the input of an asymmetric Mach-Zehnder (AMZ) demodulator. The polarization-sensitive AMZ demodulator has a differential delay of 80 ps, and its temperature is stabilized using a thermo-electric cooler. A fiber Bragg grating filter is used to select the center channel. The optical signal was tapped-off for clock recovery before the amplifier and detected by either a single photoreceiver or a balanced photoreceiver (for DBPSK only). For the case of OOK detection the AMZ demodulator was bypassed.

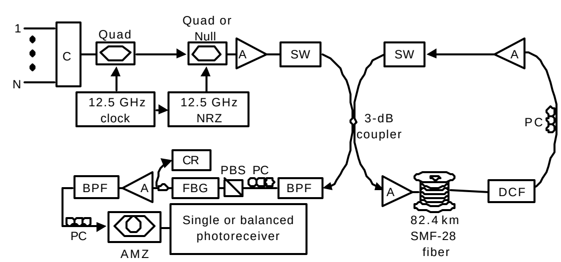

Fig. 1. Experimental setup. Number of channels N: 7 or 9, C: coupler, SW: switch, A: EDFA, DCF: dispersion compensating fiber, PC: polarization controller, BPF: bandpass filter, PBS: polarization beam splitter, FBG: circulator and fiber Bragg grating filter, CR: clock recovery, AMZ: asymmetric Mach-Zehnder demodulator.

Fig. 2 shows the bit-error-rate (BER) versus distance for RZ-DBPSK and RZ-OOK for the center wavelength in a 7-channel DWDM system with channel spacing of 25 GHz. DBPSK already shows advantage over OOK even for relatively short distances (≤ 400km). This is due to the fact that our demux fiber grating introduces an extra dispersion penalty that is partially compensated for by the AMZ demodulator.

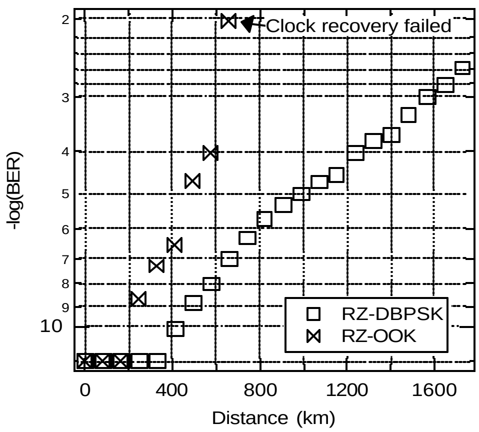

Fig. 2. Comparison of BER performance for RZ-DBPSK and RZ-OOK formats versus distance for the case of 7-channel of 25 GHz spacing at 12.5 Gb/s (PRBS: 2^7-1).

Furthermore, the improvement becomes truly dramatic for longer distances where the nonlinearity due to XPM coupled with tight channel spacing is significant. The performance difference increases with distance, as the tilt of the BER versus distance for OOK is significantly steeper compared to DBPSK. At about 600km, the eye degradation in OOK is so severe that the clock recovery fails to track the data, while the DBPSK signals are transmitted much further, up to 1730km at a BER of ≈ $2.5 \cdot 10^{-3}$. This relative performance improvement of DBPSK versus OOK increases with distance. The error-free distance in our loop is partly limited by a large VOA-induced loss of about 6dB that brings total loss per 82.4km span up to 43dB, but even then we observe in Fig. 2 a higher nonlinearity tolerance for DBPSK. Note that the optimum channel powers that provide the best system performance in both DBPSK and OOK cases are used in Fig. 2. Fig. 3 depicts further improvement of RZ-DBPSK transmission of nine 25 GHz spaced channels at 12.5 Gb/s when a balanced photoreceiver is utilized. Compared to a single photoreceiver, as in Fig. 2, the BER is about 10^{-6} at the distance of 1730km for the center channel corresponds to about 4.2dB increase in SNR. The upper and lower eye diagrams in Fig. 3 depict back-to-back and 2000km transmissions. Our circulating loop test shows that it is possible to transmit nine 12.5 Gb/s RZ-DBPSK signals with 25 GHz spacing to about 3000 km of SMF-28 fibers. The measured BER of the center channel at the receiver with balanced detectors was about $3x10^{-3}$. The corrected BER would be 10^{-15} using SuperFEC with 25% overhead for OC-192 signals.

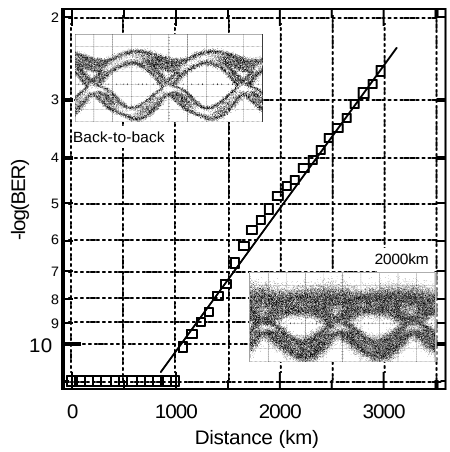

Fig. 3. BER performance of 12.5 Gb/s RZ-DBPSK versus distance for a 9-channel system with balanced detection.

Conclusions

We demonstrated that RZ-DBPSK modulation format has significant advantages versus RZ-OOK format in terms of fiber nonlinearities for a 12.5 Gb/s system with 25-GHz channel spacing over SMF-28 fiber. Using a regular photoreceiver, the net improvement of SNR amounts to 3.3dB for RZ-DBPSK relative to RZ-OOK at 1730km and increases with distance. Further improvement of an aggregate SNR to 4.2dB is achieved by using balanced detection.

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