NONLINEAR PENALTY REDUCTION OF RZ-DBPSK VERSUS RZ-OOK MODULATION FORMAT IN FIBER COMMUNICATIONS

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Abstract *We demonstrated RZ differential binary phase shift keying format has more than 3dB net improvement of signal-to-noise ratio versus RZ on-off keying format due to greater nonlinearity tolerance in both single channel and WDM systems.*

Introduction

Recently, there has been a great deal of interest in the differential binary phase shift keying (DBPSK) modulation format that significantly improves system performance relative to conventional on-off keying (OOK) modulation format [1-3]. In these papers a balanced photoreceiver was used that by itself provides typically about 3dB improvement in SNR, so that the net effect of DBPSK tolerance to the fiber nonlinearity was masked. Better understanding of nonlinear dynamics of DBPSK is vital for the next generation system designs using DBPSK modulation. In this paper, we present a direct comparison of RZ-DBPSK versus RZ-OOK system performance and some insights into key physical mechanisms responsible for higher tolerance of DBPSK with respect to the fiber nonlinearities.

Experimental results and discussion

The experimental setup is shown in Fig. 1.

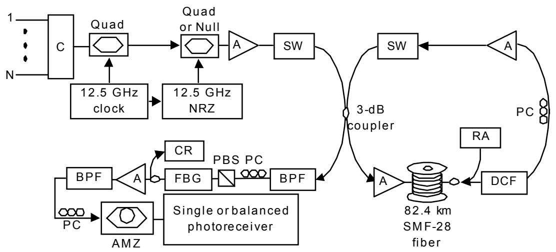

Fig. 1. Experimental setup. Number of channels N: 1, 7 or 9, C: coupler, SW: switch, A: EDFA, RA: Raman amplifier, DCF: dispersion compensating fiber, PC: polarization controller, BPF: bandpass filter, PBS: polarization beam splitter, FBG: circulator and fiber Bragg grating filter, CR: clock recovery,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

For single channel, a DFB laser (1546.9 nm) is coupled into a lithium niobate Mach-Zehnder modulator (MZM) driven by a 12.5 GHz sine wave producing a RZ optical pulse train. For DWDM test, seven or nine DFB lasers (25-GHz spaced) are combined using a fiber coupler before launching into the MZM. The RZ optical pulse (50% duty cycle) is encoded with 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 the peak-to-peak voltage of $2V_\pi$ (or V_π). The RZ-DBPSK or RZ-OOK signals are amplified and launched into a recirculating loop through an acousto-optic switch. All the channels at the same polarization are launched into a loop that consists of 82.4 km of SMF-28 fiber followed by 10.9 km of dispersion compensating fiber. Two EDFAs are used to boost the launch optical power into the SMF-28 span and to compensate for the loss in the switch and coupler. Backward-pumped Raman pre-amp with 9 dB on-off gain is used in some test cases. Due to the short loop length, a polarization controller is inserted in the loop for long-haul transmission tests, to compensate for the polarization-dependent losses. The output signal is filtered, polarization controlled and splitted 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 was temperature stabilized by a thermo-electric cooler. A fiber Bragg grating filter is used to select the center channel for the DWDM test case. An optical path was tapped-off for clock recovery before the amplifier and detected by either a single photoreceiver (for DBPSK or OOK) or a balanced photoreceiver (for DBPSK only). For the case of RZ-OOK detection the AMZ demodulator was bypassed.

A key advantage of DBPSK modulation format is that the power is homogenously distributed since there are no missing pulses, in contrast to an OOK format. As was pointed out in [1-3] this mitigates the cross-phase modulation (XPM) – induced pulse-pattern effect in WDM systems. However, even in a single channel case with no cross-phase modulation DBPSK has a significant advantage versus OOK. Indeed, Fig. 2 shows improvement of BER by as much as about 4.3 orders of magnitude for RZ-DBPSK compared to RZ-OOK in the same setup. This corresponds to the signal-to-noise ratio (SNR) improvement of about 3.3dB. Note that the optimum channel powers are 0.7dBm and 3.7dBm for the OOK and DBPSK cases respectively. Thus, the optimum peak power of the RZ pulses for both formats is the same providing a 3dB difference in the channel power.

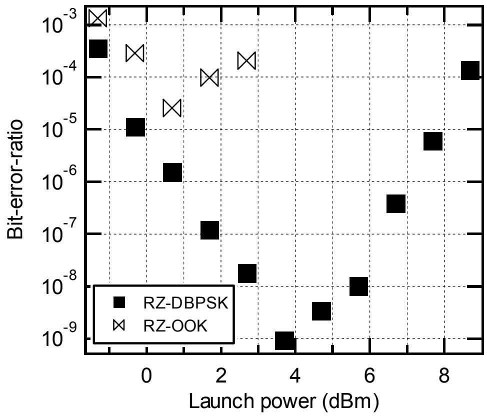

Fig. 2. Comparison of BER performance for RZ-DBPSK and RZ-OOK formats versus launched power for the case of a single channel at 12.5 Gb/s (PRBS: 2^7-1) at a distance of 1730 km. Raman gain: 9 dB.

Having estimated the net performance improvement due to a higher nonlinearity tolerance of RZ-DBPSK vs. OOK in a single channel system we further analyze WDM transmission to show the relative advantage of DBPSK in terms of XPM. Obviously, XPM is more pronounced when the channel spacing is tight. Fig. 3 shows BER dependence on distance for RZ-DBPSK and RZ-OOK for the center wavelength in a 7-channel system with channel spacing of 25 GHz. The measurements showed an advantageous performance of DBPSK in the linear regime for distances up to 400km. This is due to the fact that our demux fiber grating introduces an extra dispersion penalty which is partially compensated for by the AMZ demodulator. For longer distances where the nonlinearity is significant there is a drastic improvement of DBPSK performance versus OOK. The performance difference increases with distance, as the tilt of BER vs. 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 longer, up to 1730km at BER ≈ $10^{-2.6}$. The error free distance in our loop is partly limited by large VOA-induced losses of about 6dB. With the total losses per 82.4km loop adding up to 43dB, we observe in Fig. 3 a higher nonlinearity tolerance of DBPSK. The relative performance improvement of DBPSK vs. OOK increases with distance. Note that the optimum channel powers that provide the best system performance in both DBPSK and OOK cases are used in Fig. 3. Fig. 4 shows further improvement of RZ-DBPSK transmission when a balanced photoreceiver is utilized. Compared to the regular photoreceiver, as in Fig. 3, the BER ≈ 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. 4 depict the back-to-back and 2000km transmissions.

Conclusions

We demonstrated that RZ-DBPSK modulation format has significant advantages versus RZ-OOK format in terms of intra-channel self-phase modulation and four-wave mixing, as well as the inter-channel XPM tolerance for a 12.5 Gb/s system with 25-GHz channel spacing for 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 of 4.2dB is achieved by using balanced detection.

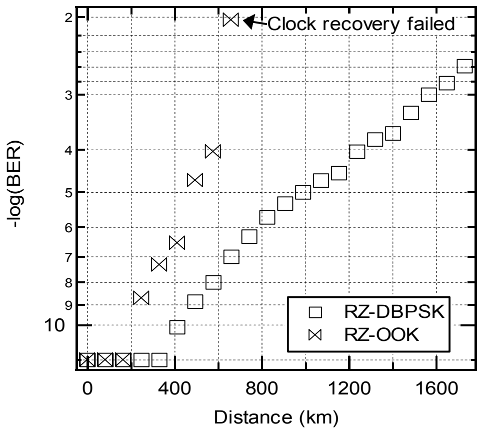

Fig. 3. Comparison of BER performance for RZ-DBPSK and RZ-OOK formats versus distance for the case of 7-channel of 25 GHz spacing at 12.5 Gb/s (PRBS: 2^7-1). No Raman amplifier.

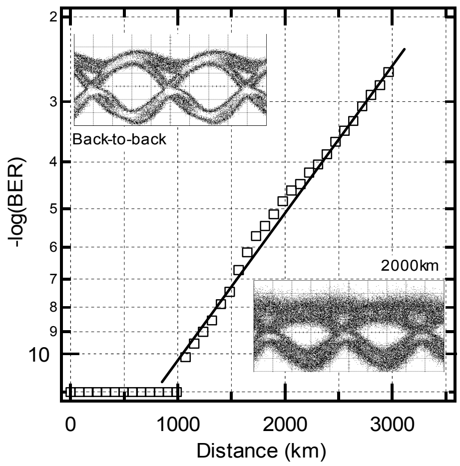

Fig. 4. BER performance of RZ-DBPSK vs. distance for 9-channel system with no Raman amplifier. Balanced photoreceiver was used.

References

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