20×112Gbit/s, 50GHz spaced, PolMux-RZ-QPSK straight-line transmission over 1540km of SSMF employing digital coherent detection and pure EDFA amplification

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Abstract: By using PolMux-RZ-QPSK modulation format and digital coherent detection, we have demonstrated 20×112Gbit/s DWDM transmission over 1540km of SSMF without using Raman amplification or optical dispersion compensation.

Introduction

Recently, 100GbE long-haul (LH) optical transmission has become a hot research topic. Several groups have experimentally demonstrated DWDM transmission using different modulation formats such as NRZ [1], vestigial NRZ [2-3], NRZ-DQPSK [4], RZ-DQPSK [5-7], PolMux-RZ-(D)QPSK [8-12], and OFDM [13,14]. With digital coherent detection, PolMux-RZ-QPSK is shown to be promising for high-speed transmission due to its high spectral efficiency as well its tolerance toward chromatic dispersion (CD) and polarization-mode dispersion (PMD). By using this modulation format, distributed Raman amplification and inline optical dispersion compensation, Ref. 8 has demonstrated 10x110Gbit/s DWDM transmission over 2375km of SSMF with realistic terrestrial span length. Although distributed Raman amplification brings in significant performance gain, it introduces considerable operational issues. Therefore it is important to consider whether EDFA-only optical amplification can be used for 100GbE long-haul transmission applications. Recently, we have demonstrated 20x107Gbit/s DWDM transmission over 1005km of SSMF by using RZ-DQPSK modulation format, EDFA-only amplification and 200GHz channel spacing [7]. In this paper, we experimentally explore the performance of 100GbE LH transmission using PolMUX-RZ-QPSK modulation format with 50GHz channel spacing. We report that twenty 50GHz-spaced 112Gbit/s signals have been successfully transmitted over 1540km (13×80km+5x100km) of straight-line SSMF.

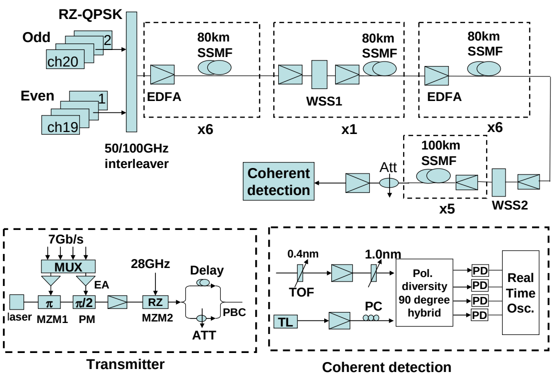

Fig.1. Experimental setup. TOF: tunable optical filter, TL: tunable laser, ATT: attenuator, EA: electrical amplifier

Experiment

The experimental setup is shown in Fig. 1. We have two 112Gbit/s PolMux-RZ-QPSK transmitters (the odd and the even), each modulating ten 100GHz spaced wavelengths. The odd and the even channels are combined by using a 50GHz flat-top interleaver. For the 20 channels, eight (ch1, 2, 4, 5, 6, 8, 11 and 16) come from ECL laser array (full c-band tunable, linewidth of ~100KHz) while the other 11 wavelength channels come from a DFB laser array (about 1nm tuning range and <2MHz linewidth). The PolMux-RZ-QPSK transmitter consists of two Mach-Zehnder modulators (MZM1 and MZM2), one phase modulators (PM), a polarization-maintaining EDFA, and a polarization-multiplexing unit. The first two modulators, MZM1 and PM1, are each driven by a 28Gbit/s data stream (Data A and B, accordingly) to provide 0/π and 0/0.5π phase modulation, respectively. MZM2 is driven by a 28GHz clock to carve out 50%-duty-cycle RZ (return-to-zero) pulses. The 28Gbit/s data is obtained by time-multiplexing four 7Gbit/s PRBS signals (each with pattern length of 2^{11}-1). Note that the two 28Gbit/s data signals are de-correlated by introducing different bit delays with respect to each other (the resulted pattern length of the 28 Gig baud signal is 2^{13}-4). The polarization-multiplexing is achieved by dividing and recombining the signal with 322 symbol delay using a polarization beam combiner. The transmission line consists of 13 spans of 80 km of SSMF (average span loss of 17dB), 5 spans of 100km of SSMF (average span loss of 21dB) and EDFA-only optical amplification. No optical dispersion compensation is used in this experiment. After span 6 and 13, two optical WSSs are introduced to block the accumulated noise peak occurring at 1530-1540 region (the gain profiles of some of the used EDFAs are not flattened). At the receiver, the measured channel is selected by two tunable filters, OTF1 (0.4nm) and OTF2 (1nm). Polarization-and phase-diverse coherent detection uses a polarization-diversity 90-degree hybrid, a tunable ECL local oscillator (about 100 kHz linewidth) and four single-ended photodetectors. The distortion from direct square detection of the signal component is mitigated by using a relatively high local-oscillator-to-signal power ratio, which was set to be 20 dB in this experiment. Note that the input signal polarization state was not controlled, and an arbitrary mix of each transmitted polarization state was incident on the photodetectors. For each measurement, the LO is tuned to within 1GHz of the transmit laser. The sampling and digitization (A/D) function is achieved by using a 4-channel digital storage scope with 50 Gs/s sample rate and 16GHz electrical bandwidthh. The

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captured data is then post-processed using a desktop PC. The detail procession can be found in Ref. [15]. For this experiment, errors were counted over 20×60,000 symbols (20 data sets, each data sets consists of 60,000 symbols) so that the average BER for 112Gb/s PolMux-RZ-QPSK signal is based on 4.8 $\times 10^{6}$ bits.

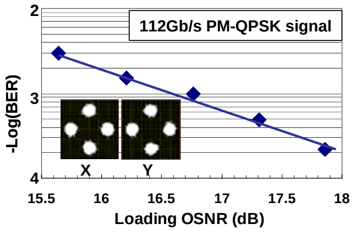

Fig. 2. Back to back BER performance vs. loading OSNR.

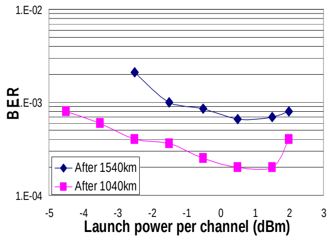

Fig. 3. BER vs. launch power after 1040/1540km.

Fig. 2 shows the measured back-to-back BER curve as a function of OSNR (0.1 nm reference bandwidth), where the insert is the corresponding constellation. From Fig. 2, we can see that the required OSNR at BER 1e-3 is 16.7 dB, which is very close to that reported in Ref. [8]. In Fig. 3, we give the measured BER of channel 12 versus launch power per channel. Two cases with different transmission distance are considered. For the first case, we remove the last 5 spans, so the transmission distance is 1040km. Second case is with all 18 spans (1540km). For both cases, the optimal launch power per channel locates between -0.5 to 1.5 dBm. In Fig. 4 we show the measured BER of all the twenty channels under 1.5dBm/ch launch power. The corresponding optical spectrum after 1540km is shown in Fig. 5, where the constellations of channel 12 after transmission are inserted. All the measured BER is below 1e-3. The measured OSNR for all the 20 channels is greater than 22.5dB (0.1nm ASE bandwidth, 23±0.5 dB). Removed the last fiver span fiber (500km) and reducing the input power into the EDFA at the receiver, the OSNR of channel 12 and 20 is reduced from 26 dB and 26.5 dB to 19.5dB and 18.6 dB, respectively. The measured BER versus OSNR is shown in Fig. 6. About 5.5 dB OSNR margin is seen for channel 12, which is among the worst channels, and about 6.5 dB OSNR margin is observed for channel 20 when the transmission distance is 1040km. We carried out another experiment to evaluate the PMD tolerance. A commercial three-stage all-order PMD emulator is inserted between the transmitter and the transmission line, and the mean DGD is set to be 35ps. No significant BER performance degradation was observed for 50 measurements.

Conclusions

By using EDFA-only optical amplification, we have successfully transmitted twenty 50GHz-spaced PolMux-RZ-DQPS4K signals over 1540 km of straight-line SSMF with BER smaller than 1x10-3. There is greater than 5dB OSNR margin when the transmission distance is 1040km. This experiment demonstrates that about 1000km reach can be achieved at 112Gb/s data rate and 2bit/s/Hz spectral efficiency without using Raman amplification or optical dispersion compensation in the real system.

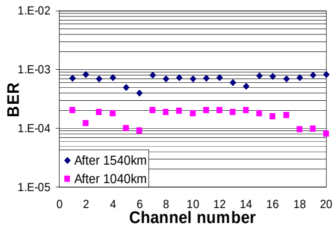

Fig. 4. 20 channel performance after 1040/1540km.

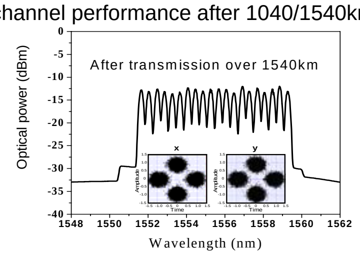

Fig. 5. Monitored optical spectra at 1540km.

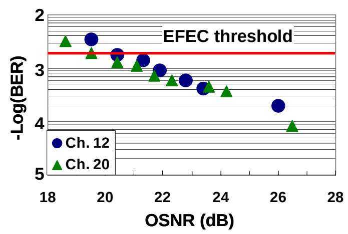

Fig. 6. OSNR margin measurement of ch. 12 and ch. 20 after 1040km.

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