8×200-Gbit/s Polarization-Division Multiplexed CS-RZ-DQPSK Transmission over 1200 km of SSMF

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Abstract
8x200-Gbit/s polarization-division multiplexed DQPSK transmission system over 1200 km of SSMF has been successfully demonstrated. BER well below 1E-4 has been achieved for CS-RZ-DQPSK signal with an OSNR of 23.29 dB.

Introduction
Polarization-division multiplexing (PDM) has been intensively studied to double the capacity of the transmission system using differential quadrature phase-shift keying (DQPSK). It has been shown in both labs and field trials that PDM transmission systems can achieve stable transmission performance using automatic polarization control [1, 2]. With the rapid improvement of automatic polarization control [3, 4] to track the polarization fluctuations in field-installed transmission systems [5], PDM is a very promising technique to dramatically increase the capacity of existing transmission systems.

In this paper, we report the results of a 8×200-Gbit/s PDM-DQPSK transmission system over 1200 km standard single mode fiber (SSMF) in lab environment. Carrier suppressed return-zero DQPSK (CS-RZ-DQPSK) has been employed for the system and bit-error-ratio (BER) well below 1E-4 has been achieved with an optical signal-to-noise-ratio (OSNR) of 23.29 dB.

Fig. 1 shows the setup for the transmission experiment. At the transmitter site, eight continuous-wave (CW) distributed feedback (DFB) lasers with wavelength range from 1549.62 nm to 1558.17 nm in 200 GHz channel spacing are multiplexed using a polarization-maintaining arrayed waveguide grating (AWG) and then launched into a pulse carving module and a DQPSK modulation module. The CS-RZ pulse carving module is implemented by using a dual-drive Mazh-Zehnder modulator (DD-MZM) biased at transmission null point. The DQPSK modulation module consists of a data multiplexing module (4:1 MUX) in which 50-Gbit/s electrical data are generated by electronically multiplexing four channels of 2^7-1 pseudo-random bit sequence (PRBS) data at 12.5-Gbit/s with suitable time delay between each other. The two output data at 50-Gbit/s of the electric 4:1 MUX are served as I and Q signals for the following DQPSK modulation through D-type flip-flops (DFF) and amplifications. 108-bit relative time delay is introduced between the I and the Q signals to avoid pattern correlation. The data rate after the DQPSK modulation module is 100-Gbit/s, which is then doubled to 200-Gbit/s though PDM by using a polarization beam splitter (PBS) and a polarization beam combiner (PBC). A polarization controller (PC) is inserted after the DQPSK modulation module to control the polarization of the output of the DQPSK modulation module which is equally split into two orthogonal polarizations by the first PBS. A suitable relative delay is introduced between the two orthogonally polarized signals to avoid pattern correlation.

The eight wavelength division multiplexed (WDM) signals with 200-Gbit/s DQPSK signals are amplified first by a boost amplifier and then launched into the 1200 km transmission link which consists of 15 spans of SSMF with link length of 80 km and corresponding dispersion compensation module (DCM) in each span. Each span loss is compensated by Erbium doped fiber amplifier (EDFA) only.

At the receiver site, the eight WDM signals are first de-multiplexed (DEMUX) optically and then amplified by a pre-amplifier. After the pre-amplification, a tunable optical filter with 1 nm bandwidth is used to further increase the OSNR of the signals. The polarization of the output of the tunable optical filter is then controlled by a polarizationcontroller, which is followed by a polarizer to select one of the two PDM 100-Gbit/s signals for demodulation. The selected 100-Gbit/s signal channel is demodulated into 50-Gbit/s I and Q components by using a free space based tunable interferometer with a free spectral range of about 55 GHz. The tunable interferometer converts the optical phase modulation to intensity modulation which can then be detected directly. In the setup, an integrated balanced photo-detector with 45 GHz bandwidth is adopted to increase the OSNR tolerance. After the 100-Gbit/s optical signal is converted to 50-Gbit/s electric I and Q signals, 50-Gbit/s data and 25 GHz clock are recovered by using a clock data recovery (CDR) module. By using a 1:4 electric DEMUX, the recovered 50-Gbit/s data is then de-multiplexed into four channels of 12.5-Gbit/s data on which BER measurement can be performed.

In our experiment setup, no automatic polarization control is implemented and the polarization is controlled manually. In the experiments, BER fluctuation due to polarization fluctuation has been observed. Fortunately,

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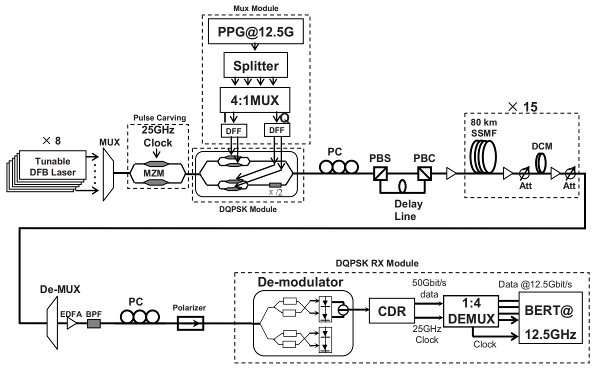
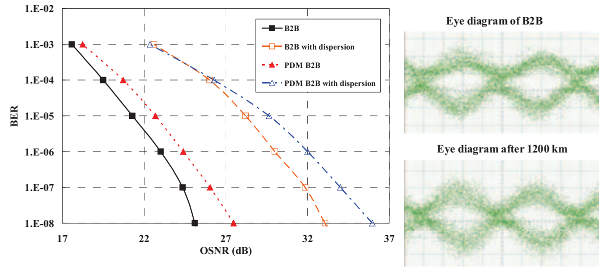


Fig.1 System diagram of 200-Gbit/s PDM DQPSK signals transmission over 1200 km SSMF. MUX: multiplexer; SSMF: standard single mode fiber; DCM: dispersion compensation module; Att: attenuator; DFF: D-type flip-flop; PBS: polarization beam splitter; PBC: polarization beam combiner; PC: polarization controller; CDR: clock data recovery; DEMUX: de-multiplexer.

the polarization fluctuation in our lab environment is a slow process which allows us to perform measurement before the polarization changes significantly. It has been observed that a fairly stable BER can last for tens of minutes. The optical signal-to-noise-ratio (OSNR) versus bit-error-ratio (BER) for back-to-back (B2B) transmission is shown in Fig. 2(a). By removing the components for PDM in the experiment setup shown in Fig. 1, the B2B transmission of 100-Gbit/s CS-RZ-DQPSK signal is also carried out and the result is shown in Fig. 2(a) for comparison. Compared with 100-Gbit/s CS-RZ-DQPSK, it shows that OSNR penalty for 200-Gbit/s PDM CS-RZ-DQPSK is less than 1 dB at BER of 1E-3 and gradually increases with lower BER. At BER of 1E-8, the OSNR penalty is more than 2 dB. The higher OSNR penalty at lower BER is believed to be due to the crosstalk between the two orthogonal polarized signals because of imperfect polarization control as well as PMD and PDL in the link. At lower OSNR, the noise is the dominant source of impairment which limits the performance of both 100-Gbit/s CS-RZ-DQPSK signal and 200-Gbit/s PDM CS-RZ-DQPSK at the same magnitude, the OSNR penalty is hence fairly insignificant. At higher OSNR, the noise is small and the crosstalk between the two orthogonal polarized signals due to imperfect polarization control as well as polarization mode dispersion (PMD) and polarization dependent loss (PDL) in the link becomes the dominant source of impairment, which then leads to higher OSNR penalty on 200-Gbit/s PDM CS-RZ-DQPSK signal.

To investigate the impact of fiber dispersion on the performance, a section of SSMF of 1150 m is inserted into the B2B setup at the receiver site before the optical de-multiplexer, which introduces a dispersion of about 20 ps/nm into the B2B system. The OSNR versus BER under this circumstance is also shown in Fig. 2(a) for comparison. Compared with the case of 200-Gbit/s B2B PDM CS-RZ-DQPSK without fiber dispersion, this 20 ps/nm dispersion leads to about 4 dB OSNR penalty at BER of 1E-3. The same measurement is also carried out



(a) (b)

Fig. 2 (a) Measured B2B BER for 100-Gbit/s and 200-Gbit/s PDM transmission with and without 20 ps/nm dispersion; (b) Measured eye diagrams after balanced detection of one polarization for 200-Gbit/s PDM system in case of B2B and after 1200 km SSMF transmission.

on 100-Gbit/s B2B CS-RZ-DQPSK and the result is shown in Fig. 2(a) for comparison. The difference between the two curves at low BER is slightly larger than that of B2B transmission without dispersion.

The eight channels of 200-Gbit/s PDM CS-RZ-DQPSK signal are then launched into the SSMF link of 1200 km. The dispersion of the link is compensated completely. The received eye diagram of one polarization after balanced detection is shown in Fig. 2(b). The received eye diagram for B2B case is also shown in Fig. 2(b) for comparison. The BER for both polarizations after 1200 km transmission has been measured. Both polarizations show roughly the same BER which fluctuates in the range from 6E-6 to 2E-5. After 1200 km SSMF transmission, the received OSNR is 23.29 dB. Compared to the B2B case, about 1 dB OSNR penalty is incurred at the achieved BER. The results show that with proper polarization tracking devices [3], polarization multiplexed high speed transmission is possible.

Conclusions

We have successfully demonstrated the transmission of 8 ×200-Gbit/s PDM DQPSK over SSMF link of 1200 km. BER well below 1E-4 has been achieved with an OSNR of 23.29 dB. The results show that long haul transmission system based on PDM technique is feasible.

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References

1. D. Van den Borne et al, IEEE/OSA J. Lightwave Technol., 25 (2007) pp. 222 – 232.
2. M. Yagi et al, proceeding of OFC/NFOEC 2008, OThT7.
3. B. Koch et al, IEEE Photonics Technology Letters, 20(2008), pp. 961 – 963.
4. M. Martinelli et al, IEEE/OSA J. Lightwave Technol., 24(2006), pp. 4172 – 4183.
5. P. C. Noutsios, proceeding of International Symposium on Signals, Systems and Electronics 2007, pp. 323 – 326.