2´40 Gbit/s RZ-DQPSK transmission over 263 km of fiber with tunable chromatic dispersion compensator

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Abstract: *We report on 2×40 Gbit/s RZ-DQPSK transmission over a 263 km fiber link. Sufficient resilience against nonlinear phase noise and band limitation in a 40Gbit/s WDM DEMUX is achieved with a Q factor of 17.5 dB. The back-to-back Q factor is > 20 dB, and the receiver sensitivity of –27.5 dBm is 0.2 dB better than for RZ-ASK even though the data rate is twice as high.*

Introduction

With demands to increase capacity, increase reach and reduce cost, there has been growing interest in developing alternative modulation formats for high bit rate optical transmission systems [1-5]. A simple alternative to double the existing transmission capacity without optical bandwidth increase is to use Differential Quadrature Phase Shift Keying (DQPSK). Combined with RZ coding its robustness against XPM is also large because the intensity is not modulated by the data. The theoretically possible receiver sensitivity of DQPSK receiver is better than for intensity modulation. Here we report on 2×40 Gbit/s (40 Gbaud) RZ-DQPSK transmission over 263 km with a Q factor > 20 dB.

Transmission setup

Fig. 1 shows the RZ-DQPSK 40 Gbaud transmission setup. The transmitter employs a 16:1 Infineon multiplexer that processes 16 2.5 Gbit/s data streams, mutually delayed by multiples of 8 bits, SHF modulator drivers for a Triquint dual drive DPSK modulator. It is followed by an in-house developed all-fiber temperature-stabilized Mach-Zehnder interferometer with a differential delay of 3 symbol durations. The polarization dependent phase shift is < 500 MHz and the extinction ratio is ~24 dB. A piezo fiber stretcher is included in one of the arms for an active phase control. A quadrature control loop based on a 10 kHz lock-in scheme stabilizes the interferometer phase. As its input signal we use the RF power which occurs in the photodetected signal at one of the interferometer outputs. The photoreceiver bandwidth is about 8 GHz and does therefore not cover the clock signal. Only when the two optical signals are superimposed in quadrature there is no interference and hence no RF power. The 10 kHz phase modulation has a depth of ~0.01 rad (rms). A Triquint dual drive pulse carver driven at half the clock rate generates the RZ-DQPSK signal for transmission. The optical frequency is 192.5 THz (1557.366 nm).

The receiver employs optical preamplifiers, a flat-top C band DWDM DEMUX (Optun) and an integrated-optical Mach-Zehnder demodulator with a delay of 4 symbol durations. For proper reception of in-phase and quadrature data channels, the phase difference of delay demodulator is set to 45° or 135° using microheaters. The demodulator outputs are connected to two high-speed photodetectors from u2t, which in turn are connected to differential inputs of a 1:16 Infineon demultiplexer that uses standard clock and data recovery circuits. An advantage here is that we do not need an extra high-speed photodiode to recover the clock from 40 GHz intensity modulation. A 2^7-1 PRBS was transmitted. Note that the demodulated bit patterns in in-phase and quadrature data channels differ from the transmitted ones. The half rate clock signals in transmitter and receiver are generated by VCOs from WORK Microwave GmbH.

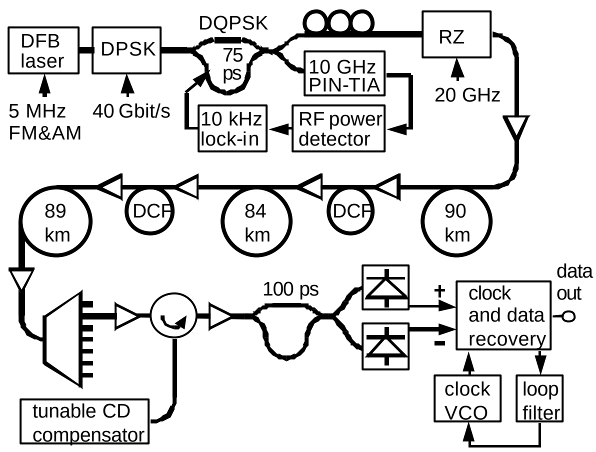

Fig. 1: 40 Gbaud RZ-DQPSK transmission setup

Experiment

The aim of this transmission experiment is to demonstrate 2×40 Gbit/s RZ-DQPSK transmission and compare its performance to that of the RZ-ASK and RZ-DPSK modulation formats in terms of receiver sensitivity and OSNR. For RZ-DPSK operation, the all-fiber Mach-Zehnder interferometer at the TX is left out. For RZ-ASK operation, both interferometers and one photodiode are left out. The optical signal is transmitted over 3 fiber spans with a total length of 263 km. These are 170 km of SSMF, 60 km of NZDSF, and 33 km of DSF. DCF with a total dispersion of –2713 ps/nm was inserted between first and second stages of the two inline EDFAs. The residual dispersion was compensated by a thermally tunable dispersion compensator. It was set to –470 ps/nm, while the total tuning range is –300 to –700 ps/nm.

Fig. 2 shows measured BERs vs. optical preamplifier input power for RZ-DQPSK, RZ-ASK, and RZ-DPSK modulation formats. The back-to-back Q factors for these modulation formats are 20.9 dB (for both I and Q data channels), 26.6 dB, and 29.5 dB, respectively. The corresponding back-to-back receiver sensitivities are –27.5 dBm (for both I and Q data channels), –27.3 dBm, and –33.6 dBm. They are equivalent to OSNRs of 29.7, 27.7, and 23.8 dB/0.1nm, respectively. With the 263 km fiber link in place, the Q factors are reduced to 17.5 dB (for I and Q data channels), 19.6, and 20.4 dB, respectively. As can be seen from Figure 2, the DQPSK receiver sensitivity is almost the same as for ASK. However, DQPSK transports 80 Gbit/s whereas ASK transports only 40 Gbit/s. When the sensitivities are compared on the basis of photons/bit (not photons/symbol) then DQPSK is 3.2 dB better than ASK, and 3.1 dB worse than DPSK. All 2.5 Gbit/s subchannels are bit error free, with almost identical sensitivities.

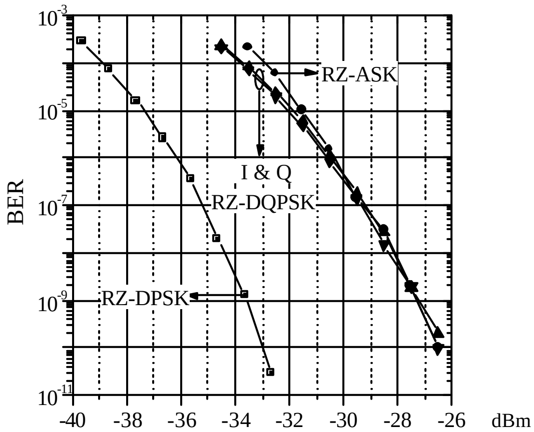

Fig. 2: BER vs. power at optical preamplifier input for different modulation formats.

Figure 3 shows 2×40 Gbit/s RZ-DQPSK eye diagrams back-to-back (top) and after 263 km transmission (middle) for I and Q data channels. A slight vertical asymmetry is due to different optical powers at the two photodiodes. For comparison, the bottom diagram with 3 lines was recorded with a 0° or 90° interferometer phase difference (instead of 45° or 135° for normal DQPSK demodulation). The eye diagrams are well open, both back-to-back and after transmission over 263 km of fiber.

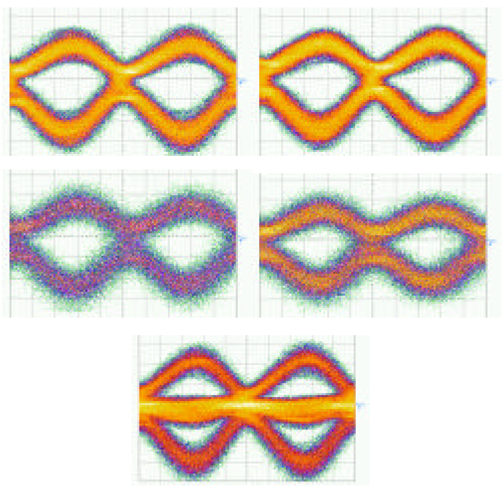

Fig. 3: 2x40 Gbit/s RZ-DQPSK I & Q eye diagrams back-to-back (top) and after 263 km of fiber (middle). Bottom diagram is back-to-back with wrong interferometer phase.

The I and Q data channels were tested (in one 2.5 Gbit/s subchannel) to be error-free during 1 h each, but these measurements were interrupted (before errors occurred) for occasional phase adjustment in the receiver interferometer, and polarization adjustment. Shorter transmission spans were also tried, 258 km (5 km less SSMF) and 253 km (10 km less SSMF but increased link dispersion because a –342 ps/nm DCF module was also taken out). Error-free transmission was possible, though not extensively tested. The chromatic dispersion compensator had to be set to –390 ps/nm (for 258 km) and –635 ps/nm (for 253 km), respectively. In those cases as well as for 263 km (Fig. 3) the eye diagrams before and after transmission had similar shapes, which suggests that the compensator did not introduce a significant penalty. This is remarkable because DQPSK is about twice as sensitive to chromatic dispersion as DPSK.

However, as the signal is transmitted, the in-phase part of optical amplifier noise modulates the pulse amplitudes. Self phase modulation converts this into a random phase modulation which limits permissible link lengths. This nonlinear phase noise is described in [6, 7]. It scales with the square of the length and linearly with the symbol rate (taking into account that the linewidth tolerance scales also linearly with the symbol rate). Launch powers were 4...6 dBm for the 3 spans in the present experiment, and the laser linewidth is < 2 MHz according to the Triquint data sheet. The setup could be made less sensitive against phase noise if the interferometer delay in the receiver were shortened to 1 bit. In theory this should at least double the permissible transmission distance but we don't know precise experimental limits yet. Definitely, the use of FEC will in practice relax the problem.

In [6, 7] the linear phase noise caused by the optical amplifier noise in quadrature with the signal is also discussed. Note that this is not strictly necessary because linear phase noise is automatically part of any sensitivity calculation in which optical amplifier noise is taken into account.

Conclusion

We have transmitted 2×40 Gbit/s RZ-DQPSK signals error-free over a 263 km fiber link. A 40Gbit/s tunable chromatic dispersion compensator and a standard 40Gbit/s DWDM DEMUX are used; fiber capacity is thereby doubled. The receiver sensitivity is –27.5 dBm. The back-to-back Q factor is > 20 dB. Even after transmission the Q factor is 17.5 dB.

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