

8x160-Gbit/s, 1.6-bit/s/Hz RZ-DQPSK Polarization-Multiplexed Transmission over 230 km of Fiber Link

Biljana Milivojevic (1), A. Fauzi Abas (1), A. Hidayat (1), Suhas Bhandare (1), David Sandel (1), Reinhold Noé(1), Martin Guy (2), Martin Lapointe (2)

1: Univ. Paderborn, EIM-E, Warburger Str. 100, D-33098 Paderborn, Germany, milivojevic/hidayat/fauzi/suhas/sandel@ont.upb.de; noe@upb.de; 2: TeraXion, mguy/mlapointe@teraxion.com

Abstract 4x40Gbit/s data is transmitted on 8 WDM channels over 230 km fiber. Residual chromatic dispersion for 192.5THz channel was equalized using tunable dispersion compensation. Polarizations, Inphase and quadrature channels are automatically demultiplexed using LiNbO₃-based device and 1-bit interferometer.

Introduction

Polarization division multiplex [1-3] and DQPSK [2-7] transmission each can double fiber capacity by their increased spectral efficiency. Both techniques have been combined to transmit 4x10 Gbit/s per WDM channel [2, 3]. Here we report for the first time to our knowledge 4x40 Gbit/s per WDM channel transmission with automatic polarization control as well as a tunable chromatic dispersion compensation.

Transmission setup

Fig. 1 shows the RZ-DQPSK polarization division multiplex (PoIDM) 4x40 Gbit/s per WDM channel transmission setup. Eight 100GHz-spaced WDM channels (192.3 ... 193.0 THz) are combined with equal polarizations and modulated together. The electrical part of the transmitter employs a 16:1 Infineon multiplexer which processes 16 2.5 Gbit/s 2⁷-1 PRBS data streams, mutually delayed by multiples of 8 bits, and 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 3symbol 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 active phase control. At one interferometer output a 192.5-GHz optical bandpass filter (BPF), a photoreceiver with a bandwidth of about 12 GHz, and a subsequent RF diode detector are used to measure the RF power carried by the optical DQPSK signal. When the two optical signals are superimposed in quadrature, there is no interference and hence no RF power, except for the clock frequency that is outside the photoreceiver bandwidth. A quadrature control loop based on a 10 kHz lock-in detection scheme stabilizes the interferometer phase by minimizing the RF power. The 10 kHz phase modulation has a depth of ~0.01 rad (rms). The interferometer delay is a half-integer multiple of the inverse channel separation which means that in-phase and quadrature data streams are combined with alternating polarities from one WDM channel to the next. The channel spacing is fine-tuned so that each WDM channel contained a proper DQPSK signal.

A Triquint dual drive modulator driven at half the clock

rate carries 8ps pulses and thereby generates the RZ-DQPSK signal for transmission.

Finally, the DQPSK signal is split and recombined with orthogonal polarizations and a differential delay equal to an integer number of bits. Since this polarization multiplexer was available, interleaving of orthogonally polarized pulses in the time domain was not tested. However, it is known that pulse interleaving increases the vulnerability against PMD distortions [8].

The optical signals are transmitted over 4 fiber spans with a total length of 230 km. These contain 170 km of SSMF and 60 km of NZDSF. DCF with a total dispersion of -2713 ps/nm is inserted between inline EDFAs. Fiber and DCF launch powers are +4.0 ... -0.5 dBm and -3 ... -4.8 dBm per WDM channel, respectively. EDFA input powers are -10.5 ... -15 dBm per WDM channel.

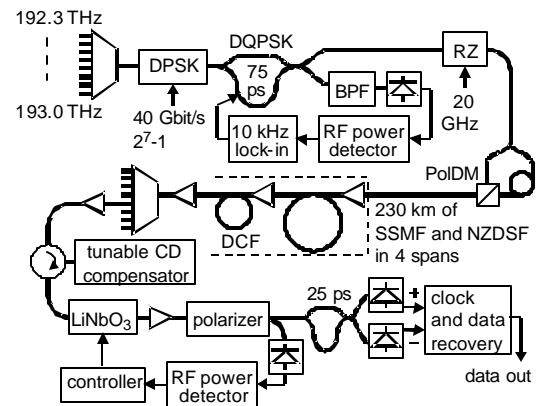


Fig. 1: 4x40Gbit/s per channel, RZ-DQPSK PoIDM transmission

The receiver employs optical preamplifiers and a flat top C band DWDM DEMUX from Optun. To receive the 192.5 THz (1557.366 nm) channel, a thermally tunable dispersion compensator was used. It is based on a FBG and is coupled via circulator. It was set to -440 ps/nm, while the total tuning range was from -300 to -700 ps/nm.

A LiNbO₃ polarization controller transforms the incoming signals so that the wanted polarization passes a fiber polarizer. Another 12-GHz photoreceiver and a subsequent RF diode detector

detect the broadband interference between both polarization channels. A controller minimizes this interference by proper setting of the LiNbO₃ polarization controller.

Another Mach-Zehnder interferometer, with a delay of one symbol duration, demodulates the signal. For proper reception of in-phase and quadrature data channels, the phase difference of the delay of the demodulator is set to either 45° or 135°, using a piezo fiber stretcher. The demodulator outputs are connected to two high-speed photodetectors from u2t, which in turn are connected to the differential inputs of a 1:16 hfineon demultiplexer with standard clock and data recovery. An advantage here is that an extra photodiode to recover the clock from the 40 GHz intensity modulation is not necessary.

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.

Results

Fig. 2 shows measured Q factors of I and Q data channels, for all 8 WDM channels back-to-back, and for the dispersion-compensated 192.5 THz channel after 230 km. Error free transmission was always possible for all channels with Q=15 dB.

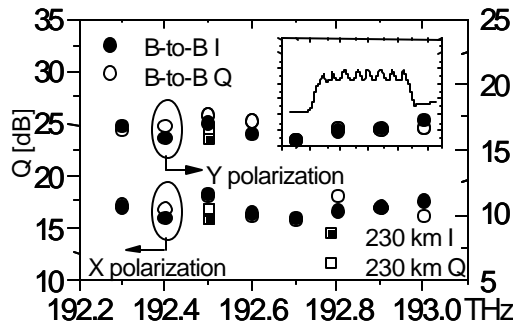


Fig. 2: Measured Q factors of I & Q channels in 2 polarizations for 8 WDM channels (inset).

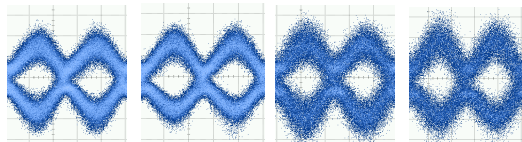


Fig. 3: Eye diagrams in one polarization, (from left) back-to-back in I channel, Q channel and after 230 km in I and Q channel.

Corresponding eye diagrams are shown in Fig. 3 for the 192.5 THz channel in one polarization. The other polarization is very similar.

Fig. 4 shows electrical interference spectra measured in the 12-GHz photoreceiver after the polarizer. Best case (where interference should disappear because polarization is aligned) and worst case (with both

polarizations totally mixed) and are displayed (up and down respectively). The corresponding total RF power are -22 and -8.5 dBm, respectively.

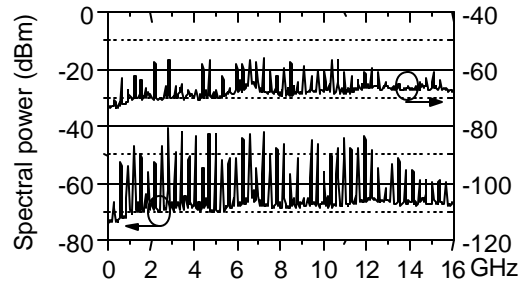


Fig. 4: Electrical interference spectra measured in the 12-GHz photoreceiver after the polarizer.

The eye diagrams before and after transmission had identical shapes, which suggests that the compensator itself did not introduce a significant penalty to the system, even though DQPSK is more sensitive to chromatic dispersion than DPSK or ASK. 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 [9]. 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). The linewidth of the 192.5 THz laser is 10 MHz. Definitely, the use of FEC will relax the problem in practice. In [9] 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 when optical amplifier noise is taken into account.

Conclusions

We have demonstrated transmission of 160 Gbit/s (4x40 Gbit/s RZ) in two polarizations and differentially encoded in two quadratures per channel in 8 WDM channels. A 40Gbit/s tunable chromatic dispersion compensator and a standard 40Gbit/s DWDM DEMUX are used. Fiber capacity is quadrupled. The Q factor was ≥ 15 dB after transmission over 230 km of fiber.

References

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