Penalty-free Transmission of Multilevel 240 Gbit/s RZ-DQPSK-ASK using only 40 Gbit/s Equipment

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Abstract *Combining four-level phase modulation with binary amplitude modulation and polarisation multiplexing at 40 Gbaud, we present the first experimental implementation of 240 Gbit/s RZ-DQPSK-ASK. We demonstrate transmission over a 50 km fibre span without sensitivity degradation.*

Introduction

The focus on optical multilevel modulation formats over the recent years has led to demonstrations of 4-level communication at a symbol rate of 40 Gbaud and up to 16 levels at 10 Gbaud [1-4]. The most common approach is to combine differential binary phase shift keying (DBPSK) or differential quadrature phase shift keying (DQPSK) with amplitude shift keying (ASK) to encode multiple bits per symbol.

Multilevel modulation formats allow for generation of signals with much higher bit rates than binary modulation formats using state-of-the-art electronic and opto-electronic equipment. Additionally, as several transmission impairments—such as dispersion—scale with the symbol rate rather than the bit rate, multilevel modulation allows for ultra-high bit rate multilevel signals to have much larger dispersion tolerance than binary formats at the same bit rate.

In this paper, we present the first experimental implementation of optical multilevel modulation using eight symbol levels at a symbol rate of 40 Gbaud. We combine DQPSK with ASK, and thus directly generate a 120 Gbit/s signal using 40 Gbit/s equipment, and employ polarisation multiplexing to obtain a 240 Gbit/s signal that is transmitted over a 50 km fibre span. This experiment verifies the suitability of multilevel optical communication even at bit rates of several hundred Gbit/s.

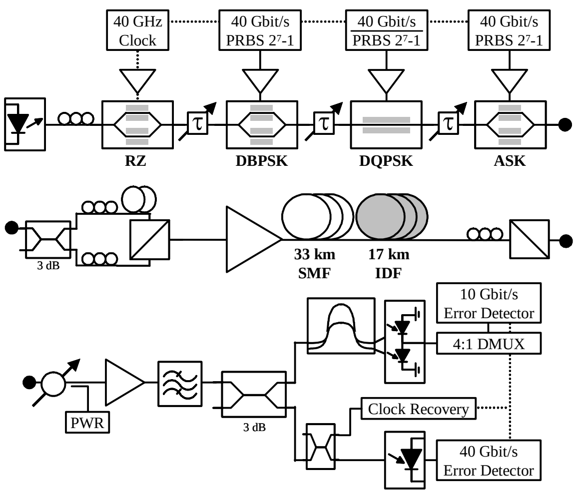

Fig. 1: Simplified experimental setup showing the transmitter (top), transmission span with polarisation multiplexing (middle) and the receiver (bottom).

Measurement setup

The experimental setup is illustrated in Fig. 1. Continuous wave (CW) light at a wavelength of 1550 nm was first modulated by a single drive Mach-Zehnder (MZ) modulator biased at a half-intensity point, and driven with a 40 GHz clock signal having an amplitude equal to the modulator switching voltage V_π. The resulting 40 GHz pulse train—with a pulse width equal to 50% of the symbol period—was then phase modulated using a second MZ modulator biased at a null point and driven with a differential 2^7–1 bit pseudo-random bit sequence (PRBS) data signal with 2 V_π amplitude. Then, an 80 Gbit/s RZ-DQPSK signal was generated by a successive phase modulator driven by an inverted 2^7–1 bit 0.5 V_π PRBS signal. Finally, amplitude modulation was added in a third MZ modulator driven with a 2^7–1 bit PRBS data signal, where the modulator bias and drive signal amplitude were adjusted to obtain the desired extinction ratio on the ASK signal. The resulting signal was thus RZ-DQPSK-ASK with a bit rate of 120 Gbit/s. By measuring the signal transit time between all modulators we ensured that all data signals were decorrelated.

The extinction ratio of the ASK signal is a trade-off between good eye opening for the ASK signal and good eye opening for the demodulated DQPSK signal. We found that an extinction ratio of 4.5 dB resulted in equal receiver sensitivities for both the ASK and DQPSK signals, hence resulting in the optimum performance for the system as a whole. Therefore, an extinction ratio of 4.5 dB was used for all measurements.

The signal was polarisation multiplexed to 240 Gbit/s by splitting the signal in two branches using a 3 dB coupler, delaying one arm to decorrelate the data patterns before combining the signals using a polarisation beam combiner. We transmitted the signal over one 50 km fibre span consisting of 33 km standard single mode fibre (SMF) followed by 17 km inverse dispersion fibre (IDF). The dispersion was 17 ps/nm/km for the SMF and –36 ps/nm/km for the IDF, resulting in a residual dispersion of less than 5 ps/nm at the signal wavelength of 1550 nm. After the transmission span, the signal was polarisation demultiplexed using a polariser before the receiver.

At the receiver input, the signal was attenuated to the

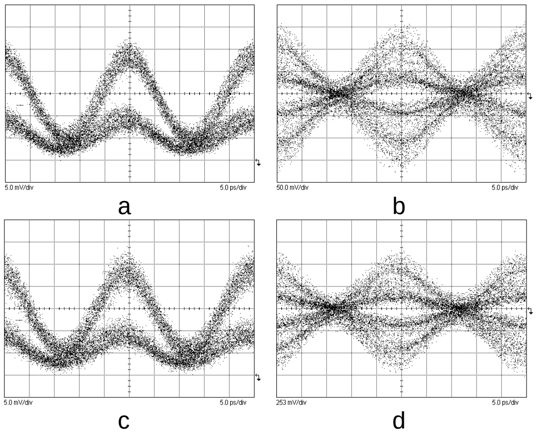

Fig. 2: Eye diagrams of the generated signal (a) and demodulated signal in the back-to-back configuration (b). The received signal after transmission is shown in (c), along with the demodulated signal in (d).

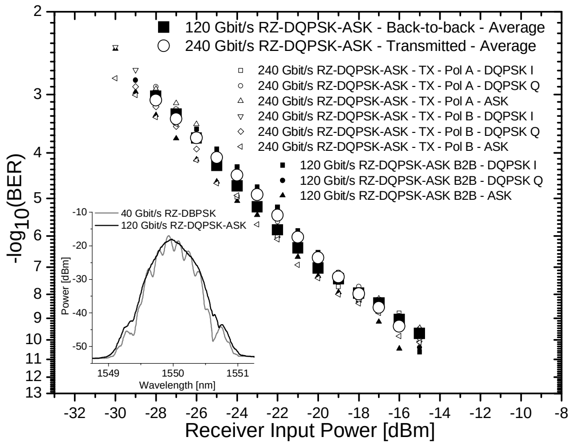

Fig. 3: BER measurements for the back-to-back case and after transmission. The inset shows the optical power spectrum of 40 Gbit/s RZ-DBPSK and 120 Gbit/s RZ-DQPSK-ASK.

desired receiver input power and then amplified by an erbium doped fibre amplifier (EDFA). A 1.3 nm optical band-pass filter suppressed the out of band amplified spontaneous emission noise. Then the signal was split into two branches, one for DQPSK detection and one for ASK detection. In the ASK branch, the signal was directly detected using a 50 GHz photodetector and errors detected using a 40 Gbit/s error detector. The DQPSK signal was demodulated using a one-bit delay demodulator and received by a 45 GHz balanced photodetector. As pre-coding was not utilised, and due to the lack of a programmable 40 Gbit/s error detector, the received signal was demultiplexed to 10 Gbit/s and errors counted using a programmable 10 Gbit/s error detector.

The use of two error detectors allowed for simultaneous measurement of bit error rate (BER) of both the amplitude and phase information. All DQPSK and polarisation tributaries were measured one after another.

Results and Discussion

Fig. 2a shows the eye diagram of the generated 120 Gbit/s signal, with 4.5 dB extinction ratio. The demodulated signal is shown in Fig. 2b. The many levels on the eye of the demodulated signal is due to delay demodulation of pulses with different amplitudes [4]. The corresponding eye diagrams of the signals after polarisation multiplexing, transmission and polarisation demultiplexing are shown in Fig. 2c and Fig. 2d, respectively. No signal degradation is visible.

We measured a receiver sensitivity of –16.6 dBm for the 120 Gbit/s RZ-DQPSK-ASK signal in the back-to-back configuration for a BER of 1.0×10^{-9}. This can be compared to the receiver sensitivity of 40 Gbit/s RZ-DBPSK, which was found to be –33.1 dBm, a difference of 16.5 dB. 80 Gbit/s RZ-DQPSK and 80 Gbit/s RZ-DBPSK-ASK were also investigated, and here we found differences in the receiver sensitivity of 6.7 and 8.6 dB, respectively, compared to 40 Gbit/s RZ-DBPSK. The sum of these (15.3 dB) is very close to the 16.5 dB receiver sensitivity difference observed for 120 Gbit/s RZ-DQPSK-ASK. Thus we have very low excess implementation penalty for 120 Gbit/s RZ-DQPSK-ASK.

We also measured the BER curves after transmission, and the results are presented in Fig. 3. Measurements for all ASK and DQPSK tributaries and both states of polarisation are shown, in addition to the average value. There was almost no degradation of the signal quality after polarisation multiplexing, transmission and polarisation demultiplexing, as the receiver sensitivity was found to be –16.5 dBm.

The inset in Fig. 3 shows the optical power spectrum of 40 Gbit/s RZ-DBPSK and 120 Gbit/s RZ-DQPSK-ASK. As the symbol rate is the same for both formats, the spectral width is the same. Thus, even if the bit rate is three times higher (six with polarisation multiplexing), the spectral width and thus many of the transmission impairments such as chromatic dispersion are almost identical.

Conclusion

We have presented 240 Gbit/s optical multilevel transmission, using RZ-DQPSK-ASK and polarisation multiplexing. This signal was successfully transmitted over a 50 km fibre span with no signal degradation.

Acknowledgements

This work was partially funded by The Danish Council for Strategic Research project MultiSpeed, and by COST action 291. ITF Optical Technologies is acknowledged for supplying the DQPSK demodulator.

References

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