Performance Comparison between 120 Gbit/s RZ-DQP-ASK and RZ-D8PSK over a 480 km Link

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Abstract: This paper experimentally presents the first direct comparison between two 120-Gbit/s 8-ary formats and show that both can be superior over different distances. The performances of two formats are also evaluated over three different dispersion-maps.

OCIS codes: (060.4510) Optical communication; (060.5060) Phase modulation

1. Introduction

Differential detection is regarded as a promising scheme for short-range high-speed transmission systems, for instance, metro-networks as it provides low receiver complexity and cost. The scheme is capable of detecting not only differential phase shift keying (DPSK) but also differential-phase and amplitude shift keying (DP-ASK) modulation formats [1, 2]. Currently, both formats experimentally reach the same record bit-rate (on a single wavelength) of 240 Gbit/s through 8-level DPSK (D8PSK) and quadrature DP-ASK (DQP-ASK) [3, 4].

DQP-ASK and D8PSK, in fact, are similar in many ways. For instance, both provide a symbol-rate of 3 bit/symbol, occupy similar spectral width, and have comparable transmitter/receiver complexity. However, since the symbols of the two formats are distributed differently, it is difficult to speculate which format would provide the better performance, particularly after transmission limited by nonlinear fiber effects. On one hand, D8PSK is likely to suffer more from fiber nonlinearities since the angular distance between symbols (in the constellation) is half of that of DQP-ASK. On the other hand, DQP-ASK is expected to experience severe nonlinear degradation as the format contains two different power levels. Evaluating the system performance of the two modulation formats over various transmission distances is, thus, essential to determine the suitable one for certain applications.

In this paper, we experimentally present the first direct comparison of the back-to-back and transmission performances between 40 Gbaud return-to-zero (RZ)-DQP-ASK and RZ-D8PSK over various distances (up to 480 km) and quantify the minimum bit-error-rate (BER) of the two modulation formats as a function of the transmission reach. The results reveal that both formats can be superior but over different distances. The system performances of the two signals over 480 km are also evaluated with three different dispersion maps. In addition, we theoretically analyze the optimum back-to-back extinction ratio (ER) in the case of DQP-ASK for the best system performance. Lastly, we compare the two signals at 40 Gbaud as it corresponds to 120 Gbit/s, which is highly relevant for forthcoming 100 Gigabit Ethernet (GbE) implementations.

2. Experimental Setup

As illustrated in Fig. 1, the RZ-DQP-ASK/D8PSK transmitter consisted of a 1 MHz linewidth DFB laser, a 31 GHz I/Q modulator, a 35 GHz phase modulator (PM), and two chirp-free Mach-Zehnder Modulators (MZMs). The I/Q modulator was driven by two of 40 Gbit/s binary data streams (D1 and D2), providing 80 Gbit/s DQPSK at the output. The signal was then fed into either the MZM or the PM, which was driven by the third 40 Gbit/s binary data stream (D3). The former added amplitude modulation while the latter created a π/4 phase shift onto DQPSK for DQP-ASK and D8PSK generation, respectively. Lastly, the following MZM was used to generate a RZ format with 50% duty cycle. The optical signal-to-noise ratio (OSNR) of the two signals after the transmitter was also adjusted to be ~ 52 dB to ensure that the OSNRs at the receiver are equal. The signal spectra of the two formats are depicted in Fig. 2. All data streams (D1, D2, D3) used in this work were decorrelated pseudo random bit sequences (PRBSs) with the length of 2^{11}-1, which is limited by the programming capability of an error detector (ED).

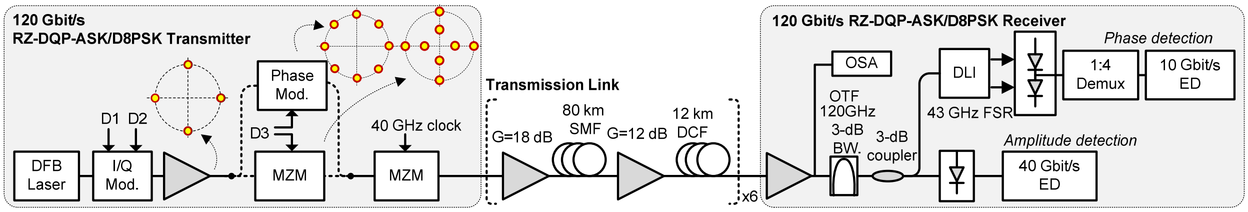

Fig. 1. Experimental setup of the investigated system and the signal constellations (inset). The link shows the periodically compensated dispersion map. The OSA denotes the optical spectrum analyzer.

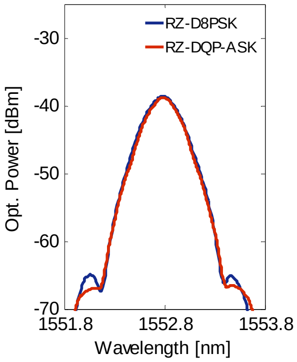

Fig. 2. Signal spectra of 120 Gbit/s RZ-DQP-ASK/D8PSK.

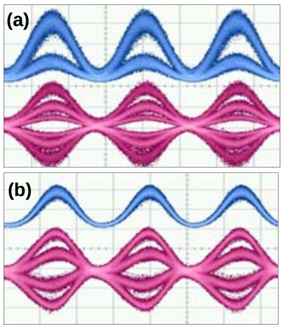

Fig. 3. Detected signals from (blue) amplitude and (red) phase detection branches of (a) RZ-DQP-ASK and (b) RZ-D8PSK

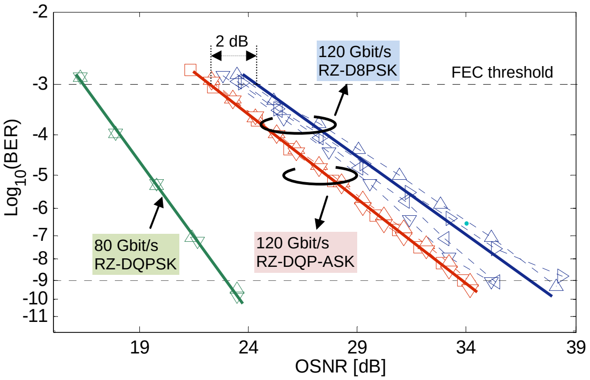

Fig. 4. Back-to-back BER performance of RZ-DQP-ASK and RZ-D8PSK in comparison to that of RZ-DQPSK at the same baud-rate.

Next, the 480 km transmission link was realized by six spans of 80 km standard single mode fiber (SSMF) and double-stage Erbium-doped fiber amplifiers (EDFAs) with a 12 km dispersion compensation fiber (DCF) in between. The average loss of the SMFs and DCFs in each span were measured to be 18 and 12 dB, respectively. The launch power into the DCFs was kept 5 dB lower than that into SMFs to reduce the impact of fiber nonlinearities.

At the receiver, the signal was split into two branches by a 3-dB coupler for the amplitude and the phase detection. For the phase detection, the signal was differentially demodulated by a delay line interferometer (DLI) with a free spectral range (FSR) of 43 GHz (non-ideal) and the demodulated signal was detected by a 40 GHz balanced detector. The detected signals were electronically demultiplexed by a 1:4 demultiplexer and fed into an ED, which was programmed with the expected differentially demodulated bit patterns (due to the lack of the pre-coding). For the amplitude detection, the signal was directly detected by a 40 GHz photodetector and the detected signal was fed into a 40 Gbit/s ED. The detected signal eye diagrams from the two branches are illustrated in Fig. 3.

3. Back-to-back performance

Fig. 4 shows the back-to-back BER performance of 120 Gbit/s RZ-DQP-ASK and RZ-D8PSK as a function of signal OSNR in comparison to that of RZ-DQPSK at the same baud-rate (40 Gbaud) reported in [5]. The dashed lines represent the measured error rates corresponding to binary decision thresholds of all amplitude and/or phase tributaries for the two modulation formats. Each phase tributary was measured individually by applying phase offsets to one arm of the DLI ($\pm\pi/4$ for DQP-ASK, and $\pm\pi/8$, $\pm3\pi/8$ for D8PSK), resulting in 3 (including the amplitude tributary) and 4 curves, respectively. According to [3, 4], BER performance of the system is the average of the dashed lines for DQP-ASK but the average multiplied by 4/3 for D8PSK.

Theoretically, it is well-known that the symbol error rate (SER) for M-DPSK and $M>2$ is, in the high-SNR limit, proportional to $\mathrm{erfc}[(E_s\,(1-\cos(\pi/M))/N_0)^{1/2}]$, where erfc is the complementary error function, and E_s/N_0 the SNR per symbol [6]. Assuming the two amplitude levels of DQP-ASK to be a and b (with $a<b$), the ASK tributary would (in the high-SNR limit) have a bit error rate proportional to $\mathrm{erfc}[(b-a)/(2N_0^{1/2})]$. The minimum overall BER is, still in the high-SNR limit, obtained when the DPSK inner circle tributary (with energy per symbol $E_s=a^2$) and the ASK tributary performs equally. This yields $(b-a)^2=8a^2\sin^2(\pi/8)$, from which the theoretical optimum ER is found as $\mathrm{ER}=(b/a)^2=4.34=6.4$ dB. At the optimum ER, we expect the D8PSK to perform 1.6 dB worse than DQP-ASK. However, in the experiment we found the optimum ER to be 4.7 dB (similar to that reported in [4]) and observed 2-dB superior performance in the case of RZ-DQP-ASK. The difference in between the theoretical and experimental optimum ER indicates that the DQPSK tributary performs slightly worse than ideal. The reason is imperfections in the delay interferometer, the balanced detector, and the electrical demultiplexer, causing an extra penalty on the DQPSK tributaries. Nevertheless, in Fig. 4 we found that for BER = 10^{-3}, RZ-DQP-ASK and RZ-D8PSK require 6 and 8 dB higher OSNR than that of RZ-DQPSK at the same baud-rate, which is in good agreement with [3, 4]. Note that such predetermined BER threshold can achieve the corrected BER = 10^{-15}, providing the forward error correction (FEC) overhead with enhanced Reed-Solomon (RS) with concatenation (e-FEC) is applied [7].

4. Transmission performance

For transmission investigations of the two modulation formats, we plot in Fig. 5 and 6 BER performances (computed from all measured tributaries) of the two systems as a function of the launch power into the SMFs over various distances. As expected, the curves in both figures illustrate the optimal SMF launch power, which is a trade-off between OSNR and the fiber nonlinearity, i.e., self-phase modulation (SPM). The curves also show that the optimal launch power decreases from to 5 dBm and from 9 to 6 dBm for DQP-ASK and D8PSK as the reach increases, which we attribute to the accumulated SPM-induced phase rotation and the SPM-induced phase noise.

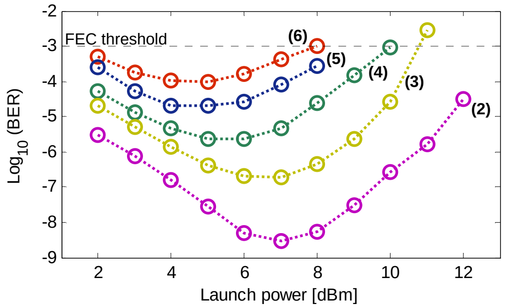

Fig. 5. Measured BER performance of DQP-ASK as a function of launch power over the indicated number of 80 km spans

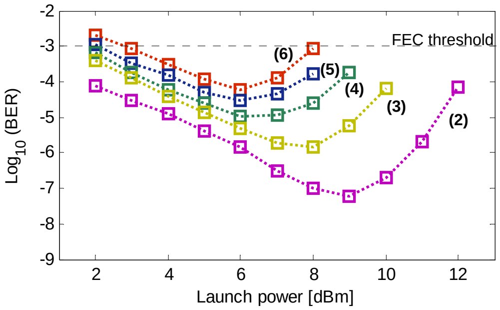

Fig. 6. Measured BER performance of D8PSK as a function of launch power over the indicated number of 80 km spans

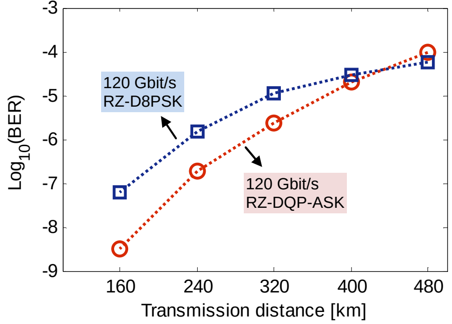

Fig. 7. Minimum BER of the two modulation formats as a function of transmission distances

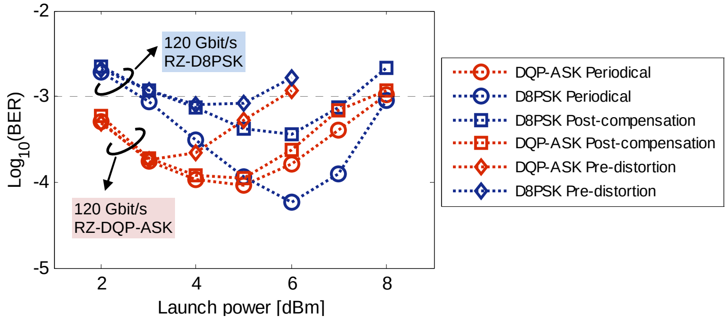

Fig. 8. System performance of the two modulation formats over a 480 km link with three different dispersion maps.

In Fig. 7, we plot the minimum BER (at the optimal launch power) found in Fig. 5 and 6 as a function of the transmission reach. We observe that DQP-ASK outperforms D8PSK at short distances, as we can expect from theory. However, as the reach increases (so does the accumulated SPM), its performance gradually approaches with that of D8PSK and eventually becomes worse at 480 km. This is because the two rings of DQP-ASK experience different SPM-induced phase shift, causing severe signal phase distortion.

Lastly, in fig. 8, we evaluate the system performance of the two signals over a 480 km link with 3 different dispersion maps: (a) a periodical compensated link as used in previous measurements, (b) a post-compensation link, and (c) a pre-distortion link. The post-compensation link was prepared by placing all the DCF modules after the 6x80km SMFs while the pre-distortion link is achieved by placing a 4 km DCFs directly in front of the periodical compensated link, which has been suggested in [8] for the system performance improvement. Nevertheless, in this work we find that, in contrast to [8], the periodical compensated link provides the best performance whereas the pre-distortion link appears to be the worst scenario for the two modulation formats. Still, more work is required to optimize dispersion maps and power levels in such links.

5. Conclusion

We experimentally demonstrated that the performance of DQP-ASK is superior to that of D8PSK over short distances (up to 400 km). We also found ~1.5 dB difference between the theoretical and experimental optimal ER of DQP-ASK. Lastly, we showed that, among three evaluated dispersion maps, the periodical compensated and the pre-distortion links appear to be the best and the worst scenarios, respectively. This work was supported by Swedish Foundation for Strategic Research (SSF), the Swedish Governmental Agency for Innovation Systems (VINNOVA) within the 100 GET program, and the Knut and Alice Wallenberg Foundation.

4. References

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