Coding Gain of FEC Encoded 21.42Gb/s RZ-DQPSK Using an Electrical Differential Quaternary Precoder

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Abstract *We report a measured gross coding gain of 6.8dB for 21.42Gb/s RZ-DQPSK using standard FEC in combination with differential precoding. Furthermore we show that RZ-DQPSK has approximately a 2dB higher FEC coding gain than RZ-DPSK.*

Introduction

Recently the return to zero optical differential quadrature phase shift keying (RZ-DQPSK) modulation format attracted attention because of its advantageous properties for increasing the spectral efficiency and its robustness towards fibre impairments [1,2]. For practical DQPSK transmission systems a differential precoder is an indispensable component which can only be omitted for laboratory experiments if bit pattern generators (BPG) or bit error ratio tester (BERT) are programmed accordingly [3]. However, if forward error correction (FEC) schemes are used with the DQPSK modulation format, differential precoding is mandatory. According to our knowledge there have been no experimental results of FEC encoded DQPSK transmission presented before.

In this contribution we give the required optical signal to noise ratio (OSNR) of 21.42Gb/s FEC encoded RZ-DQPSK and compare the results with binary FEC encoded RZ-DPSK at 10.71Gb/s. For the experiments we used a standard FEC encoding technique according to the ITU-T G.709 specification.

Measurement set-up

The experimental set-up consisted of five different sections according to figure 1. The first section was used for generating two de-correlated electrical differentially and FEC encoded data sequences. It consisted of a combined BPG and optical transport unit two (OTU-2) framer which generated an optical amplitude shift keying (ASK) FEC encoded signal with pseudo random bit sequence (PRBS) payload. The OTU-2 framer used a standard Reed Solomon code (255/239) with 7% overhead. Then the optical signal was converted to the electrical domain by a photodiode (O/E) and a 10.71 Gb/s clock and data recovery (CDR) unit. The electrical output signal was then split and delayed in order to generate two de-correlated FEC encoded data signals. Both signals and the clock signal were connected with a hardware realisation of a quaternary differential precoder according to [3]. The second section was an RZ-DQPSK transmitter which consisted of an external cavity laser (ECL) operating at 193.4 THz followed by a Mach-Zehnder modulator (MZM) for pulse carving (duty cycle of 50%) followed by a phase modulator (PM) and a second MZM for DQPSK modulation. The PM and second MZM were driven by the differentially and FEC encoded data sequences from section 1. The electrical driving signal for the MZM was delayed by 14ns to cancel the transit time of 14ns between PM and MZM.

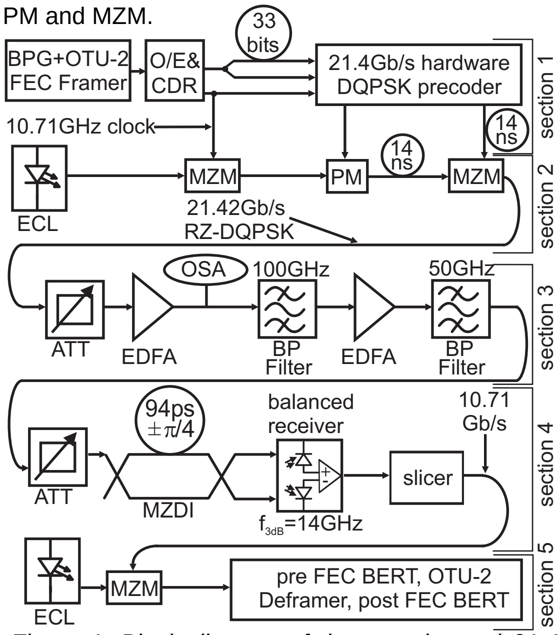

Figure 1: Block diagram of the experimental 21.42 Gb/s FEC encoded RZ-DQPSK transmission set-up.

The optical 21.42Gb/s RZ-DQPSK signal was then connected with section 3 which was used for noise loading and OSNR measurement (0.1nm resolution bandwidth). It consisted of a variable optical attenuator (ATT) followed by two erbium doped fibre amplifiers (EDFA) with bandpass (BP) filters (f_{3dB}=100GHz and 50GHz) for reduction of amplified spontaneous emission (ASE) noise.

Section 4 was used for demodulating the 21.42Gb/s RZ-DQPSK signal. It consisted of a temperature controlled Mach-Zehnder delay interferometer (MZDI) with a delay of 94ps in one arm and an additional phase difference of $+\pi/4$ and $-\pi/4$, respectively. This way the in-phase (I) and quadrature (Q) component of the RZ-DQPSK signal were measured separately on a data rate of 10.71Gb/s per tributary. Both outputs from the MZDI were connected to a low-noise balanced receiver with a 3dB bandwidth of 14GHz followed by a slicer.

In section 5 the signal was ASK modulated in order to feed the detected data into an optical BERT. The optical BERT combined a pre-FEC BERT, FEC de-framer, and post FEC BERT.

For measurements with the RZ-DPSK modulation format at the same symbol rate we omitted the PM in section 2 and used a binary differential precoder according to [4]. Additionally the phase difference between both arms of the MZDI was equal to 0º.

As a comparison we also conducted measurements without FEC. We used a BPG with de-correlated PRBS 2^{23}-1 as inputs for the precoder and measured the BER directly after the slicer without programming the BERT.

Results and discussion

The required OSNR for RZ-DPSK and RZ-DQPSK transmissions using (i) OTU-2 frames with FEC and (ii) PRBS 2^{23}-1 data without FEC is plotted in figure 2. Note that the data rate for RZ-DQPSK is twice that of RZ-DPSK.

First of all we compare RZ-DQPSK with RZ-DPSK. At a BER of 10^{-13} we measured without FEC a difference of 6.0dB / 8.0dB for the in-phase component and for the quadrature component, respectively. The 2dB difference between in-phase and quadrature components is due to the non exactly matched drive amplitude for the PM.

However, the OSNR requirements of RZ-DQPSK compared to RZ-DPSK can be reduced from 6.0dB / 8.0dB to 3.9dB / 5.4dB when FEC is used. If the same data rate is considered the effective noise bandwidth for RZ-DQPSK is reduced by a factor of two in comparison to RZ-DPSK. For a more optimal RZ-DQPSK transmitter this can result in almost the same OSNR requirements for RZ-DPSK and RZ-DQPSK (3.9dB - 3dB = 0.9dB) while at same time the required bandwidth for RZ-DQPSK is halved resulting in higher spectral efficiency, higher dispersion and PMD tolerance and relaxed electrical component requirements.

From figure 2 one can also derive the gross coding gain of FEC in combination with RZ-DQPSK and RZ-DPSK. For RZ-DQPSK the gross coding gain is 6.8dB and 7.3dB, respectively, whereas for RZ-DPSK, we obtained 4.6dB which is slightly worse than the theoretical limit shown in [5]. Thus, we measured an improved coding gain of more than 2dB for DQPSK due to the smaller slope gradient [6] of the RZ-DQPSK BER curves.

Figure 3 shows the corrected BER after FEC vs. the BER before FEC correction. We notice that the curves for both modulation formats are in a good agreement, thus the correction capabilities of the FEC are modulation format independent if noise limited measurements are considered.

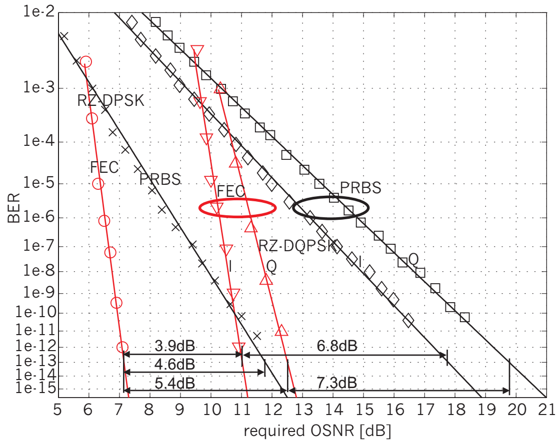

Figure 2: BER vs. required OSNR for both RZ-DQPSK tributaries and RZ-DPSK. Markers: □/◇: RZ-DQPSK with PRBS 2^{23}-1 data; ∆/∇: RZ-DQPSK with FEC; x: RZ-DPSK with PRBS 2^{23}-1 data; o: RZ-DPSK with FEC.

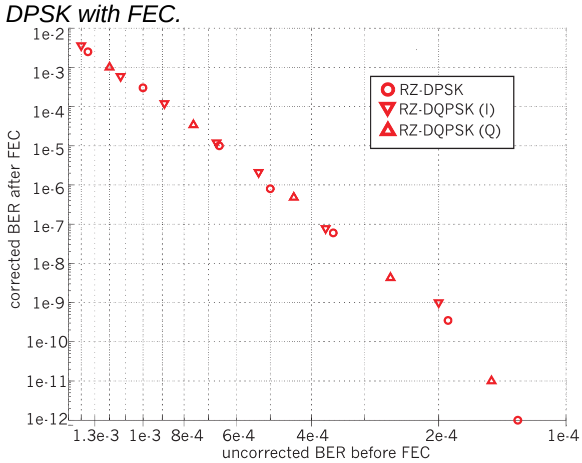

Figure 3: Measured corrected BER after FEC vs. uncorrected BER for both RZ-DQPSK tributaries and RZ-DPSK, markers according to figure 2.

Conclusions

We investigated the BER performance of RZ-DQPSK using standard FEC techniques. Comparing 21.42Gb/s RZ-DQPSK to 10.71 Gb/s RZ-DPSK the OSNR difference can be reduced to approximately 4dB if FEC is used. Furthermore, we determined experimentally the gross coding gain of standard FEC in combination with RZ-D(Q)PSK (6.8dB/7.3dB), which is approximately 2dB higher than for RZ-DPSK.

References

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