Electrical dispersion compensation for different modulation formats with optical filtering

Chunmin Xia, Werner Rosenkranz
Chair for Communications, University of Kiel, Kaiserstraße 2, D-24143 Kiel, Germany, E-mail: cx@tf.uni-kiel.de

Abstract: We present electrical dispersion compensation by using maximum-likelihood-sequence-estimation (MLSE) and decision-feedback-equalization for different modulation formats. Especially, MLSE performance with strong optical filtering is investigated.

OCIS codes: (260.2030) Dispersion; (060.2360) Fiber optics links and subsystems

1. Introduction

Electrical dispersion compensation (EDC) technique has been considered as a potentially cost efficient approach to upgrade optical communication systems' performance. Meanwhile, advanced modulation formats such as optical duobinary (ODB) and differential phase shift keyed (DPSK) are proposed to enhance the transmission capacity. A combination of the two techniques is expected to achieve further overall performance improvement. However, conventional EDC performance is limited by the square law detection in on-off keying (OOK) systems. Moreover, different advanced modulation formats will further enhance this kind of nonlinearity due to the special setups either at the transmitter side or receiver side and have thus influence on the EDC performance. [1] has shown that linear equalization on chromatic dispersion (CD) mitigation is limited for ODB and DPSK systems. We investigate more efficient EDC techniques including maximum likelihood sequence estimation (MLSE) and decision feedback equalization (DFE). Three kinds of impairments resulting from CD, polarization mode dispersion (PMD) and strong optical filtering are considered. In addition, recent research has shown that ODB and DPSK modulation exhibit larger tolerance to strong optical filtering [2,3]. In this work, we investigate the EDC performance of CD and PMD with strong optical filtering for different modulation formats.

2. Simulation setup

We concentrate on pre-amplified 10Gb/s optical systems with standard single mode fiber (SSMF, dispersion coefficient D=17ps/km/nm). Three modulation formats with non-return-to-zero (NRZ) pulse shape are considered: OOK, ODB and DPSK. The system setup is illustrated in Fig.1. We assume Gaussian optical bandpass filter (OBPF) with 3-dB bandwidth of 50GHz or 10GHz and a Butterworth electrical lowpass filter (ELPF) with 3-dB bandwidth of 7GHz. As shown in Fig.1, $OBPF_1$ and $OBPF_2$ correspond to the multiplexer and de-multiplexer in a WDM system. For the weakly filtering case, $OBPF_2$ with 50GHz is assumed and OBF_1 is omitted, which corresponds to the single channel case. Both $OBPF_1$ and $OBPF_2$ with 10GHz (corresponds to the narrow channel spacing in WDM systems) are assumed for strong optical filtering case. For ODB system, the transmitter includes a precoder and a Bessel ELPF [4] and the receiver is identical to OOK receiver. For DPSK system, conventional receiver setup is replaced with Mach-Zehnder delay-interferometer (MZDI) and a balanced detector. Two kinds of equalizers are examined: DFE and MLSE. As trade off of performance and complexity, we assume a DFE with feedforward filter of 4 delay-taps and a feedback filter of 2 delay-taps (FFE[4]-DFE[2]) and a MLSE with memory of 2 (MLSE[2]). Two-fold oversampling is assumed. Minimum mean square error (MMSE) is used to optimize the coefficients of DFE. MLSE is processed based on a look-up table method [6]. We focus on the EDC performance and an ADC with infinite resolution is assumed.

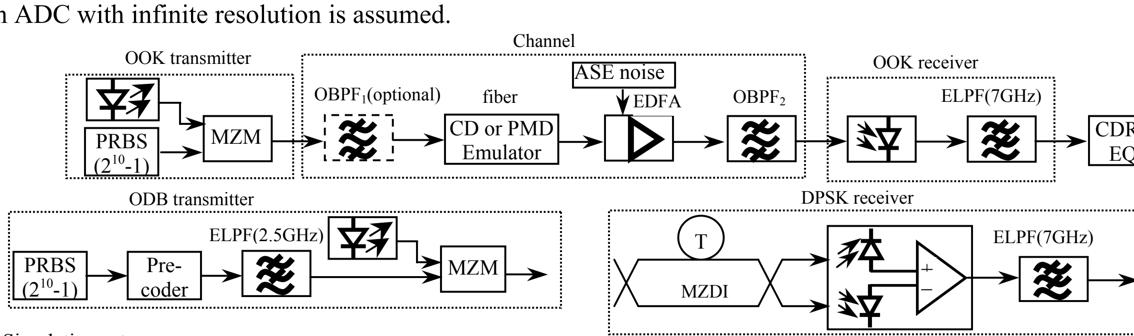


Fig.1. Simulation setup.

3. Comparison between MLSE and DFE on CD and PMD mitigation

We examine the performance of DFE and MLSE on CD compensation first. We compare the required optical signal to noise ratio (OSNR) to achieve a bit error ratio (BER) of $5 \cdot 10^{-4}$, which is sufficient for error-free operation with FEC. As shown in Fig.2, EDC performance exhibits great difference for different modulation formats. DFE shows very small performance improvement for both DPSK and ODB. Severe asymmetrical nonlinear distortion in ODB system limits DFE performance [5]. In DPSK systems, EDC performance is limited by the conversion from phase to intensity with a delay-interferometer and balanced detection [6]. Additional simulations show that the performance degradation is not as severe with single detection. This demonstrates that not phase-to-intensity conversion but balanced detection mainly limits EDC performance.

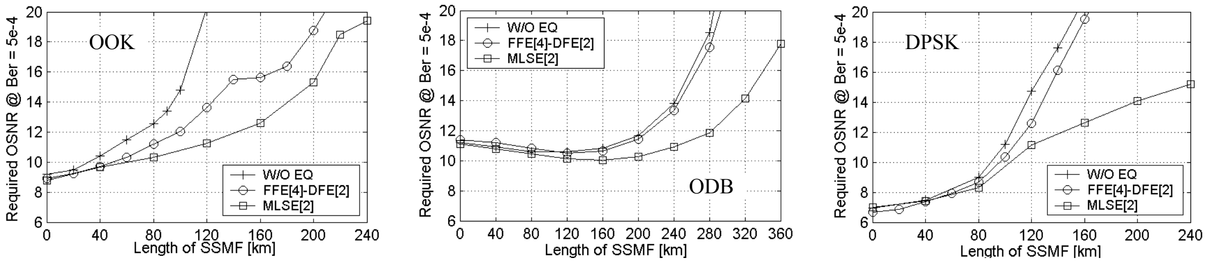


Fig.2. Required OSNR at BER=5e-4 versus length of SSMF with and without using EDC for different modulation formats, data rate 10Gb/s, $OBPF_2$=50GHz, without using $OBPF_1$.

In order to compare EDC performance on first order PMD mitigation, the required OSNR versus differential group delay (DGD) is shown in Fig.3. The difference of performance improvement between DFE and MLSE is smaller compared to the case on CD mitigation. This is because first order PMD results in linear distortions in the electrical domain. Both OOK and ODB exhibit similar performance improvement through EDC, however less improvement for DPSK is observed. This demonstrates that balanced detection degrades EDC performance for both CD and PMD. Note that required OSNR for b2b is a little higher than that shown in fig.2, because 2-ASE modes are used for PMD case and one ASE mode is assumed for CD case.

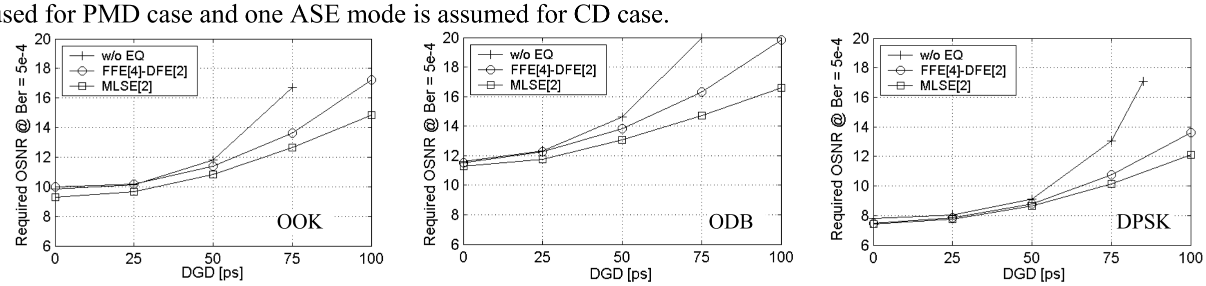


Fig.3. Required OSNR at BER=5e-4 versus DGD with and without using EDC for different modulation formats, data rate 10Gb/s, $OBPF_2$=50GHz, without using $OBPF_1$.

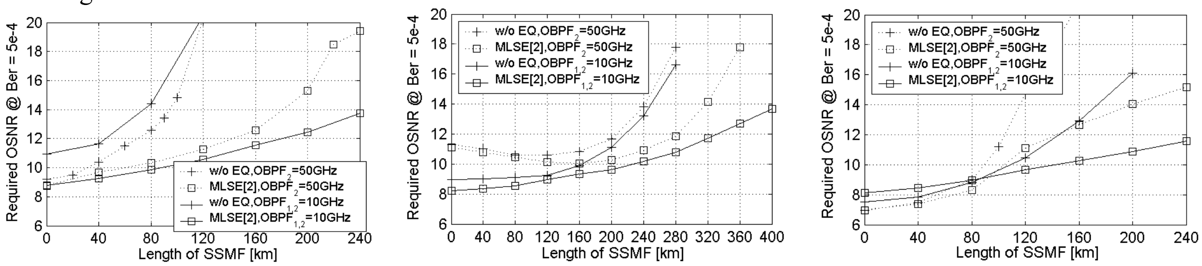
4. MLSE on CD and PMD mitigation with strong and weakly optical filtering

Strong optical filtering has two opposite effects: eliminating more ASE noise and resulting in more distortions. First of all, EDC directly benefits from elimination of ASE noise. Secondly, EDC can compensate at least partially the distortions from strong filtering. Moreover, different modulation formats have different tolerance to strong filtering as well as to CD and PMD. Therefore, EDC performance with strong filtering has to be studied carefully for different modulation formats. Optical filtering causes nonlinear distortion after direct detection. MLSE can compensate the nonlinear distortion more efficiently than DFE, therefore, only MLSE is considered in this section.

The required OSNR versus length of SSMF for strong or weakly filtering with and without MLSE is shown in Fig.4. Without EDC, OOK shows about 2.5dB penalty due to strong filtering. This means that the benefit from elimination of more ASE noise is outperformed by the distortions. However, DPSK benefits from strong filtering for higher dispersion values. This results from two aspects: on the one hand, the signal spectrum becomes narrower after filtering and hence has more tolerance to CD in spite of more distortion caused by strong filtering itself. On the other hand, balanced detection can compensate some distortions from strong filtering. For ODB, about 3dB gain is achieved by using strong filtering for b2b. This is because ODB modulation itself has larger eye-opening penalty for b2b due to the conversion of 3-level signal into 2-level signal. Strong optical filtering can reshape this kind of "V" shape eye into normal NRZ-shape eye and thus achieves less penalty.

However if MLSE is applied, substantial improvement can be achieved for strong filtering for all formats because MLSE can compensate partially the distortions from strong filtering. For OOK and ODB, MLSE can achieve even better performance for strong filtering, especially for larger dispersion values. This demonstrates that

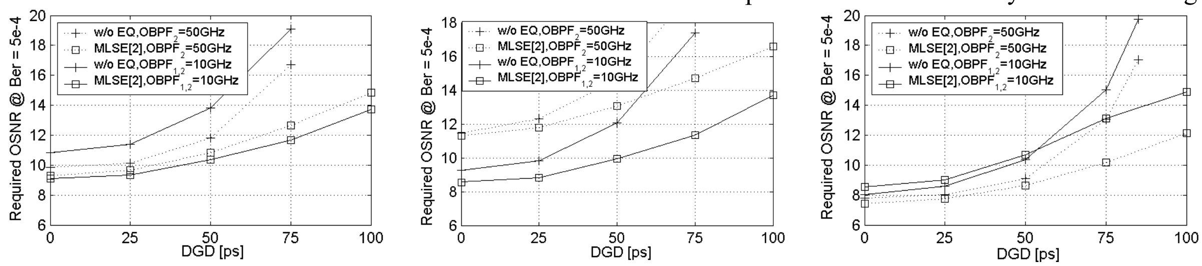
MLSE can compensate efficiently the distortions caused by strong filtering in OOK and ODB systems. However, for DPSK, MLSE cannot compensate effectively the distortion due to strong filtering, especially for short distance. This is again due to the balanced detection.



OOK ODB DPSK

Fig.4. Required OSNR at BER=5e-4 versus length of SSMF with and without using EDC for different modulation formats with weakly ($OBPF_2$=50GHz, without using $OBPF_1$) and strong ($OBPF_1$= $OBPF_2$=10GHz) optical filtering, data rate 10Gb/s.

When strong optical filtering interacts with first order PMD, the results are shown in Fig.5. Strong optical filtering for OOK and DPSK results in larger penalty when DGD is increased. This means that strong filtering aggravates the PMD effect. This can be well compensated for OOK, whereas for DPSK again the balanced detection results in only small improvement by MLSE equalizer. However, for ODB the signal spectrum is approximately by a factor of 2 smaller compared to OOK and DPSK. Thus the 10GHz filter results in less distortions and the benefit of noise elimination is dominant. Similar improvement is observed by MLSE as in Fig.4.



OOK ODB DPSK

Fig.5. Required OSNR at BER=5e-4 versus DGD with and without using EDC for different modulation formats with weakly ($OBPF_2$=50GHz, without using $OBPF_1$) and strong ($OBPF_1$= $OBPF_2$=10GHz) optical filtering, data rate 10Gb/s.

4. Conclusions

Through the comprehensive comparison and analysis of EDC performance by using MLSE and DFE with strong as well as weakly optical filtering for different modulation formats, we conclude as follows: (1). On CD mitigation, DFE shows negligible improvement for ODB due to the nonlinearity enhancement. Both DFE and MLSE are limited in DPSK due to the balanced detection. Whereas, on PMD mitigation, EDC shows similar performance for all modulation formats due to the linear distortions resulting from the first order PMD. (2). ODB can obtain most benefits from strong optical filtering. Less degradation due to strong optical filtering is achieved in DPSK compared to OOK. MLSE can compensate the distortions from strong optical filtering more effectively for OOK and ODB compared to DPSK.

References

[1] V. Curri, R.Gaudino, A.Napoli and P.Poggiolini, “Electronic equalization for advanced modulation formats in dispersion-limited systems”, IEEE photonics technology letters, Vol.16, No.11, Nov.2004, pp.2556~2558.

[2] C. Xie, L. Moeller and R.Ryf, “Improvement of optical NRZ- and RZ-Duobinary transmission systems with narrow bandwidth optical filters”, IEEE photonics technology letters, Vol.16, No.9, Sept.2004, pp.2162~2164.

[3] P.J.Winzer, S. Chandrasekhar and H. Kim, “Impact of filtering on RZ-DPSK reception”, IEEE photonics technology letters, Vol.15, No.6, Jun.2003, pp.840~842.

[4] W. Kaiser, T. Wuth, M. Wichers and W. Rosenkranz, “Reduced complexity optical duobinary 10Gb/s transmitter setup resulting in an increased transmission distance”, IEEE Photonics Technology Letters, August 2001, pp. 884-886.

[5] C. Xia and W. Rosenkranz, “Performance enhancement for duobinary modulation through nonlinear electrical equalization”, ECOC 2005, Glasgow, Scotland, Sept. 2005, paper Tu4.2.3.

[6] M. Cavallari, C.R.S. Fludger and P.J. Anslow, “Electronic signal processing for differential phase modulation formats”, OFC2004, Anaheim, USA, paper TuG2.