Electrical Equalization for Duobinary and Phase Shift Keyed Modulation Formats

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ABSTRACT
We investigate the advanced electrical equalization techniques on various impairments mitigation for different modulation formats by using decision feedback equalizer and maximum likelihood sequence estimator. Three kinds of impairments resulting from chromatic dispersion, polarization mode dispersion and strong optical filtering are considered.
Keywords: electrical equalization, decision feedback equalizer, maximum likelihood sequence estimation, modulation formats, chromatic dispersion, polarization mode dispersion and strong optical filtering.

1. Introduction

Electrical dispersion compensation (EDC) techniques by using different equalizers such as feedforward equalizer (FFE) and decision feedback equalizer (DFE) have 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 FFE 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 DFE. Three kinds of impairments resulting from CD, polarization mode dispersion (PMD) and strong optical filtering are considered.

2. System 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.

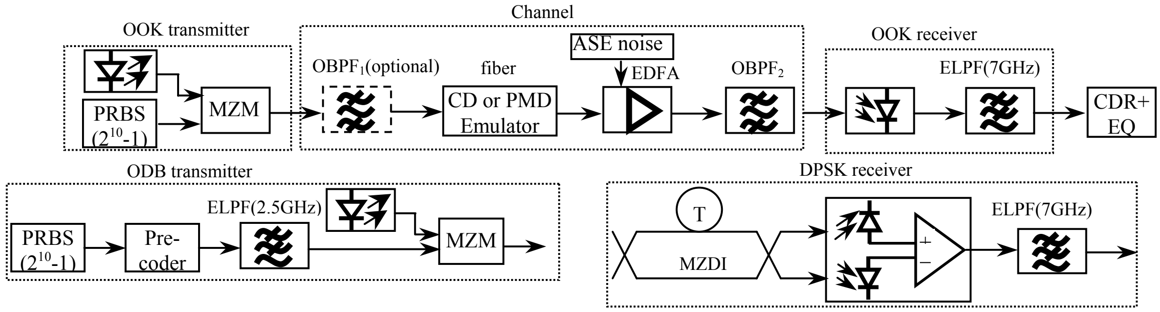

Figure 1: System Setup

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3. EDC on CD Mitigation

We examine the performance of DFE and MLSE on CD compensation in this part. 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 to achieve 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]. Only MLSE exhibits its advantage for larger transmission distance. 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.

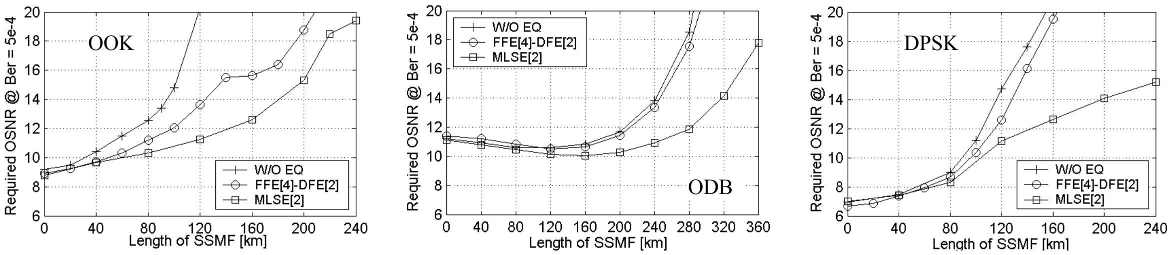


Figure 2: Required OSNR at BER=5e-4 versus length of SSMF with and without using EDC for different modulation formats, data rate 10Gb/s, $OBPF_2$=50GHz, without using $OBPF_1$.

4. EDC on PMD Mitigation

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 of 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.

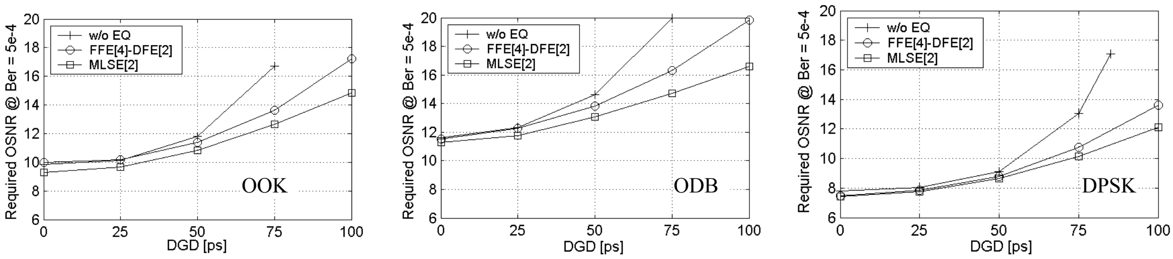


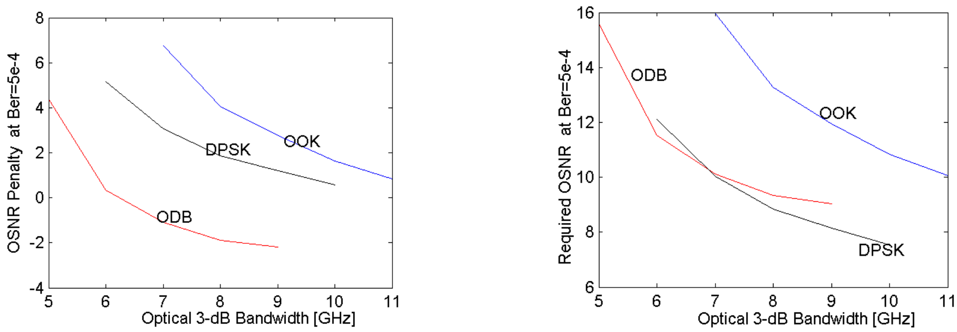
Figure 3: Required OSNR at BER=5e-4 versus DGD with and without using EDC for different modulation formats, data rate 10Gb/s, $OBPF_2$=50GHz, without using $OBPF_1$.

5. EDC on Mitigation of Distortion due to Strong Optical Filtering

In WDM systems, strong optical filtering will result in undesired signal distortions for the case of narrow channel spacing. In dispersion compensated linear systems, the distortions due to strong optical filtering become the main impairment, which can be compensated by using electrical signal processing.

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 [2,3]. Therefore, EDC performance with strong filtering has to be studied carefully for different modulation formats. Optical filtering causes nonlinear distortions after direct detection. MLSE can compensate the nonlinear distortion more efficiently than DFE, therefore, only MLSE is considered in this section.

First of all, without using MLSE, the OSNR penalty (compared to weakly filtering with $OBPF_2$=50GHz) with strong optical filtering for different modulation formats is shown in Fig.4 (a). From Fig.4 (a) we can see that ODB can achieve the most benefit from strong optical filtering. 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. OOK shows the smallest tolerance to the strong optical filtering, which means that the benefit from elimination of more ASE noise is outperformed by the distortions. DPSK exhibits larger tolerance to strong optical filtering compared to OOK because DPSK based on balanced detection can compensate partially the strong optical filtering. The required OSNR for different modulation formats is show in Fig.4 (b), which shows that with strong optical filtering, ODB and DPSK approach the similar receiver sensitivity thanks to the 3-dB advantage of DPSK based on balanced detection.



(a) (b)

Figure 4: (a) Required OSNR penalty at BER=5e-4 (compared to weakly filtering case with $OBPF_2$=50GHz) versus optical filtering bandwidth of $OBPF_2$ and $OBPF_1$ for different modulation formats, data rate 10Gb/s.

(b) Required OSNR at BER=5e-4 versus optical filtering bandwidth of $OBPF_2$ and $OBPF_1$ for different modulation formats, data rate 10Gb/s.

Secondly, we examine the MLSE performance on compensation the distortion resulting from strong optical filtering. The required OSNR versus optical filter bandwidth with and without MLSE process is shown in Fig.5. MLSE can compensate effectively the distortion due to strong optical filtering for OOK and ODB systems, however, less improvement is observed for DPSK. This is once again due to the balanced detection of DPSK.

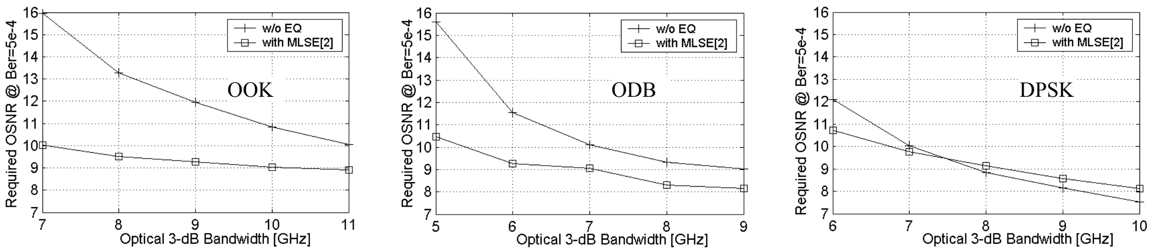


Figure 5: Required OSNR at BER=5e-4 versus optical filtering bandwidth of $OBPF_2$ and $OBPF_1$ with and without using EDC for different modulation formats, data rate 10Gb/s.

6. Conclusion

We compare and evaluate EDC performance by using MLSE and DFE for different modulation formats and draw the following conclusions: (1). On CD mitigation, DFE shows negligible improvement for ODB due to the unsymmetrical nonlinear distortion. Both DFE and MLSE are limited in DPSK due to the balanced detection. (2). Performance difference of EDC on PMD mitigation is less than that on CD mitigation for different modulation formats because first order PMD causes linear ISI in the electrical domain. (3). ODB can obtain most benefits from strong optical filtering due to its narrower bandwidth. DPSK can achieve less degradation due to strong optical 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.