Performance Enhancement for Duobinary Modulation Through Nonlinear Electrical Equalization

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Abstract *A nonlinear electrical equalization technique is proposed to improve the performance in optical duobinary modulation system. We show that more than 1000ps/nm dispersion tolerance improvement and comparable performance to MLSE equalizer can be achieved.*

Introduction

Various advanced modulation formats have been proposed to increase the transmission capacity in optical long haul transmission systems [1,2]. Especially, Optical Duobinary Modulation (ODB) is very attractive as it combines large Chromatic Dispersion (CD) tolerance with moderate implementation complexity [1-4]. Recently, Electronic Dispersion Compensation (EDC) is considered as cost-effective solution to upgrade the system performance in both single mode fiber long haul systems and multimode fiber short links [1-4]. Combination of advanced modulation format such as ODB with proper EDC technique can further enhance the overall performance [3,4]. However, recent research has shown that only moderate improvement for ODB can be achieved by using conventional EDC including Feed Forward Equalizer (FFE) and Decision Feedback Equalizer (DFE) [1-3]. Better performance can be obtained by using Maximum Likelihood Sequence Estimation (MLSE) with oversampling [3,4], however, MLSE is much more complicated to implement and not cost-effective. In this work, based on the analysis of nonlinear ISI characteristics in ODB systems, a nonlinear electrical equalizer setup based on Voterra theory [5,6] is proposed to mitigate the CD in ODB system. We show that additional 1000ps/nm dispersion tolerance can be achieved.

Nonlinear ISI in ODB system

We generate 10Gb/s ODB signal according to the scheme described e.g. in [7] using a 4.1GHz Bessel low-pass filter and a single drive Mach-Zehnder modulator in push-pull configuration. Thus an optical pseudo-ternary signal is created. The reason for the limited performance of EDC on CD mitigation in optical communication is due to the nonlinear characteristics of the square-root operation of modulation and absolute square operation of direct detection. This kind of nonlinearity will be enlarged by the transformation from three-level signals into two-level signals in ODB receiver. Actually, the large dispersion tolerance of ODB can be understood as follows. The ‘1 0 1’ bits combination will be encoded as ‘1 0 –1’ or ‘-1 0 1’. The distortions incurred on the ‘0’ level from neighbouring ‘1’ and ‘-1’ levels will cancel out and thus result in less distortion (including linear and nonlinear distortion) on ‘0’ level but more distortion on ‘1’ level. Therefore, severe asymmetrical nonlinear ISI in ODB system limits the EDC performance. This explains why no significant performance improvement can be achieved in case of ODB in comparison with conventional NRZ-OOK [1-4].

We propose a nonlinear electrical equalizer based on Volterra theory to mitigate this kind of nonlinear ISI. For illustration, the equalizer setup NL[2,2]-FFE[1]-DFE[2] is shown in Fig.1. This designation means FFE of order 1, DFE of order 2 and nonlinear order 2 for both filters. The nonlinear parts have been marked with dashed boxes. We note that NL-FFE-DFE can be considered as the extension of a normal FFE-DFE including the nonlinear ISI mitigation.

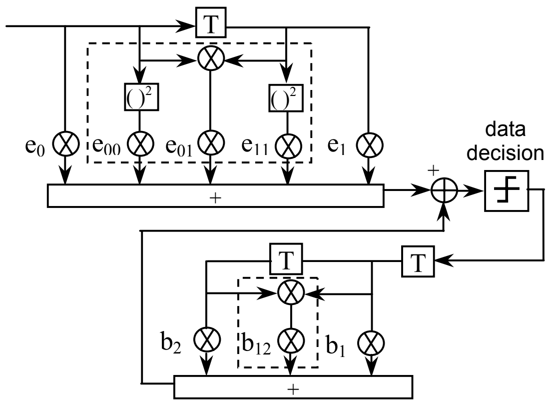

Fig.1: Setup of NL[2,2]-FFE[1]-DFE[2]: nonlinear part of setup marked with dashed boxes.

Results and discussions

First of all, ASE noise is not considered. The Eye-Opening Penalty (EOP) is calculated compared to ideal NRZ b2b case. We consider the following three kinds of equalizer setups: NL[2,1]-FFE[4]-DFE[1], FFE[6]-DFE[2] and FFE[20]-DFE[1]. FFE[20]-DFE[1] is chosen to be compared with NL[2,1]-FFE[4]-DFE[1] having the same number of total coefficients for FFE and DFE, respectively. FFE[6]-DFE[2] is as an example to show that 1-tap DFE is enough to mitigate the post-cursor ISI. The coefficients are optimized based on minimum mean square algorithm. The EOP of received signal with and without equalization are plotted in Fig.2. At target of 2dB-EOP, the dispersion limited transmission distance is limited to about 200km without equalization. As mentioned earlier, there is no remarkable improvement with normal FFE-DFE. Nonlinear FFE-DFE however exhibits superior performance. More than 70km distance or equivalent 1000ps/nm dispersion tolerance gain can be achieved. The received eye-diagrams after 270km SSMF are shown in Fig.3. As indicated previously, Fig.3(a) exhibits more distortion with '1' level than with '0' level. Equalization does not display evident improvement with normal FFE-DFE. Good eye opening can be observed through the nonlinear equalization. All of these results confirm that the normal EDC is limited by the nonlinear ISI, which can be mitigated effectively by using nonlinear FFE-DFE.

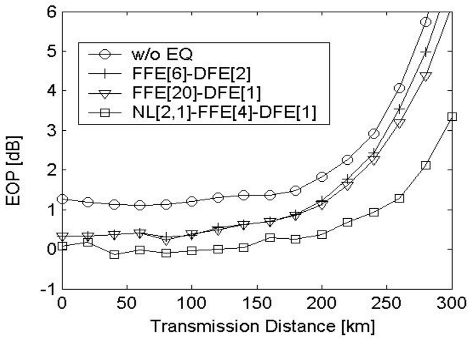

Fig.2: EOP versus transmission distance over SSMF with and without equalization.

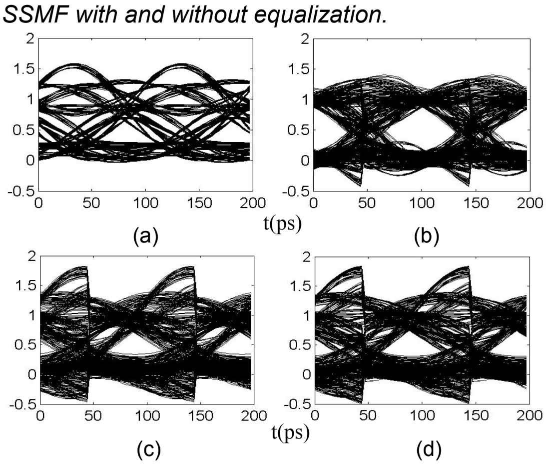

Fig.3: Received eye-diagrams over 270km SSMF. (a) without equalization. (b) with NL[2,1]-FFE[4]-DFE[2]. (c) with FFE[6]-DFE[2] (d) with FFE[20]-DFE[1].

Better performance can be achieved with higher nonlinear order. More simulations demonstrate that one delay tap for DFE part is enough to eliminate the post-cursor ISI, which can be also seen from Fig.3(c), (d). In addition, it is important to mention that nonlinear ISI cannot be eliminated efficiently by increasing the order of normal FFE-DFE.

The influence of ASE noise on EDC performance is investigated by Monte-carlo simulations. The receiver consists of an EDFA and a 50GHz optical Gaussian filter followed by a photodiode and a 7GHz 3rd Butterworth filter. Optimum receiver for a nonlinear channel consists of a match filter with symbol rate sampling and followed by Viterbi algorithm minimizing the error probability through selecting the most probable sequence (MLSE). The match filter, which is too complex to be implemented for high-speed optical receiver, is generally replaced with a low pass filter with successive oversampling. MLSE with 2-fold oversampling can approach the optimum receiver and thus better performance can be achieved. In this part, we compare the performance between the nonlinear FFE-DFE and MLSE with oversampling of 1 and 2 as well as the normal FFE-DFE. Fig.4 shows the BER versus OSNR in 0.1nm bandwidth for different EDC schemes after 270km SSMF. NL[2,1]-FFE[4]-DFE[1] outperforms FFE[20]-DFE[1] with about 1.8dB gain at BER=1e-6. NL[2,1]-FFE[4]-DFE[1] can achieve the similar performance compared to MLSE of memory 2 with oversampling of 1. NL[3,1]-FFE[4]-DFE[1] outperforms MLSE of memory 1 with 2-fold oversampling. Memory of 1 is enough for channel estimation with 2-fold oversampling. Moreover, NL[3,1]-FFE[4]-DFE[1] can achieve about 3dB gain at BER=1e-6 compared to FFE[20]-DFE[1].

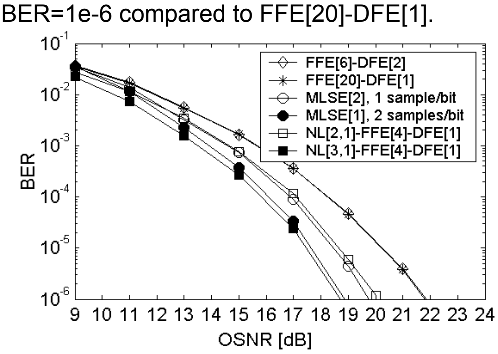

Fig.4: BER versus OSNR for various equalization schemes over 270km SSMF.

Conclusions

Based on the analysis of nonlinear ISI in optical duobinary modulation systems, a nonlinear equalization technique is introduced and proposed. We demonstrate that the nonlinear equalizer setup can mitigate the nonlinear ISI efficiently and hence superior performance compared to normal FFE or DFE and comparable performance to MLSE can be achieved.

References

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