Improved EDC Performance for Different Duobinary Modulation Formats with Optical Filtering

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Abstract

Nonlinear EDC including nonlinear Volterra based equalizer and MLSE are investigated and compared for different duobinary formats with optical filtering at 43Gb/s data rate.

Introduction

Electrical dispersion compensation (EDC) in optical fiber communications has been paid much attention to [1-4]. Previous works [1, 2] showed that EDC performance at the receiver side is strongly dependent on the modulation format with direct detection. Especially, delay-tap based equalizers including feedforward equalizer (FFE) and decision-feedback equalizer (DFE) were shown negligible improvement for optical duobinary (ODB) [2,5]. Recently, investigations [4] based on commercial maximum-likelihood sequence estimator (MLSE) with a memory of 2 showed that larger improvement was achieved for ODB generated by strong optically filtered (SOF) differential-phase-shift-keying (DPSK) signal (noted as "SOF-ODB") than ODB based on electrical low-pass filter (ELF) (noted as "ELF-ODB"). We show through numerical study that EDC shows more improvement for SOF-ODB than ELF-ODB mainly due to the large noise reduction by the narrowband optical filtering in SOF-ODB. We show that in conjunction with nonlinear EDC, especially MLSE, ELF-ODB can even outperform SOF-ODB on the dispersion tolerance if the same narrowband optical filter is applied for both formats.

System setups

The system setups for ELF-ODB and SOF-ODB at a data rate of 43Gb/s are shown in Fig.1. For ELF-ODB, a 5^{th}-order Bessel ELF with a cut-off frequency of 10.75GHz is used to generate the pseudo three-level electrical signal. For SOF-ODB, a DPSK signal is generated first of all and converted into three-level signal by a Gaussian optical bandpass filter (OBF) with a 3dB-bandwidth of 26GHz at the receiver side [5]. The three-level signals are converted into two-level signals after detection for the both cases. The two formats share the same channel which contains 80km standard single mode fiber (SSMF) and two-stage EDFA. Different amount of residual dispersion is set by adjusting the length of DCF. The span loss is fully compensated by the two-stage EDFA. ASE noise from EDFA dominates and nonlinearity of fibers is not taken into account. For the receiver, the 3dB-bandwidths of OBF for ELF-ODB are assumed to be 80GHz and 26GHz (same for SOF-ODB) for weak and strong optical filtering cases, respectively.

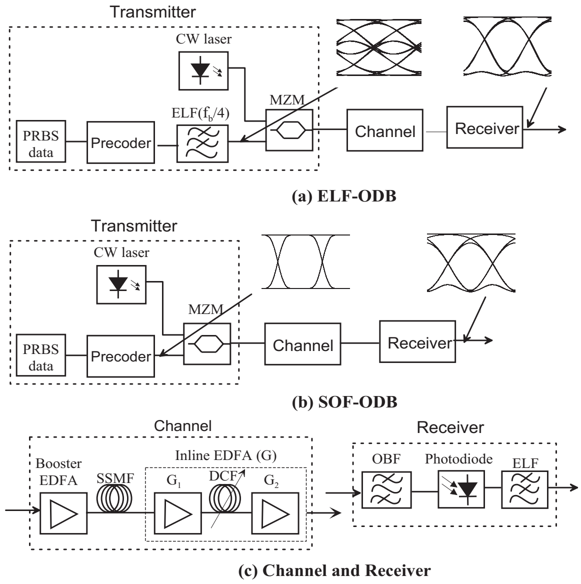

Figure.1 system setups, (a) ELF-ODB, (b) SOF-ODB, (c) the channel and receiver.

EDC considerations

Two kinds of nonlinear equalizers are considered: (i) Nonlinear FFE-DFE based on nonlinear volterra theory [3]: NL(2,1)-FFE(4)-DFE(2) with nonlinear order of 2 and 1, filter order of 4 and 2, for FFE and DFE, respectively. Note that above assumptions are based on the trade off between performance and complexity. (ii) MLSE with a memory of n: MLSE(n). Two-fold sampling is assumed for both cases. The coefficients of NL-FFE-DFE is optimized by using recursive least square (RLS) algorithm and the branch metric of MLSE is based on the chi-square distributed probability density function (PDF). An infinite resolution of ADC is assumed in order to focus on the performance. Monto-Carlo simulations are carried out to achieve a BER of 5×10^{-4} (FEC threshold) based on at least 100 errors count.

Results and discussions

The required OSNR (in 0.1nm) by using NL(2,1)-FFE(4)-DFE(2) is shown in Fig.2. First of all, without EDC, ELF-ODB with weak optical filtering (80GHz) requires larger OSNR than SOF-ODB, especially with less dispersion. This is because much ASE noise is filtered out by the narrowband OBF (26GHz) used by SOF-ODB. This is confirmed by the fact that ELF-

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ODB with an OBF of 26GHz approaches SOF-ODB. Secondly, with EDC, about 25ps/nm additional dispersion can be tolerated by using NL(2,1)-FFE(4)-DFE(1) for the three cases at an OSNR of 18dB. Our additional studies show that more improvement is achieved by increasing the nonlinear order while small improvement is observed by increasing the filter order.

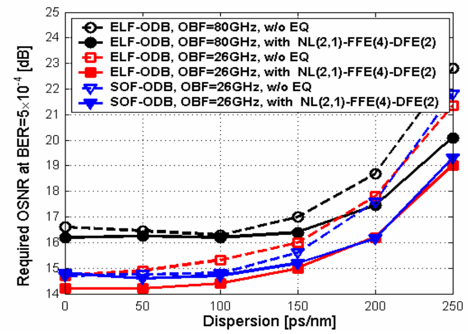

Figure.2 Required OSNR at BER=5×10^{-4} versus the dispersion for ELF-ODB and SOF-ODB with and without using NL(2,1)-FFE(4)-DFE(2).

The results by using MLSE(3) are shown in Fig.3. At an OSNR of 18dB, the transmission distance is extended to about 275km for ELF-ODB with weak filtering (80GHz) and 360km for ELF-ODB with strong filtering (26GHz). However, about 330km is observed for SOF-ODB. This demonstrates that MLSE shows better performance for ELF-ODB than SOF-ODB if the same narrowband OBF is applied.

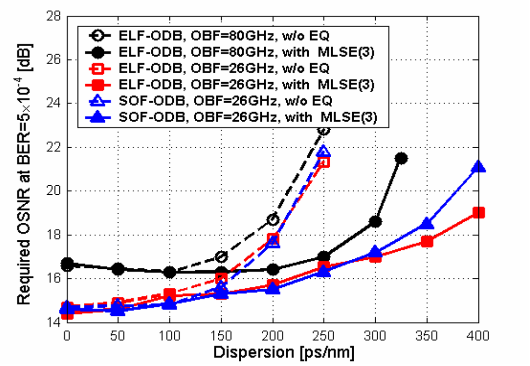

Figure.3 Required OSNR at BER=5×10^{-4} versus the dispersion for ELF-ODB and SOF-ODB with and without using MLSE(3).

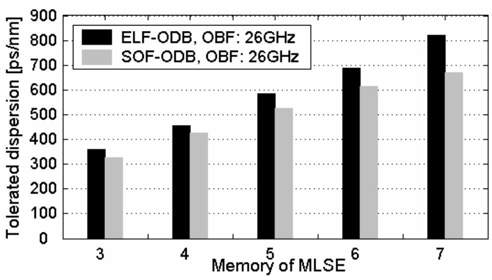

Figure.4: Tolerated dispersion for ELF-ODB and SOF-ODB by using an MLSE with different memories at an OSNR of 18dB to achieve BER=5×10^{-4}.

Comparisons between Fig.2 and Fig.3 indicate that MLSE achieves much better improvement than NL-FFE-DFE at larger dispersion cases. Next, we examine the tolerated dispersion at an OSNR of 18dB for ELF-ODB and SOF-ODB by using MLSE(n) with different memories (n=3, 4, … , 7) and the results are shown in Fig.4. Fig.4 shows that the overall tolerated dispersion for ELF-ODB outperforms SOF-ODB with the same OBF (26GHz), especially by using an MLSE with a large memory. This can be explained from the spectra of the two formats before and after narrowband optical filtering, shown as Fig.5. First of all, before filtering, the spectral width of ELF-ODB is much smaller than that of SOF-ODB. After filtering, the spectrum of SOF-ODB approaches that of ELF-ODB. Therefore, certain amount of higher frequency components of SOF-ODB is cut through filtering and hence more signal power is lost for SOF-ODB. In other words, more reduction of OSNR occurs for SOF-ODB (2.24dB, through calculation) than for ELF-ODB (1.02dB) due to the narrowband filtering. On the other hand, after filtering, ELF-ODB shows narrower spectrum than SOF-ODB. The signal with narrow spectrum has potentially high tolerance to dispersion. Therefore, the same amount of dispersion results in shorter ISI span for ELF-ODB than for SOF-ODB. Consequently, an MLSE requires relatively less memory for ELF-ODB than for SOF-ODB to compensate the same amount of dispersion.

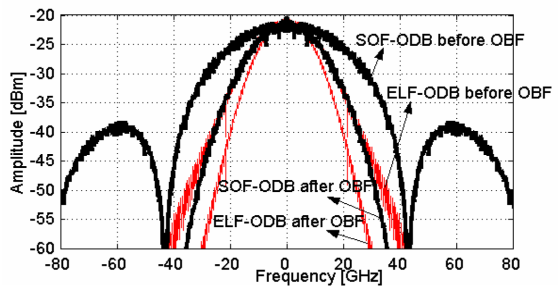

Figure.5: Spectra of SOF-ODB and ELF-ODB before and after optical filtering.

Conclusions

Nonlinear EDC including nonlinear Volterra equalizer and MLSE is investigated for ELF-ODB and SOF-ODB at 43Gb/s. We show that in conjunction with EDC, SOF-ODB shows more dispersion tolerance mainly due to the increased noise reduction by narrowband filtering. We demonstrate that with the same narrowband filter, ELF-ODB outperforms SOF-ODB in the dispersion tolerance together with MLSE.

References

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