Coherent CD Equalization for 111Gbps DP-QPSK with One Sample per Symbol Based on Anti-Aliasing Filtering and MLSE

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Abstract: We propose a coherent detection scheme with one sample per symbol. MLSE is used to compensate for ISI introduced by anti aliasing filtering. 50,000 ps/nm of CD is fully compensated with only 1 dB penalty.

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1. Introduction

Digital compensation of chromatic dispersion (CD) in 40Gbps and 100Gbps coherent optical fiber communication systems is of great interest nowadays [1]-[3]. The common practice for CD compensation is to use fractional space equalizers, with two samples per symbol or more. It is well known that in undistorted media, sampling at the symbol rate forms sufficient information to recover the digital data [4]. However, when the channel introduces linear distortions, e.g., CD, a full information about the received analog signal is required in order to apply digital compensation. Sampling this signal at the symbol rate without preceding filtering violates the Nyquist sampling theorem, causing aliasing effect that results in performance degradation. On the other hand, using anti aliasing filter (AAF) prior to symbol rate sampling introduces heavy low pass filtering (LPF) which, in turn, causes heavy inter symbol interference (ISI). The optimal equalizer, in the sense of minimum probability of error, for channel with ISI is maximum likelihood sequence estimator (MLSE). In this paper we propose the use of MLSE after CD equalization to compensate for ISI introduced by AAF. Recently, several works were published dealing with symbol space equalizers, accompanied by AAF, in order to reduce cost and complexity of VLSI implementation [1], [2]. Both published works deal with low CD values and [1] shows significant power penalty due to the combined aliasing-ISI conflict explained above. Here, it is shown that the combination of AAF together with MLSE allows full equalization with one sample per symbol of transmission of 111Gbps over CD of up to 50,000 ps/nm, with only 1dB of OSNR penalty.

2. System Model

Fig. 1 depicts the single polarization-channel model out of the simulated dual-polarization quadrature phase shift keying (DP-QPSK) 111 Gbps system. . Only a single polarization-channel is examined (including both in-phase and quadrature components) at baud rate of 27.75 Gbaud.

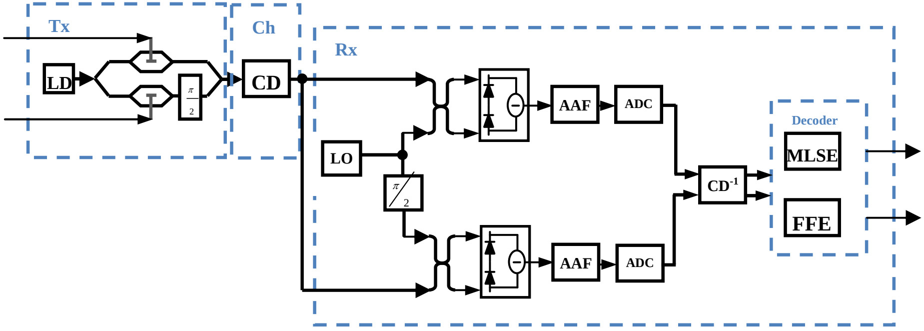
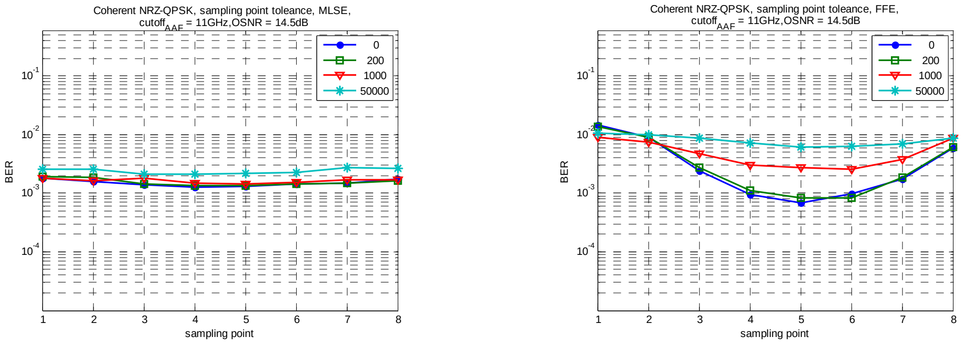


Fig. 1 System block diagram

The optical transmitter and optical front end of the receiver are identical to those presented in [1]. The channel is assumed to be linear with chromatic dispersion (indicated by CD in Fig. 1). Each of the balanced detectors outputs corresponding to in-phase and quadrature components is followed by an AAF, modeled by a 5th order Butterworth LPF. In turn, the signal at each lane is sampled and quantized by an analog to digital converter (ADC) at sampling rate of 27.75 Giga-samples/sec with 5-bit resolution. The two lanes are fed to the CD equalizer, indicated by CD^{-1} in Fig. 1. The CD equalizer is designed according to a zero forcing criterion, and can be implemented either in the time or in the frequency domain [5]. The CD^{-1} output is further decoded by MLSE in order to mitigate the AAF ISI effect. In the simulation 200,000 bits are used to ensure sufficient statistics for bit error rate (BER) of 10^{-3}. The number of states in the MLSE is 16; histogram estimation method is used for channel estimation with training sequence of 50,000 observations, which are subsequently discarded from BER calculation [6]. As an alternative to MLSE, feed forward equalizer (FFE) with 13 taps using least mean squares (LMS) criterion is used for comparison.

3. Simulation results

As opposed to fractional spaced equalizer, a single sample per symbol equalizer may become extremely sensitive to the sampling location within the symbol timeslot (sampling phase). Consequently, sensitivity analysis to the sampling phase of the proposed scheme is carried out. In the simulation each symbol is represented by 8 samples, giving 8 possible sampling phase values. BER results vs. sampling phase as obtained by the MLSE equalizer and by the FFE equalizer (both at OSNR=14.5dB) are presented in Figs. 2 (a) and 2 (b), respectively, for different CD values.

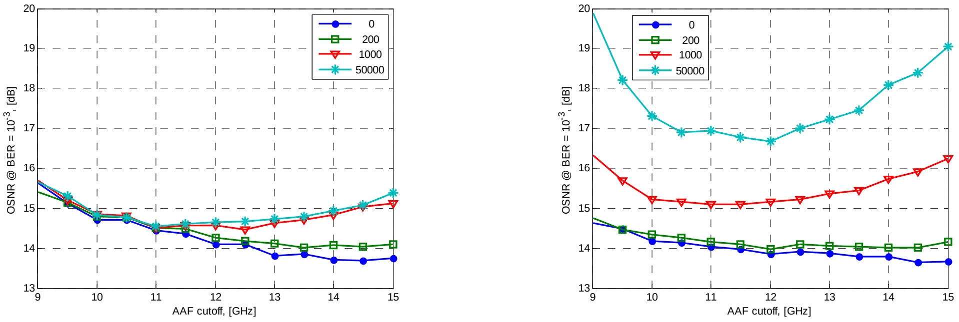


(a) **(b)**

Fig. 2 Sensitivity to sampling point (a) MLSE (b) FFE equalizer

Fig. 2 (a) reveals that the combination of CD equalizer followed by MLSE is insensitive to sampling phase. On the other hand, it is observed in Fig. 2 (b) that the FFE equalizer is sensitive to sampling phase, also observed in [1] and [4].

A set of Monte-Carlo simulations was performed to determine the optimal AAF bandwidth to ensure pre-FEC BER value of 10^{-3}. The simulation results are summarized in Fig. 3.



(a) **(b)**

Fig. 3 ONSR required for 10^{-3} BER as a function of AAF cutoff frequency obtained with (a) MLSE (b) FFE equalizer

It can be seen in Fig. 3 (a) that the proposed system with MLSE decoder enables full compensation of CD up to 50,000 ps/nm. Furthermore, the ISI that is introduced by the AAF is completely compensated with an OSNR penalty of 1 dB only, as compared to the case of back to back (B-t-B) transmission. While the B-t-B system with 19GHz AAF cutoff frequency requires 13.7 dB of OSNR for BER of 10-3, the case of CD=50,000 ps/nm reaches the same BER value with 14.7dB of OSNR. It is also observed in Fig. 3 (a) that for AAF cutoff frequency values higher than 11GH, the aliasing effect leads to performance degradation which can not be compensated by the MLSE, emphasizing the requirement of using an AAF in a symbol-spaced sampling system. Similarly, a set of simulations was performed using a symbol spaced FFE equalizer, and the results are presented in Fig. 3 (b). It can be noted that for high CD values the system performance is severely degraded, despite the fact that optimal sampling phase is used.

4. Conclusion

It is shown here that in coherent detection, a symbol spaced equalizer preceded by an appropriate anti-aliasing filter (AAF) and followed by MLSE can be used to compensate up to 50,000 ps/nm of CD with only 1dB OSNR penalty. The MLSE is required to compensate for the ISI introduced by the AAF, while FFE introduces significant power penalty for large CD values. Moreover, as opposed to FFE, the MLSE is insensitive to sampling phase in a symbol-spaced system. The proposed scheme of symbol-spaced sampler enables the use of 27.75Giga-samples/sec ADCs in 111Gbps coherent digitally equalized system with full compensation of chromatic dispersion. In addition, it allows significant VLSI hardware relaxation, reduced power consumption, and reduced cost.

5. References

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