Study of the Electronic Dispersion Compensation for 2.5 and 10 Gb/s Transient and Adiabatic Chirped Directly Modulated Lasers

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ABSTRACT

In this paper we report the results of the effect of electronic dispersion compensation (EDC) when directly modulated lasers with different chirp characteristics at 2.5 and 10 Gb/s are used. The extracted parameters of directly modulated lasers that were used in this work have been previously verified by simulations and experiments. The performance efficiency of EDC is evaluated in terms of eye opening penalty degradation associated with the signal transmission over standard single mode fiber. Eye opening penalty measurements reveal significant performance improvement for all the examined cases. The transmission limits of standard single mode fiber links using electronic feedforward equalizer and decision feedback equalizer are presented. The benefit of electronic dispersion compensation on directly modulated based systems is that it offers great potential to applications in metro/access networks with high data rates.

Keywords: Directly modulated laser, dispersion compensation, feedforward equalizer, decision feedback equalizer.

1. INTRODUCTION

Driven by the rapidly increasing data traffic demands, high speed transmission systems have become more attractive in the applications that are cost sensitive and need high data traffic growth. For metro/access networks, the cost is very critical factor and is strongly dependent with the cost of terminal equipment. Hence, effective low cost transmitters such as directly modulated lasers (DMLs) could be utilized. DMLs are the workhorses of metro/access systems since they provide low cost, small size, low driving voltage and high output power compared to using external modulated lasers (EMLs).

However, the frequency chirp characteristics of DMLs significantly limit the achievable non-dispersion-compensated transmission distance over standard single mode fiber (SSMF) to less than 10 Km at 10 Gb/s [1] and to 100 Km at 2.5 Gb/s. In [1] they have proposed the use of special fiber with negative characteristics as a solution of the mitigation of chirp problem. However, other solutions should be utilized when SSMF is already deployed. Adaptive electronic processing in the receiver [2], [3], [4] is our proposed approach that is steadily becoming a viable long-term solution.

The majority of studies focus on the use of electronic dispersion compensation (EDC) for EML based systems in order to combat the chromatic dispersion associated with the transmission link [2], [3[, [4]. Only few studies [5], [6] focus on chirped DMLs. However, an important point that should be referred is that no detailed studies have been reported to evaluate the performance improvement when EDC is considered for DMLs having different chirp characteristics. The extracted parameters of DMLs that were used in this study have been previously verified by simulations and experiments [8]. In this paper, we report for the first time to our knowledge the impact of using Feed Forward Equalizer (FFE) and Decision Feedback Equalizer (DFE) in the performance of transient and adiabatic chirped DMLs at 2.5 Gb/s and 10Gb/s.

2. SIMULATION SET UP AND PARAMETERS ARRANGEMENTS

The performance of DMLs strongly depends on the characteristics of the laser frequency chirp. The chirp $\Delta\nu(t)$ of a DML is related to the laser output power $P(t)$ through the expression

$$\Delta\nu(t) = \frac{\alpha}{4\pi}\left(\frac{d}{dt}[\ln(P(t))] + \kappa P(t)\right) \tag{1}$$

where α is the linewidth enhancement factor and κ is the adiabatic chirp coefficient [6]. In (1) the first term is a structure independent ‘transient’ chirp and the second term is a structure-dependent ‘adiabatic’ chirp [6]. Some DMLs exhibit strong adiabatic chirp while some others strong transient chirp. Therefore, the DMLs can be classified into adiabatic and transient chirp dominated DMLs [8]. The chirp significantly affects the pulse

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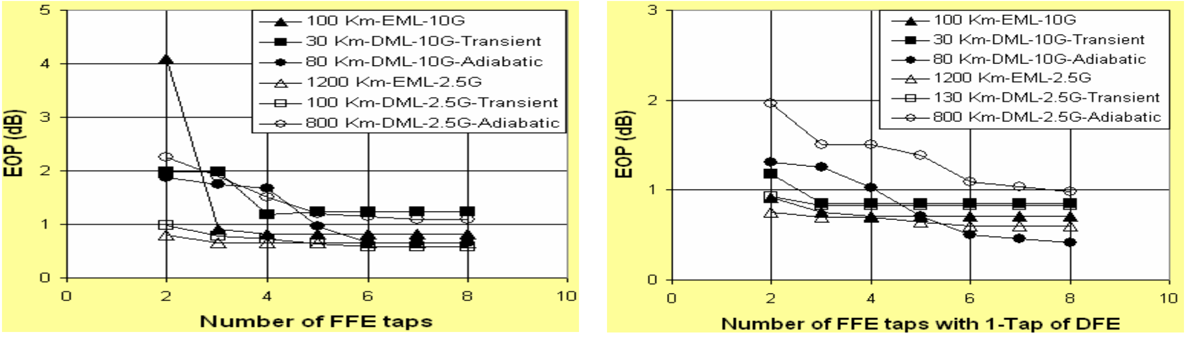
propagation, causing the leading edges to have slightly different frequencies and consequently different group velocities. The laser rate equation parameters for transient and adiabatic chirp dominated DMLs were reported in [8] where they have been also verified by both simulations and experiments and used in this work in order to perform system studies. Assumptions have been made only about the 10 Gb/s adiabatic dominated DML parameters.

For our simulations, we assumed a 10 Gb/s and 2.5 Gb/s non-return to zero (NRZ), PRBS of length 2^{23} -1. An extinction ratio of 15 dB was assumed when using EMLs (as a benchmarking case) and 8.2 dB when using DMLs. The signals were transmitted over SSMF with D = 16ps/km/nm. The interaction of the laser chirp with chromatic dispersion was the dominant source of distortion in the simulations. The performance criterion used in all cases to evaluate the performance of the received signals was the eye opening penalty (EOP). In the EOP calculation the first ten bits have been excluded.

EDC based on the techniques of FFE and DFE were considered [4], [7]. The algorithm that was used in order to calculate the optimum taps coefficients for each case was the least mean square (LMS). The goal of that algorithm is to minimize the mean squared error (MSE) between the desired equalizer output and the actual equalizer output. It is controlled by the error signal which is derived by the output of the equalizer with some other signal which is the replica of transmitted signal. The DFE version of the equalizer is non-linear process that uses the same algorithm but it subtracts the interference by the already detected data offering advanced performance characteristics. The equalizers that were used were fractionally spaced equalizers (T/2). The DFE(5,1) (with five means the number of tap coefficients in the FFE and one is the tap coefficient at the DFE) has been identified as the best equalizer after extensive simulations studying the performance of all possible combinations of equalizer's. Results for the simpler FFE based EDC are also reported.

3. SIMULATION RESULTS

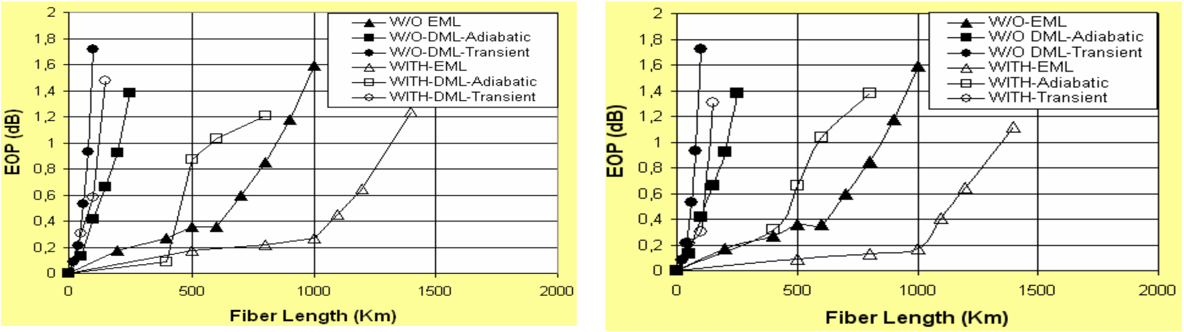
Figure 1 shows the effect of varying the number of FFE taps after transmission over SSMF for all DMLs and EMLs that were used. The transmission distances that were selected for Fig.1 are closely related with the distance limits of EDC for 1 dB penalty for each case that will be presented later. For the use of FFE alone, increasing the number of taps more than five, it did not offer a reasonable improvement. For some cases such as 100 Km EML at 10 Gb/s, 30 Km transient dominated DML at 10G, 1200 Km EML at 2.5 Gb/s, 100 Km adiabatic dominated DML at 2.5 Gb/s there is a saturation in the performance improvement with >3 taps in the FFE. However, for the FFE and DFE combination the optimum performance is observed for the DFE (5,1). The only exception case for DFE is for adiabatic dominated DML at 2.5 Gb/s for 800 Km where the saturation in the performance improvement exists after 6 taps in the FFE. The adding of more taps in the DFE part did not improve the performance significantly for any transmission distances and for any laser that was used in this simulation study. Due to the fact that FFE (5) is the optimum case for FFEs, we selected the five-tap FFE and one tap of DFE combination as the optimum equalizer in terms of performance against complexity.



(a) (b)

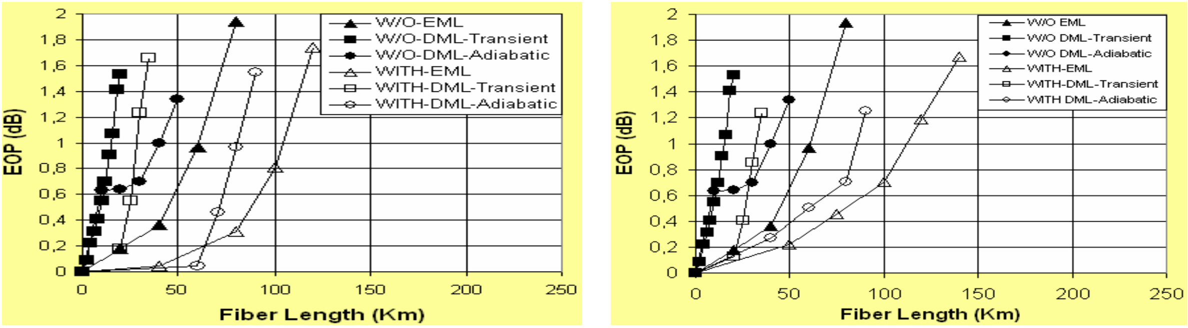
Figure 1: EOP versus Number of FFE taps after SSMF transmission for various FFE and DFE configurations: (a) FFE only (b) FFE with 1 Tap DFE.

Figures 2, 3 illustrate the eye opening penalty in terms of transmission length for DMLs and EMLs at 2.5 Gb/s (Fig.2) and 10 Gb/s (Fig.3) respectively with and without optimum equalizer of FFE (5) and DFE (5,1). The received eye diagrams for the distances corresponding to 1 dB – penalty are presented in Fig. 4, without and with equalizer (the back to back eye is also shown) for the case of DFE (5,1). The solid symbols in Fig. 2,3 symbolize the cases of without equalizer, whereas the open symbols represent the cases with equalizer. The distances achieved for EMLs and DMLs corresponding to 1-dB penalty and the percentage improvement for each case are summarized in table 1 for FFE (5) and DFE (5,1) equalizers.



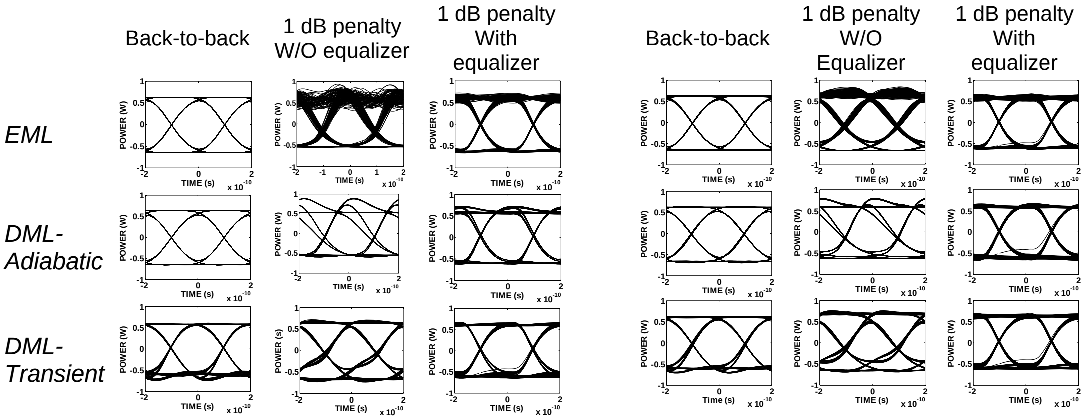
(a) (b)

Figure 2: EOP versus Fiber Length for 2.5 Gb/s without and with equalizer (a) FFE (5), (b) DFE (5,1). The trendlines in figures are drown as a guide for the eye.



(a) (b)

Figure 3: EOP versus Fiber Length for 10 Gb/s without and with equalizer (a) FFE (5), (b) DFE (5,1). The trendlines in figures are drown as a guide for the eye.



(a) (b)

Figure 4: Eye diagrams for DFE (5,1) at (a) 2.5 Gb/s and (b) 10Gb/s.

Figure 1 illustrates the fact that DFE offers better performance than FFE. The transmission limits that can be achieved by using adiabatic dominated DMLs is better that transient dominated DMLs. Hence, the use of EDC on these DMLs offers more pronounced performance improvement than transient chirp dominated DMLs (212%-300% over 100%-68%). Equalizers exhibit better performance for the adiabatic chirp DMLs, whereas the percentage performance improvement of transient chirp dominated DMLs has similarities to what observed with EMLs. Another important point that should be referred is that the performance improvement of DFE over FFE is not so pronounced for the case of adiabatic chirped DML. Furthermore, it is worthy to note that the use of EDC offers performance improvement of the adiabatic chirp dominated DMLs much better than EMLs.

	Transmission distance(Km) W/O equalizer (1 dB penalty)	***Improvement (FFE)***		***Improvement (DFE)***	
		Km	***%***	***Km***	***%***
EML (10G)	60	100	67%	110	83%
EML (2.5G)	870	1320	52%	1350	55%
DML - 10G (Adiabatic)	40	80	200%	85	212%
DML - 10G (Transient)	16	28	75%	32	100%
DML– 2.5G (Transient)	80	120	50%	135	68%
DML– 2.5G (Adiabatic)	200	600	300%	600	300%

Table 1: Improvement performance of FFE(5) and DFE(5,1) at 2.5 and 10 Gb/s with 1 dB penalty.

4. CONCLUSIONS

This work highlights the effectiveness of FFE, DFE equalizers in conjunction with DMLs that characterized by the fact that their extracted parameters have been verified by simulations and experiments. The transmission distance limits of 2.5 Gb/s and 10 Gb/s DMLs using SSMF fiber and EDC are reported. Finally, EDC equalized DMLs based systems are particularly attractive for metro/access networking applications at high data rates that require moderate signal improvement and low cost.

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