Chromatic dispersion monitoring in electronic dispersion equalizers using tapped delay lines

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Abstract: We propose a chromatic dispersion monitoring technique by analyzing the tap coefficients in electronic dispersion equalizers using tapped delay lines without needing additional hardware. This technique is robust to varying optical signal-to-noise ratio. The successful chromatic dispersion monitoring is demonstrated by simulation and experiment.

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References and links

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1. Introduction

Recently, electronic dispersion compensation (EDC) has drawn considerable research interest to mitigate optical chromatic dispersion (CD) distortions. The most promising receiver based equalizers include feed-forward equalizers (FFE), decision feedback equalizers (DFE), and maximum likelihood sequence estimators (MLSE) [1]. At 10 Gb/s, the sophisticated MLSE receiver is already commercially available [2] and FFE/DFE based products have been tested for emerging telecom standards [3]. We anticipate electronic equalizers will be prevalent in optical networks. On the other hand, there is a strong need for optical performance monitoring in terms of efficient network monitoring and maintenance [4]. Different approaches have been proposed and demonstrated to monitor various parameters, such as optical power, wavelength, optical signal-to-noise ratio (OSNR), and chromatic dispersion (CD). Most of them need additional hardware to realize their functions [5]. CD is one of the important parameters to monitor. In this letter, we propose a CD monitoring technique by analyzing the tap

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coefficients of tapped delay lines, which are generally used in FFE and DFE. Thus the inter-symbol interference (ISI) factor is calculated out to monitor CD. This technique does not require additional hardware in EDC receivers using tapped delay lines. This technique has about 10% uncertainty when OSNR changes from 10 dB to 30 dB. We further verify the technique by simulation and experiment and find a consistent CD monitoring range of 500~2000 ps/nm.

2. Technique principle

Figure 1(a) shows the technique principle for CD monitoring in EDC receivers. The optical data signal is distorted by CD in transmission fibers. The distortion spreads the power of one bit to adjacent bits, resulting in the ISI between neighboring bits. After O/E conversion, an electronic equalizer, in particular FFE recovers the distorted signal. In such an equalizer, the current value, pre- and post-cursors of the received signal are linearly weighted by the tap coefficients and summed to produce the output. As a result, the tap coefficients are strongly determined by ISI effects. Hence, the information of ISI effects or chromatic dispersion can be extracted by analyzing the tap coefficients and CD monitoring is realized without additional hardware, or additional cost. This monitoring scheme can achieve a fast response through adaptive algorithms, which can be in the order of microsecond [1]. The proposed technique can be also extended to other equalizers using tapped delay lines, such as DFE and FFE+DFE.

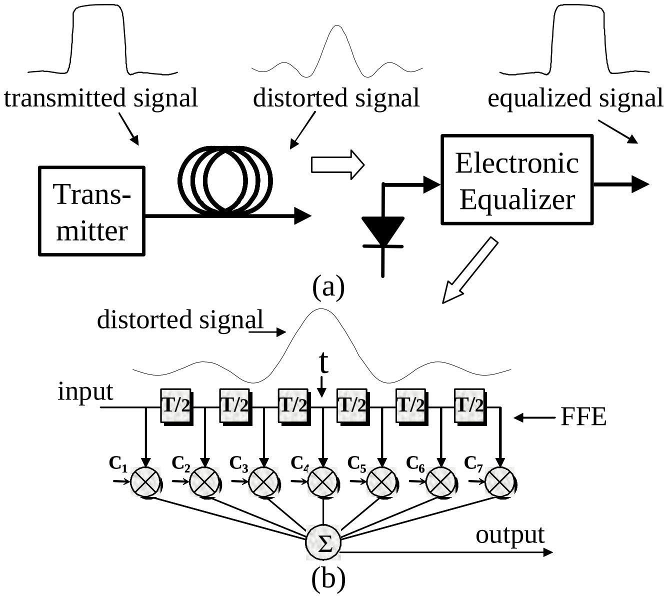

Fig. 1. (a) The principle of CD monitoring in EDC receivers; (b) the definition of ISI factor in this work.

In this work, the FFE has 7 taps with half-bit delay (half-spaced) as shown in Fig. 1(b). The tap coefficients are $C_1 \sim C_7$. The C_4 corresponds to the current bit at t moment. We align the C_4 to the centre of eye diagram or optimal sampling phase. We can plot $C_1 \sim C_7$ in order, called tap shape. In this arrangement, the tap shape is symmetrical around C_4 in theory. From the equalization principle, C_n represents the ISI component from the bit at $t - n \cdot T/2$. If we consider CD distortion producing ISI within a delay of one bit period, which corresponds to C_2 and C_6 in Fig. 1(b), we can define an ISI factor:

$$f_{ISI} = k(C_2 + C_6)/C_4 \tag{1}$$

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where k is calibration parameter decided by the difference between simulation and experiment. Equation (1) includes the one-bit ISI components from pre- and post-bit. It is possible to use only pre (C_2) or post-bit (C_6) for ISI factor calculation. However, the inclusion of pre- and post-cursors together increases the tolerance of the sampling phase shift. By normalized to C_4, the ISI factor is independent of the input signal and noise powers, which also correspond to different OSNR values.

3. Results and discussions

In this work, we construct linear CD transmission systems to verify the monitoring scheme in simulation and experiment, respectively. In simulation, the transmitter consists of 10 Gb/s NRZ-ASK modulation. A CD emulator generates variable CD. The distorted signal is combined with ASE noise and passes a 40 GHz bandwidth optical filter. The O/E conversion is simulated by square-law detection. The following electrical filter is a 5th order Bessel low pass filter with 7 GHz bandwidth. The signal is then fed to the FFE, which adopt the least mean-square (LMS) algorithm to minimize the mean-square-error (MSE). After the convergence of the LMS algorithm, the resultant tap coefficients are used to calculate the ISI factor by (1). The ISI factor as a function of the CD is then investigated by changing the CD value.

Figure 2(a) and (b) shows some examples of tap shapes with different CD and OSNR. The tap coefficients are discrete values and the solid curves in Fig. 2(a) and (b) enable a clear comparison. As expected, the tap shapes change systematically with the CD. The OSNR also changes the tap shapes. For example, C_4 at 2000 ps/nm changes from 1.3 to 1.7 when OSNR increases from 15 dB to 30 dB. However, Fig. 2(c) shows that the ISI factors change about 10% when OSNR varies from 10 dB to 30 dB, which is a small sensitivity to ASE noise.

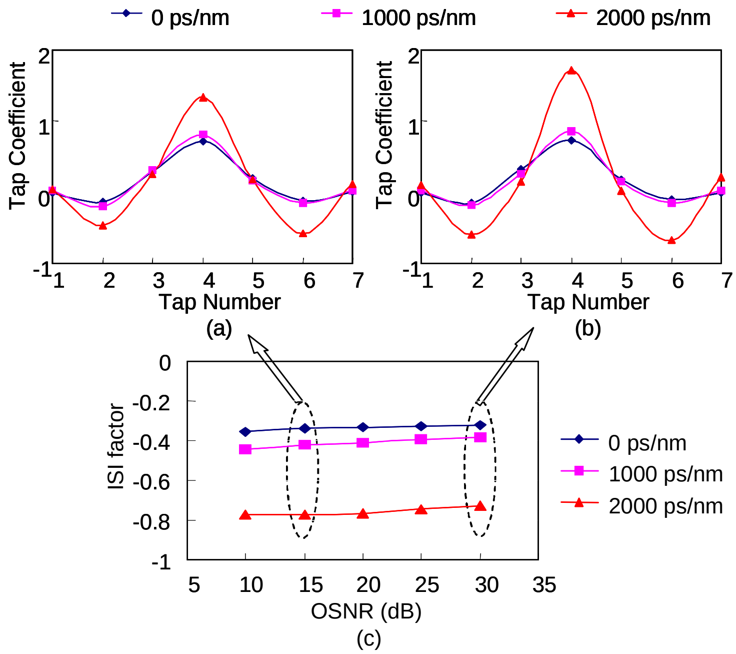

Fig. 2. (a) The tap shapes when OSNR is15 dB, (b) when OSNR is 30 dB, and (c) the ISI factors with different OSNR and CD.

The solid curve in Fig. 3 shows the ISI factor as a function of the CD, which is calculated in a CD range of 0~2400 ps/nm with 200 ps/nm spacing. As the CD increases, the ISI factor decreases which means the ISI effects increasing. The ISI factor within 500 ps/nm CD is almost unchanged because the ISI effects are week in such a dispersion range. However, the ISI factor shows a strong correlation to CD in the range of 500~2000 ps/nm. After the 2200

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ps/nm CD, the ISI factor increases again, which causes ambiguity for CD monitoring. The main reason is the strong CD spreading the power of the bits far away to adjacent bits, which are not included in (1). In addition, it is possible to use a more complicated expression in (1) to cover a wider CD range.

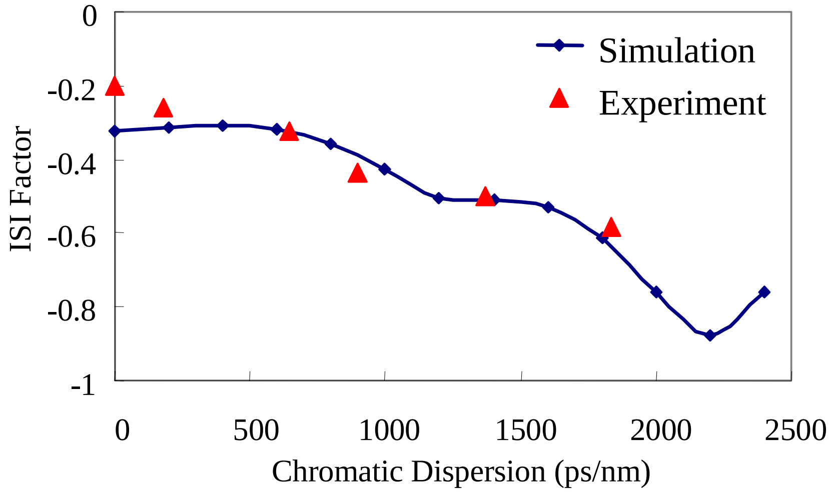

Fig. 3. The simulation and experimental results of CD monitoring.

Finally, we verify the monitoring scheme by an experiment with a similar setup to that in simulation. Several different length standard single mode fibers (D≈ 17 ps/nm/km @ 1550 nm) are used for variable CD. The input power into the fibers is kept below 0 dBm to avoid any nonlinear effects. An EDFA is used to boost the optical power after the fibers. A high-speed oscilloscope is used to record the pattern traces, which are saved and loaded into a computer for signal processing. The traces are normalized to the average power of “1” level, which corresponds to the limiting amplification. The traces are then filtered by a 5th order Bessel low pass filter with 5 GHz bandwidth to match the signal format in simulation. The filtered traces are equalized by the FFE and the resultant tap coefficients are used to calculate the ISI factor by (1). The calibration parameter k in (1) is set to be 0.7. The ISI factor is then used to predict the CD according to the function relationship acquired from simulation. As shown in Fig. 3, the experimental monitoring results generally agree with the simulation in the range of 500~2000 ps/nm, which is most interesting in the applications of the proposed new telecom standards [3]. The maximal monitoring error occurs at 900 ps/nm CD with a difference of about 150 ps/nm.

The ISI factor is determined not only by the CD distortion but also the signal format, OSNR, electrical bandwidth, polarization mode dispersion (PMD) and nonlinearity. Hence, further improvement of CD monitoring to the proposed technique may include more calibrations, as well as a more comprehensive expression to replace (1), or multiple receiver ISI factors for multi-parameter monitoring. However, the relative CD monitoring discussed in this paper may be simpler and more practical.

4. Conclusions

In this letter, we have proposed a chromatic dispersion monitoring technique for electronic dispersion equalizers using tapped delay lines. The inter-symbol factor (ISI) factor is calculated from the tap coefficients to monitor the chromatic dispersion and no additional hardware is required in addition to EDC receivers. This technique has about 10% uncertainty when OSNR changes from 10 dB to 30 dB. The successful chromatic dispersion monitoring results have been demonstrated by simulation and experiment in a most interesting chromatic dispersion range of 500~2000 ps/nm.

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