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Digital chromatic dispersion compensation in coherent transmission system using a time-domain filter

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ABSTRACT

High bit rates optical communication systems pose the challenge of their tolerance to linear and nonlinear fiber impairments. We demonstrate the chromatic dispersion equalization employing a time-domain filter in a 112-Gbit/s polarization division multiplexed quadrature phase shift keying coherent system. The required tap number of the filter is analyzed from anti-aliasing and pulse broadening. The dynamic range of the filter is evaluated by using different number of taps.

Key Words: Coherent detection, chromatic dispersion, time-domain dispersion equalization, polarization division multiplexed quadrature phase shift keying.
OCIS codes: (060.1660) Coherent communications; (060.2330) Fiber optics communications

1. INTRODUCTION

Fiber impairment such as chromatic dispersion (CD) severely impacts the performance of high speed optical transmission systems [1,2]. Digital coherent receivers allow equalization of fiber dispersion in the electrical domain [3], and have become the most promising alternative approach to dispersion compensation fibers (DCFs). In this paper, a time-domain fiber dispersion finite impulse response (FD-FIR) filter is developed to compensate the CD in a 112-Gbit/s non-return-to-zero polarization division multiplexed quadrature phase shift keying (NRZ-PDM-QPSK) coherent transmission system. The principle of the FD-FIR filter is analyzed by numerical simulations. The lower limit of the required tap number is determined for the first time by the dispersion induced pulse broadening, and the upper limit is calculated based on the analysis of anti-aliasing. The dynamic range of the filter is investigated by the variation of tap number in CD equalization.

2. PRINCIPLE OF TIME-DOMAIN FD-FIR FILTER

The FD-FIR filter is a time-domain feed-forward digital filter, of which the tap weight a_k can be described as the following expressions [3],

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$$a_k = \sqrt{\frac{jcT^2}{D\lambda^2 z}} \exp\left(-j \frac{\pi c T^2}{D\lambda^2 z} k^2 \right) \qquad -\left\lfloor \frac{N^A}{2} \right\rfloor \le k \le \left\lfloor \frac{N^A}{2} \right\rfloor \tag{1}$$

$$N^A = 2 \times \left\lfloor \frac{|D|\lambda^2 z}{2cT^2} \right\rfloor + 1 \tag{2}$$

where D is the CD coefficient, λ is the central wavelength of optical wave, z is the fiber length, T is the sampling period, $\lfloor x \rfloor$ denotes the nearest integer less than x, and N^A is the required tap number determined by the anti-aliasing [3], which means the pass-band of FD-FIR filter needs to be lower than the Nyquist frequency.

Meanwhile, we can also determine the filter length based on the broadening of a pulse propagating in the dispersive fiber channel [2,4]. For the Gaussian pulse, the tap number of the FD-FIR filter can be calculated according to the broadened pulse duration [2,4],

$$N^P = 2 \times \left\lceil \frac{1}{\pi c T^2} \sqrt{\pi^2 c^2 T^4 + 4\lambda^4 D^2 z^2} \right\rceil + 1 \tag{3}$$

where $\lceil x \rceil$ denotes the nearest integer larger than x.

Table 1. The tap number calculated by pulse broadening and anti-aliasing (D=16 ps/nm/km)

Fiber length (km)	Tap number N^P by pulse broadening	Tap number N^A by anti-aliasing	N^P/N^A (%)
20	7	9	77.8
600	157	243	64.6
1000	259	403	64.3
2000	517	807	64.1
4000	1031	1615	63.8

The tap numbers for different fiber lengths analyzed from pulse broadening and anti-aliasing are illustrated in Table 1. We find that most of the tap numbers obtained from pulse broadening are around 60% of the value calculated from the anti-aliasing analysis, which is consistent with the reported empirical factor of 0.6 [3]. The tap numbers derived from pulse broadening and anti-aliasing are considered as the lower and upper bounds on the required number of taps for an effective CD compensation, respectively.

3. SIMULATION INVESTIGATION OF PDM-QPSK TRANSMISSION SYSTEM

The setup of the 112-Gbit/s NRZ-PDM-QPSK coherent transmission system established in the VPI simulation platform is illustrated in Fig. 1 [5]. The data output from four 28-Gbit/s pseudo random bit sequence (PRBS) generators are modulated into two orthogonally polarized NRZ-QPSK optical signals by two Mach-Zehnder modulators, which are then integrated into one fiber channel by a polarization beam combiner to form the 112-Gbit/s NRZ-PDM-QPSK optical signal. In the coherent receiver, the received optical signals are mixed with the local oscillator (LO) laser to be transformed into four electrical signals by the photodiodes, which are then digitalized by the 8-bit analog-to-digital convertors (ADCs) at twice the symbol rate. The central wavelength of the transmitter and the LO lasers are both 1553.6

nm, and the transmission fibers are all with the CD coefficient D=16 ps/nm/km.

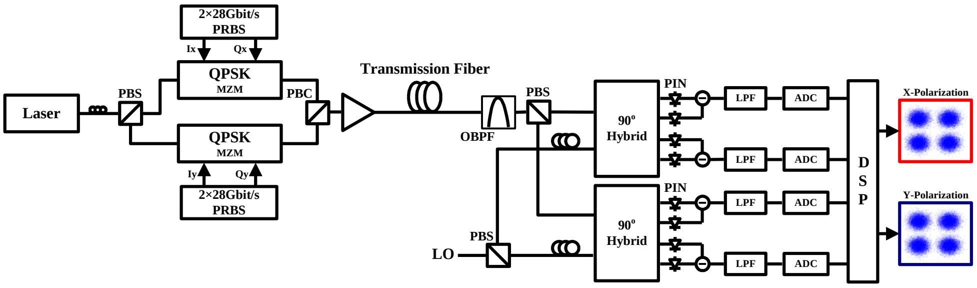

Fig. 1. Schematic of 112-Gbit/s NRZ-PDM-QPSK coherent optical transmission system

4. SIMULATION RESULTS

The CD equalization for 20 km and 600 km fibers using the FD-FIR filter with different number of taps are illustrated in Fig. 2. The results indicate that the filter achieves the best performance when employing the tap number between the values derived from pulse broadening and anti-aliasing. The performance of the filter will degrade, if the tap number is less than the number N^P or exceeds the number N^A. This is because the inadequate taps can not generate sufficient delay for dispersion compensation, and the redundant taps will lead to the pass-band of the filter exceeding the Nyquist frequency to result in the aliasing phenomenon. Figure 2(a) also shows that the FD-FIR filter does not achieve a satisfactory CD equalization performance for 20 km fiber by using either the tap number (N^A=9) obtained from anti-aliasing or the tap number (N^P=7) derived from pulse broadening. This penalty can be compensated by using a post-added 3-tap least mean square (LMS) adaptive filter or by increasing the sampling rate from 2 samples per symbol (Sa/Sy) to 8 Sa/Sy in the ADCs modules, as shown in Fig. 2(a). In the x-axis of 8 Sa/Sy, the T value in Eq. (2) and Eq. (3) is decreased by a factor of 4.

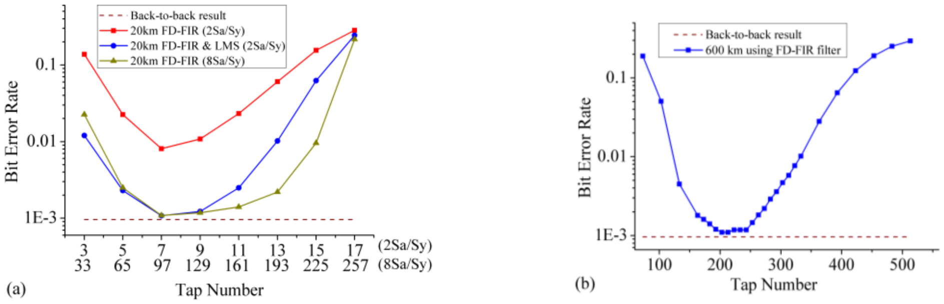

Fig. 2. CD compensation with different tap number at OSNR 14.8 dB, (a) 20 km fiber, (b) 600 km fiber

5. CONCLUSIONS

In this paper, the time-domain FD-FIR filter is developed to equalize the CD in a 112-Gbit/s NRZ-PDM-QPSK coherent system. For the first time to our knowledge, we demonstrate the analytical expression of the lower bound on the required tap number base on the dispersion induced pulse broadening, which is consistent with the empirical factor [3]. Simulation results indicate that the filter shows the best performance when employing the tap number between the values calculated from the analysis of pulse broadening and anti-aliasing.

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