# A PMD Monitoring Scheme for Direct-Detection Optical OFDM Systems Using Code-Assisted Optical Subcarriers

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**Abstract:** A PMD monitoring scheme is proposed for direct-detection optical OFDM systems by adding a pair of code-assisted optical subcarriers. Code correlation technique is used to retrieve DGD values over 0-25ps with <2-ps average monitoring error.

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## 1. Introduction

Polarization mode dispersion (PMD) is among the key system parameters for optical signal transmission. It induces rotation to the states of polarization (SOP) of the optical carrier and subcarriers, thus leads to possible unrecoverable power fading to the optical signal [1]. Recently, optical orthogonal frequency division multiplexing (OFDM) system has been widely recognized as an effective means to realize the future high-speed flexible optical networks [2,3], for its flexible bandwidth and high spectral efficiency. In order to assure the quality of the optical OFDM signals over a network, low-cost and effective in-line optical performance monitoring techniques are highly desirable to be incorporated to the intermediate network nodes.

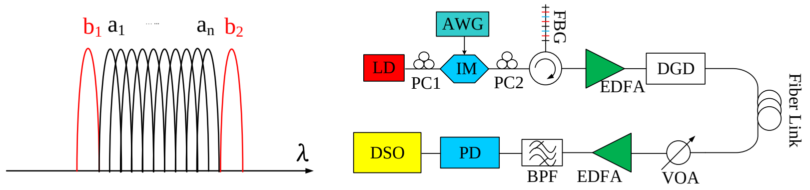
In this paper, we propose and characterize a simple and novel PMD monitoring scheme for direct-detection optical OFDM (DDO-OFDM) signals, such that a simple signal monitoring module can be built at each intermediate network node, without the use of any expensive coherent receiver. To date, there has been no previous work on PMD monitoring in DDO-OFDM systems. Here, we propose to incorporate a pair of code-assisted optical subcarriers to the DDO-OFDM signal during signal generation. It is shown that by applying simple code correlation procedures to the detected DDO-OFDM signal at those two inserted code-assisted subcarriers, the amplitude of the obtained correlation peaks can be used to derive the DGD values over a range of 0 to 25 ps. Only simple code correlation procedures are required. The proposed scheme offers a simple and low-cost solution to realize in-line PMD monitoring for future high-speed flexible optical network.

## 2. Operation Principles

At the receiver of detecting DDO-OFDM signals, a photodiode is used to directly convert the optical signal into an electrical signal. Under the effect of DGD suffered by the optical signal, the misalignment of the SOPs among the optical carrier and the optical subcarriers creates interference among themselves during signal beating at the photodiode, which leads to power fading over the power spectrum of the detected signal given by Equation.1 [1] when input signal is equally split into each polarization mode,

$$\left|H(f_k,\Delta\tau)\right| = \left|\cos(\pi f_k \Delta\tau)\right| \tag{1}$$

where $\Delta\tau$ is the DGD value and $f_k$ is the frequency of subcarrier. Owing to the relative flat power spectrum of the input optical OFDM signal, such cosine-like PMD-induced power fading would be imposed over the signal's spectrum. Two optical subcarriers coded with orthogonal binary Gold CDMA code sequences are added as the first and the last subcarriers in the OFDM signal spectrum, during signal generation, as in Fig. 1(a).



(a) (b)

Fig. 1 The generated optical OFDM spectra, where $a_i$ ($i=1,\ldots n$) are the data subcarriers and $b_1$ & $b_2$ are the inserted code-assisted subcarriers; (b) Experimental setup.

At the monitoring module, part of optical signal is detected and code correlation procedures are performed to obtain the two individual correlation peaks of those two inserted code-assisted optical subcarriers. The correlation results represent the relative powers of these two frequency components, which is given by

$$y_1 = A\cos(\pi f_1 \Delta\tau) \tag{2}$$

$$y_2 = A\cos(\pi f_2 \Delta\tau) \tag{3}$$

where $y_1$ and $y_2$ are the magnitude of the correlation peaks, $A$ is the amplitude of system transfer response, $f_1$ and $f_2$ are the respective frequencies of the two code-assisted optical subcarriers, and $\Delta\tau$ is the average DGD value. Hence, the unknown value of $\Delta\tau$ can easily be solved from both equations (2) & (3).

## 3. Experiments and Results

Fig. 1(b) shows the experimental setup to verify our proposed PMD monitoring scheme. Traditional DDO-OFDM system using radio frequency (RF) up-converter was implemented. A total bit rate up to ~10 Gbps of OFDM signal was generated by an Arbitrary Waveform Generator. The output electrical signal was then converted to a DDO-OFDM signal, via a 10GHz optical intensity modulator. The amplified optical signal was then filtered, via a fiber Bragg grating (FBG), with a 3-dB bandwidth of 17 GHz, so as to generate the single sideband DDO-OFDM signal, which provided better robustness against fiber chromatic dispersion. PC2 was used to adjust polarization to equally split signal into two polarization mode of single mode fiber. A ProDelay$^{\text{TM}}$ device was used as a DGD emulator. The optical attenuator was to control the optical signal-to-noise ratio (OSNR). The optical signal was detected, via a P-I-N photodiode with 10-GHz bandwidth. The detected electrical signal was sampled and stored by a real-time digital sampling oscilloscope (DSO) and offline digital signal processing was employed to perform correlation between the designated codes with the received signal.

Fig. 2(a) shows the result of characterization measurements by setting the DGD emulator to values of 0.68 ps, 6.35 ps, 9.23 ps, 14.96 ps and 20.83 ps, under different OSNR values (0.1-nm bandwidth) of 15 dB, 20 dB, 25 dB and 30 dB. It could be noticed that our proposed scheme could successfully monitor the PMD value from 0 to 25 ps in DDO-OFDM transmission under different OSNR values. The average error was less than 2 ps. We have also performed measurements after transmission over 100-km standard single-mode fiber. The average monitoring error slightly increased to 2.2 ps, as shown in Fig. 2(b). This was mainly attributed to the inadequate filtering by the FBG, and much better result was expected if the FBG could have a narrower passband, close to 10-GHz bandwidth.

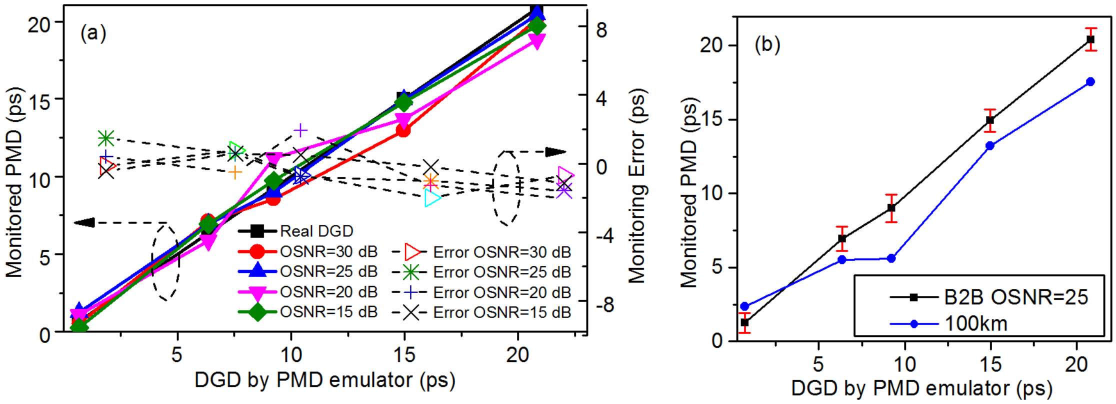


Fig. 2 (a) Back-to-back measurement results and monitoring errors of DGD values from 0 to 25 ps, under OSNR values from 15 dB to 40 dB. (b) Error bar of back-to-back monitoring at OSNR=25 dB and measurement results after 100-km transmission.

## 4. Summary

We have proposed and experimentally characterized a novel PMD monitoring scheme for DDO-OFDM signals using a pair of code-assisted optical subcarriers. The DGD value of the signal can be monitored over a range of 25 ps with an average monitoring error of less than 2 ps. PMD monitoring after 100-km fiber transmission was also characterized. This work was partially supported by a research grant from HKRGC (GRF CUHK410512).

## 5. References

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