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Simultaneous chromatic dispersion monitoring and optical modulation format identification utilizing four wave mixing

Sheng Cui [a,b,c], Chen Qiu [a,b,c], Changjian Ke [a,b,c,*], Sheng He [a,b,c], Deming Liu [a,b,c]

[a] School of Optical and Electronic Information, Huazhong University of Science and Technology, Hubei, China
[b] National Engineering Laboratory for Next Generation Internet Access System, Wuhan, Hubei, China
[c] Wuhan National Laboratory for Optoelectronics, Wuhan, Hubei, China

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ABSTRACT

This paper presents a method which is able to monitor the chromatic dispersion (CD) and identify the modulation format (MF) of optical signals simultaneously. This method utilizes the features of the output curve of the highly sensitive all-optical CD monitor based on four wave mixing (FWM). From the symmetric center of the curve CD can be estimated blindly and independently, while from the profile and convergence region of the curve ten commonly used modulation formats can be recognized with simple algorithm based on maximum correlation classifier. This technique does not need any high speed optoelectronics and has no limitation on signal rate. Furthermore it can tolerate large CD distortions and is robust to polarization mode dispersion (PMD) and amplified spontaneous emission (ASE) noise.

1. Introduction

In order to support a wide range of data traffic and enhance operation flexibility optical networks are nowadays becoming more heterogeneous [1,2]. In such networks optical performance monitoring (OPM) and modulation format identification (MFI) are essential techniques for intelligent network management and optimal optical signal acquirement and demodulation [3–7]. Such techniques can provide key information of the optical signals such as the CD, polarization mode dispersion (PMD), optical signal to noise ratio (OSNR), modulation format and the number of multiplexed polarizations.

Among the many CD monitors proposed by now [8,9], the all-optical chromatic dispersion monitors based on ultra-fast nonlinear effects are attractive because they can be used to monitor the CD distortions in a modulation format and bit rate transparent manner and are relatively simple, thus cost-effective to be deployed at low cost optical nodes or transmission systems without coherent receivers. In previous works, we proposed a highly sensitive all optical CD monitor based on exponential power transfer function (PTF) provided by FWM in highly nonlinear fibers (HNLFs) [9]. This method is then improved to expand the CD monitoring range, be robust to PMD and OSNR influence, and accommodate on–off keying (OOK) and advanced modulation formats [10]. In this paper it is demonstrated that the highly sensitive all-optical CD monitor can also be used to realize MFI function. The topic of MFI has been well explored for radio communications. Nonetheless, MFI for fiber optic communications still remains underdeveloped. By now four different optical MFI methods have been proposed: (1) MFI from the constellation diagram with the use of k-means [3]; (2) MFI from signal cumulants [4]; Both of the two methods rely on very complicated blind demodulation process, and require costly full-fledged coherent receivers; (3) MFI from the asynchronous amplitude histograms or asynchronous delay-tap plots, which has limited CD tolerance (about 500 ps/nm) because these features are distorted by CD [5,6]; (4) MFI from signal Stokes space representation [7], which is developed for polarization multiplexed signals and also requires coherent receivers for CD compensation. Furthermore these methods have a single function of MFI and are not able to monitor CD distortions. Thus it is desirous to aggregate CD monitoring and MFI functions in a single device to enhance the operational efficiency and reduce the cost.

In this paper, we propose a simple CD monitoring and MFI method without using high cost coherent receivers or any high speed optoelectronic devices. The highly sensitive all optical CD monitor [9] is used to monitor the variations of the signal instantaneous power distribution against CD which are unique for signals with different MFs. The features of the output curve of the CD monitor including its symmetric center, profile and

* Corresponding author at: School of Optical and Electronic Information, Huazhong University of Science and Technology, Hubei, China. Fax: +86 27 87556188.
E-mail address: cuisheng@hust.edu.cn (S. Cui).

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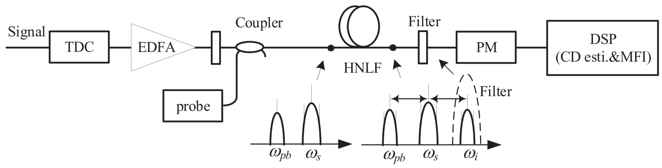

Fig. 1. Setup of the CD monitoring and MFI module. EDFA: Erbium-doped fiber amplifier, and PM: Power meter.

convergence region are utilized to realize blind CD estimation and MFI simultaneously. With this method ten widely used MF including on–off keying and advanced modulation formats with single and dual polarizations can be identified using a simple algorithm based on maximum correlation classifier. Furthermore the CD tolerance limit is also expanded as the features are not distorted by CD. This paper is organized as follows: Section 2 reviews the working principles of the all optical CD monitor. Section 3 describes the features of the output curves of the CD monitor for signals with different MFs and explains the physical mechanism behind. Based on these features the MFI method is proposed. The whole CD estimation and MFI algorithm are described and are carried out to validate the effectiveness of this method in Section 4 followed by a brief conclusion.

2. Principles of the CD monitor

The setup of the FWM based CD monitoring and MFI module is shown in Fig.1. The optical signal with unknown CD and MF is tapped from the optical link and fed into the module. The tunable dispersion compensator (TDC) is used to apply a series of CD onto the signal. The signal is then amplified by the EDFA and input into the HNLF with a continuous probe wave ω_{pb}. A new idler wave at $\omega_i = 2\omega_s - \omega_{pb}$ is generated from the FWM in the HNLF and extracted by the band pass optical filter at the fiber output. The output idler wave instantaneous power is given by

$$P_i = P_{pb}\cdot G(P_s) = P_{pb}\,(\gamma P_s L)^2[\,\sinh(gL)/gL]^2, \quad (1)$$

with

$$g^2 = -\,\Delta\beta\left(\Delta\beta/4 + \gamma P_s\right). \quad (2)$$

Here P_{pb} ,γ,L, g and $\Delta\beta$ are the input probe wave power, fiber nonlinear coefficient, fiber length, parametric gain and linear phase mismatch, respectively. When the linear phase mismatch $\Delta\beta$ satisfies $-4\gamma P_s \le \Delta\beta \le 0$, exponential gain occurs [11]. The exponential gain $G(P_s)$ provides an exponential PTF between the signal and idler wave instantaneous powers. For the same input average power the nonlinear PTF gives preferential gain to signals with higher peak power, thus results in higher output average power $\bar{P}_i$. In other words the CD monitor output is sensitive to the input signal instantaneous power distribution which, as we know, changes with CD distortions. So CD can be monitored by simple average power measurement with cheap slow optical detectors. As demonstrated in our previous works, using the exponential PTF the output contrast of the CD monitor can be greatly improved compared to the previous monitors using a quadratic PTF [9]. The output curve of the CD monitor is symmetric about the zero-dispersion point, as CD induced optical pulse distortions are the same for CDs with the same magnitude but opposite sign. Thus using a simple symmetric center search algorithm in combination with a TDC, the zero CD point and the residual CD can be easily identified [10]. The position of the symmetric center is only determined by CD and is insensitive to PMD and OSNR, thus CD can be monitored independently. Numerical simulation shows that CD can be accurately estimated for signals with OSNR larger than 10 dB and differential group delay (DGD) smaller than 10 ps.

It is noteworthy that the optical signals consist of random symbol sequence and the output idler average power $\bar{P}_i$ which is measured with a slow optical detector is actually the averaged result over a large number of symbols, thus independent on the specific symbol sequence pattern. In other words $\bar{P}_i$ is only determined by the statistical distribution of the signal instantaneous power which, in turn, is dependent on the signal MF, as will be shown later.

3. Principles of the MFI method

The output curves of the CD monitor for signals with different MFs are shown in Figs. 2 and 3. Ten modulation formats are considered and the device parameters used are the same as that reported previously [10]. The FWM based nonlinear PTF has an order of about 5.5. The TDC sweeping range is 0–320 ps/nm. The results are obtained by numerical simulations using VPI Transmission-Maker V8.6 based on nonlinear Schrödinger equation and split-step Fourier method. There are two noteworthy points. First, only 40 GBaud signals are considered, but all of the curves can be rescaled to any baud rate using the (1/baud rate)^2 scaling along the

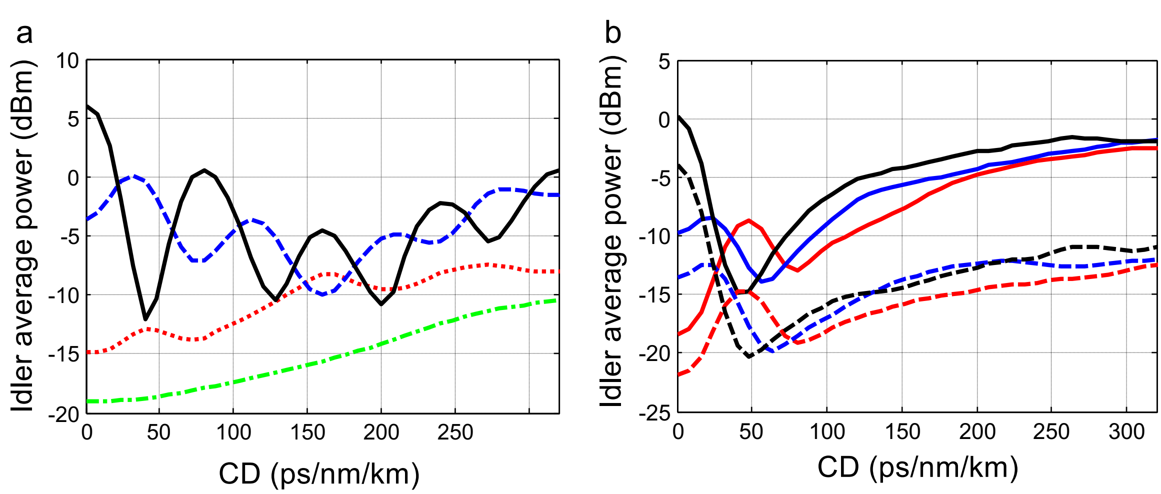

Fig. 2. (a) The CD monitoring curves of 33% RZ (solid), CSRZ (dashed), NRZ (dotted) and ODB (dash dotted) signals. (b) The curves of single (solid) and dual (dashed) polarization 33% RZ (black)/CSRZ (blue) /NRZ (red) 16-QAM (solid) signals for CD=0 ps/nm, OSNR=30 dB and DGD=0 ps. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)