A novel chromatic dispersion monitoring technique for 16/64-QAM system based on asynchronous amplitude histogram*

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A novel chromatic dispersion (CD) monitoring technique based on asynchronous amplitude histogram (AAH) for higher order modulation formats is proposed in this paper. Without demodulating the signal, in the monitoring scheme, the received signal is sampled asynchronously, and thus clock information and high-speed sampling units are unnecessary, resulting in low cost and high reliability. Simulations of CD monitoring technique for non-return-to-zero/return-to-zero (NRZ/RZ) 16- and 64-quadrature amplitude modulation (QAM) systems with different optical signal-to-noise ratios (OSNRs) and duty cycles are investigated, and the tolerance of the scheme is also discussed. Simulation results show that the presented CD monitoring technique with high sensitivity can be applied to monitor the residual CD of a transmission link in the next-generation optical networks.

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In order to increase the spectral efficiency, the higher order modulation format, such as 16- and 64-quadrature amplitude modulation (QAM), is believed to be a promising technology in the next-generation optical networks at the rates of 100 Gbit/s per channel and beyond[1]. As fiber chromatic dispersion (CD) is an important transmission impairment in the high bit rate transmission links, the online monitoring for CD has become more and more significant. Optical performance monitoring (OPM) with properties of low cost and high reliability is needed in order to ensure high quality and robust transmission. Various techniques of OPM have been proposed, for example, asynchronous amplitude histogram (AAH) evaluation is a promising method for evaluating the quality of received signal. It's sensitive to CD, optical signal-to-noise ratio (OSNR) and polarization-mode dispersion (PMD), and thus OPM technique has been proposed to monitor Q-factor and OSNR of signal, such as on-off-keying (OOK) and differential phase-shift keying (DPSK)[2,3]. Further study on CD and PMD monitoring technique has been investigated and demonstrated[4,5].

The method of CD monitoring based on average Q-factor proposed in Ref.[6] can no longer be applied to the higher order modulation formats. While utilizing the characteristics of AAH in Ref.[7], it can be used to monitor CD of multi-phase-shift keying (MPSK) signal, but it isn't valid for QAM which is modulated both in phase and amplitude. Similarly, the CD monitoring for DPSK signal is also based on the AAH which only abstracts one peak of it[8]. There are also other optical CD monitoring techniques[8-11]. However, the proposed CD monitoring techniques are limited to monitor phase-shift keying signal, and the CD monitoring for any generalized M-ary quadrature amplitude modulation (M-QAM) signal in high-rate optical communication system has not been concerned.

In this paper, a simple method of residual CD monitoring for higher order QAM signals is proposed and demonstrated, which is based on AAH. With the proposed technique, clock information and high-rate sampling units are not indispensable, so we can just utilize simple electronics and post processing without additional hardware, resulting in low cost and high reliability. Furthermore, the factor has high sensitivity to signals of QAM, which can be used in higher order modulation formats.

In the proposed scheme, non-return-to-zero/return-to-zero (NRZ/RZ) 16-QAM and 64-QAM signals modulated both in amplitude and phase are used as the measured signals. When modulus of measured signals' amplitude is taken, we can get three and nine amplitudes from 16-QAM and 64-QAM, which present to be three and nine peaks in corresponding AAH, respectively. As shown

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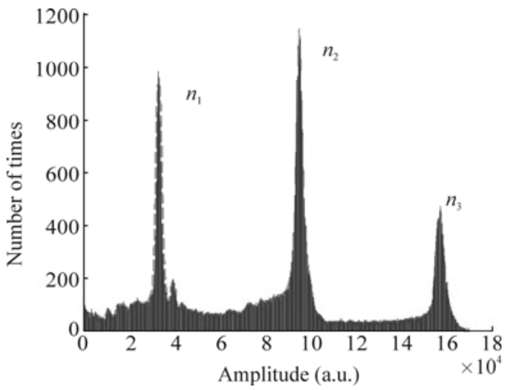
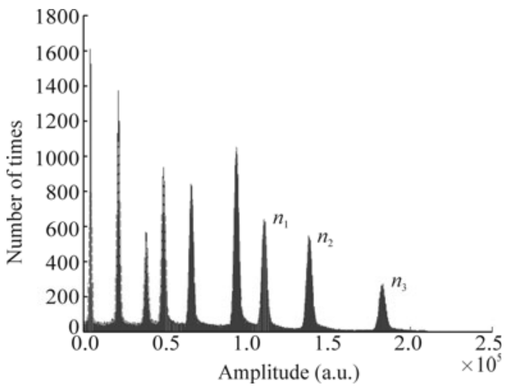
in Fig.1, 16- and 64-QAM signals are sampled asynchronously. From the histogram, we can see exactly that the location of each peak corresponds to a particular power level of M-QAM constellation. And there are nine power levels in 64-QAM constellation, similar to 16-QAM signal, so we only demonstrate the transmitted waveform of 16-QAM in this paper.



(a)



(b)

Fig.1 (a) AAH for 100 Gbit/s NRZ-16-QAM system with *CD*=16 ps and (b) AAH for 160 Gbit/s NRZ-64-QAM system with *CD*=2 ps

In general, for such a system, the transmitted waveform of 16-QAM can be expressed as follows, where the three items of the expression represent three power levels of 16-QAM constellation.

$$A(z,t)=\sum_{k_1} S_{k_1}.g(t-k_1T_s,z)+\sum_{k_2} S_{k_2}.g(t-k_2T_s,z)+\sum_{k_3} s_{k_3}.g(t-k_3T_s,z)\ , \quad (1)$$

where S_{k_n} (n=1, 2, 3) is the k_nth transmitted information symbol, and T_s is the symbol period. $g(z,t)$ is the transmitted pulse, and in practical application, the laser output is generally Gaussian pulse, so $g(z,t)$ can be written as

$$g(z,t)=\frac{g_0T_0}{T_D}.\exp(-\frac{t^2}{2T_D^2})\ , \quad (2)$$

where $T_D=(T_0^2-j\beta_2 z)^{1/2}$, g_0 is the initial pulse, T_0 is the half-pulse-width (at 1/e-intensity point), and β_2 is CD of the optical fiber.

Shape of each Gaussian pulse can be distorted by CD along fiber length z as

$$T_1/T_0=[1+(\beta_2 z/T_0^2)]^{1/2}\ . \quad (3)$$

We can find that the pulse width varies with the fiber's CD (β_2). Similar to T_0, T_1 denotes the half-pulse-width (at 1/e-intensity point) after fiber. Therefore, considering the function of dispersion only, Gaussian pulse keeps the Gaussian pulse shape but reduces in amplitude and widens in pulse width when traveling along the fiber, neglecting the loss of fiber and nonlinear penalties[7].

As AAH has high sensitivity to CD of fiber, a tiny CD's change causes the width and height of peaks to show obvious difference, where the number of times in the corresponding peak also changes. In particular, we define a factor F_{CD} in order to monitor the value of fiber's CD, which can be endured in the optical communication system.

$$F_{CD}=10\lg(\frac{n^3}{n_1n_2n_3})\ . \quad (4)$$

In the scheme, we monitor CD by measuring number of times in the highest three peaks. Then approximate each peak in histogram with a smoothing function in order to get the number of times that occur in the three highest peaks, which are marked as n_1, n_2 and n_3, respectively, as shown in Fig.1, where n denotes the whole number sampled asynchronously. Theoretically, signal of 16- and 64-QAM's corresponding number of times in peaks will be different with the variance of CD. Therefore, CD monitoring can be achieved easily and precisely. Furthermore, F_{CD} here has high sensitivity to CD in the result of our simulation.

The proposed CD monitoring technique for 16- and 64-QAM system is shown in Fig.2. The simulation setup for 16-QAM or 64-QAM system and CD monitoring scheme are achieved by softwares of OptiSystem and Matlab, respectively. Particularly, the presented scheme can be applied to monitor the residual CD of a transmission link in high-rate optical communication system as shown in Fig.3. As shown in Fig.2, laser operating at 1550 nm is externally modulated by two dual $LiNbO_3$ Mach-Zehnder modulators (MZMs) in order to generate NRZ/RZ-16/64-QAM signal, which is driven by a 2^{21}-1 pseudorandom binary sequence (PRBS) signal at 100 Gbit/s for 16-QAM and 160 Gbit/s for 64-QAM, respectively. Then signal travels along a length of fiber which consists of single-mode fiber (SMF), dispersion compensation fiber (DCF) and erbium-doped fiber amplifier (EDFA). The preset CD is realized by changing the lengths of SMF and DCF, and OSNR is controlled through adding amplified spontaneous emission (ASE) by EDFA and gaining the signal power by optical amplifier. Therefore, we can realize different CD monitoring and analyze the effect of CD on signals under different OSNR systems.

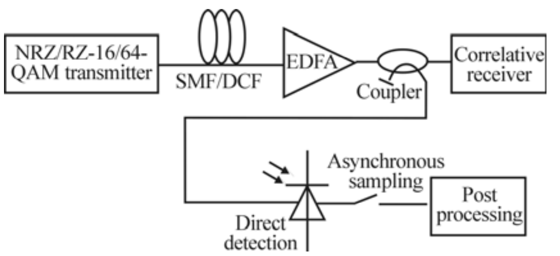


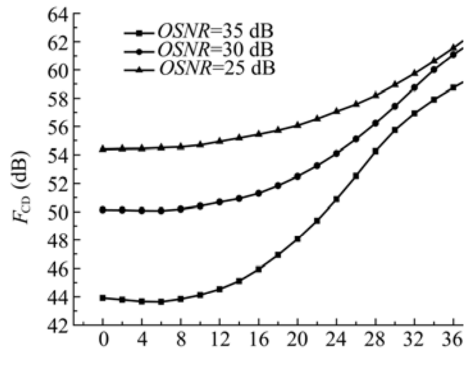
Fig.2 Simulation setup for monitoring CD of NRZ/RZ-16/64-QAM signals

Fig.3 Schematic diagram of the transmission link

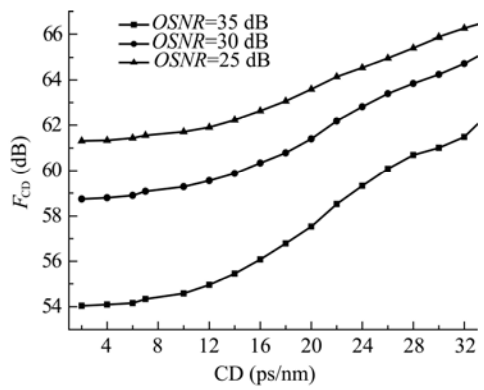
At the receiver, the signal is directly detected without demodulation after coupling, then asynchronously sampled and analyzed. Thus each amplitude histogram is obtained with 21234 samples at an asynchronous sampling rate which is much lower than the symbol rate. With the proposed technique, F_{CD} versus CD values is calculated and shown in Fig.4 for NRZ/RZ-16-QAM and -64-QAM systems under different OSNR values.

From Fig.4(a) and (b), we can see that the curve is smooth when CD value is smaller than 12 ps. It's because the smaller CD values have less impact on signal's property in 25 Gsym/s 16-QAM system. Compared with 16-QAM signal, factor F_{CD} has much higher sensitivity to CD but smaller monitoring range in 160 Gbit/s 64-QAM system, because the impact of CD rises precipitously as the square of the symbol rate, and the monitoring range is reduced accordingly[8].

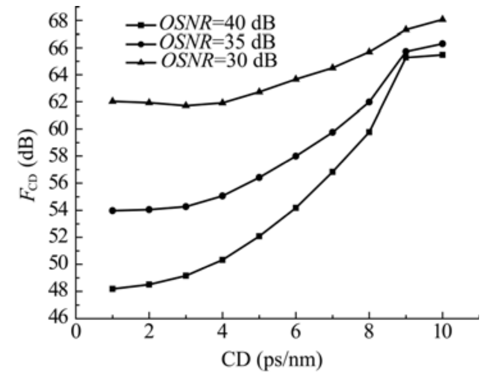
Comparing Fig.4(a) with (b) and (c) with (d), we can learn that CD sensitivity of RZ-16/64-QAM signal is lower than that of NRZ-16/64-QAM signal, because of different lasting time of high-amplitude symbol pulse. As we know, RZ pulse shape contains some low-amplitude pulses which result in the number of zero signal amplitudes considerably reduced for a given total number of samples in the amplitude histogram. Thereby, the given total number of samples reduces, and from Eq.(4), we can find that the CD sensitivity reduces. Fig.5 illustrates the F_{CD} versus CD in RZ-16/64-QAM system with different duty cycles of 50%, 65% and 75%. From Fig.5 we can see that for either 16-QAM or 64-QAM signal, the less duty cycle, the lower CD sensitivity. However, 64-QAM signal has much higher monitoring sensitivity and smaller range.



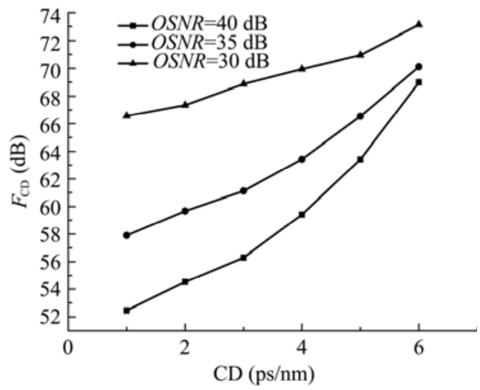
(a) 25 Gsym/s NRZ-16-QAM system



(b) 25 Gsym/s RZ-16-QAM system



(c) 160 Gbit/s NRZ-64-QAM system



(d) 160 Gbit/s RZ-64-QAM system

Fig.4 F_{CD} versus CD for NRZ/RZ-16-QAM and -64-QAM systems with different OSNR values

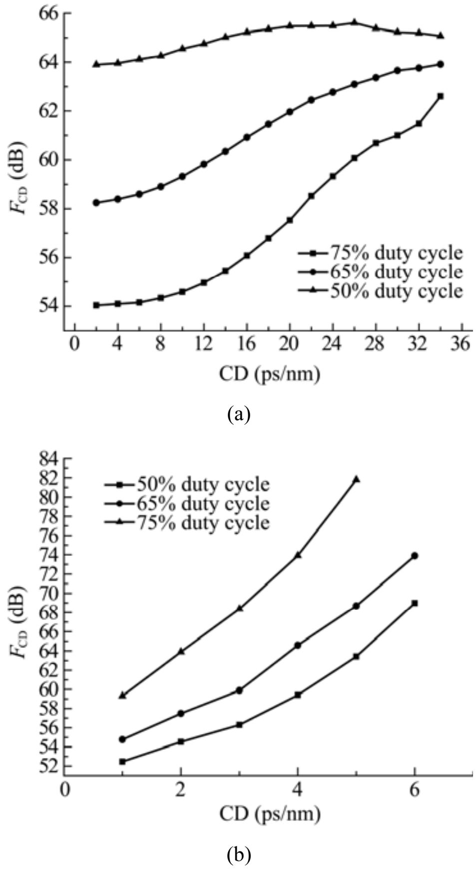


Fig.5 F_{CD} versus CD for (a) 25 Gsym/s RZ-16-QAM signal and (b) 160 Gbit/s RZ-64-QAM signal with different duty cycles

In this paper, we propose a CD monitoring scheme based on AAH evaluation method, which can be applied to higher order modulation formats. Furthermore, simulations of CD monitoring for 16- and 64-QAM systems are presented, and the effects of OSNR and duty cycle on the CD monitoring are also investigated. In the presented method, we get a high CD sensitivity through calculating the number of times occurring in the highest three peaks. With advantages of high CD sensitivity, low cost and simple realization, it can be used in monitoring the residual CD of a transmission link in high-rate optical communication system. Moreover, this proposed monitoring technique can also be applied to much more higher order modulation signals.

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