A novel chromatic dispersion monitoring method for 400 Gbit/s 256 QAM fiber-optic system based on asynchronous amplitude sampling*

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(Received 10 October 2015)

A novel chromatic dispersion (CD) monitoring technique based on asynchronous amplitude sampling (AAS) is proposed for a higher modulation format and higher rate system. The dispersion and other impairment factors can be separated with the definition of monitoring parameter *M*. A 400 Gbit/s 256 quadrature amplitude modulation (QAM) system is built using Optisystem13.0 beta software. Simulations of CD monitoring technique for different bandwidths of sampling Gaussian filter, optical signal to noise ratios (*OSNRs*) and duty cycles are investigated, and the tolerance is also discussed. Simulation results show that the method can be less affected by noise, and a higher accuracy of 600 ps/(nm·km) can be achieved. The technique supports a wide range of data traffic and enhances operation flexibility of optical networks.

Document code: A **Article ID:** 1673-1905(2015)06-0453-4

DOI 10.1007/s11801-015-5195-7

Single-carried wave 400 Gbit/s optical transmission systems with large capacity and high spectral efficiency have gradually become the mainstream of next-generation communication networks. However, some factors, such as chromatic dispersion (CD) and the phase noise (PN), seriously affect the performance of the system. Therefore, the monitoring of dispersion with high precision and wide range has attracted great attention[1-5].

Recently, Xiurong Ma et al[6] monitored CD of the non-return-to-zero on-off keying (NRZ-OOK) signal by evaluating the distance ratio of delay tap sampling. The CD monitoring range for 10 Gbit/s system can reach nearly ±900 ps/(nm·km), but for 40 Gbit/s only ±60 ps/(nm·km). Linghao Cheng et al[7] put forward a method using the squared difference of optical power to monitor the residual dispersion of transmission link, but this approach only can perform very well when the dispersion is greater than 340 ps/(nm·km). Xinliang Zhang et al[8] studied the supervision of dispersion of 40 Gbit/s NRZ differential phase shift keying (DPSK) system by asynchronous amplitude histogram (AAH) to extract a peak value of power. Thomas Shun Rong[9] and Faisal Nadeem Khan et al[10] used the artificial neural network (ANN) to realize monitoring the optical signal to noise ratio (*OSNR*), CD and polarization mode dispersion (PMD) in 40/56 Gbit/s return-to zero (RZ) differential quadrature phase shift keying (DQPSK) and 40 Gbit/s NRZ 16 quadrature amplitude modulation (QAM) systems. Their monitoring ranges of the *OSNR* and CD are 10—30 dB and −500—500 ps/(nm·km), respectively. In summary, the *OSNR* and CD monitoring ranges of most methods above are not wide, the accuracy is not high, and the methods are difficult to implement. Furthermore, as far as we know, the research of dispersion monitoring for 64/256 QAM fiber-optic transmission system has not been reported yet.

In this paper, a simple method of residual CD monitoring for 400 Gbit/s fiber-optic 256 QAM signals is proposed and simulated. Based on asynchronous amplitude sampling (AAS), the relationships between the high-order digital sampling characteristics and CD, the power of signal and noise are studied. With the help of the factor *M* we define, which only depends on dispersion, we can easily separate the dispersion factors and noise factors, so as to realize the full supervision range of 0—600 ps/(nm·km) with high precision and high sensitivity. Furthermore, in this scheme, clock information and high-speed sampling units are unnecessary, resulting in low cost and high reliability.

A 400 Gbit/s DP-256 QAM optical transmission system includes optical transmitter, fiber optic links and optical receiver. Besides, monitor system includes optical

* This work has been supported by the National Natural Science Foundation of China (No.61274121), the Natural Science Foundation of Jiangsu Province (No.BK2012829), and the Scientific Research Foundation of Nanjing University of Posts and Telecommunications (No.NY212007).

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coupler, direct detection and asynchronous sampling, as shown in Fig.1. In order to monitor CD, the 256 QAM signal $A(t)$ can be detected for asynchronous sampling through the optical coupler, which can be expressed as

$$A(t)=\sqrt{\frac{2E_0}{T_s}}I_{k_I}\cos(2\pi f_c t)-\sqrt{\frac{2E_0}{T_s}}Q_{k_Q}\sin(2\pi f_c t),\ 0<t\le T_s, \quad (1)$$

where (I_{kI}, Q_{kQ}) are the coordinates of 256 QAM signal constellation map with $k_I(k_Q)$ =1, 2, …, 8, f_c is the frequency of optical carrier, T_s is the symbol period, and E_0 is the minimum amplitude.

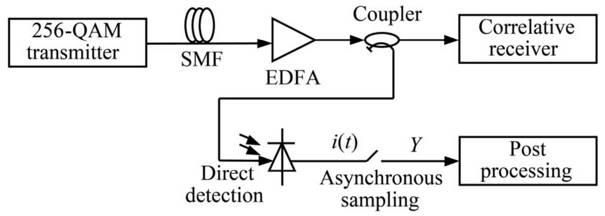


Fig.1 Proposed CD monitoring system based on AAS

According to the theory of asynchronous sampling[11,12], the sampling signal Y can be expressed as

$$Y(t)=\sum_{k_1}S_{k_1}\cdot e(t-k_1T_s)+\cdots+\sum_{k_{21}}S_{21}\cdot e(t-k_{21}T_s), \quad (2)$$

where 21 items of the expression represent 21 power levels of 256 QAM constellation, $S_{kn}(n$=1, 2, …, 21) is the k_nth transmitted information symbol, T_s is the symbol period, and $e(t)$ is the transmitted pulse.

Consider a fiber-optic transmission system where the data signals are corrupted by the amplified spontaneous emission (ASE) noise and the fiber CD. For simplicity, other transmission impairments, such as PMD and fiber nonlinearity, are assumed to be negligible. In that case, the first three raw moments of the distribution of the samples are given by

$$\begin{aligned}\mu_1&=E[Y^1]=P_n+P_0\\ \mu_2&=E[Y^2]=1.5P_n^2+3P_0P_n+P_0M_4\\ \mu_3&=E[Y^3]=3P_n^3+9P_0P_n^2+6P_0^2P_nM_4+P_0^3M_6\end{aligned}, \quad (3)$$

where P_0 is the signal power, P_n is the noise power which is equal to $4\sigma^2$, and the parameters M_4 and M_6 which are defined for a symbol sequence {...x_{k-1}, x_k, x_{k+1}...} are given by

$$\begin{aligned}M_4&=\frac{1}{T_s}\int_{-T/2}^{T/2}E\left[\left|\sum_{k=-\infty}^{+\infty}x_k e(\tau-kT_s)\right|^4\right]\mathrm{d}\tau\\ M_6&=\frac{1}{T_s}\int_{-T/2}^{T/2}E\left[\left|\sum_{k=-\infty}^{+\infty}x_k e(\tau-kT_s)\right|^6\right]\mathrm{d}\tau\end{aligned}. \quad (4)$$

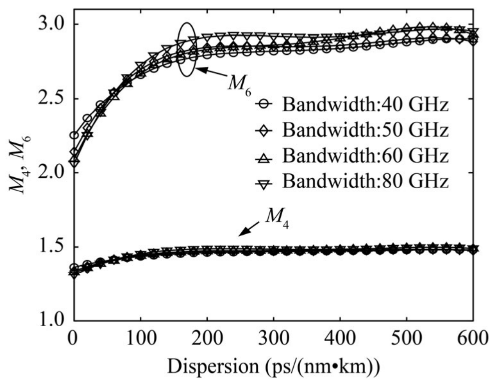
According to Eqs.(3) and (4), the parameters M_4 and M_6 depend on the accumulated CD of the link and their values have less relationship with noise. Thus, we define a parameter M_{CDR} to monitor CD, which is a ratio of M_4 to M_6 expressed as

$$M_{CDR}=M_6/M_4. \quad (5)$$

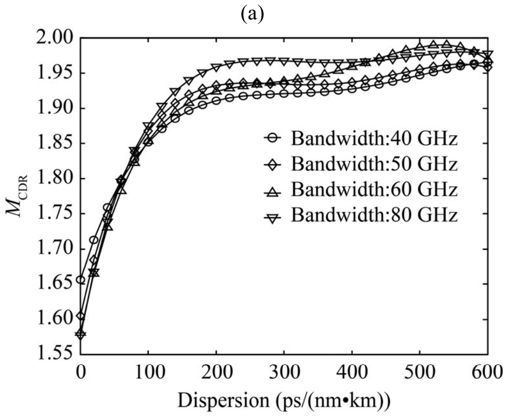
Similar to M_4 and M_6, the parameter M_{CDR} is up to CD and does not depend on the power of noise. Hence, using Eq.(5), we can calculate M_{CDR} and monitor the CD of the 400 Gbit/s DP-256 QAM optical transmission system.

Gaussian filter has the function of shaping the optical pulse, so the influence of Gaussian filter bandwidth is needed to be studied. Setting the bandwidth of the Gaussian filter to be 40 GHz, 50 GHz, 60 GHz and 80 GHz, the simulation curves of M_4, M_6 and M_{CDR} are shown in Fig.2, in the condition of no introducing noise. From Fig.2(a), it can be seen that when the bandwidth of the Gaussian filter increases, M_4 and M_6 curves have a slight change, but the overall trend remains invariable. So the bandwidth has little effect on CD. From Fig.2(b) we can see that with different Gaussian filter bandwidths, the slopes of the M_{CDR} curves are all sharp, which means that it still has high sensitivity to the CD in the range of 0—200 ps/(nm·km). To sum up, this system is suitable for the Gaussian filters with different bandwidths.

Given that the current common channel spacing is 50 GHz in DWDM system, the bandwidth of the Gaussian filter is 50 GHz in our case.



(a)



(b)

Fig.2 (a) M_4, M_6 and (b) M_{CDR} versus CD at different Gaussian filter bandwidths

With the same system settings and format of transmission signal, we change the *OSNRs* of optical signal, and set *OSNRs* at 10 dB, 15 dB, 20 dB, 25 dB and 30 dB, respectively. By the simulation, the curves of M_4, M_6 and M_{CDR} versus CD with different *OSNRs* are obtained, which are shown in Fig.3.

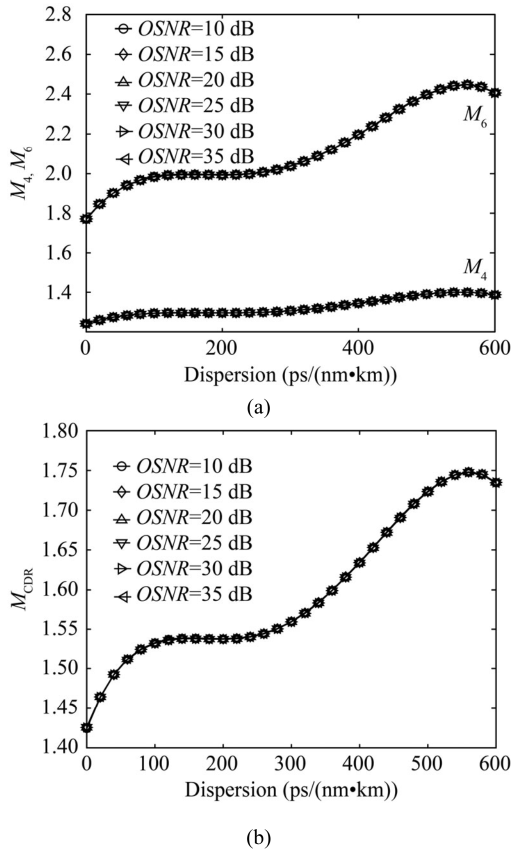


Fig.3 (a) M_4, M_6 and (b) M_{CDR} versus CD at different *OSNRs*

From Fig.3, for different *OSNRs*, the curves of M_4, M_6 and M_{CDR} are nearly overlapped, which means the noise has little impact on the dispersion factor M_{CDR}, and the result is well consistent with Eqs.(4) and (5). Meanwhile, from Fig.3(b), it can be seen that M_{CDR} increases in the whole range of 0—600 ps/(nm·km). Especially, in the ranges of 0—100 ps/(nm·km) and 200—550 ps/(nm·km), the slopes of the curves are all sharp, which means high sensitivity. In short, in the circumstance of high-order symbol rate, different noise levels have no effect on 256 QAM dispersion monitoring. Therefore, the system can realize monitoring in the whole range from 0 ps/(nm·km) to 600 ps/(nm·km) with high precision.

Setting the *OSNR* to be 0 dB and the bandwidth of Gaussian filter to be 50 GHz, the influence of different signal duty cycles, such as 1, 66%, 50% and 33%, on the dispersion curve is studied, and the results are shown in Fig.4. Fig.4 shows that the trends of M_4, M_6 and M_{CDR} curves at different duty ratios are similar with each other. So the system is independent of signal duty cycle, and it is suitable for various types of signals.

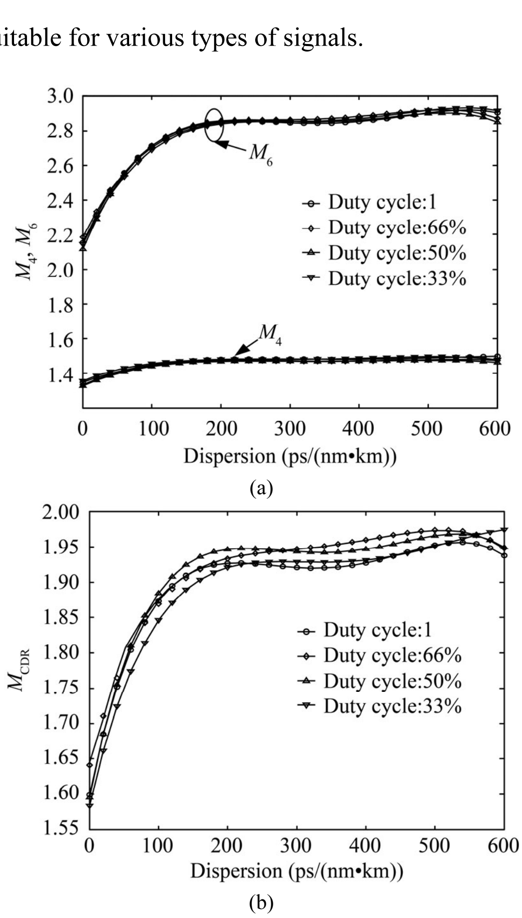


Fig.4 (a) M_4, M_6 and (b) M_{CDR} versus CD at different duty cycles

Conclusively, we can use the parameters of M_4, M_6 and M_{CDR} for high-rate and advanced modulation optical system to realize monitoring CD precisely in a wide range. And the precision is not affected by the bandwidth of Gaussian filter, *OSNR* or the duty cycle of signals.

In this paper, we propose a CD monitoring scheme based on AAS evaluation method. It can be applied to 400 Gbit/s and 256 QAM optical systems. Furthermore, the effects of bandwidth, *OSNR* and duty cycle on the CD monitoring are also investigated. In the method we propose, high sensitivity and wide range of CD monitoring can be obtained, and the whole monitoring range is from 0 ps/(nm·km) to 600 ps/(nm·km). With only a simple photoelectric detector and signal processing, the method does not need clock signal, resulting in low cost and high reliability. Most importantly, the method has a significant impact on the optical fiber communication system of 256 QAM dispersion monitoring.

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