A novel chromatic dispersion monitoring method in terms of SOA spectral shift

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In this paper a novel low power online chromatic dispersion (CD) monitoring method is presented, which employs spectral shift in the semiconductor optical amplifier (SOA). The advantage of this method lies in that the required input power can be much reduced, and the filter output can be used in the dynamic CD compensation system. The simulation indicates that the filtered power decreases with CD increases, and that the monitoring range increases as the filter bandwidth increases.

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With the development of high speed electronic and opto-electronic technology, 40-Gb/s single channel is maturing. Taking the interaction of nonlinearity and chromatic dispersion (CD), and polarization mode dispersion (PMD) into consideration, the dispersion tolerance is about ±20 ps/nm in the 40-Gb/s return-to-zero (RZ) optical communication system[1]. In addition, temperature changes will cause extra CD variation. So online residual CD monitoring and dynamic dispersion compensation are necessary. At present, online CD monitoring methods include vestigial sideband[2] or single sideband[3], clock level[4], subcarrier monitoring[5] and fiber spectral broadening. The sideband, clock level and subcarrier methods involve high speed O/E unit, and the fiber spectral broadening method needs high power optical amplifiers for the weak Kerr effect in fiber. In this paper, a novel low power online CD monitoring method is presented, which employs the spectral shift of semiconductor optical amplifier (SOA). Because the nonlinearity in SOA is much stronger than that in fiber, the input power can be greatly reduced.

Schematic of the proposed CD monitoring method is shown in Fig. 1. The input of the SOA is an optical signal with variable residual CD, the output is sent to the filter followed a PIN. As the dispersion influences the gain saturation of the SOA and the output spectral shift, the wing of the output spectrum can be used to measure the residual CD. We get the wing power by the filter and the input power by a power meter (PM). The processing circuit is used to mitigate the influence of total power fluctuating.

Assuming the case of a Gauss pulse with residual dispersion d, the input electric field can be written as

$$\begin{aligned} A_{\mathrm{in}}(T) = & \frac{\sqrt{P_0}}{\sqrt{1+ikd}} \\ & \times \exp\left[\frac{T^2}{2\tau_0^2(1+ikd)}\right]\exp(-i\omega_0 T), \end{aligned} \tag{1}$$

where $T = t - z/v_g, k = \lambda^2/(2\pi c\tau_0^2), \tau_0$ is the pulse width without dispersion, ω_0 is the carrier frequency, λ is the optical wavelength of the carrier, and P_0 is the peak power without dispersion.

The differential gain of the SOA satisfies[6]

$$\frac{\mathrm{d}G(T)}{\mathrm{d}T} = \frac{G_0 - G(T)}{\tau_c} - \frac{P_{\mathrm{in}}(T)}{E_{\mathrm{sat}}}[e^{G(T)} - 1], \tag{2}$$

where G_0 is the unsaturated single-pass amplifier gain of the SOA, τ_c is the carrier lifetime, E_{sat} is the saturation energy, and $G(T)$ is the differential gain of the SOA. $G(T)$ is got by solving Eq. (2), and thus the electric field of the output signal

$$\begin{aligned} A_{\mathrm{out}}(T) &= A_{\mathrm{in}}(T)\cdot\exp\left[\frac{1-i\alpha}{2}G(T)\right] \\ &= \frac{\sqrt{P_0}}{\sqrt{1+ikd}}\exp\left[\frac{T^2}{2\tau_0^2(1+ikd)} + \frac{G(T)}{2}\right] \\ &\quad \times\exp\left\{-i\left[\omega_0 T + \frac{\alpha G(T)}{2}\right]\right\}, \end{aligned} \tag{3}$$

where α is the chirp parameter of the SOA. The second exponent function decides the output phase. The instantaneous frequency shift of the output signal can be written as

$$\Delta\nu = \frac{\alpha}{4\pi}\frac{\mathrm{d}G(T)}{\mathrm{d}T}. \tag{4}$$

At the head of the pulse, $G(T)$ decreases quickly for the gain saturation. Thus the instantaneous frequency shifts toward the long-wavelength side. Furthermore, the lower frequency part rises, as shown in Fig. 2(a). When CD increases, the pulse turns flat, and the gain saturation effect becomes weak. In another word, the absolute value of $\mathrm{d}G(T)/\mathrm{d}T$ decreases while CD increases, as shown in Fig. 3. It can be seen from the figure that the signal chirp of the SOA output decreases as CD increases. As a result, the frequency shift decreases, and the power rising of the lower frequency part damps, as shown in Fig. 2(b).

Thus, filtering the lower frequency part can get the residual CD. The power decreases as CD increases, reaching its maximum when dispersion is zero, and

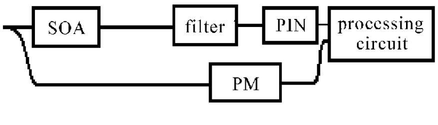

Fig. 1. The system configuration.

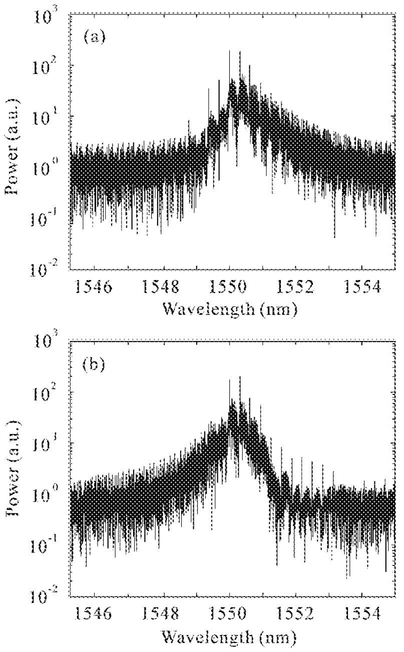

Fig. 2. The SOA output spectrum of a 40-Gb/s RZ signal without dispersion (a) and with dispersion of 10 ps/nm (b).

going constant with large CD.

In our simulation, G_0=30 dB, τ_c=300 ps, E_{sat}=2 pJ, and the optical carrier wavelength is 1550 nm. The input signal is a 2^7-1 pseudo random sequence in 40-Gb/s RZ code, with duty cycle=1/2 and average power=0 dBm. The output spectrum of the SOA is shown in Fig. 2, where the Fig. 2(a) represents the case without dispersion, and the Fig. 2(b) represents the case of 10 ps/nm dispersion.

Using a Gauss filter model, we obtain the filtered power as shown in Fig. 4. The center wavelength of the filter is 1552.6 nm, which shifts eight times the 40-Gb/s signal's sideband space. The dashed, solid, dash-dot and dotted represent different filters whose 1/e bandwidths are 0.32, 1, 1.5 and 2 nm, respectively. And the curves are normalized, the peak powers of the curves are −9.9, −2.5, 3.3 and 7.1 dBm. We can see from the figure that the CD monitoring range increases with the increase of the filter bandwidth. We can decrease the filter width to reduce the CD monitoring range, and thus improve the monitoring precision. But too narrow bandwidth leads to too low output power and ripple in the filtered power. Considering the typical range of the 40-Gb/s RZ system residual CD, the filter bandwidth can be chosen as 1.5−2 nm. Moreover, our simulation indicates that the chirp caused by negative or positive CD enhances or reduces the SOA spectral shift, respectively, which results in that the left half of the curves in Fig. 4 is slightly higher than the right half.

In addition, when the saturation energy of the SOA is low, a low input power is sufficient to saturate the SOA, and thus the input power in our method can be reduced. While P_{in} is near or higher than the saturation power, nonlinearity will be very strong and causes CD to shift negatively about several ps/nm. The typical carrier lifetime of the SOA is around 200 – 300 ps, which is far longer than the 40-Gb/s signal pulse period, so the change of τ_c cannot influence greatly the CD measurement.

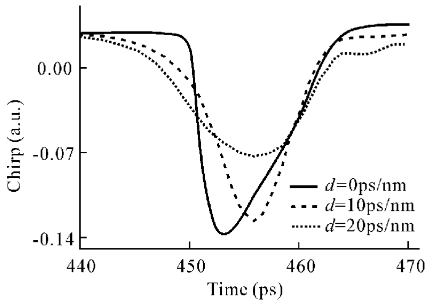

Fig. 3. The signal chirp of the SOA output decreases as CD increases. The solid, dashed and dotted represent dispersion of 0, 10, and 20 ps/nm, respectively.

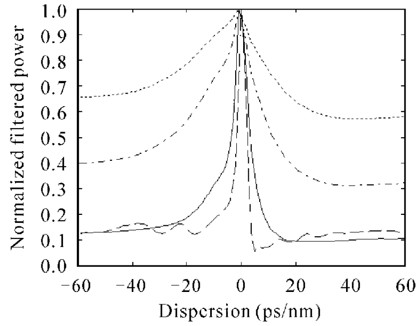

Fig. 4. Comparison of the output of the filters with different bandwidth. The filter bandwidth of dashed, solid, dash dot and dotted curves are 0.32, 1, 1.5 and 2 nm, and the peak powers are −9.9, −2.5, 3.3 and 7.1 dBm, respectively.

A novel low power online CD monitoring method is presented in this paper. This method employs spectral shift in the SOA, and a narrowband filter is used to get the wing power of the shifted signal spectrum. The advantage of this method is that the required input power can be reduced to about 0 dBm, and the filter output can be used as the feedback signal of dynamic CD compensation system. The simulation indicates that filtered power decreases as CD increases, the monitoring range increases as the filter width increases, and that too high input power will cause small CD offset.

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