Chromatic dispersion monitoring using semiconductor optical amplifier

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Abstract An all-optical real-time chromatic dispersion (CD) monitoring technique is proposed and demonstrated for 40 Gbit/s differential phase-shifts keying (DPSK) signal, utilizing the cross modulation effects of semiconductor optical amplifier (SOA). The optical power of the output spectral components, which is from the probe’s frequency up to the signal bandwidth, is used for CD monitoring. This technique provides a wide monitoring range with large variation scale. The impacts of the polarization mode dispersion (PMD) and the optical signal-to-noise ratio (OSNR) on the CD monitoring results are theoretically analyzed and then experimentally investigated, showing that they have slight influence on the monitoring results within a certain range. Furthermore, simulated results for quadrature phase shift keying (QPSK) signal at 80 Gbit/s are also demonstrated, indicating that this technique is suitable for advanced modulated format as well.

Keywords optical performance monitoring, chromatic dispersion (CD), semiconductor optical amplifier (SOA), cross modulation

1 Introduction

In recent years, as the bit rate increases in demand for capacity, the chromatic dispersion (CD) effect on the optical system cannot be ignored and has been a crucial factor that limits transmission capacity and distance in high-speed optical fiber communication system. Thus, the CD monitoring is essential for long-haul optical fiber transmission network in order to achieve adaptive and exact dispersion compensation [1,2]. Several approaches of CD monitoring have been reported in recent years, for instance, using asynchronous amplitude histogram evaluation (AAHE) method [3–5], employing asynchronous delay-tap sampling (DST) technique [6,7], utilizing nonlinear effects [8–10], using radio frequency (RF) spectral analysis [11–14], and exploiting digital signal processing [15–17]. It is crucial for a simple CD monitoring to be less affected by other coexisting impairments, including polarization mode dispersion (PMD) and amplified spontaneous emission (ASE) noise. In addition, real-time CD monitoring is especially important, since the degradation varies with time in the dynamic optical networks. Moreover, it is better for a CD monitoring to be deployed in all-optical domain. This avoids optical-to-electrical conversion and accommodates the high-speed systems, and has the potential to be integrated into a single chip inside the optical nodes.

A CD monitoring technique using a semiconductor optical amplifier (SOA) has been reported [10]. However, this approach is only suitable for return-to-zero (RZ) signal, and cannot provide independent CD measurement from other impairments. In this paper, we propose a CD monitoring technique using the cross modulation effect of SOA for 40 Gbit/s differential phase shift keying (DPSK) system. The spectral component, which is from the probe’s frequency up to the signal bandwidth, is extracted out for CD monitoring. The CD up to 1000 and 700 ps/nm are experimentally measured for non-return-to-zero (NRZ) DPSK signal and return-to-zero (RZ) DPSK signal, respectively. The impact of PMD and optical signal-to-noise ratio (OSNR) is also investigated, indicating that they have slight influence on the monitoring results within a certain range. This method transfers the RF-based monitoring technique [12] into all-optical domain for higher speed signal and maintains the characters of small PMD sensitivity, owing to the less polarization dependence of the cross modulation effect in the SOA. It provides a wide monitoring range with large variation scale, and it is...
feasible integrated into a single chip. Furthermore, this technique can well accommodate the quadrature phase shift keying (QPSK) signal. The CD monitoring result for 80 Gbit/s QPSK signal is also theoretical simulated and investigated.

2 Operation principle

The idea for the CD monitoring scheme is derived from two validated conclusions. The first one is the total amount of RF power, ranging from the DC up to the signal bandwidth, increases with the accumulated CD and hence can be used to monitor the CD for DPSK signal. This had been reported in Ref. [12]. While the other one is the intensity-to-field conversion can be performed using the cross modulation effect of the SOA. In this sense, the RF characteristics of the pump signal is mapped onto the optical spectrum of the probe via the SOA, which will be theoretically analyzed later. Thus, the power of the probe spectral component, which is from the probe’s frequency up to the signal bandwidth, can be used to monitor the CD of the signal.

At the receiver, a strong pump signal and a weak continuous wave (CW) probe are injected into the SOA. Due to cross gain modulation (XGM) and cross phase modulation (XPM) effect, the gain and the phase shift of the output probe are modulated by the intensity of the pump signal through the carrier dynamics of the SOA, while insensitive to the phase information of the pump signal [18,19]. Moreover, the gain and phase shift are approximately linear to the intensity of the pump signal while the SOA locates in saturation state. As a result, through the SOA, the temporal field of the probe is modulated by the temporal intensity of the signal. The optical spectrum around the output probe is related to the RF spectrum of the signal, which is the power spectrum of its temporal intensity. The operation principle is illustrated in Fig. 1. The total spectra of the pump signal and probe before and after SOA are illustrated in Figs. 1(a) and 1(b), and their carrier frequencies are \( f_p \) and \( f_p \), respectively. Similar results achieving the RF of high speed signal are demonstrated using the XPM of nonlinear media [20,21].

In our scheme, the spectral components of the output probe, which is from the probe’s frequency up to the signal bandwidth, is extracted out by an optical band-pass filter (BPF), and used to measure the CD for the DPSK signal. This method transfers the RF-based monitoring technique into all-optical domain for higher speed signal and maintains the characters of small PMD sensitivity, owing to the less polarization dependence of the cross modulation effect in the SOA. Furthermore, it is feasible integrated into a single chip.

\[
P(\text{CD}) = \int_{f_p}^{f_p + B} |F_{\text{probe}}(f)|^2 df,
\]

where \( F_{\text{probe}}(f) \) is the spectrum at the output of SOA, and \( B \) is the baud rate of the DPSK signal. In practice, the filtered spectral components are slightly deviated from \( f_p \) (i.e., the \( f_p \) is exclusive), in order to avoid the strong but slightly-variant carrier of the probe, and thus achieves a high monitoring sensitivity. \( P(\text{CD}) \) increases monotonously with the increase of accumulated CD on the received signal. Parameter \( F \), which denotes the relative power change, is introduced to monitor the CD of the signal, and defined as

\[
F = \frac{P(\text{CD})}{P(0)}.
\]

3 Experiment and results

The experimental setup for 40 Gbit/s (N)RZ-DPSK systems is shown in Fig. 2. A distributed feedback laser operating at 1554.72 nm is externally modulated to a (N) RZ-DPSK signal by a LiNbO\(_3\) Mach-Zehnder modulator (MZM), which is driven by a \( 2^{31} - 1 \) pseudorandom binary sequence signal at 39.81 Gbit/s. A second MZM is used as a pulse carver for RZ-DPSK signal. An erbium-doped fiber amplifier (EDFA1) and a variable optical attenuator (VOA1) are used to adjust the optical power to 0 dBm,

![Fig. 1 Optical spectrum (a) before and (b) after SOA](image-url)