Novel in-band OSNR monitoring method based on polarization interference

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We propose a novel in-band optical signal-to-noise ratio (OSNR) monitoring method based on polarization interference. The method realizes a monitoring accuracy of ±0.5 dB within the range of 9–34 dB. Our results indicate that the proposed method is transparent to bitrate and modulation format, as well as independent of polarization mode dispersion and chromatic dispersion.

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Optical signal-to-noise ratio (OSNR) is a key optical performance monitoring indicator because it can be correlated with the end-terminal bit error rate (BER) and is transparent to not only bit rate but also modulation format[1]. With the acknowledgment of OSNR, we can set up, optimize, estimate, and evaluate lightpath provisioning[1] in optical WDM links, especially in a dynamically reconfigured wavelength-division multiplexing (WDM) system.

In earlier decades, OSNR monitoring involved the use of traditional out-of-band techniques, which assume that amplified spontaneous emission (ASE) noise exhibits a flat spectrum over a wide range[2]. However, out-of-band techniques are no longer accurate with the application of dense WDM (DWDM) systems and the introduction of reconfigurable optical add/drop multiplexers and optical cross connect; these innovations mean that out-of band noise level can no longer accurately represent real noise. This backdrop drove researchers to develop new methods of OSNR monitoring. Polarization-based techniques, mainly the polarization-nulling method, isolate optical signals from ASE noise by using different polarization properties produced by polarizers[3]. This technique is simple but can be inaccurate if received signals suffer from polarization-dependent losses, such as polarization mode dispersion (PMD) and polarization dependent loss (PDL). Interferometer-based techniques separate ASE noise from optical signals on the basis of different coherence properties[4,5]. Despite the benefits of such approaches, the Mach-Zehnder delay interferometer is only a notch filter that eliminates not only signals, but also a portion of ASE noise; this deficiency gives rise to the need to calibrate device parameters. These parameters depend on the power spectra of signals and noise, which increase the complexity of interferometer-based monitoring methods. The orthogonal delayed-homodyne technique requires a polarization controller to ensure that two branches have equal optical power and that the monitoring result is not sensitive to minor variations in OSNR[6,7]. Researchers have proposed some other techniques, such as beat noise analysis techniques[2], asynchronous histograms[8], asynchronous delay tap sampling, and artificial neural network statistical machine learning[9].

In this letter, a novel OSNR monitoring method based on the polarization interference technique is demonstrated and testified. The method is independent of PMD and chromatic dispersion (CD), and is suitable for systems characterized by bit rates and modulation formats.

The scheme for the proposed OSNR monitoring module is shown in Fig. 1.

The key idea of our monitoring module is the elimination of signals at several frequencies to enable the reading of noise power at these frequency points. Theoretically, a polarizer can completely block a linearly polarized signal if the azimuth of the signal and the angle of the polarizer are orthogonal. If the polarization states of a signal vary with frequency, the polarizer cannot block the entire signal. When polarizer angle is orthogonal to some linear polarized frequency components of the signal, corresponding hole burning of the spectrum is observed at these specific frequencies, whose power represents noise level. The entire spectrum is similar to an interference spectrum.

In our module, the dotted box is introduced to test the level of noise power. The signal is split into two orthogonal polarization components by using a polarization

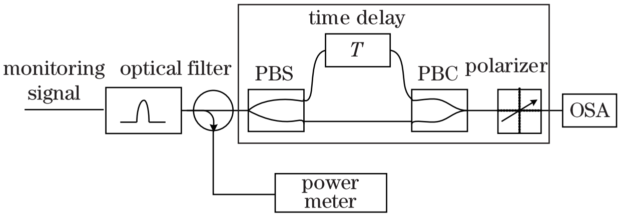

Fig. 1. Schematic of the proposed OSNR monitoring module.

beam splitter (PBS). The two polarization components are then recombined using a polarization beam combiner (PBC) after the signal on the upper branch passes through an optical time delay. The two polarization components interfere with each other when they are placed after a polarizer. The polarizer is rotated to identify the angle position where some signal frequency components suffer from destructive interference. The corresponding minima power $P_{\min}$ from an optical spectrum analyzer (OSA) is then recorded. If the power meter registers P_{total} as the power level, the OSNR can be derived as

$$\text{OSNR} = 10\log\left[\frac{\gamma\beta P_{\text{total}}}{2(1-\gamma)P_{\min}} - 1\right], \qquad (1)$$

where γ is the power split ratio of the coupler and β is the insertion loss of components, such as PBS and PBC.

The essence of the polarization interference method is its reading of noise power level at certain frequency points from the OSA. The accuracy of this method is highly related to the accuracy of the noise power level shown on the OSA. From the point of display, a higher OSA resolution leads to a clearer spectrum and a more accurate power level reading. From the point of signal elimination, a higher polarizer extinction ratio leads to better separation. A larger time delay also leads to more interference points and a better ASE noise power level reading.

To verify the performance of the proposed OSNR monitoring system, we set up a tested simulation system (Fig. 2). Several different scenarios are considered: those with different modulation formats, different bit rates, PMD, CD, and PDL.

In the simulation system, the bandwidth of the filter is set to 5 times the value of the symbol rate (R_s). Since the proposed monitoring method is of in-band type, the filter bandwidth is appropriate as long as it is wider than or equal to the main lobe. The PBS and PBC are all set to 0°. Time delay changes with the symbol rate of a signal; such delay is usually several times the value of the symbol rate.

First, the interference spectrum are obtained for a 40-G DQPSK signal with an actual OSNR level of 12 dB under different conditions (Fig. 3). The first condition considers only ASE noise and D_{ub} (upper branch delay) = 0, which corresponds to a situation in which a signal is eliminated and only noise is left; here, the line represents the noise level. The second condition is $D_{\text{ub}} = 2\ T$ with only ASE noise. The third condition is $D_{\text{ub}} = 2\ T$ with ASE noise and the first-order PMD (DGD = $R_s/2$). The fourth is $D_{\text{ub}} = 2\ T$ with ASE noises and 1 020 ps/nm CD. The fifth condition is $D_{\text{ub}} = 2\ T$ with ASE noise and 3-dB PDL.

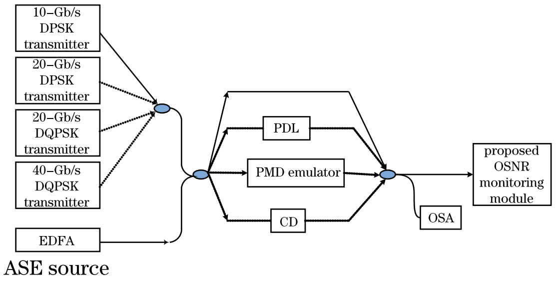

Fig. 2. Schematic of the tested simulation system. DPSK: differential phase-shift keying; EDFA: Er-doped fiber amplifier.

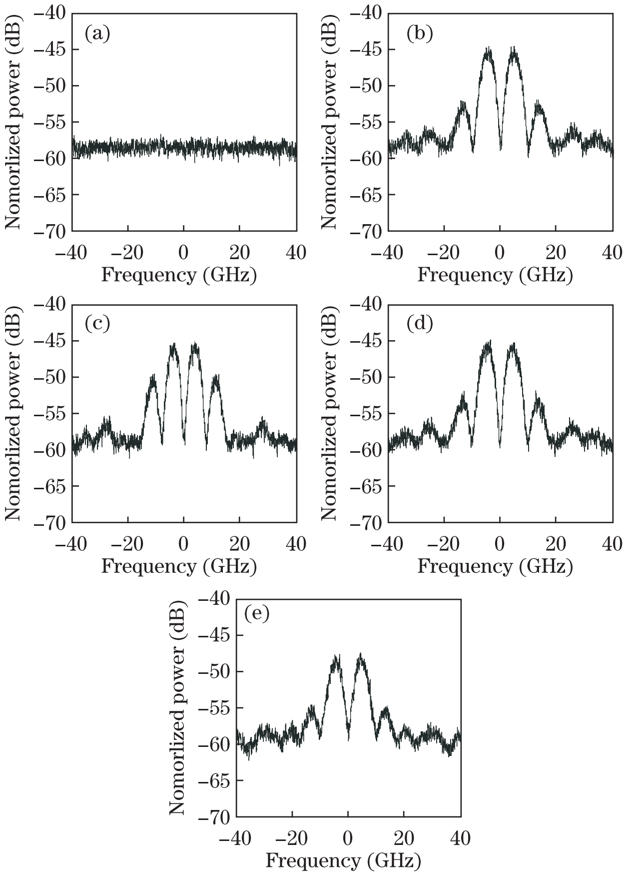

Fig. 3. Output spectrum of OSA. (a) $D_{\text{ub}} = 0$ and (b) $D_{\text{ub}} = 2\ T$ with only ASE noise; $D_{\text{ub}} = 2\ T$ with (c) ASE noise and PMD, (d) ASE noise and CD, and (e) ASE noise and PDL.

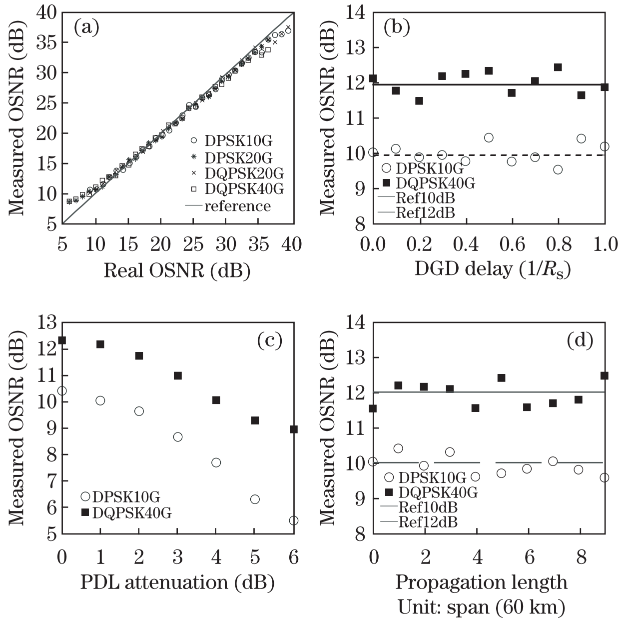

Fig. 4. Measured OSNR versus (a) real OSNR, (b) DGD, (c) PDL, and (d) CD (D = 17 ps/km·nm).

The comparison of Figs. 3(a)–(d) shows that the power level at destructive interference points is the same as the value of the line in Fig. 3(a), which can accurately represent noise level; CD has no influence on optical spectrum; with PMD, the destructive interference points shift from their original location, but the noise power level does not change. If PDL exists, the noise level is attenuated and the measured OSNR departs from the actual value.

We subsequently measured the OSNR using the proposed monitoring module and compared the measurement with the actual OSNR under different situations. Under an actual OSNR of 5–40 dB, we measured the OSNR for different bit rate DPSK and DQPSK systems. The results shown in Fig. 4(a) reveal that this method is independent of bit rate and modulation format. If measurement accuracy is limited to ± 0.5 dB, the measured range of the proposed method is 9–34 dB. If 12 and 10 dB are chosen as the reference OSNRs of DQPSK and DPSK systems, respectively, then measurement accuracy with the effects of PMD, CD, and PDL are considered. Figures 4(b) and (c) show that the measurement errors are all within ± 0.5 dB under different PMDs and CDs, confirming that the monitoring system is robust against PMD and CD. The errors increase if PDL exists in a system. If we select an error range of ±1 dB, the allowable PDL range is within 2 dB.

In conclusion, we demonstrate and validate a novel in-band OSNR monitoring method based on polarization interference, which exhibits ±0.5 dB precision that ranges from 9 to 34 dB. This method is transparent to bit rate and modulation format and is independent of PMD and CD. The monitoring method also has a PDL tolerance of 2 dB if the acceptable error is set to ±1 dB.

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