A novel robust OSNR monitoring technique with 40-dB dynamic range using phase modulator embedded fiber loop mirror

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Abstract: A novel in-band OSNR monitoring technique using phase modulator embedded fiber loop mirror (PM-FLM) is proposed and demonstrated. Monitoring error can be kept <0.25dB for OSNR between 0 to 40dB in 10-Gb/s non-return-to-zero (NRZ) system.

OCIS codes: (060.2330) Fiber optics communications; (120.5060) Phase modulation;

1. Introduction

In order to assure the signal integrity and performance of all channels in wavelength division multiplexing (WDM) networks, it is essential to monitor the optical signal-to-noise ratio (OSNR) of each wavelength channel. Recently, several polarization-assisted methods [1]-[3] have been recently proposed to monitor the true in-band OSNR. Polarization-nulling [1] is a promising approach for its simplicity, insensitivity to chromatic dispersion (CD), and high measurement sensitivity. However, it is susceptible to polarization-mode dispersion (PMD), as PMD can induce depolarization of the modulated optical signal and therefore the assumption of polarized data signal becomes invalid [4]. Recently, polarization-nulling with off-center narrow-band filtering technique [5] has been proposed to improve its robustness against PMD. However, this technique has tight requirements on the filter's finesse, especially when the signal bandwidth is not broad enough or the channels are too densely spaced. Thus, it is not suitable for non-return-to-zero (NRZ) signals. Another challenge to the polarization-nulling method is the partial polarization of the ASE noise by polarization hole-burning (PHB) in the optical amplifiers and by polarization-dependent loss (PDL) in network elements. When the ASE has a non-zero degree of polarization (DOP), the OSNR measurement based on the assumption of unpolarized ASE becomes inaccurate [6].

In this paper, we propose and experimentally demonstrate a new robust in-band OSNR monitoring scheme using a phase modulator embedded fiber loop mirror (PM-FLM), based on the uni-directional phase modulation characteristics in the travelling-wave type phase modulator. By monitoring the output power of a fiber loop embedded with a travelling-wave type phase modulator driven by low-frequency sinusoidal signal, the OSNR could be determined in a very accurate manner. The measurement errors were less than 0.25 dB for OSNR between 0 to 40 dB in a 10-Gb/s NRZ system, showing high sensitivity and larger dynamic of the proposed technique. This technique was also shown experimentally to be PMD insensitive, CD insensitive, bit-rate independent and immune to partially polarized noise.

2. Proposed PM-FLM for OSNR Monitoring

The idea of our proposed scheme is to estimate the incoherent noise from the input signal by inducing uni-directional phase modulation in an optical fiber loop mirror. In traveling-wave type optical phase modulators, the RF driving electrode is located at one side of the optical waveguide which is close to the optical input port to maximize the modulation efficiency when the input light traverses the device in the forward direction. However, if the input light propagates in the backward direction, instead, the phase modulation efficiencies will not be as good as that in the forward direction case. This kind of uni-directional phase modulation induces phase difference to the signal traveling in counter-propagating directions when the optical phase modulator is put inside a fiber loop mirror, that is, PM-FLM, enabling the loop mirror to perform OSNR monitoring, as described as follows.

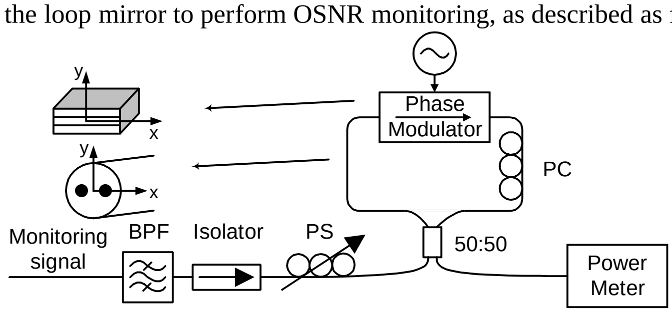

Fig. 1. Schematic diagram of the proposed OSNR monitoring module. PC: polarization controller, BPF: optical bandpass filter, PS: polarization scrambler.

Fig. 1 shows the schematic diagram of our proposed OSNR monitoring module. Our proposed OSNR monitoring module consists of a fiber loop mirror embedded with a low-frequency sinusoidal signal driven optical phase modulator (i.e. PM-FLM), a polarization scrambler (PS) at the input port and an optical power meter at the output port. The optical phase modulator is pigtailed with polarization-maintaining fibers (PMF) at both input and output ends. The polarization controller inside the loop is set to produce a polarization rotation of $\pi/2$ for signals through both directions. In this way, periodic transmission and reflection bands in the output spectrum can be obtained [7]. When the induced phase difference is 0 or π, the signal would experience constructive interference and destructive interference, respectively. Consequently, the input signal can be switched out or reflected back periodically. As a result, the signal power can be extracted in the case of constructive interference and the noise level can be extracted in the case of destructive interference for the data signal.

Under normal operation, the polarization controller (PC) inside the fiber loop was first adjusted to optimize the polarization of the counter propagating signals through the optical phase modulator. Once this step is completed, no further polarization control is needed inside the fiber loop and the OSNR measurement result is independent of input polarization since there is a polarization scrambler at the input port. The polarization scrambled signal is then fed into the fiber loop mirror and is split into CW and CCW paths. A low frequency sinusoidal signal is used to drive the optical phase modulator to scan through different amount of phase differences between the counter-propagating signals and an optical power meter is used to track the maximum and the minimum output powers (P_{max} and P_{min}). The OSNR can be derived as [8]:

$$OSNR(dB/0.1nm) = \frac{P_{sig,in} \cdot NEB_f}{P_{ASE,in} \cdot 0.1nm} = \frac{(1-r) \cdot NEB_f}{[r(1-D_{sig}) - (1+D_{sig})] \cdot 0.1nm} \quad (1)$$

where $r=P_{max}/P_{min}$, NEB_f is the noise equivalent bandwidth (NEB) of the band-pass filter (BPF) at the module input, and D_{sig} is the distinctness of interference. Note that the component losses can be ignored as both signal and noise experience almost exactly the same amount of component loss.

3. Experiments and results

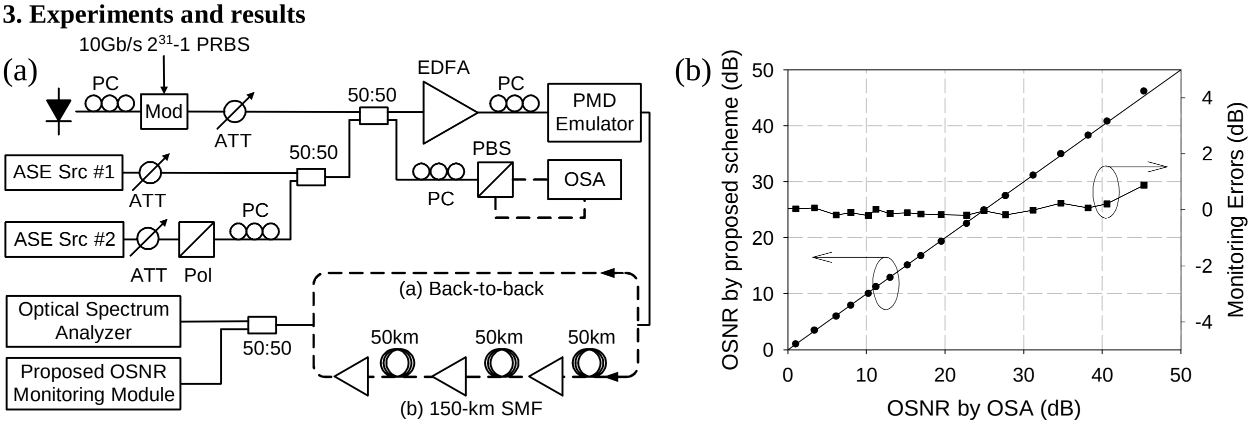

Fig. 2. (a) Experimental setup. PC: polarization controller, ATT: optical attenuator, OSA: optical spectrum analyzer, EDFA: erbium doped fiber amplifier; (b) Measured OSNR and monitoring errors

The proposed OSNR monitoring scheme was experimentally characterized in a 10-Gb/s NRZ on-off keying (OOK) system, as shown in Fig. 2(a). The signal source was a DFB laser at 1545.6 nm, externally modulated by a LiNbO3 optical intensity modulator with 10-Gb/s 2^{31}-1 PRBS NRZ data. An EDFA was used to produce different levels of amplified spontaneous emission (ASE) noise, which was then combined with the modulated signal by a 3-dB fiber coupler. The OSNR level was controlled by the optical attenuators before the fiber coupler and it was adjusted from 0 dB to 40 dB in our experiment. The noise-added signal was then amplified by another EDFA and a PMD emulator was inserted to simulate the effects of different differential group delay (DGD) values varying from 0 ps to 50 ps. Finally, the composite signal was fed to an optical spectrum analyzer (OSA) and also to our proposed OSNR monitoring module, for comparison. The band-pass filter (BPF) bandwidth was about 1 nm, which was wide enough to cover the whole signal spectrum. The implementation of the BPF may be static or tunable to implement a static or shared OSNR monitor respectively. The sampling time of the optical power meter was set to be 20 ms, which was fast enough compared with the speed of variation in the output power, and was slow enough to eliminate the interference dependence on the signal pattern. The total measurement time for our scheme was within 30 seconds. D_{sig} and D_{ASE} were measured to be about 0.975 and 0.01, respectively, in our experiment.

Fig. 2(b) compares various levels of monitored OSNRs by our proposed scheme with conventional OSNR measurements by linear interpolation. The OSNRs agreed very well with the reference OSNRs. The measured monitoring error was less than 0.5 dB for OSNR varying from about 0 dB/0.1 nm to 40 dB/0.1 nm. This shows high sensitivity and large input dynamic range of the proposed scheme.

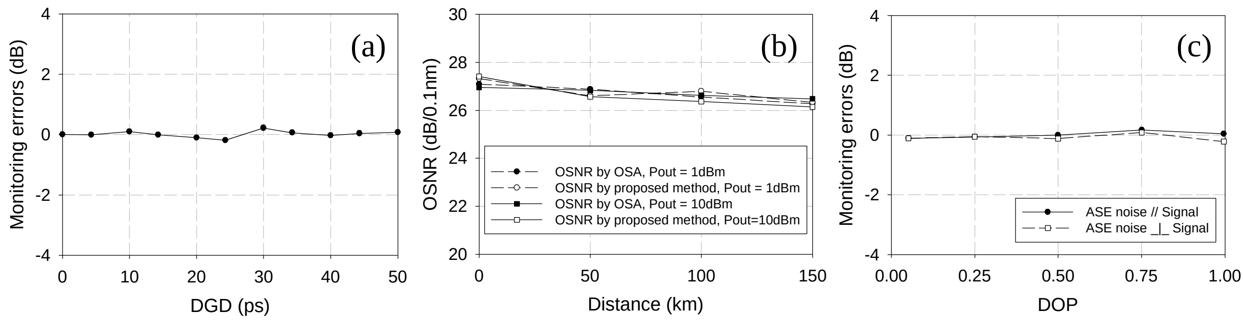

Fig. 3. (a) Monitoring errors under different DGDs for 25-dB OSNR; (b) OSNR monitoring results in a 150-km SMF link (PMD <1.5ps, Pout=1 and 10 dBm respectively); (c) Monitoring errors for partially polarized ASE with different DOPs and alignment (dark for parallel, white for orthogonal) to signal for 25-dB OSNR

Fig. 3(a) shows the monitoring errors when DGD was introduced. For reference, the OSNR was set to be 25 dB/0.1 nm by the OSA. The monitoring error was smaller than 0.25 dB for DGD varying from 0 ps to 50 ps, which shows high PMD robustness of our proposed scheme.

Next, the performance of our scheme after 150-km single mode fiber (SMF) transmission was investigated. An erbium-doped fiber amplifier (EDFA) was added after each 50-km SMF span and the output power from each EDFA was maintained at 1 and 10 dBm, respectively. Fig. 3(b) shows that the monitoring errors were negligible, indicating that our scheme was rather insensitive to both the chromatic dispersion, typical value of PMD (< 1.5ps in our case), and power in long-haul transmission in SMF.

The influence of partially polarized ASE to our scheme was also investigated. Partially polarized ASE was generated by combining the output of a polarized ASE source with the output of an unpolarized ASE source using a 3-dB coupler. Two independent attenuators were used to control the DOP of the resulting ASE. The DOP of the unpolarized ASE source was measured to be 5.16%, while the polarized source had a DOP of 99.69%. A polarization controller was used to set the polarization of the ASE either aligned with or orthogonal to the signal polarization. The polarization alignment of the signal and noise components was determined using a polarization beam splitter (PBS) and an optical spectrum analyzer (OSA) as shown in Fig. 2(a). The signal was nulled in one branch of the PBS, then the polarized part of the ASE was nulled either in the same branch or the orthogonal branch to obtain the desired state of polarization. Fig. 3(c) shows that the monitoring errors were smaller than 0.25dB for different values of noise DOP, showing that our proposed scheme is insensitive to partially polarized ASE noise. This further confirms the robustness of our proposed OSNR monitoring scheme against partially polarized ASE. Compared with the polarization nulling method which could induce non-negligible monitoring error under partially polarized ASE [6], our scheme shows a higher robustness to operate in practical environment.

Finally, the data rate dependency of our proposed scheme was investigated. Monitoring error was kept smaller than 0.3 dB for bit-rate from 2.5Gbps to 10Gbps.

4. Summary

We have proposed a novel and simple in-band OSNR monitoring technique using phase modulator embedded fiber loop mirror (PM-FLM). Various characterization experiments have shown that the proposed technique has high accuracy, high sensitivity and large dynamic range in OSNR measurements. For instance, the monitoring errors were less than 0.25 dB for OSNR between 0 to 40 dB in a 10-Gb/s NRZ system. This technique has also been shown to be PMD insensitive, CD insensitive, bit-rate independent, and robust to partially polarized ASE noise, as well. This work was partially supported by a grant from the Research Grants Council of Hong Kong SAR, China.

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