

## Polarization-Nulling Method for Monitoring OSNR in WDM Network

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For the efficient operation and maintenance of a modern dynamic WDM network, it is necessary to monitor various parameters including the channel power, wavelength, and optical signal-to-noise ratio (OSNR), etc [1]. In particular, OSNR is an important parameter to be monitored for the estimation of the quality of transmitted signal. This paper reviews the current status of the OSNR monitoring technique based on the polarization-nulling method.

Previously, OSNR has been measured by using the linear interpolation technique, in which the ASE noise was measured in between the channels and then interpolated into the signal's wavelength. However, in dynamically reconfigurable networks, WDM signals are added/dropped or cross-connected directly in the optical layer. Thus, each channel could traverse through different routes and different number of optical amplifiers. In addition, the noise spectrum is not uniform in these networks due to the optical filtering occurred in every node. As a result, the accumulated noise level could be quite different from channel to channel. Thus, these noises located within the signal's bandwidths (and consequently the "true" value of OSNR) cannot be measured by the conventional linear interpolation technique [1].

Recently, a unique OSNR monitoring technique has been proposed by utilizing the different polarization properties of signals and ASE noises [2]-[6]. Fig. 1 shows the operating principle of the polarization-nulling method. The polarization state of the optical signal incident on the OSNR monitor could be linear, circular, or elliptical. However, this arbitrarily polarized signal could be changed to a linearly polarized signal simply by using a polarization controller. The linearly polarized signal and unpolarized ASE noise could then be split into two orthogonal polarization components (in which one polarization component consists of signal and ASE noise, while the other has ASE noise only) by using two linear polarizers. Thus, the signal power together with the polarized ASE noise could be measured by using the linear polarizer aligned to the signal's polarization. On the other hand, only the polarized ASE noise (i.e., half of total ASE noise) could be measured by using the second linear polarizer, which is aligned to be orthogonal from the signal's polarization. Thus, using the polarization-nulling method, it is possible to monitor the "true" value of OSNR by measuring the signal and noise powers right at the signal's wavelength.

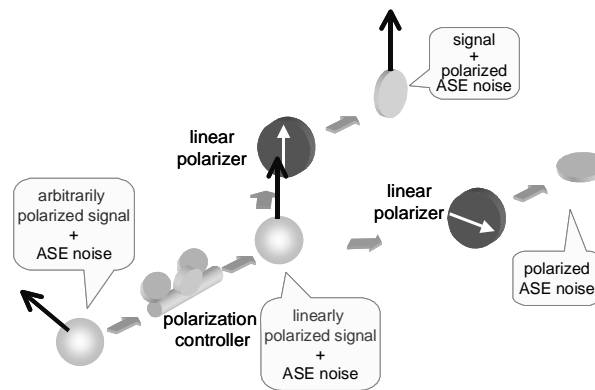


Fig. 1. The operating principle of the polarization-nulling method

Up till now, the polarization-nulling method appears to be the only practical solution capable of measuring the in-band ASE noise. However, the performance of this technique could be affected by the polarization-mode dispersion (PMD), nonlinear birefringence, and in-band crosstalk (caused by four-wave mixing or multi-path interference) [2]-[7]. In addition, for the use in the transmission link consisted of aerial fibers, this method

should be able to track the fast fluctuation of the state-of-polarization (SOP) of optical signal caused by winds and electric currents in the neighboring power lines [8]-[10]. Several techniques have been developed to overcome some of these problems [3]-[6]. These techniques either calibrated out the small amount of signal power leaked into the noise in the orthogonal polarization state (due to PMD or nonlinear birefringence) by using an additional optical filter or measured the noise power at the side of the signal's spectrum to mitigate the effect of PMD. However, the accuracy of the polarization-nulling method could still be deteriorated if the noise is partially polarized due to the polarization-dependent loss (PDL) in the transmission link [11]. Thus, we carried out in-depth analyses on this effect to assess the practicality of the OSNR monitoring technique based on the polarization-nulling method.

We evaluated the effects of PMD, nonlinear birefringence, in-band crosstalk, fast polarization fluctuation, and PDL on the performance of the polarization-nulling method. The results showed that this method could monitor OSNR with accuracy of better than  $\pm 1$  dB, even when the differential group delay (DGD) and in-band crosstalk were as large as 60 ps (@ OSNR  $\leq 27$  dB) and 20 dB (@ OSNR = 24 dB), respectively. The effect of the signal depolarization caused by nonlinear birefringence was measured to be negligible even in a highly nonlinear transmission link (when the improved method was used) [3]-[4]. We also investigated the effect of PDL on the accuracy of the polarization-nulling method. The results showed that, as long as the PDL/span was smaller than 0.2 dB (as in most current systems [12]), the OSNR could be monitored accurately by using the polarization-nulling method even in a long-distance system ( $\sim 4000$  km). For example, when the PDL/span was 0.2 dB, the probability that the error in the measured OSNR became larger than 1 dB was merely  $10^{-4}$  in the transmission link made of 50 amplifier spans. However, if the PDL/span was increased to 0.3 dB, the maximum number of amplifier spans could be reduced to 23 to achieve the same error probability. To verify the possibility of using the polarization-nulling method in the field, we measured OSNR of the optical signals transmitted through a 120-km long aerial fiber link for one week. In this aerial fiber link, SOP of the optical signal was measured to be fluctuated at  $\sim 0.3$  Hz and 60 Hz due to winds and electric currents in the neighboring power lines, respectively. Despite of these slow and fast fluctuations, the polarization-nulling method could monitor OSNR with accuracy better than  $\pm 1$  dB (@ OSNR = 19 ~ 28 dB). No significant degradation in the monitoring accuracy was observed during this long-term measurement.

In summary, we reviewed the current status of the OSNR monitoring techniques based on the polarization-nulling method. The results show that the polarization-nulling method can be used for monitoring OSNR in a dynamic WDM network and enhance its operation and maintenance.

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