OSNR Monitoring Using Double-Pass Filtering and Dithered Tunable Reflector

Chun-Liang Yang and San-Liang Lee, *Member, IEEE*

***Abstract*—A simple scheme for measuring signal and noise powers of multiwavelength channels is realized by using double-pass filtering and a dithered reflector. The noise is passed through a tunable filter twice in order to obviate the need of an optical filter with very steep transfer function, while the signal power is measured at the output of a partial reflector that follows the filter. We demonstrate the optical signal-to-noise ratio (OSNR) measurement with a voltage-controlled optical filter and a dithered tunable reflector. It can provide polarization insensitive monitoring and high immunity to the influence of residual signals. The experiments show that it can measure up to 44-dB OSNR with an error < 0.4 dB.**

***Index Terms*—Fabry–Pérot interferometer (FPI), fiber networks, optical performance monitoring, optical signal-to-noise ratio (OSNR) monitoring, wavelength-division multiplexing.**

I. INTRODUCTION

OPTICAL signal-to-noise ratio (OSNR) is one of the critical parameters to be monitored in dense wavelength-division-multiplexed (DWDM) networks [1]. A combination of polarization rotators and linear polarizers [2]–[4] or different combinations of optical filters [5]–[8] have been proposed. The schemes that use polarization-selective components are generally subject to the influence of the polarization fluctuation during signal transmission. For the optical filtering approaches, it is generally difficult to use a single tunable optical filter (TOF) to measure both the signal and noise powers. Here, we demonstrate a technique that passes the noise through a TOF twice in order to obtain high rejection on the adjacent signal channels. It also uses a partial reflector to allow simultaneous measurement of signal and noise powers. Dithering the reflector can enlarge the measurable OSNR range.

II. OPERATION PRINCIPLES

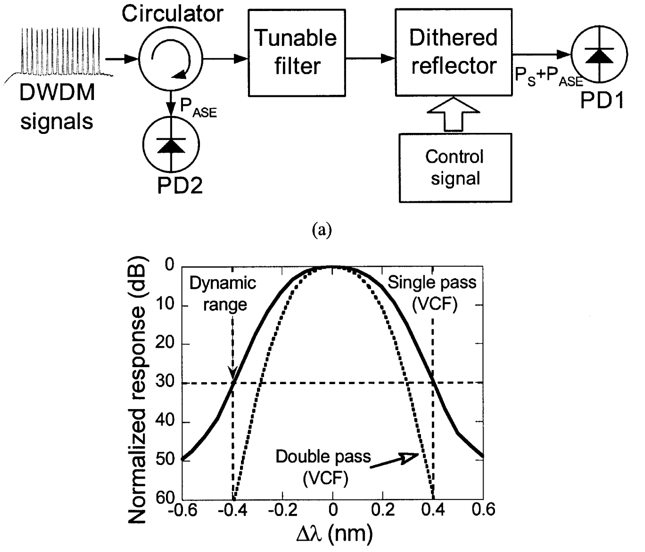

Fig. 1. Schematic diagram of the proposed monitoring module: (a) block diagrams, and (b) tunable filter response. The double-pass response was calculated from the measured single-pass response.

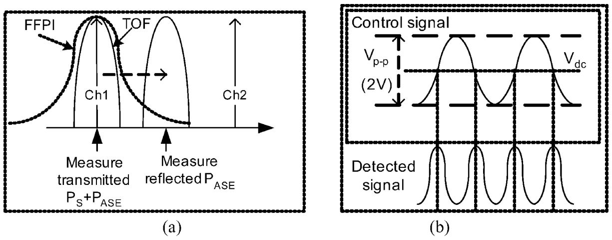

Fig. 2. Transmission responses (a) of the TOF and partial reflector during signal and noise power measurement and (b) control signals for the FPI and the detected signals. The control signal includes a dc voltage and a 2.5-kHz dithering signal. The frequency of the detected signal is doubled.

The optical filtering approach for OSNR measurement usually uses two optical filters alternately [8]: one with wide enough bandwidth to accomadate the signal spectrum for measuring the signal power and the other with narrow enough bandwidth to reject the adjacent channels for measuring the noise power. Fig. 1 shows the schematic of the proposed scheme and the filter response during the signal and noise measurement. The key concept is to pass the signal and noise through the TOF once and twice, respectively. This allows narrowing the bandwidth for noise measurment with simple configuration. Fig. 1(b) shows that the spectral response of a TOF may be sharp enough to select 50-GHz spaced DWDM channels, but its 30-dB suppression at a 50-GHz frequency offset is not good enough for measuring the noise power between two 100-GHz spaced channels. By passing through the filter twice, the suppression at the same frequency offset increases to 60 dB. This results in a significant increase in the dynamic range for OSNR monitoring. This scheme is especially advantageous for monitoring channels of denser spacings.

Fig. 2(a) illustrates the transmission responses of the TOF and partial reflector during signal and noise measurement. The TOF is aligned to the channel position during signal power mea-

---

Manuscript received November 21, 2003; revised February 12, 2004. This work was supported in part by the Computer and Communications Research Laboratory, Industrial Technology Research Institute, Taiwan, under Grant T1-92019-9 and in part by the National Science Council, Taiwan, under Grant NSC92-2219-E011-003.

The authors are with the Department of Electronic Engineering, National Taiwan University of Science and Technology, Taipei 106, Taiwan, R.O.C. (e-mail: sanlee@et.ntust.edu.tw).

Digital Object Identifier 10.1109/LPT.2004.826731

surement but to the middle between two adjacent channels for measuring the noise power. The signal power is measured at the output of the partial reflector, while the noise is measured at the circulator output. The double-pass filtering scheme was used in an optical spectrum analyzer (OSA) to improve its dynamic range [9]. The input and output beams can be directed to different trajectories for separate coupling, but it usually requires sophisticated tuning controls and optics. Adding a reflector after a transmission-type TOF can simplify the tuning control.

One potential problem of the double filtering scheme is the residual signals arising from the unwanted reflection of the module and the circulator leakage. The residual signals will affect the accuracy of noise measurement. The problem is especially critical for monitoring multiple channels at large OSNR conditions where the signal is much stronger than the noise, so tiny leakage or reflection from the module can strongly affect the detected noise power. This problem can be solved by adding a dithering signal onto the reflector.

III. Experimental Demonstration

To demonstrate the proposed approach, we performed experiments with commercial available components, including a voltage-controlled filter (VCF) of which the spectral response is shown in Fig. 1(b), and a fiber Fabry–Pérot interferometer (FPI) as the reflector. The bandwidth and finesse of the FPI are 24.9 GHz and 195, respectively. Three distributed feedback lasers are used to generate DWDM channels of 100-GHz spacing. The laser sources with data modulation are amplified by an Erbium-doped fiber amplifier to generate signals of different OSNRs. By adding dithering signal shown in Fig. 2(b) to control the FPI, the reflectivity is modulated. Consequently, the detected noise that is reflected from the FPI can be separated from the residual signals. The dithering signal to control the FPI includes a dc voltage (V_{dc}) that is used to scan and track the channel position. Since the output signal is maximal at the middle of the dithering signal, the detected signal and noise occur at twice the dithering frequency, as illustrated in Fig. 2(b). The signal power is detected at the peak value of PD1 signal, while the noise power is detected by PD2 as the PD1 signal reaches minimum. The channel tracking of the FPI is performed by coupling a portion of the filtered signal to a built-in detector of which the voltage is used to adjust V_{dc}.

Fig. 3 shows the output spectra of the monitoring module as the OSNR is around 44 dB and, meanwhile, the VCF is aligned at the middle between Channels 2 and 3 for noise measurement. It is clear that the signals are not completely suppressed, and it is hard to monitor large OSNR cases with a single-pass configuration, as shown in Fig. 3, Curve (a). The signals are expected to be suppressed further as they are reflected by the FPI and pass through the VCF again. By comparing Curves (b) and (c) in Fig. 3 that corresponds to the cases that the reflector (FPI) is operated at the reflected mode and transmission mode, respectively, one can clearly observe the residual signals. This will strongly influence the measured noise power.

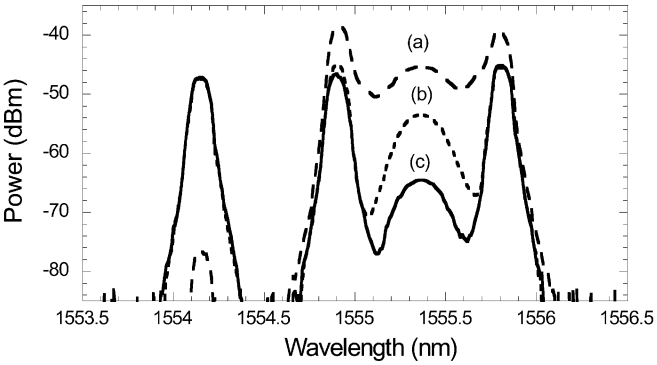

Fig. 3. Measured output spectra as the VCF is aligned at the middle between Channels 2 and 3. Curve (a): VCF output. Curve (b): circulator output (PD2) while the FPI is at the reflection mode. Curve (c): circulator output (PD2) while the FPI is at the transmission mode.

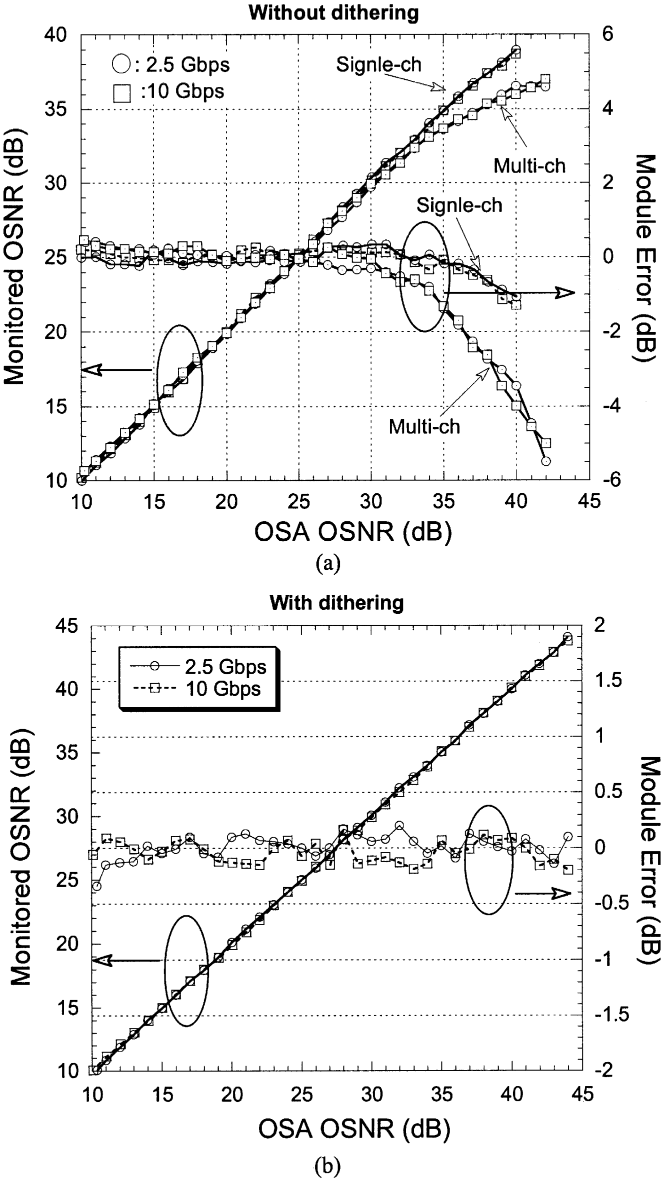

Fig. 4. Measured OSNR values and errors for bit rates of 2.5 and 10 Gb/s: (a) without dithering for one or three channels, and (b) with dithering for three input channels.

Fig. 4 depicts the OSNR monitoring results using our proposed scheme. The results are almost the same for bit rates of 2.5 and 10 Gb/s. The results measured with a high-performance OSA are used as the reference. The monitoring without dithering is limited to OSNR value up to 31 dB with less than

0.5-dB error due to the residual signals. For three-channel input, the error increases considerably as the input OSNR is larger than 30 dB. This limitation can be overcome by dithering the FPI. Fig. 4(b) shows that the error is less than 0.4 dB for three channels with dithering over OSNR values between 10 and 44 dB. In our experiments, the measurable OSNR is limited by the maximal OSNR value that can be generated with the signal and noise sources.

IV. DISCUSSION AND SUMMARY

For no-dithering cases, the influence of the residual signals on the measurable OSNR increases with the channel number. Assuming that the residual signals result mainly from the VCF reflection, the minimal requirement on the return loss of the VCF for no-dithering monitoring can be approximately expressed as

$$Rl_{\min}(\mathrm{dB}) = 10 \cdot \log_{10}(\mathrm{OSNR}_o) + 10 \cdot \log_{10}(\mathrm{Ch}) + K + L_0 \tag{1}$$

where OSNR_o is the reference OSNR and Ch is the number of channels. All channels are assumed to have identical input power. The parameter K accounts for the error tolerance and difference in filter bandwidth between the TOF and OSA (0.1 nm), while L_0 represents the double path loss of TOF plus the loss of the reflector (1.2 dB). Equation (1) was obtained by deriving the expressions for the one-pass signal power and the double-pass noise power and assuming a finite return loss for the VCF. L_0 is measured to be 6.0 dB and K is 2.25 for 1 dB of error tolerance in OSNR value and 0.23-nm TOF bandwidth. The no-dithering data shown in Fig. 4(a) for single channel and three channels indicate the return loss of the TOF is around 47 dB from the calculation using (1). This number matches very well with the measured return loss of the VCF. From (1), to measure up to 30 dB of OSNR the return loss needs to be larger than 50.3 and 53.3 dB for 16 and 32 channels, respectively. Therefore, the required return loss becomes difficult to achieve for measuring dozens of channels with high OSNR values without using the dithering approach. Dithering the reflector can relax the requirement and allows using other types of filters that might have larger residual reflection.

The FPI acts as a partial reflector to provide a transmission path for the signal during signal power measurement but to reflect the noise during noise measurement. Since the TOF alone is sharp enough for signal power measurement, a low-finesse FPI or other types of tunable reflectors can be used as the partial reflector. The dithering frequency can be compromised between the monitoring speed and detection sensitivity. During our experiments, the dithering frequency is limited to 2.5 kHz, the maximal tuning frequency of the FPI. Larger dithering voltage can be used to obtain better signal detection but consume more power. In our experiments, the peak-to-peak voltage is 2 V.

Many network applications require fast OSNR monitoring over an entire wavelength band. The monitoring speed for our approach is currently limited by the tuning speed of the TOF, which needs 5 s to sweep over a 45-nm band. The FPI can be tuned to cover a 45-nm band in 10 ms. Thus, the monitoring speed for one channel is limited by the wavelength settling time (30 ms) of the TOF, assuming that the electronic signal processing time is negligible. The speed can be improved by choosing a faster-tuned TOF.

In summary, our approach passes the noise through a tunable filter twice in order to obviate the need of an optical filter with very steep transfer function. Dithering the control signal of the reflector is the key to avoiding the influence of the residual signals. The approach is relatively insensitive to the polarization fluctuations since the entire module can be made to have polarization-independent characteristics. We demonstrate up to 44-dB OSNR monitoring by using commercial fiber-pigtailed components.

REFERENCES

[1] D. C. Kilper and W. Weingartner, "Monitoring optical network performance degradation due to amplifier noise," *J. Lightwave Technol.*, vol. 21, pp. 1171–1178, May 2003.

[2] M. Rasztovits-Wiech, M. Danner, and W. R. Leeb, "Optical signal-to-noise ratio measurement in WDM networks using polarization extinction," in *Proc. Eur. Conf. Optical Communications (ECOC'98)*, Sept. 1998, pp. 549–550.

[3] J. H. Lee, D. K. Jung, C. H. Kim, and Y. C. Chung, "OSNR monitoring technique using polarization-nulling method," *IEEE Photon. Technol. Lett.*, vol. 13, pp. 88–90, Jan. 2001.

[4] C.-L. Yang and S.-L. Lee, "Novel technique for simultaneous channel and OSNR monitoring," in *Proc. Optical Fiber Communications (OFC 2003)*, Mar. 2003, pp. 756–758.

[5] W. Chen, S. Zhong, Z. Zhu, W. Chen, and Y. Chen, "Integrated performance monitoring PLC circuit for WDM system," in *Proc. Optical Fiber Communications (OFC 2003)*, Mar. 2003, pp. 706–707.

[6] K.-U. Chu, K.-Y. Park, S. B. Lee, C.-H. Lee, S.-Y. Shin, and Y. J. Oh, "A simple and low-cost optical channel analyzer for a dense wavelength-division multiplexing system," in *Proc. Optoelectronics and Communications Conf. (OECC 2000)*, July 2000, pp. 474–475.

[7] Z. Tao, Z. Chen, L. Fu, D. Wu, and A. Xu, "Monitoring of OSNR by using a Mach-Zehnder interferometer," *Microwave & Optical Technol. Lett.*, vol. 30, pp. 63–65, July 2001.

[8] J. Chappell and S. DeMange, "Optical signal-to-noise ratio characterization demands precision and flexibility," *WDM Solutions*, vol. 2, no. 6, pp. 55–60, Nov. 2000.

[9] C. Hentschel, D. M. Baney, J. Vobis, W. V. Sorin, L. Stokes, J. Beller, P. Hernday, C. M. Miller, V. McOmber, and S. W. Hinch, *Fiber Optic Test and Measurement*, D. Derickson, Ed. Englewood Cliffs, NJ: Prentice-Hall, 1998, pp. 101–115.