Novel Techniques for Optical Performance Monitoring in Optical Systems

Chun-Kit Chan*, Yuen-Ching Ku, Lian-Kuan Chen
Department of Information Engineering, The Chinese University of Hong Kong, Shatin, N.T. Hong Kong SAR

ABSTRACT

In this paper, different kinds of optical performance monitoring (OPM) techniques, in particular the optical signal-to-noise ratio (OSNR) monitoring and chromatic dispersion (CD) monitoring, are reviewed. Then recent trend of multiple-parameter simultaneous monitoring is examined.

Keywords: Optical performance monitoring, OSNR, chromatic dispersion, alignment, modulation, histogram

1. INTRODUCTION

Optical performance monitoring (OPM) is an indispensable element for the quality assurance of an optical network. It is because OPM can provide several important network functions including (i) providing feedback in adaptive compensators and equalizer (ii) control of network elements (iii) link set-up, control and optimization, and (iv) fault forecasting, detection, diagnosis, localization as well as resilience mechanism activation.

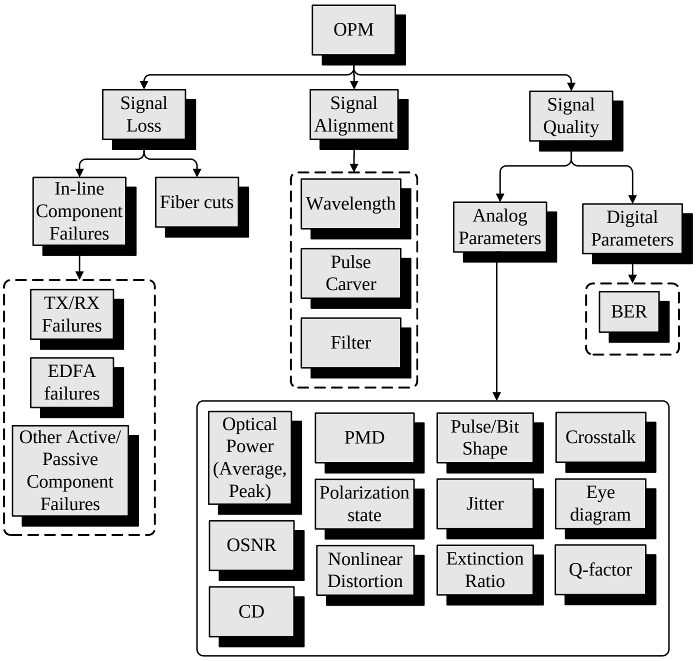

Fig. 1. The broad spectrum of optical performance monitoring (OPM)

OPM may include monitoring of different analog or digital parameters of the transmission system, including signal wavelength, power, signal integrity, OSNR, bit-error-rate (BER), Q-factor, chromatic dispersion, polarization mode dispersion, and the conditions of in-line components as shown in Fig. 1. In this paper, we will discuss mainly on the monitoring of optical signal-to-noise ratio (OSNR), chromatic dispersion (CD), component alignment status, and multiple-parameter simultaneous monitoring.

2. OPTICAL SIGNAL-TO-NOISE RATIO (OSNR) MONITORING

Techniques for OSNR monitoring can be classified into two categories: out-of-band and in-band, depending on whether the noise power is measured outside or within the wavelength channel passband.

The traditional out-of-band OSNR monitoring technique involves measuring and interpolating the noise power from adjacent channels using optical spectrum analyzer (OSA), arrayed waveguide grating (AWG) or tunable filters [1-3]. Though simple, out-of-band monitoring is not always reliable because different channels may traverse dissimilar optical paths and experience unflat EDFAs gains creating different transport history as shown in Fig. 2.

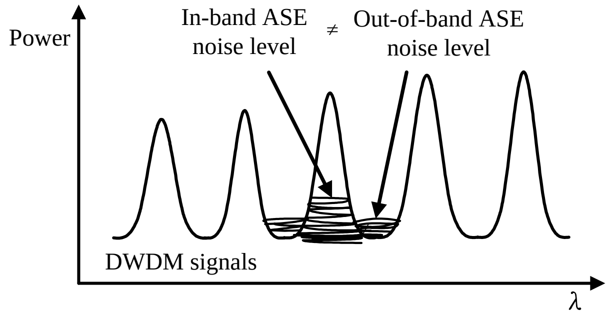

Fig. 2. Out-of-band noise level may not be equal to in-band noise level in spectrum-interpolated noise measurement

In order to measure the true in-band noise, in-band OSNR monitoring techniques have been proposed.

In sub-carrier multiplexing (SCM) methods [4], each wavelength signal is associated with a sub-carrier. The electrical carrier-to-noise ratio (CNR) of the sub-carrier will be determined and the OSNR is obtained through a mathematical relationship with CNR. The drawback of SCM is that sub-carrier may degrade the original signal.

In noise spectrum analysis, usually the total optical power and electrical noise power are measured by an optical power meter and an RF spectrum analyzer, respectively, after eliminating the signal component or by measuring outside the modulation frequency [5]. Then, the OSNR with mathematical formulae relating beat noise power densities and OSNR can be derived. This method is robust to PMD, but sensitive to CD.

Polarization assisted analysis makes use of the assumption that the signal component is polarized while the ASE noise component is unpolarized [6]. By using polarization controller and polarizer, the output is adjusted to measure either total power or ASE noise power. Generally this class of technique has large errors in networks under influence of strong PMD and polarization dependent loss [7]. Fig. 3 shows that the monitoring error can be as large as 25 dB. The monitoring error is basically due to the signal power underestimation and noise power overestimation caused by PMD-induced signal polarization rotation as shown in Fig. 4(a). To solve this problem, off-center narrow-band optical filtering [8] was proposed to reduce the signal power leakage so as to improve the PMD robustness of polarization nulling method [9], as illustrated in Fig. 4(b). Also, transmitter-side polarization scrambling [10] was shown to be effective to reduce the influence of DOP analysis method [11] by PMD.

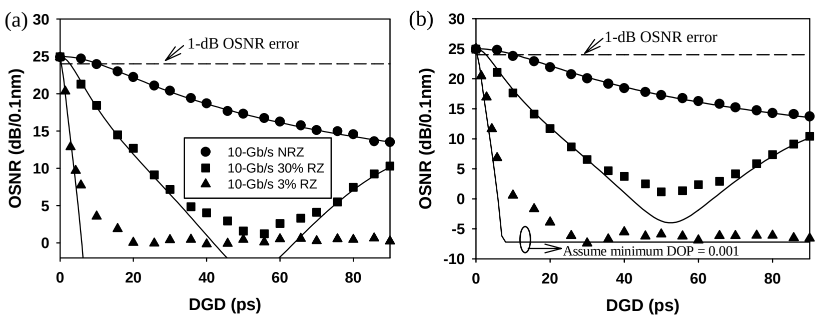

Fig. 3. (a) OSNR for polarization-nulling and (b) OSNR for DOP-based OSNR monitoring under different DGD values (Straight lines: numerical calculations using Super-Gaussian pulse)

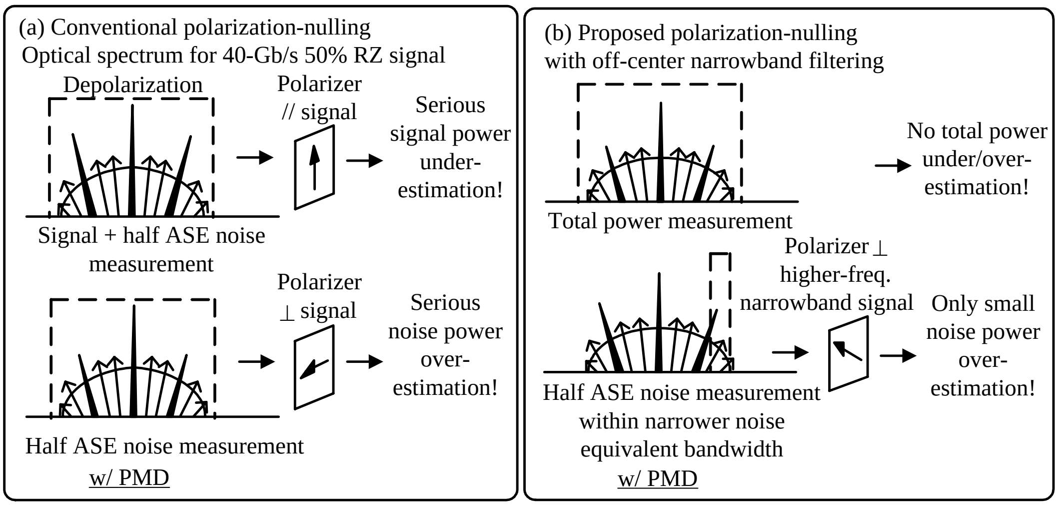

Fig. 4. Effect of PMD on (a) conventional polari541zation-nulling and (b) polarization-nulling with off-center narrowband filtering

Recently, we proposed and demonstrated a new technique to monitor OSNR using a phase modulator embedded fiber loop mirror (PM-FLM) [12] as shown in Fig. 5. This technique is based on the assumption that signal is coherent while ASE noise is incoherent. By using a PM-FLM driven by low frequency RF sinusoidal signal, the transfer function can be periodically shifted (Fig.6). As a result, the data signal and ASE noise can be periodically separated and so an output power meter can track the power difference to deduce the OSNR. This method has high dynamic range and robust to PMD and partially polarized noise.

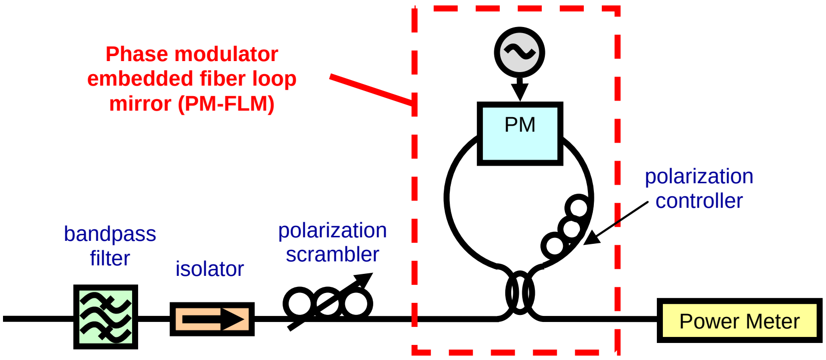

Fig. 5. Schematic diagram of the proposed OSNR monitoring module

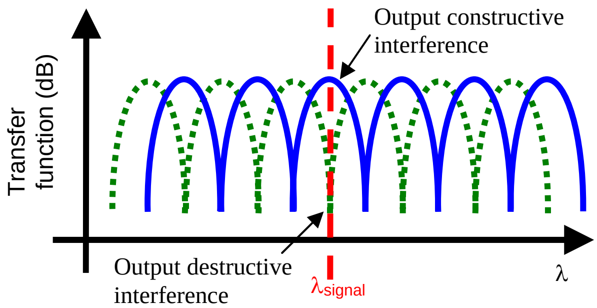

Fig. 6. Transfer function periodically shifted from minimum (dotted) to maximum (solid) by driving the phase modulator with sinusoidal signal

3. CHROMATIC DISPERSION (CD) MONITORING

In order to adaptively compensate chromatic dispersion so that the induced signal degradation can be minimized, chromatic dispersion monitoring is required to provide feedback control. Many chromatic dispersion monitoring techniques have been proposed. Most of them make use of chromatic dispersion induced fading effect of signal sideband.

In sub-carrier ratio method [4], RF tones are added to the data to modulate light at the transmitter side. Since sub-carrier would experience fading under dispersion, CD can be monitored by measuring the powers of different sub-carriers at the receiver.

Another similar technique to monitor chromatic dispersion is to measure the regenerated clock component in NRZ systems and faded clock component in RZ systems under dispersion [13]. The main advantage is that no modification is needed at the transmitter side.

Chromatic dispersion can also be monitored by sideband optical filtering [14]. Since the upper side band and lower sideband of a signal have different frequencies, they travel at different speeds in dispersive medium. Therefore by filtering out the upper and lower sideband of a signal separately and compare their arrival times, the chromatic dispersion can be measured. This technique is highly sensitive, but high speed electronic is needed.

Recently, we proposed and demonstrated a new technique for monitoring chromatic dispersion using birefringent fiber loop (BFL) [15]. By feeding a signal into a fiber loop which consists of a high-birefringence (Hi-Bi) fiber, an RF spectral dip can be produced at a particular frequency which depends on the length of the Hi-Bi fiber as shown in Fig. 7. Since the RF power at the spectral dip is proportional to the accumulated chromatic dispersion, the dispersion experienced by the signal can be deduced from the measured RF power at a specific chosen frequency. This technique is polarization insensitive, requires no modification at the transmitter, and provides large monitoring range.

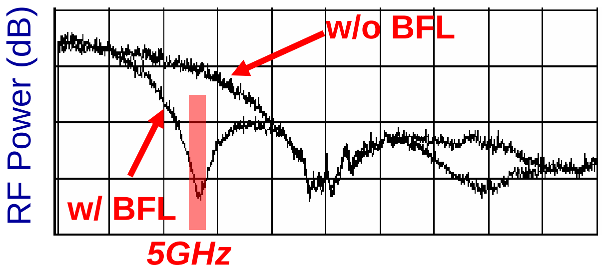

Fig. 7. RF spectral dip produced by birefringence fiber loop (BFL)

4. ALIGNMENT MONITORING

Alignment monitoring refers to the monitoring of alignment status of different cooperating components. It is essential for proper operation of an optical system. For example, for proper generation of return-to-zero differential phase shift keying (RZ-DPSK) signal, the pulse carver and the data modulator has to be well aligned. Fig. 8 illustrates that signal waveform would be corrupted if pulse carver and data modulator are not well-aligned. Therefore, alignment monitoring is desirable to provide a feedback signal for automatic alignment.

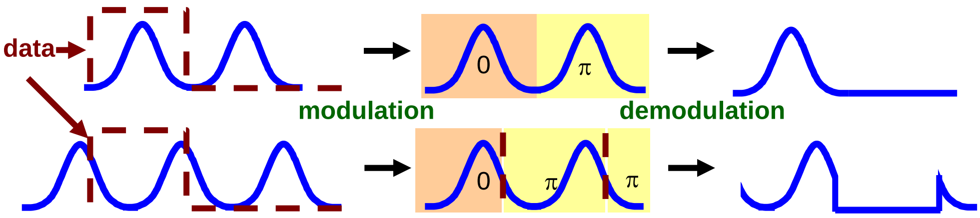

Fig. 8. Signal waveform is corrupted if pulse carver and data modulator are not well-aligned.

In [16], it has been proposed to monitor the alignment status in RZ-DPSK system by measuring the power variation after a polarizer, which is induced by the reduction of signal's DOP due to the timing-misalignment after propagation in an intentionally introduced finite DGD. However, the monitoring power dynamic range is small.

In [17], we took a different approach to monitor the alignment between pulse carver and data modulator. It was observed that phase variation occurs inside the pulses when there is certain misalignment as illustrated in Fig. 8(a). The phase variation corresponds to frequency shift in spectrum. Therefore by filtering out a narrow slice from the edge of the signal spectrum, any misalignment-induced spectrum broadening will be translated into an increased output power from the optical filter as shown in Fig. 8(b). Thus, the degree of misalignment can be determined. This scheme is simple and provides a large monitoring power dynamic range.

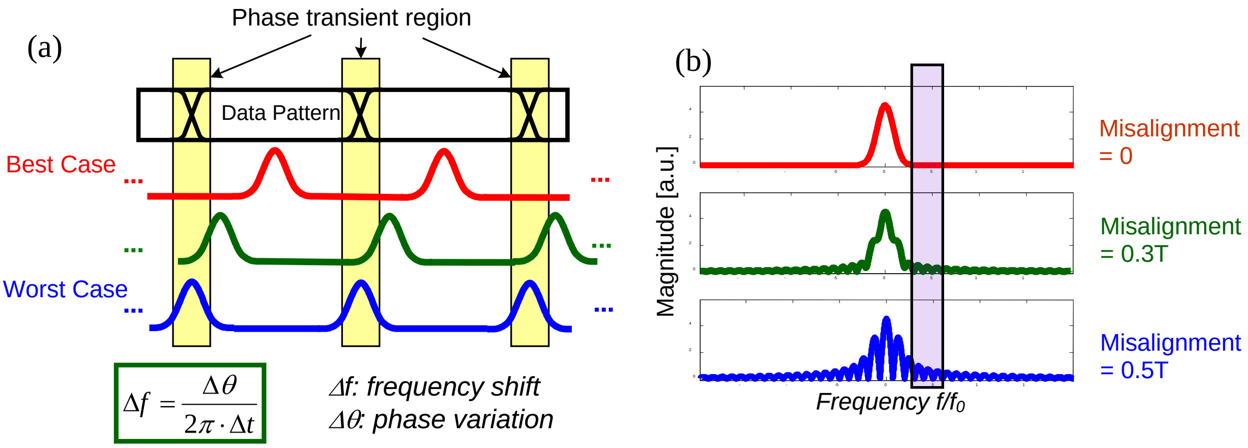

Fig. 8. (a) Illustration of timing alignment between pulse carver and data modulator (b) Calculated signal spectra with timing alignment between pulse carver and data modulator of 0, 0.3T, and 0.5T in a 10Gb/s RZ-DPSK system with ~0.28T pulsewidth.

Besides RZ-DPSK, recently we proposed and successfully demonstrated the use of two-tap asynchronous sampling technique to monitoring the pulse-carver and data-modulator alignment status for RZ-OOK modulation format [18]. As shown in Fig. 9(a), signal samples are taken at a rate of $1/T_s$, which can be much slower than the system clock. Each sample point consists of two measurements (x and y) separated by a fixed time delay Δt. The x and y values are then plotted in pars to form a two-tap scatter plot as shown in Fig. 9(b).

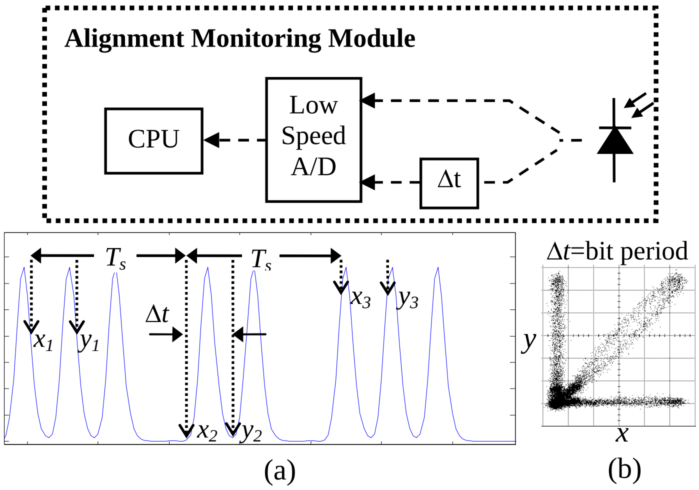

Fig. 9. (a) Delay-tap asynchronous sampling. Ts=sampling period, Δt=timing offset within each sample. (b) Two-tap scatter plot for RZ-OOK signal at Δt=bit-period

This plot provides signal waveform characteristics similar to eye diagram. Therefore, misalignment status can be observed from its evolution. Fig. 10 shows the two-tap scatter plots obtained at different modulation timing misalignments. We have shown in [18] that the increasing dispersion and rotation of the sample points on the diagonal can serve as effective parameters to evaluate the alignment status. This scheme only requires low-speed electronics and is robust to environment disturbance.

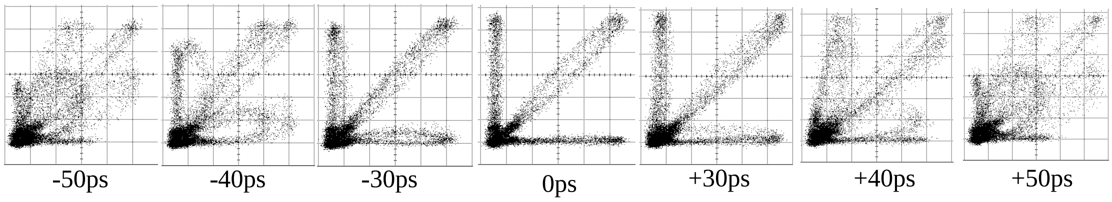

Fig. 10. Two-tap scatter plots for different modulation timing misalignments

5. RESEARCH TRENDS

While early OPM options focused on monitoring a particular type of impairment at a time, it is not uncommon that several impairments may affect the monitoring metric simultaneously. In this case, attempts have usually been made to monitor one type of impairment to the exclusion of the others. The current research trend, however, is to use simultaneous monitoring techniques that can quantify multiple signal degradations concurrently, thereby achieving more cost-effective OPM. Optical spectrum analyzer (OSA) is perhaps the most common technique to monitor signal power, wavelength, and OSNR. However, it is bulky and does not provide distortion information. Other research techniques are possible. For example, we have recently proposed and demonstrated simultaneous OSNR and PMD monitoring using RF spectral dip analysis assisted with a local large-DGD element [19] which monitors OSNR by measuring the RF spectral dip power level and monitor PMD by measuring frequency shift of the RF spectral dip. Also, optical sampling techniques [20] and histogram analysis techniques [21] have raised much research interest to unify the monitoring of different parameters.

6. SUMMARY

In summary, this paper reviews various optical performance monitoring schemes, with focus on OSNR, chromatic dispersion and alignment status monitoring. The current trend towards using simultaneous monitoring techniques as more cost-effective OPM options is also highlighted.

REFERENCES

1. “OSNR,” circadiant tech brief, 2002.
2. H. Suzuki and N. Takachio, “Optical signal quality monitor built into WDM linear repeaters using semiconductor arrayed waveguide grating filter monolithically integrated with eight photodiodes,” *Elec. Lett.*, 35(10) , 836-837 (1999).
3. C.L. Yang and S.L. Lee, “OSNR monitoring using double-pass filtering and dithered tunable reflector,” *IEEE Photon. Technol. Lett.*, 16(6), 1570-1572 (2004).
4. G. Rossi, T. E. Dimmick, and D. J. Blumenthal, “Optical performance monitoring in reconfigurable WDM optical networks using subcarrier multiplexing,” *J. Lightwave Technol.*, 18(12), 1639-1648 (2000).
5. C.J. Youn, K.J. Park, J.H. Lee, and Y.C. Chung, “OSNR monitoring technique based on orthogonal delayed homodyne method,” *IEEE Photon. Technol. Lett*., 14(10), 1469-1471 (2002).
6. M. Raztovits-Wiech, M. Danner, and W.R. Leeb, “Optical signal-to-noise ratio measurement in WDM networks using polarization extinction,” in *Proc. Europ. Conf. Optical Commun. (ECOC)*, 1998.
7. M.H. Cheung, L.K. Chen, and C.K. Chan, “On robustness of in-band polarization-assisted OSNR monitoring schemes against PMD,” in *Proc. CLEO/PR*, 2003.

8. M.H. Cheung, L.K. Chen, and C.K. Chan, "PMD-insensitive OSNR monitoring based on polarization-nulling with off-center narrowband filtering," *IEEE Photon. Technol. Lett.*, 16(11), 2562-2564 (2004).
9. J.H. Lee, D.K. Jung, C.H. Kim, and Y.C. Chung, "OSNR monitoring technique using polarization-nulling method," *IEEE Photon. Technol. Lett.*, 13(1), 88-90 (2001).
10. G.W. Lu, M.H. Cheung, L.K. Chen, and C.K. Chan, "Simple PMD-insensitive OSNR monitoring scheme assisted by transmitter-side polarization scrambling," *Optics Express.*, 14, 58-62 (2006).
11. M. Petersson, H. Sunnerud, M. Karlsson, and B.E. Olsson, "Performance monitoring in optical networks using stokes parameters," *IEEE Photon. Technol. Lett.*, 16(2), 686-688 (2004).
12. Y.C. Ku, C.K. Chan, and L.K. Chen, "A novel robust OSNR monitoring technique with 40-dB dynamic range using phase modulator embedded fiber loop mirror," in *Prof. OFC/NFOEC*, Paper OWN6, 2006.
13. Z. Pan, Q. Yu, Y. Xie, S.A. Havstad, A.E. Willner, D.S. Starodubov, and J. Feinberg, "Chromatic dispersion monitoring and automated compensation for NRZ and RZ data using clock regeneration and fading without adding signaling," in *Proc. OFC*, 2003.
14. Q. Yu, Z. Pan, L.S. Yan, and A.E. Willner, "Chromatic dispersion monitoring technique using sideband optical filtering and clock phase-shift detection," *IEEE Journal of Lightwave Technol.*, 20(12), 2267-2271 (2002).
15. Y.C. Ku, C.K. Chan, and L.K. Chen, "Chromatic dispersion monitoring technique using birefringent fiber loop," in *Proc. OFC/NFOEC*, Paper OFN2, 2006.
16. H. Kim, C.R. Doerr, P. Pafchek, L.W. Stulz, and P. Bernasconi, "Alignment monitoring of the pulse carver and data modulator for RZ-DPSK systems," *IEEE Photon. Technol. Lett.*, 15(11), 1594-1596 (2003).
17. Y.C. Ku, G.W. Lu, C.K. Chan, and L.K. Chen, "Novel technique for modulation alignment monitoring in RZ-DPSK systems using off-center optical filtering," in *Proc. OFC*, Paper OWJ4, 2005.
18. Y.C. Ku, C.K. Chan, "High-speed data and pulse-carver alignment in RZ-OOK systems using delay tap asynchronous waveform sampling," in *Proc. ECOC*, Paper Tu4.2.2, 2006.
19. G.W. Lu, M.H. Cheung, L.K. Chen, and C.K. Chan, "Simultaneous PMD and OSNR monitoring by enhanced RF spectral dip analysis assisted with a local large-DGD element," *IEEEE Photon. Technol. Lett.*, 17(12), 2790-2792 (2005).
20. C. Dorrer, D.C. Kilper, H.R. Stuart, G. Raybon, and M.G. Raymer, "Linear optical sampling," *IEEE Photon. Technol. Lett.*, 15(12), 1746-1748 (2003).
21. S.D. Dods and T.B. Anderson, "Optical performance monitoring technique using delay tap asynchronous waveform sampling", in *Proc. OFC/NFOEC*, OThP5, 2006.