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Application of asynchronous amplitude histogram method to monitoring of RZ-DQPSK signals

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Abstract: We experimentally and numerically demonstrate monitoring of optical signal-to-noise ratio (OSNR) and chromatic dispersion (CD) in optical return-to-zero differential quadrature phase-shift keying (RZ-DQPSK) signals over a broad range of values.

Introduction: Optical communication networks are developing constantly. Following the increase in demand for transmission bandwidth, new technologies are introduced in order to take advantage of the optical fiber in a more efficient way. There are several approaches to increasing the volume of transmitted information per fiber. One way is by increasing the modulation bit rate. The currently prevailing 10 Gbit/s systems are gradually being upgraded or exchanged with 40 Gbit/s systems. Another approach is by increasing the number of channels per fiber through additional wavelengths. Finally, advanced spectrally efficient modulation formats are introduced in order to increase utilization of the occupied bandwidth. RZ-DQPSK modulation format has been shown to perform well both in high-bit rate and high-spectral efficiency systems [1]. It is therefore considered a viable direction of evolution of optical networks.

As the optical systems are operated at much tighter tolerance limits their performance must be strictly supervised. Traditionally, performance monitoring has been done electronically. Increasingly, however, the transmission is being carried out exclusively in the optical domain. In order to control the quality of optical signal, optical performance monitoring (OPM) methods have been suggested [2]. In the recent literature, several methods were investigated. Among the actively researched are optical spectrum monitoring, RF component monitoring, degree of polarization monitoring, monitoring using subcarriers and pilot tones, using data correlation and asynchronous amplitude histogram. These methods provide information about one or more physical parameter, like optical signal-to-noise ratio (OSNR) or accumulated chromatic dispersion (CD).

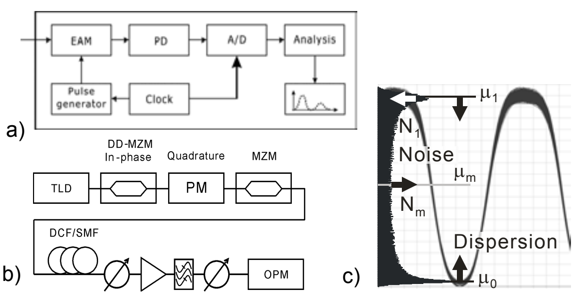

Fig. 1. Monitoring of RZ-DQPSK signal: a) optical performance monitor; b) experimental setup; c) signal waveform and histogram with measurement parameters.

In this contribution we numerically and experimentally demonstrate monitoring of OSNR and CD of RZ-DQPSK signal using asynchronous amplitude histogram method. To our knowledge, this is the first demonstration of OPM of signals with quadrature modulation.

Principle: Asynchronous amplitude histogram monitoring [3] is a method which uses statistical properties of the optical waveform to analyze the quality of signal. The principle of operation is presented in Fig. 1.a. Optical waveform is sampled in an electroabsorption modulator (EAM) which is operated by ultra-short pulses at a low repetition rate. The samples are received by a low-speed photodiode (PD) and passed to an analogue-to-digital converter (A/D). The following analysis assembles the amplitude histogram and calculates signal parameters. The device is driven by an internal clock independent of the signal clock which provides for flexibility of this method.

The amplitude histogram, shown with the source RZ-DQPSK waveform in Fig. 1.c, consists of two peaks at positions μ_0 and μ_1, corresponding to the "0" and "1" levels of the RZ signal, respectively. The μ_m level represents the average signal power. Parameters N_m and N_1 correspond to the histogram height at positions μ_m and μ_1, respectively.

The measurement of OSNR impairment is indicated in Fig. 1.c through the noise parameter. An increase in level of amplified spontaneous emission (ASE) leads to the reduction of histogram height N_1 at μ_1 and increase of histogram height N_m at μ_m. This is caused by the broadening of histogram peaks due to the signal fluctuations caused by ASE. We, therefore, define a noise parameter for RZ-DQPSK signal:

$$F_{snr,rz} = N_1 / N_m \tag{1}$$

Conversely, the measurement of CD uses the RZ pulse shaping of DQPSK signal, which under the influence of residual dispersion undergoes time broadening. This leads to inter-symbol interference, as well as reduction of peak power, which can be observed as a reduction of

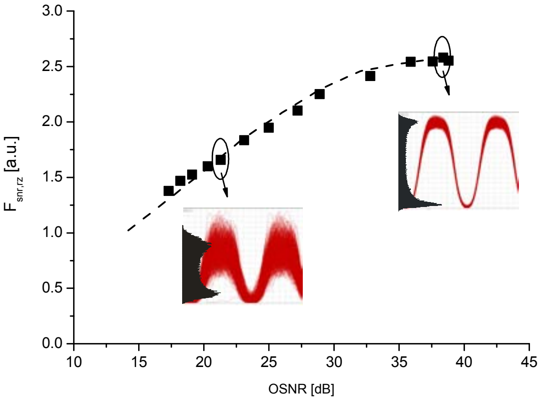

Fig. 2. RZ-DQPSK OSNR monitoring.

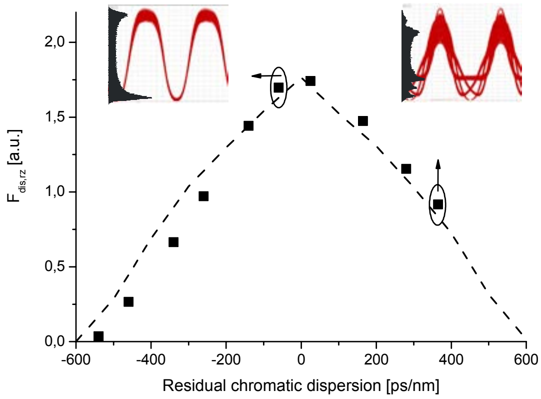

Fig. 3. RZ-DQPSK dispersion monitoring

spacing between histogram peaks μ_0 and μ_1. This is shown in Fig. 1.c. We define the dispersion parameter:

$$F_{dis,rz} = (\mu_1 - \mu_0) / \mu_m \quad (2)$$

The precision of monitoring employing the $F_{snr,rz}$ and $F_{dis,rz}$ parameters is verified in simulation and experiment.

Experiment and results: The experimental setup used for monitoring RZ-DQPSK signal is depicted in Fig. 1.b. Signal is generated using serial arrangement of two dual-drive (DD) Mach-Zehnder modulators (MZM) and a phase modulator (PM). Residual CD is introduced through a span of standard single-mode fibre (SMF) or dispersion compensating fibre (DCF). The level of OSNR is adjusted by attenuating the signal power before optical amplifier. Another attenuator, following the bandpass filter, is used to maintain constant input power to the OPM device.

Results of noise measurement are shown in Fig. 2. The noise parameter $F_{snr,rz}$ is plotted as a function of OSNR (dashed line – simulation; dots – experiment). The insets show the waveform and histogram at low and high OSNR level. Good agreement between the simulation and experiment is achieved with resolution of 1 dB between OSNR of 17 and 30 dB.

Results of monitoring CD in a 20 Gbit/s RZ-DQPSK signal are shown in Fig. 3. Parameter $F_{dis,rz}$ is plotted as a function of residual chromatic dispersion (dashed line – simulation; dots – experiment). The insets show the waveforms and histograms at corresponding points. The measurement ranges from -600 to +600 ps/nm, with 20 ps/nm resolution, without distinguishing the sign of dispersion.

The performance of $F_{snr,rz}$ and $F_{dis,rz}$ parameters is also analyzed in context of Q-factor. The results are plotted in Fig. 4. The noise parameter (solid line) is linearly proportional to Q. The dispersion parameter increases monotonically, however a calibration is required to obtain a direct relation to Q. These results prove that the asynchronous amplitude histogram OPM method can be employed in RZ-DQPSK systems. The measurements cover a wide range of expected values.

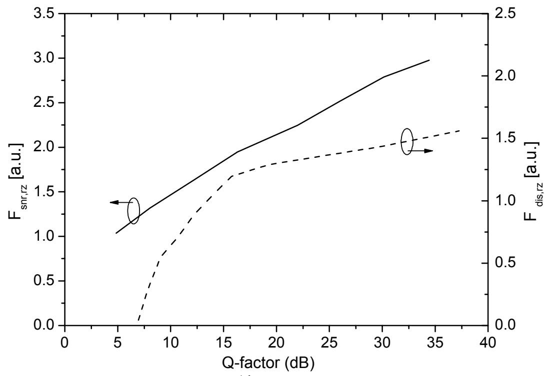

Fig. 4. Performance of $F_{snr,rz}$ and $F_{dis,rz}$ parameters as a function of Q-factor

Conclusion: In this contribution we demonstrated for the first time optical performance monitoring of RZ-DQPSK signals. Asynchronous amplitude histogram OPM method allows for an accurate and repeatable measurement of noise and chromatic dispersion. The range covers the expected parameter scope.

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