

Uncorrelated Beat Noise Measurement for Optical Signal-to-Noise Ratio Monitoring

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Abstract We present theoretical analysis and experimental demonstration of a new optical signal-to-noise ratio monitoring method using uncorrelated beat noise. The measurement errors are less than 0.6 dB in a 10 Gb/s system.

Introduction

Optical performance monitoring is important for managing the high capacity optical transmission and switching systems [1]. A number of techniques have been developed to monitor the optical signal-to-noise ratio (OSNR). The traditional optical spectrum analyzer (OSA) based OSNR estimation [2-3] may not monitor the OSNR accurately for a dynamically reconfigurable wavelength-division multiplexed (WDM) network because the measured out of band ASE noise may not be the real ASE noise in the channels of interest. The polarization nulling method [4-5] uses a polarization controller to null the signal but it is susceptible to polarization mode dispersion (PMD). The low frequency beat noise measurement [6] is simple to implement only using two photodiodes and a DSP board to measure the beat noise, but it may not be applicable for the very random data or data modulated with long pattern length. In this paper, we propose and demonstrate a novel OSNR monitoring method using uncorrelated beat noise. The method is independent of the pattern length and insensitive to PMD. An experiment for a 10 Gb/s system shows that in the OSNR range from 10 dB to 30 dB, the proposed OSNR monitoring scheme produces errors of less than 0.6 dB.

Principle of the proposed method

Fig. 1 shows the principle and the experimental setup of the proposed OSNR monitoring method. Within the OSNR monitoring module, the modulated signal with ASE noise is split into two branches by a 50:50 coupler. Then the two parts pass through the tunable optical bandpass filters BPF 1 and BPF 2, which are with the same optical bandwidth and different center frequencies. BPF 1 and BPF 2 select the channel of interest and obtain the optical signal and ASE noise for OSNR monitoring. Following BPF 1 and BPF 2 are a variable optical attenuator and a variable optical delay line used to match the power and the delay of the two paths, respectively. The outputs of the two paths are sent to a pair of balanced photodiodes, in which detection and RF subtraction are performed. An RF amplifier and RF spectrum analyser (RFSA) are used to measure the uncorrelated beat noise.

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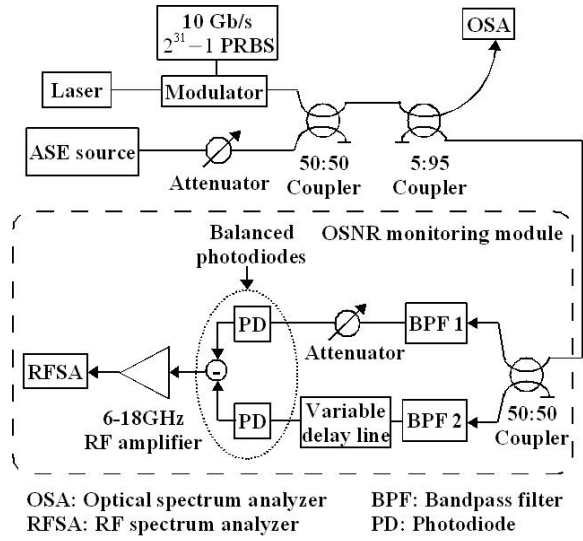


Fig. 1 Experimental setup.

The signal of each path is correlated while the ASE noise in different frequency bandwidths is uncorrelated, as the ASE noise can be modeled as additive white Gaussian noise. Subsequently, beating between signal and the ASE noise within different bandwidths is uncorrelated. We apply two identical filters with symmetrical shapes to cover the symmetrical part of the optical signal spectrum. Where the filters overlap, ASE noise is correlated; while in the other parts, ASE noise is uncorrelated. Therefore, after balanced RF subtraction, we can measure the uncorrelated beat noise in the RF domain and extract OSNR.

According to the theory of beat noise [7-8], the uncorrelated beat noise power density N_{beat} is

$$N_{beat} = A \cdot P_{sig}^2 / OSNR + B \cdot P_{sig}^2 / OSNR^2 \quad (1)$$

where $OSNR$ is optical signal-to-noise ratio, P_{sig} is the optical signal power, A and B are constants related to the photodiodes responsivity, filter shape, RF amplifier gain and the uncorrelated coefficient.

The measured optical power level in one path P_m is

$$P_m = \gamma \cdot P_{sig} (1 + C / OSNR) \quad (2)$$

where γ and C are constants related to the optical filter properties. By equations (1) and (2), the OSNR can be calculated by solving the following quadratic equation

$$\left(C^2 - \frac{B \cdot P_m^2}{\gamma^2 \cdot N_{beat}} \right) \frac{1}{OSNR^2} + \left(2C - \frac{A \cdot P_m^2}{\gamma^2 \cdot N_{beat}} \right) \frac{1}{OSNR} + 1 = 0.$$

Experimental results

The proposed OSNR monitoring method was experimentally demonstrated in a 10 Gb/s system as shown in Fig. 1. The signal source was a 1550.42 nm laser externally modulated at 10 Gb/s by a LiNbO₃ intensity modulator with 2³¹ - 1 pseudo-random binary sequence (PRBS). The ASE source was obtained from an erbium-doped fiber amplifier (EDFA). The variable optical attenuator following the ASE source was used to change the OSNR. The signal and ASE noise were coupled together by a 50:50 coupler. Then a 5:95 coupler was used to tap 5% of signal and ASE noise into an optical spectrum analyzer (OSA) for baselining the OSNR. The remaining 95% of the signal and ASE noise were sent to the OSNR monitoring module. As tunable optical filters were not available in our lab when the experiment was conducted, two arrayed-waveguide-gratings (AWG) with both 0.3 nm 3 dB bandwidth were utilized as the two optical bandpass filters (BPF 1 and BPF 2). The center frequencies of the two AWGs were temperature tuned to 1550.27 nm and 1550.57 nm.

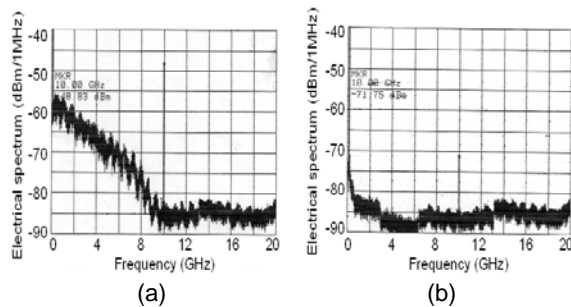


Fig. 2 Signal's RF spectrum after (a) one photodiode (b) balanced subtraction.

Fig. 2 (a) and (b) show the signal's RF spectrum from one path and balanced subtraction, respectively. The span is 20.2 GHz and the resolution bandwidth is 1 MHz. We can see that with the pair of balanced photodiodes the signal can be subtracted. After the balanced subtraction, the RF spectrum almost drops to the noise floor.

Fig. 3 (a) and (b) depict the measured uncorrelated beat noise power density at 12 GHz and the monitoring errors vs. the OSNR measured by the

OSA, respectively. The OSNR monitoring errors are the difference between the OSNR measured by the proposed method and by the OSA. In the OSNR range from 10 dB to 30 dB, the monitoring errors are less than 0.6 dB. For higher OSNR, the errors are caused by the fact that the small amount of beat noise could not be accurately obtained from the measured noise which consists of beat noise and non-beat noise.

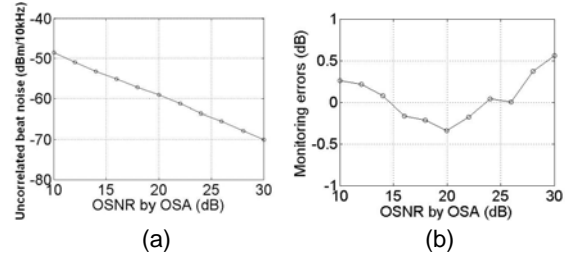


Fig. 3 (a) Measured uncorrelated beat noise power density and (b) monitoring errors vs. the OSNR measured by the OSA.

In our experiment, the two AWG center frequencies were set 0.3 nm apart. We compared the OSNR monitoring results with the case of 0.15 nm and 0.4 nm spacing. We found that with 0.3 nm spacing the monitoring has more accuracy and higher dynamic OSNR range. In practice, frequency drift of the filters or the transmitter may affect the accuracy of the proposed monitor. We tested the monitor at 20 dB OSNR, by shifting the carrier frequency from 1 GHz to 5 GHz. The monitoring errors became larger than 1 dB when the carrier frequency drift was above 4 GHz. The self-adjusting techniques are for future research.

Conclusions

We proposed a novel OSNR monitoring method by analyzing the uncorrelated beat noise. The method is insensitive to PMD and independent of data modulation format. Experimental results for a 10 Gb/s system showed that in the OSNR range from 10 dB to 30 dB, the proposed OSNR monitoring scheme produced errors of less than 0.6 dB.

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