Interferometer Based In-Band OSNR Monitoring of Single and Dual Polarisation QPSK Signals

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Abstract The in-band OSNR of SP and DP QPSK signals were measured over a range of 10 to 21dB ±1dB using a pair of polarisation independent Michelson fibre interferometers without the requirement for prior knowledge of the signal's coherence properties.

Introduction

The optical signal to noise ratio provides a quantitative measure of the amplified spontaneous emission (ASE) noise level in an optical communications signal. This noise is due to a cascading of erbium-doped fibre amplifiers (EDFA) in optical communications networks. The necessity for a reliable means of measuring the in-band optical signal to noise ratio (OSNR) of a communications channel has already been established[1]. In short, due to influence of the OSNR on the bit-error rate of the signal, its role as a feedback tool for the balancing of amplifier gain and as a measure of general network health it is imperative to have a reliable means by which to measure the in-band OSNR. Traditionally the OSNR of a channel is determined by measuring the noise level between channels and performing a linear interpolation in order to determine the noise level at the channel frequency[2]. However this becomes problematic with smaller channel spacing and is unsuitable in the case of transparent, reconfigurable WDM networks due to the use of reconfigurable optical add-drop multiplexers (ROADMs). Due to the fact that adjacent channels may have vastly different transmission histories and hence, OSNR values, the linear interpolation method is rendered useless. For this reason it is important to measure the in-band OSNR. It is possible to use the polarisation extinction of the signal, which assumes that the signal is fully polarised while the amplified spontaneous emission (ASE) noise is fully unpolarised[3]. This "polarisation-nulling" method, while immune to the effects of chromatic dispersion, can be severely undermined by the presence of polarised noise due to polarisation dependent loss and signal depolarisation due to polarisation mode dispersion (PMD). Also, the scheme is not compatible with polarisation multiplexed signals. The PMD influence may be overcome by using orthogonal polarisation heterodyne mixing. However, this relies on the assumption that the noise is fully unpolarised[4]. A mach-zehnder interferometer has been shown to address the issues of polarised noise, chromatic dispersion and PMD[5-7]. However such a device relies on prior knowledge of the coherence of the signal, must be calibrated for each modulator. This usually entails "switching off" the noise in the signal channel. Also, even if such a calibration was possible, a change in modulator bias would require recalibration of the device[8]. It is possible to circumvent this issue through use of a pair of polarisation independent Michelson fibre interferometers[9]. An expansion of the amplitude autocorrelation function about zero delay may be performed by using two different delays of magnitude less than that of the bit-period of the signal. This allows measurement of the OSNR of a noisy signal with a range of approximately 10-30dB within an accuracy of ±0.5dB and was shown to be immune to the effects of polarised noise, chromatic dispersion, modulator bias and input polarisation. The advent of coherent detection has made it possible to transmit and receive data encoded into the phase and polarisation of light. As with amplitude modulated signals, it is important to have a means of measuring the OSNR of these formats. However, difficulties occur in the case of polarisation multiplexed (POL-MUX) signals, as the standard in-band OSNR monitoring technique (based on polarisation nulling) cannot measure the OSNR for such a modulation format. Here we demonstrate the effects of various modulation formats on our system, most notably quadrature phase shift keyed signals (QPSK) and polarisation multiplexed QPSK (POL-MUX QPSK).

Experimental setup

Fig.1 shows the OSNR monitor which consists of a pair of Michelson fibre interferometers, each consisting of a pair of fibre couplers. Faraday rotator mirrors were utilised in order to negate the effect of polarisation fluctuations on the measured extinction ratio by imposing a single-pass polarisation rotation of 45°. This allowed the polarisation rotation in the fibre to be effectively "unwound"[10]. Optical delays of 5.4 and 14.5 picoseconds were used, and these

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could be measured by passing ASE through the interferometers and measuring the free-spectral range of the interfering signal using an OSA. The phase delay was changed using a piezoelectric tube (PZ) around which one arm of each interferometer was wrapped. The piezoelectric tube was driven at a low frequency by a triangle wave from a data-acquisition card (DAQ).

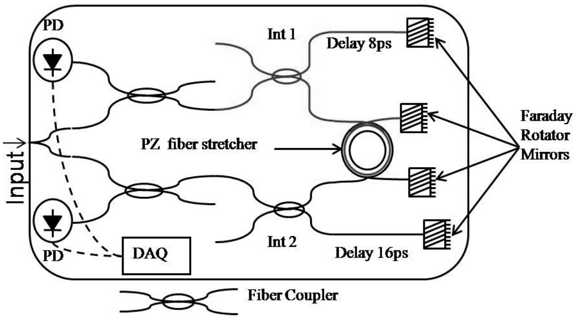

Fig. 1 OSNR monitor.

Figure 2 shows the experimental setup. For the purposes of measurements, the signal was provided by an external-cavity laser (ECL) tuned to 1549.3nm and modulated by a 12.5G QPSK signal. This was passed through a pair of Erbium-doped fibre amplifiers that were cascaded together with a 5nm filter in between. The signal was then split and one arm was fed into an optical spectrum analyser (OSA), which provided a measure of the actual OSNR using the interpolation method, and the other filtered using a 100G WDM filter (NEB = 0.6nm) and connected to the input of our OSNR monitor. The OSNR was changed by attenuating the signal before the EDFAs.

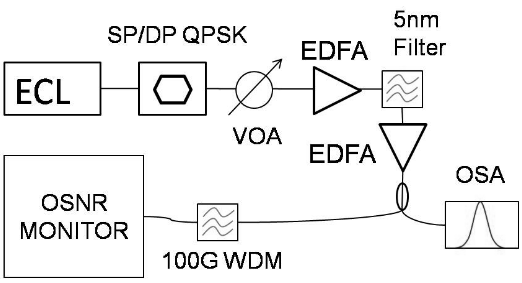

Fig. 2 OSNR monitoring setup

High sensitivity, low-speed photodiodes recorded the transmitted optical intensity as a voltage, V, which was measured at up to 200KHz per channel using a DAQ card. The photodiode voltage was seen to vary in a sinusoidal manner. The ratio of the maximum and minimum voltages, the extinction ratio, ε, is related to the visibility, μ, in the following manner: $\mu=(\varepsilon-1)/(\varepsilon+1)$, which, in a balanced interferometer can be related to the optical noise to signal ratio, r, as in equation (1).

$$r = \frac{\gamma_s(\tau_d) - \mu}{\mu - \gamma_n(\tau_d)} \quad (1)$$

Where NEB is the noise equivalent bandwidth of the channel filter used. $\gamma_s(\tau_d)$ and $\gamma_n(\tau_d)$ are the amplitude autocorrelation functions of the signal and noise respectively as a function of optical delay time, τ_d. $\gamma_n(\tau_d)$ can be found from the power transmission function of the channel filter. In the case of a single interferometer scheme, $\gamma_s(\tau_d)$ is found by switching off the noise and calibrating the extinction ratio. This is impractical in reality. However, we can expand $\gamma_s(\tau_d)$ (which has a value of 1 at zero delay) around zero delay as shown in equation 2.

$$\gamma_s(\tau_d) = 1 - \sum_{k=1}^{K} c_k \tau_d^{2k} \quad (2)$$

Only terms with powers of 2k are present as $\gamma_s(\tau_d)$ is an even function of τ_d. Substituting this equation into we arrive at equation (3)

$$\sum_{k=1}^{K} c_k \tau_{d,q}^{2k} + r\left(\mu_q - \gamma_n(\tau_{d,q})\right) = 1 - \mu_q \quad (3)$$

where the subscript *q* means we have made a series of measurements with different delays represented by $\tau_{d,\,q}$ where *q* is from 1 to *Q*. So equation (3) represents a series of linear equations with unknown values of *r* and c_k which can be solved if $Q \geq K+1$. Selecting k=1 and performing two measurements at two different delays (Q=2) is usually sufficient to obtain results within an acceptable range (30dB±1dB). From this, the OSNR may be calculated as in equation 4.

$$\begin{aligned} \mathrm{OSNR} &= 10\log_{10}\left(\frac{\mathrm{NEB(nm)}}{r\times 0.1(\mathrm{nm})}\right) \\ &= -10\log_{10}(r) + 10\log_{10}\left(\frac{\mathrm{NEB(nm)}}{0.1(\mathrm{nm})}\right) \end{aligned} \quad (4)$$

Results:

Shown in fig. 3 are the results of OSNR measurements performed using single polarization and dual polarization QPSK signals.

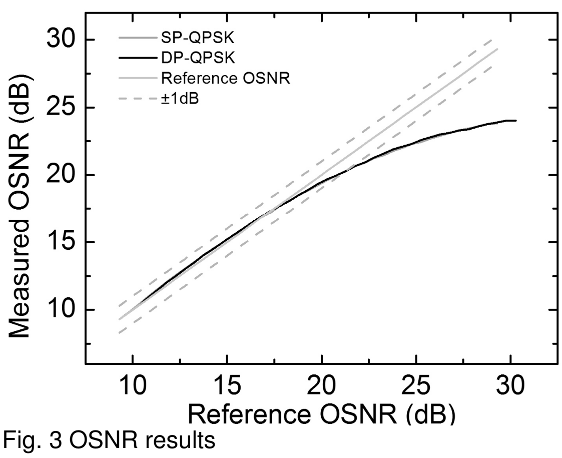

Fig. 3 OSNR results

It can be seen that a measurement range from approximately 10 to 21dB could be attained within an accuracy of ±1dB. This is some way from the measurement range of approximately 5 to 30dB ±0.5dB which was previously reported[9] using on-off keyed (OOK) amplitude modulated signals. However, it can be seen that there was no difference in measured OSNR for the SP and DP-QPSK signals which is of great importance as no other current technique appears to provide a reliable means of measuring in-band OSNR of such signals.

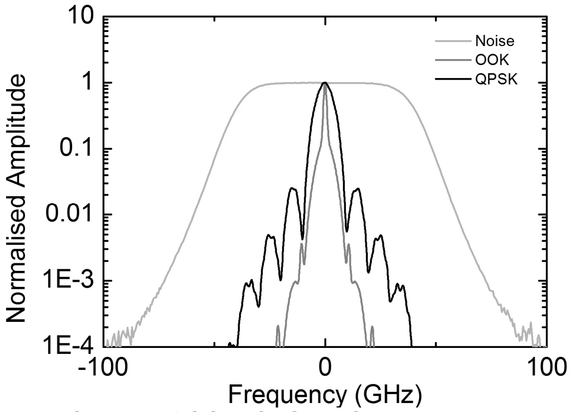

Fig. 4 Spectra of OOK, QPSK, ASE

The reason for the discrepancy in the measured vs reference OSNR may be due to the fact that the QPSK signal spectrum, as shown in fig. 4, is wider than that of the OOK signal. This would lead to poorer extinction at high OSNR values causing the OSNR to be underestimated.
Shown in fig. 5 are the amplitude autocorrelation functions of OOK and QPSK signals and filtered ASE noise. It can be seen that the QPSK signal autocorrelation decays faster than the OOK case, meaning that its coherence properties are slightly more noise-like.

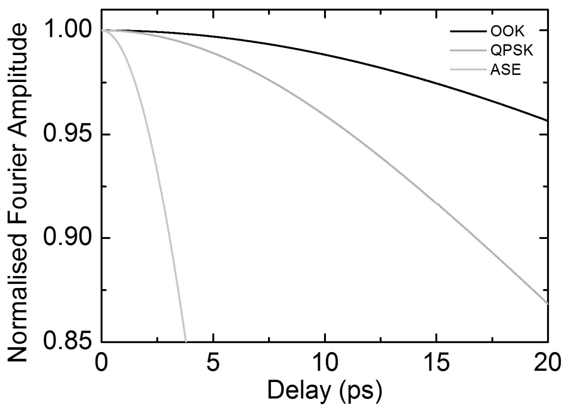

Fig. 5 Amplitude Autocorrelation Functions

Figure 6 shows a simulation of the OSNR measurement using two and six optical delays and how the use of more delay interferometers would allow a better approximation of the OSNR at higher noise values.

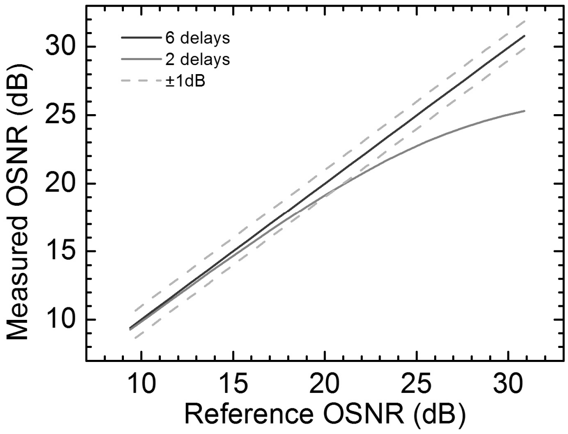

Fig. 6 OSNR simulation

Conclusions

We have shown the operation of an in-band OSNR monitor based on a pair of fibre interferometers. This allowed measurement of the in-band OSNR of polarisation multiplexed QPSK signals in a range of 10 to 21dB within an accuracy of ±1dB. We have shown by way of simulations that it would be possible to extend this measurement range through use of more delay values in the system as it would allow a more accurate approximation of the signal's coherence properties.

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