# Sensitivity of Interferometric OSNR Measurements Techniques to the Variation in Signal Extinction Ratio

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**Abstract**

*We discuss calibration requirements for interferometric OSNR measurements. We show that variation of 0.25dB in the signal extinction ratio could result in large errors in OSNR for 42.8Gb/s modulated signals.*

**Introduction**

Carriers' constant effort to reduce their cost, while attaining flexibility in offered services, has driven rapid deployment of Reconfigurable Optical Add/Drop Multiplexers (ROADMs). ROADMs serve as routing nodes in wavelength-routed networks (WRNs), in which individual wavelengths can be inserted into, or extracted from, the optical signal at each node without conversion to electronic form. In WRNs, adjacent wavelength channels can carry signals that have traversed different optical paths across the network, thus accumulating different amounts of noise power, and these variations of the noise between neighboring channels will change whenever the WRN is reconfigured. In addition, noise power between channels is often filtered by ROADMs. Therefore, the conventional method of monitoring optical signal-to-noise ratio (OSNR) (interpolation of noise power measurements made in the gaps between tightly packed WDM channels) becomes obsolete [1]. The situation calls for novel in-band OSNR measurement methods that operate within the individual channel optical bandwidth.

Several recently proposed approaches are based on interferometric techniques that distinguish the power of the coherent modulated signal from the incoherent noise power occupying the same optical band. [2-4]. A real network environment imposes constraints on the applicability of interferometric methods. Numerous parameters, such as duration, shape and chirp of the optical pulses, optical filtering along the signal path, extinction ratio (ER), and the modulator settings strongly affect interferograms of modulated signals, thus complicating the estimation of signal power and necessitating a calibration for every monitored transponder [5].

In this paper, we study inaccuracy in interferometric OSNR measurements resulting from possible ambiguity in the calibration factor. When correct calibration is used, the OSNR can be measured with 0.6 dB accuracy over 5-25 dB range. Calibration uncertainties of about 1% (e.g. arising from thermal drifts) produce somewhat tolerable OSNR errors of 1-2dB over the smaller range of 5-20dB OSNR. Larger errors further reduce the applicability range of interferometric OSNR monitoring, potentially rendering the method nearly useless. Interestingly, we find that these critical calibration errors can result from miniscule changes in signal ER ε. Indeed, changes as little as $\Delta\varepsilon = 0.25dB$ generate 1%-10% calibration error, depending on the value of the ER (larger errors correspond to higher ER) and on the way the ER was degraded.

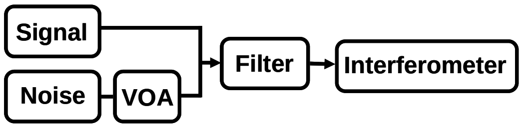


*Fig. 1 Experimental Setup*

**Experimental Setup**

Fig. 1 shows a diagram of our experimental setup. A 42.8 Gb/s NRZ, RZ and CSRZ OOK signals is combined with the noise and is filtered with a fixed optical add/drop multiplexer (OADM) with 3/10 dB bandwidth of a 67/92 GHz. The filtered signal is injected into a commercial scanning Michelson interferometer with the delay that ranges from -69ps to +69 ps. The instrument yields digitized light intensity from its constructive outputs (delay-independent contribution subtracted). The variable optical attenuator (VOA) controls the OSNR in the 5-30 dB range by adjusting amount of noise for the same signal power. Reference OSNR measurements are performed by replacing the filter and the interferometer with an optical spectrum analyzer (OSA).

To illustrate the operational principle of the interferometric OSNR monitor the Fig. 2 shows two interferograms corresponding to different amounts of noise added to the same signal with *ε=10dB* (for simplicity, only the envelopes are shown; fast oscillations at the optical frequency are ignored). The light gray curve is a nearly noiseless signal with *OSNR=30dB*, while the darker curve represents a noisy signal with *OSNR=5dB*. The addition of noise results in an increase of the intensity at zero delay $I(\tau = 0)$. Yet the intensity at the wings of the interferogram $I(\tau \geq 2.5T)$ remains the same, thus providing a measure of the signal power. However, extracting this power requires the *a priori* knowledge of the shape of the signal envelope. Once a

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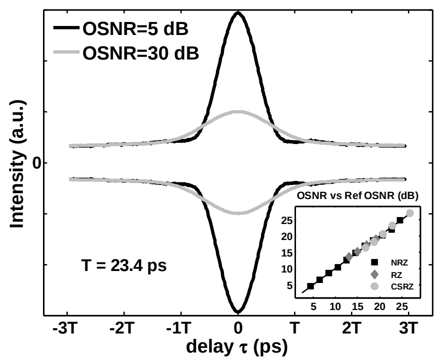


*Fig. 2 Interferogram envelopes of two NRZ signals with different OSNR values. Inset: measured OSNR as a function of reference OSNR (read by OSA).*

calibration factor $\zeta$ has been determined from a high OSNR interferogram: $\zeta = \frac{I_{cal}(\tau \geq 2.5T, OSNR = \infty)}{I_{cal}(\tau = 0, OSNR = \infty)}$, the accurate OSNR measurements are straightforward. Interferometric OSNR values as a function of the reference OSNR (from OSA) are shown in the inset.

**Results**

The interferogram shape (and the calibration $\zeta$) depends on the value of signal ER and the way it was degraded. By shifting the dc electrical bias to our Mach-Zehnder modulator we can gradually tune from the overbiased (ε=6dB) through the optimal (ε=12dB) to the underbiased regime (ε=6dB). The corresponding evolution of the top portion of the normalized envelope is shown in Fig. 3, for a signal with high OSNR. The ER changes in roughly 1dB steps from 6dB on top (overbiased) to 6dB at the bottom (underbiased). Also, the ER is coded by shades of gray, with a darker tone indicating higher ER. Note, that the fifth curve from the bottom is identical to the top light grey curve of Fig. 2 within our experimental uncertainty. It is clear from the plot that the calibration $\zeta$ (the intensity values at large delays) sweeps a wide range from 0.84 (overbiased) to 0.14 (underbiased). It changes relatively quickly with ER, up to a 20% shift in $\zeta$ per 1dB change in ER at ε=12 dB.

To explore the sensitivity of OSNR results to

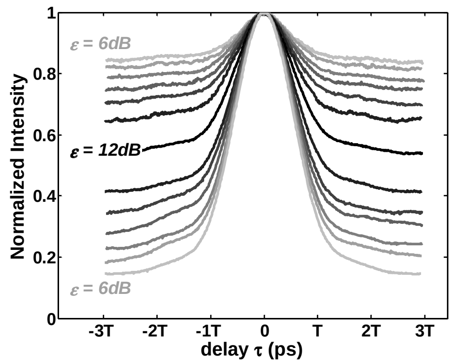


*Fig. 3 Normalized interferogram envelopes for various ER in underbiased and overbiased conditions.*

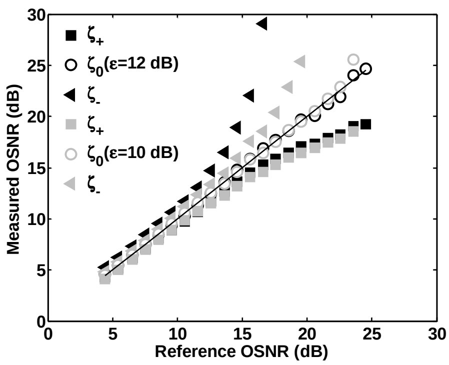


*Fig. 4 Measured OSNR as a function of reference OSNR (from OSA) with different calibration factors $\zeta$ for two modulation conditions: $\varepsilon_0 = 10dB$ and $\varepsilon_0 = 12dB$.*

changes in calibration arising from ER variations, we devised the following procedure. First, we compute three calibration factors $\zeta_0$, $\zeta_-$, and $\zeta_+$ for three high OSNR signals with very close ER values $\varepsilon_0$, $\varepsilon_0 - 0.25dB$ and $\varepsilon_0 + 0.25dB$. Then by applying these factors to the OSNR measurements of noisy signals with ER values $\varepsilon_0$ we assess the errors caused by $\zeta_-$, and $\zeta_+$. Finally, we probe a range of ER values $\varepsilon_0$ in both the overbiased and the underbiased conditions.

Illustrative examples are shown in Fig 4, which again plots measured OSNR vs reference OSNR. The first example is a nearly optimal modulation setting with $\varepsilon_0 = 12dB$ (black symbols). Second is an underbiased case with $\varepsilon_0 = 10dB$ (gray symbols). For each case the correct factor $\zeta_0$ produces OSNR measurements with a small error of 0.6dB (circles). On the other hand, application of $\zeta_-$ (triangles), and $\zeta_+$ (squares) results in large errors, diverging for high OSNR. The errors are somewhat worse for $\zeta_-$ and for higher ER. We also find that when ER is suboptimal the errors are higher in the underbiased regime.

**Conclusion**

The accurate determination of signal power (and therefore OSNR) of noisy signals requires a calibration measurement at a known high OSNR. We find that measured OSNR values are extremely sensitive to the accuracy of the calibration factor and, in turn, to the stability of modulation conditions. In fact, changes in signal ER as little as 0.25dB can induce unbounded errors for OSNR values.

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