MEASURING OSNR IN WDM SYSTEMS—EFFECTS OF RESOLUTION BANDWIDTH AND OPTICAL REJECTION RATIO

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In the last few years, we have witnessed the extensive deployment of wavelength-division multiplexed (WDM) networks. These systems are configured to allow multiple channels at different wavelengths[i] to share the same optical fiber, increasing the effective transmission rate on that fiber. But with this new technology arose a new challenge: the parameters providing direct information on system performance (such as the bit error rate (BER) and BER estimation techniques like Q-factor or eye analysis) cannot be measured directly on a multichannel system. These key parameters require spectral demultiplexing prior to making an individual evaluation of the BER performance on each demultiplexed channel. Alternatively, optical signal-to-noise ratio (OSNR) can be derived, for each individual channel, from an optical spectrum measurement to obtain indirect information about the performance of these channels and hence of the system.

Although the OSNR derived from the spectrum does not reveal effects of temporal impairments on the channel performance[ii], the fact that OSNR provides indirect information about the BER makes it the most useful parameter available from the measured spectrum[iii] and that is why it is listed as an interface parameter in ITU-T Recommendation G.692[1] and in ITU-T Recommendation G.959.1[2].

OSNR can be directly correlated to the BER using the following equation[3] (detailed in the IEC 61280-2-7 document), which justifies the fitting function used when performing BER vs. received power:

$$BER\,(SNR) = \frac{1}{\sqrt{2\pi}} \int_{SNR}^{\infty} \exp\left(-t^2/2\right) dt$$

Equation 1. BER vs. SNR equation from IEC 61280-2-7

A poor OSNR leads to a degraded BER; G.692 suggests identifying the minimum required OSNR of a given system design for a BER of 1×10^{-12}. As OSNR is an average-power low-speed measurement, it does not allow for the detection of rare bit errors[iv] and, as mentioned earlier, does not reveal the effects of temporal impairments. However, its correlation to the BER makes OSNR a key parameter to extract from the spectrum in order to provide a preliminary performance diagnosis of a multichannel system or to monitor the system and obtain advance warning of a possible BER degradation on a given channel. OSNR measurement in WDM systems is the subject of the IEC 61280-2-9[4] document and will be summarized in the next section.

OSNR Definition and Measurement Procedure

The IEC standard defines optical signal-to-noise ratio as the ratio of the signal power at the peak of a channel to the noise power interpolated at the position of the peak and is described by the following equation:

$$OSNR = 10 \times \log \frac{P_i}{N_i} + 10 \times \log \frac{B_m}{B_r}$$

Equation 2. OSNR equation from IEC 61280-2-9

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where:
P_i is the optical signal power in watts at the i^{th} channel;
Bm is the resolution bandwith of the measurement;
N_i is the interpolated value of noise power in watts measured in the resolution bandwidth[v] of the measurement (B_m) derived from the noise measured at the mid-channel spacing point[vi];
B_r is the reference optical bandwidth, typically chosen to be 0.1 nm, and the second term of the equation is used to provide an OSNR value that is independent of the instrument's resolution bandwidth (B_m) for the measurement so that results obtained with different instruments can be compared[vii].

The following figure visually describes the relevant parameters from the spectrum:

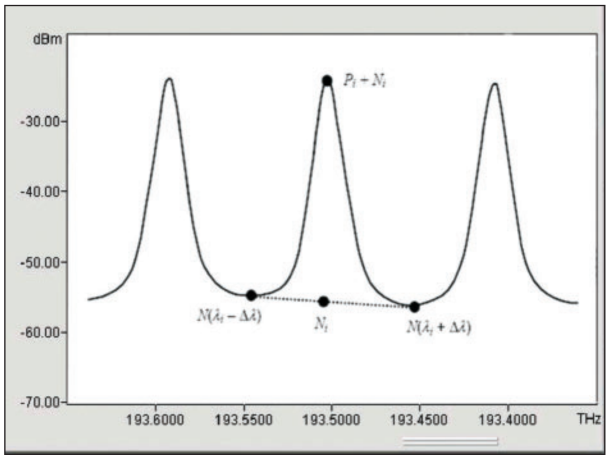

Figure 1. Graphical description of parameters required to measure OSNR on a multichannel system

The standard also identifies these key OSA characteristics that are required to perform an adequate OSNR measurement (two of these elements will be covered in greater detail below):

- The wavelength measurement range of the OSA must be wide enough to encompass all channels plus one-half of a grid spacing at each end.
- The sensitivity, defined as the lowest level at which spectral power can be measured with a specified accuracy, must be below the minimum expected channel peak power by the desired OSNR value with a margin[viii] (see optical rejection ratio below) to achieve the specified accuracy.
- The resolution bandwidth (RBW) must be wide enough to encompass the entire signal power spectrum of each modulated channel (this point will be detailed below), and must be accurately calibrated as it has a direct impact on the accuracy of the noise measurement, and that of the modulated signal when its power spectrum is larger than the RBW.
- The optical rejection ratio[ix] (ORR), the ability of an OSA to measure the noise level close to a peak, must be well below the noise level to be measured (in the instrument's RBW, a 10 dB margin is suggested[x]) so as not to add instrument-generated crosstalk of more than ~0.42 dB onto the noise measured.
- The scale fidelity of the instrument (that is, its ability to measure power correctly at different power levels) contributes to the OSNR measurement uncertainty as the peak power and the noise level are usually 15 to 35 dB apart.
- The polarization-dependent loss of the instrument adds uncertainty to the OSNR measurement because the signal power (Pi) consists of highly polarized light.
- There must be a sufficient number of data points (at least two per RBW) to sample the spectrum correctly.

The next sections detail the effects of two key parameters: the resolution bandwidth (RBW) and the optical rejection ratio (ORR).

RBW Effects and the Ideal OSA Filter Spectral Response

RBW is a key specification of the instrument. However, instrument manufacturers often specify the full-width half-maximum (FWHM or width at 3 dB) rather than the RBW since it can easily be measured by users themselves and it is generally a close approximation. Note that the FWHM is the OSA filter response to a very narrow laser source representing an ideal delta function[xi]. The RBW is in direct relation to the ORR performance of the instrument, but the filter shape differences have an important effect on the actual ORR performance so that the direct relation does not hold true between instruments with different filtering configurations. In fact, the closer the OSA filter response is to an ideal filter (described below), the better its ORR performance will be for the same RBW.

The RBW of the OSA must be wide enough to encompass all the power of the signal spectrum that is enlarged due to the data transmission rate. The following figure illustrates how a modulated signal could be underestimated when measured with a narrower-RBW OSA.

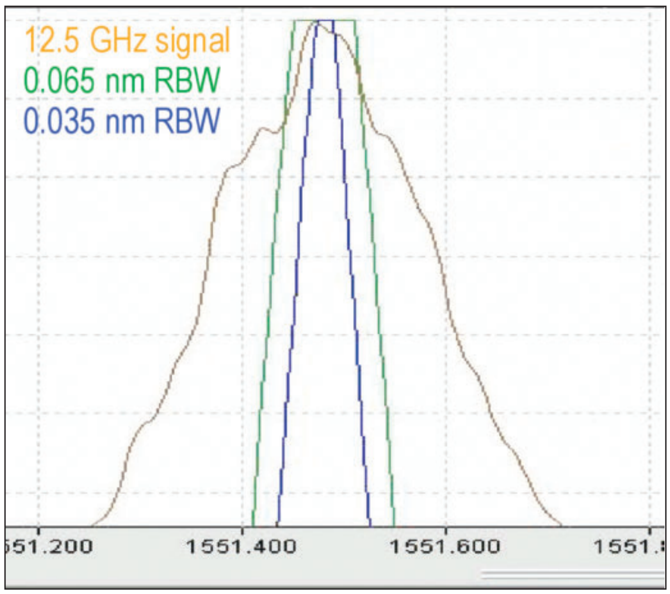

Figure 2. Broad modulated signal compared to the OSA's RBW

On the other hand, the RBW of the OSA must be kept narrow for the noise measurement to be able to properly measure the noise level close to a peak. Thus, the ideal OSA filter response to measure OSNR would be a flat-top rectangular shape that is wide enough to encompass the signal and whose edges fall down to the instrument's noise floor vertically from the peak's maximum area. That is obviously not the typical physical filter shape.

The two following figures illustrate different filter shapes of commercial grating-based OSAs[xii], compared with an ideal filter response with the same RBW as the set resolution on the instrument. The different OSA filter design leads to different spectral responses to a narrow source.

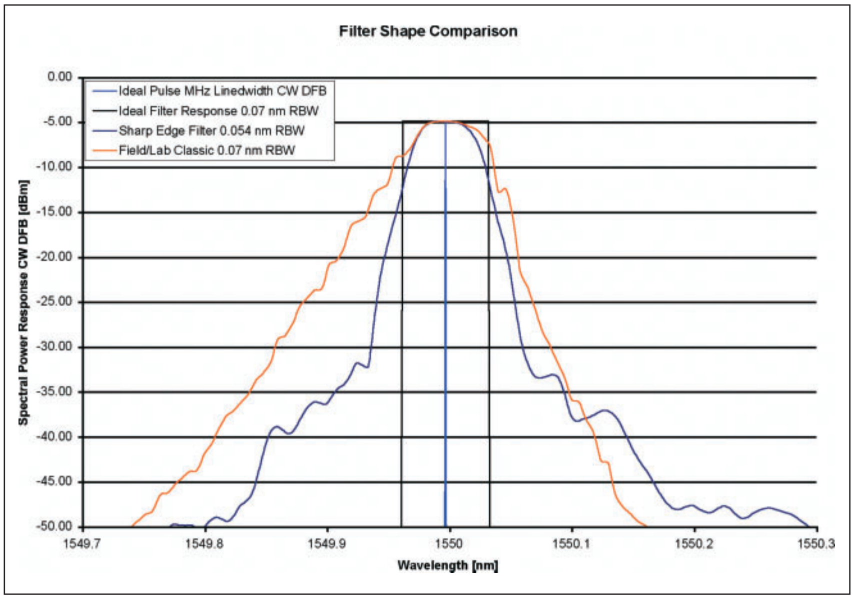

Figure 3. Ideal filter response vs. commercial grating-based OSAs for comparable RBW of ~0.05 –0.07 nm

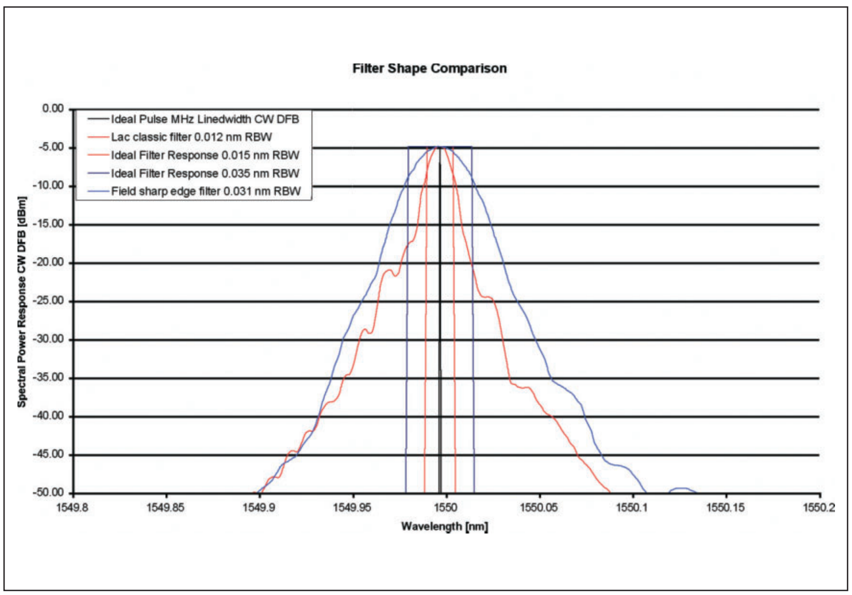

Figure 4. Ideal filter response vs. commercial grating-based OSAs for comparable high-resolution OSAs

As demonstrated below, the closer the filter spectral response of the OSA is to the ideal filter response of the same RBW, the better its OSNR measurement capability will be.

In order to obtain the best possible OSNR measurement with a non-ideal filter-response OSA, the standard suggests using a two-pass measurement for broad modulated signals; one with a narrow RBW setting to measure noise accurately close to the peak (at mid-channel spacing) and one with a broader RBW to accurately measure the signal power.

Another way to tackle the problem is to integrate the signal's power spectrum, a technique that requires a single acquisition.

The following figures illustrate how the integrated power allows a more precise estimation of the signal power with modulated carriers wider than the RBW setting of the measuring instrument.

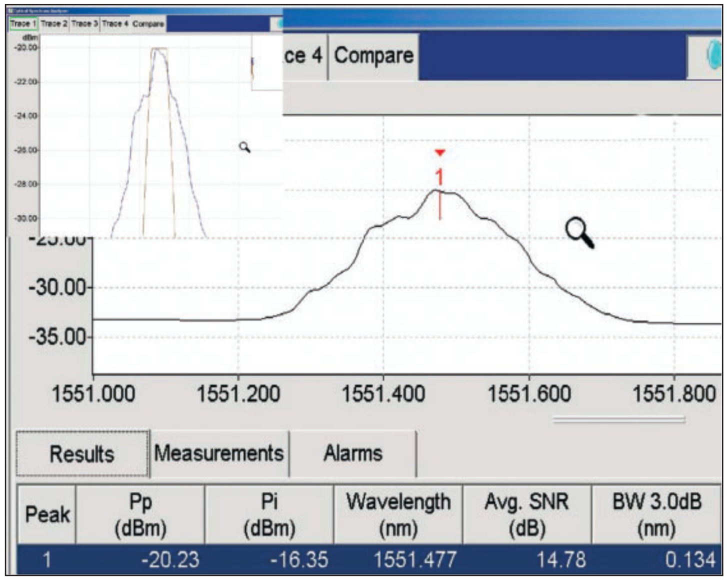

Figure 5. 12 Gbit/s modulated spectrum showing the integrating power advantage. Avg. SNR is the recommended interpolated OSNR at the signal's center wavelength; this value is automatically calculated based on integrated power when required

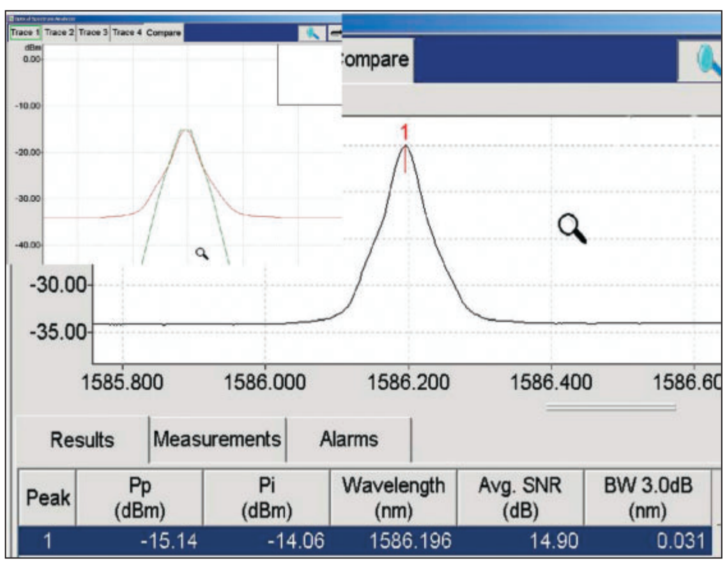

Figure 6. 2.5 Gbit/s modulated spectrum with the integrated power correction

An OSA with the capability of measuring the integrated power of the signal offers a definite advantage; when set to its optimal RBW performance, this unit can provide an OSNR value in a single scan and with high accuracy. The noise power integrated under the signal is removed in the calculation and the result achieved in a single scan with a narrow RBW (~0.03 nm) is within 0.25 dB of the actual value for Figure 5, and 0.1 dB for Figure 6, as measured independently.

As shown in the next figure, this approach emulates an ideal filter response, down to the ORR limit of the instrument, allowing for an accurate OSNR measurement, which in this case was just below 28 dB.

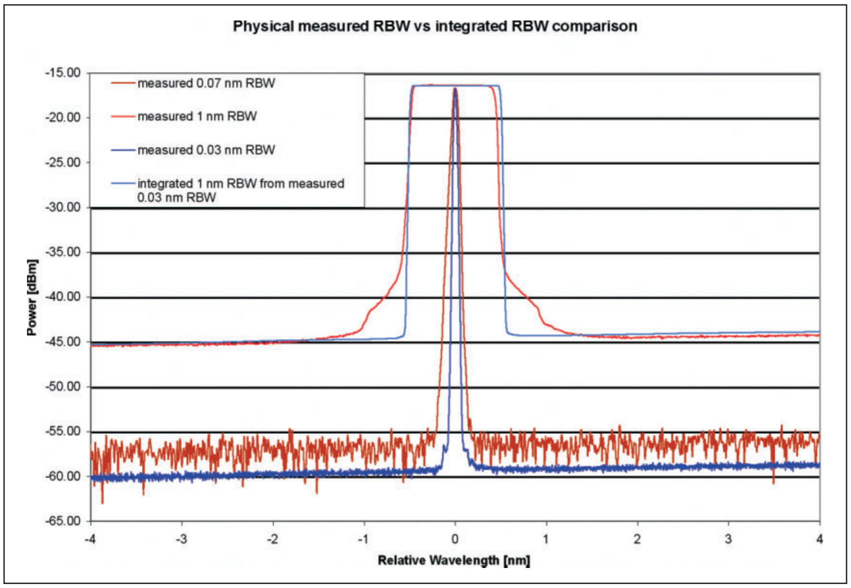

Figure 7. Ideal filter response achieved through integrated power measurement capability

An integrated RBW of 1 nm (width selected for illustration purposes), calculated from the 0.03 nm set RBW measurement, displays vertical sharp edges. This allows for an accurate OSNR measurement just at the edge of the filter response (like in the case of an ideal filter). In practice, the integration width is automatically adjusted to fit the signal's modulated spectrum width in the OSNR automated measurement (see Figure 5 and Figure 6).

Impact of Instrument's ORR on Its OSNR Measurement Capability

The ORR performance of an OSA determines its ability to measure low-level signals close to a peak. It is defined as the ratio, in dB, of the power at a given distance from the peak ($\Delta\lambda$) to the power at the peak of the OSA filter response for a given narrow input (delta function equivalent source with linewidth $\ll$ RBW of the OSA). OSA manufacturers used to specify the ORR of their instrument at 0.5 nm and 1 nm from the peak and now specify it at 0.1 nm, 0.2 nm and 0.4 nm, which are more relevant values, given the mid-channel spacing of 25 GHz, 50 GHz and 100 GHz WDM transmission systems. Typical values will be covered in the next section, but one must keep in mind the RBW setting at which this ORR value is specified.

In order to adequately measure the OSNR with a desired accuracy, the IEC 61280-2-9 suggests a required ORR at the noise measurement position (mid-channel) of at least 10 dB below the measured OSNR. For example, to measure an OSNR of 25 dB at 0.2 nm (0.2 nm around 1550 nm is 25 GHz and would be the mid-channel spacing for a channel set with a 50 GHz spacing), the ORR of the instrument at 0.2 nm must be at least 35 dB to ensure an uncertainty below 0.42 dB on the OSNR measurement.

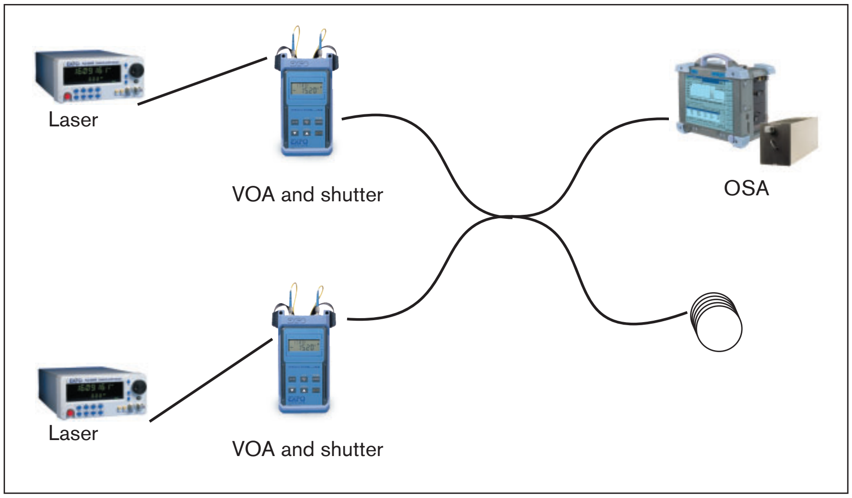

Figure 8. Setup used to evaluate OSNR capability vs. OSA's ORR

To illustrate this effect, a simple experiment can be done with the above setup (Figure 8), in which two unmodulated DFB lasers are set at a predetermined spacing (~11 GHz in Figure 9) that includes a ~1.5 GHz margin on the 12.5 GHz value required to measure mid-channel noise on the very dense 25 GHz spacing of today's most tightly spaced deployed systems. The fixed-level peak on the right (higher wavelength) can be turned off and on without affecting its stability (using a shutter), while the other peak goes through an attenuator so that its power can be adjusted to a desired level. At each measurement power level, a first measurement is made with both sources active, and a second with the shutter blocking the right peak (constant power DFB). As the attenuated peak power is reduced closer to the "skirt" of the higher wavelength peak, a measurement error is introduced (this error can be compared for different instruments).

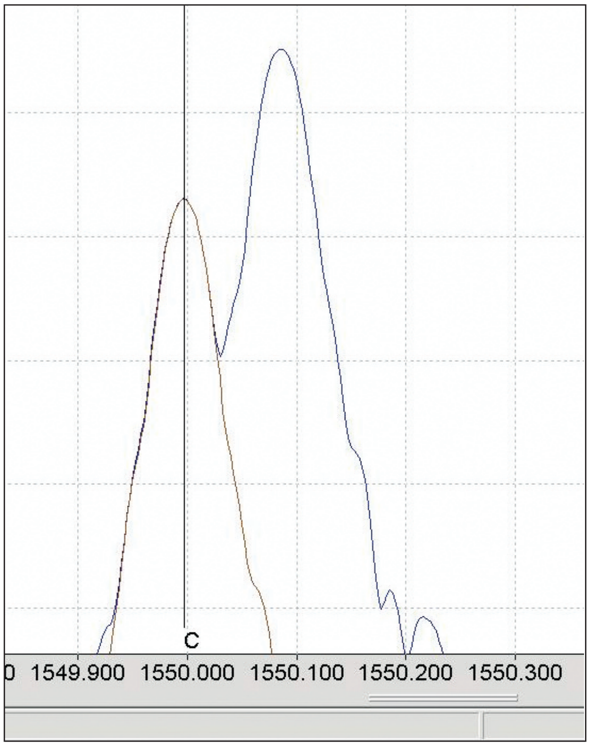

Figure 9. Evaluation of OSA's OSNR measurement capability vs. its ORR performance at ~11 GHz

The comparison between the two curves indicates if an error is made in measuring the adjustable peak. This is a good indication of how much ORR margin is available at the desired spacing to measure noise (thus OSNR) with a desired accuracy. Since this test only looks at relative power values at, or close to, the same power level (same peak measured with and without a neighbor), instrument scale fidelity errors are not introduced in the measurement and the comparison between instruments can be made without biasing the results. The value obtained when the error reaches 0.42 dB is the limit of the OSNR measurement capability for the instrument and should be at least 10 dB above the ORR value of the instrument at the given spacing.

Table 1 below and related Figure 10 show the difference in measured power introduced by the presence of the neighboring peak for the actual power difference between the peaks on four different grating-based OSAs. Two field-portable OSAs with a sharp-edge filtering configuration, one at ~0.05 nm RBW and one at ~0.03 nm RBW are compared with two laboratory OSAs with filtering configuration, representative of most lab OSAs. The lab OSAs used were two different units from different manufacturers, one with a 0.07 nm RBW, while the other is a high-end laboratory OSA with a resolution limit of ~0.01 nm RBW; this was also the value used to perform the test for the comparison. The test was stopped when the error introduced on the peak measurement was greater than the 0.42 dB uncertainty suggested by the draft standard. Although the same power-level data points were not taken for all units, there is sufficient overlap between the curves to make a fair comparison.

Power Difference Ascertained with Shutter as Reference	Sharp-Edge Field Unit ~0.05 nm RBW[5]	Classic Lab/Field Unit 0.07 nm RBW[6]	Sharp-Edge Field Unit ~0.03 nm RBW[7]	High-Resolution Lab Unit ~0.01 nm RBW[8]
Actual OSNR (dB)	Error (dB)	Error (dB)	Error (dB)	Error (dB)
0	0	0	0	0
3	-	0.3	-	-
6	0.01	0.7	-	-
9	-	1.1	-	0.03
12	0.06	1.9	0.04	-
15	-	-	-	-
18	0.24	-	0.01	0.02
21	0.68	-	-	-
24	1.35	-	0.04	-
27	-	-	-	-
30	-	-	0.12	0.16
36	-	-	0.48	0.73
39	-	-	0.88	1.55

Table 1. Error introduced on a peak measurement due to OSA ORR limitation

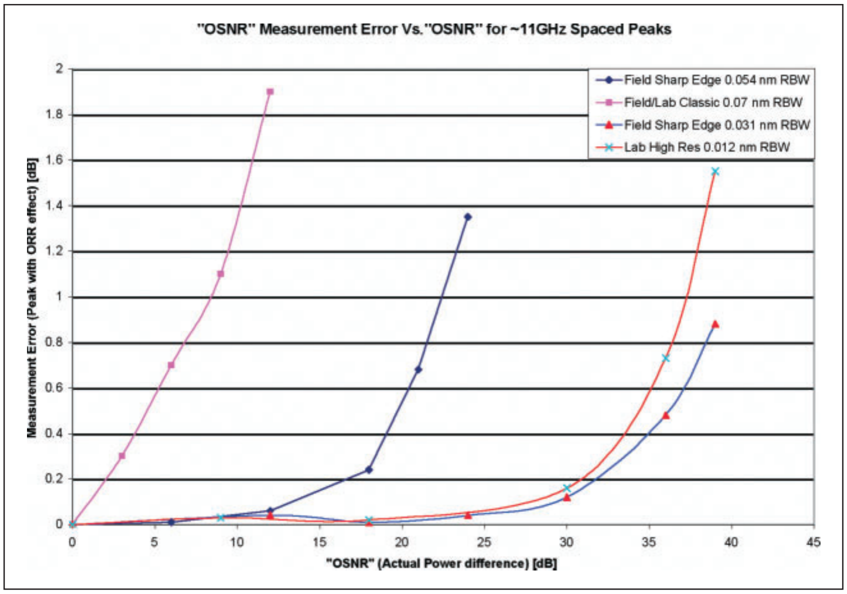

Figure 10. Error introduced on a peak measurement due to OSA ORR limitations

The results illustrate how OSAs with comparable RBW at 0.07 nm and 0.054 nm, respectively, have greatly different ORR performance, with a difference of over 10 dB in OSNR measurement capability for the same introduced error. The results also show that a sharp-edge filter OSA response with an RBW of ~0.03 nm (almost three times the ~0.01 nm RBW of the high-end lab instrument), introduces a comparable measurement error due to ORR limitations for an OSNR of up to 40 dB, which is well beyond the range of practical interest for WDM systems. This conclusion could have been anticipated by looking at the filter responses of these OSAs that were presented earlier in Figure 3 and Figure 4, as the following table indicates.

OSA Instrument Type	ORR from Figure 3 or Figure 4 [dB]	ORR Deduced from a Measurement Error of 0.42 dB (Figure 11 +10 dB Margin) [dB]
Classic Field/Lab Unit (0.07 nm RBW)	~15	~15 (~5 dB + 10 dB margin)
Sharp-Edge Field Unit (0.054 nm RBW)	~30	~28 (~18 dB + 10 dB margin)
High-Resolution Lab Unit (0.012 nm RBW)	~45	~43 (~33 dB + 10 dB margin)
Sharp-Edge Field Unit (0.031 nm RBW)	~45	~45 (~35 dB + 10 dB margin)

Table 2. Cross-validation of results between Figure 10 and Figure 3 and Figure 4

A further advantage of the sharper filter response can also be anticipated from the fact that it is closer to the ideal filter response for a given RBW. To obtain a more revealing comparison of the resulting OSNR measurement capability, these data points can be compared at a 0.1 nm normalized reference RBW using Equation 2. Applying the reference bandwidth correction (second part of the equation) yields the following curves.

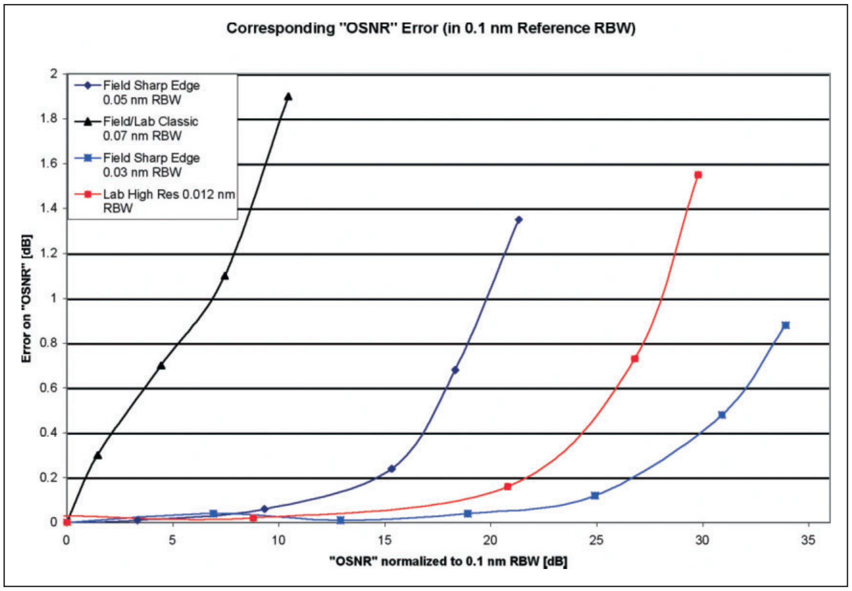

Figure 11. OSNR measurement capability normalized to 0.1 nm RBW

These results demonstrate that the filter response of the OSA has considerable impact on its ORR and performance, thus affecting its ability to measure OSNR correctly. It also shows that RBW alone is not an adequate indication of the instrument's performance in that regard. This is further emphasized when presenting the results in a normalized manner to the reference bandwidth of interest, as suggested in the draft standard recommendation for OSNR measurement.

To further demonstrate the impact of ORR on the OSNR measurement, a true OSNR measurement capability evaluation can be achieved with the following setup. Three unmodulated sources at the same power level are combined to a broadband noise source (amplified spontaneous emission or ASE source) after passing through an attenuator with shutter. The sources are unmodulated so as to avoid introducing peak power measurement uncertainties due to signals larger than the RBW. The source wavelengths are tuned to the desired spacing and their relative power to the ASE level can be adjusted with the attenuator. The true noise level can be measured by shutting the sources, and an exact OSNR measurement can be performed by comparing the peak powers to the true ASE noise level (when the peaks are shut off).

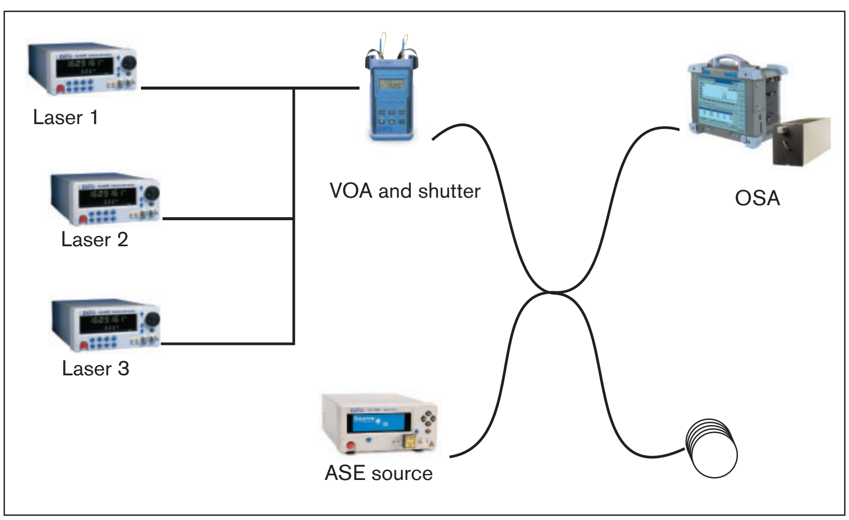

Figure 12. Setup for true OSNR measurement

Figure 13 shows the three DFB sources and the noise measured with the shutter activated, as acquired with two different commercial instruments. The sources are spaced ~25 GHz apart (0.2 nm) and the peaks are at ~20 dB above the noise level.

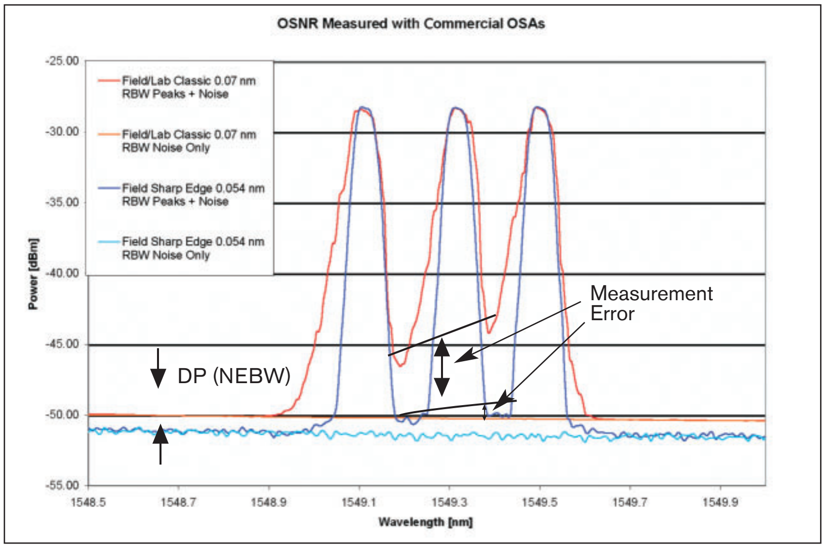

Figure 13. OSNR measurement error introduced by OSA ORR for same input signal

Applying the measurement procedure described above in accordance with the standard, the OSNR can be evaluated on the central peak. The result obtained with the interpolated noise can then be compared to that of the actual noise level (determined with the peak's shutoff and the error readily observable from the graph) and, in turn, can be quantified. The following table displays the measurement levels required for the measurement according to the standard as well as the true noise level.

OSA type	P_i on Central Peak[xiii]	N_i at Central Peak (Measured with Instrument RBW)	OSNR from Equation 2	True Noise Level (Measured with Instrument RBW)	True OSNR	Error Introduced
	[dBm]	[dBm]	[dB]	[dBm]	[dB]	[dB]
Classic Field/Lab Unit 0.07 nm RBW	−28.3	−45.0	16.61 − 1.55 = 15.06	−50.26	21.93 − 1.55 = 20.38	5.32
Sharp-Edge Field Unit 0.054 nm RBW	−28.3	−50.4	22.07 − 2.68 = 19.39	−51.4	23.08 − 2.68 = 20.39	1.0

Table 3. OSNR error introduced by ORR on true OSNR measurement

The error introduced, although slightly better than would have been expected from Figure 11 for both instruments, leads to an over-estimation of the OSNR. In the case of the field instrument with sharp-edge filter, the error is 1 dB and the measurement is clearly beyond reach for the lab/field instrument, which makes it unsuitable for measuring the OSNR of such closely spaced (25 GHz) channels. Note that, as expected, the true OSNR measurements do line up.

The same experiment can be performed using better-resolution instruments. For this case, the sources are spaced ~25 GHz apart (0.2 nm) and the peaks are at ~25 dB above the noise level.

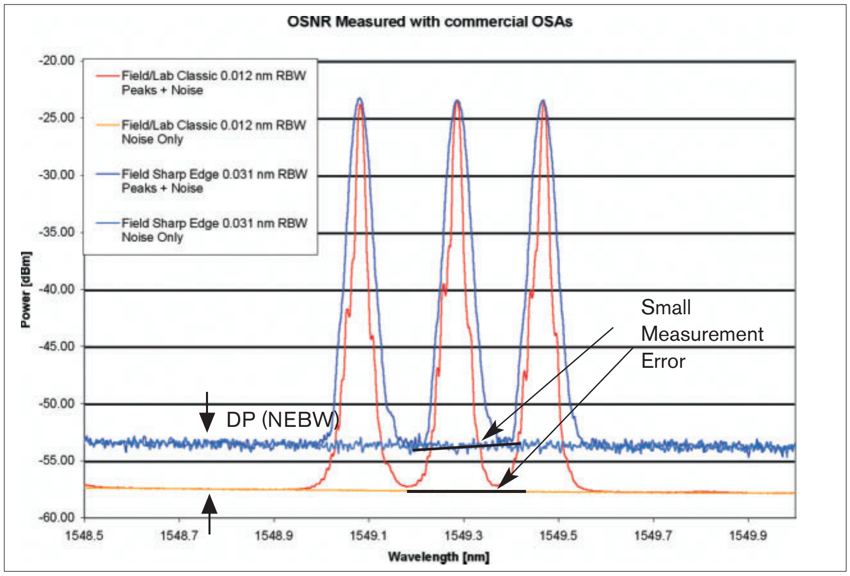

Figure 14. Error introduced on true OSNR due to OSA ORR limitations for same input signal

The same information can be extracted from this graph and the following table shows the results obtained.

The results in Table 4 show that the error introduced by both units is within or close to the required margin in the draft standard (0.42 dB) and is in reasonable agreement with what was expected from Figure 11 at 25 dB OSNR. A third row has been added to explain the discrepancy in the true OSNR observed (~1 dB in the first two rows of the table). In practice, the RBW accuracy of the high-end lab instrument used is not guaranteed when it is set to 0.01 nm and it was estimated to be closer to 0.012 nm; the OSNR calculations were redone with the correct parameters. Note that the RBW uncertainty of the field instrument is below ±10 % at the tested resolution.

OSA Type	P_i on Central Peak	N_i at Central Peak (Measured with Instrument RBW)	OSNR from Equation 2	True Noise Level (Measured with Instrument RBW)	True OSNR	Error Introduced
	[dBm]	[dBm]	[dB]	[dBm]	[dB]	[dB]
Classic Field/Lab Unit 0.01 nm RBW	–23.47	–57.2	33.73 – 10 = 23.73	–57.7	34.23 – 10 = 24.23	0.5
Sharp-Edge Field Unit 0.031 nm RBW	–23.47	–53.5	30.02 – 5.09 = 24.93	–53.8	30.33 – 5.09 = 25.24	0.31
Classic Field/Lab Unit 0.012 nm RBW (corrected)			33.73 – 9.21 = 24.64		34.23 – 9.09 = 25.14	

Table 4. OSNR error introduced by ORR on true OSNR measurement (high-resolution instruments)

Evaluating an OSA's OSNR Measurement Capability from Its ORR and RBW Specifications

The above experiments have shown how the RBW and the ORR of an OSA can affect the OSNR measurement capability of an instrument. In addition, judging an instrument by its RBW alone is not a sufficient indication of the OSA's ability to correctly measure the OSNR in accordance with the standard IEC 61280-2-9.

To complement the analysis, this section demonstrates how the OSNR measurement capability of an instrument can be deduced simply from its published RBW and ORR specifications. Alternatively, one can easily measure the true ORR performance of an OSA with a narrow linewidth input source (unmodulated laser) at the desired distance from the peak by direct observation of the OSA filter response. The OSNR measurement capability in 0.1 nm RBW is deduced from Equation 2, where the highest measurable Pi/Ni is given by the ORR specification at the desired distance from the peak and the desired margin is added (10 dB is used in the next table, as is reasonably suggested in the draft standard).

The resulting equation provides a rapid evaluation of OSNR measurement capability:

$$OSNRcapability_{0.1nm\ RBW} = ORR_{mid\text{-}channel} + 10\ x\ log_{10}\ (RBW/0.1) - 10$$

Equation 3. OSA's OSNR measurement capability at 0.1 nm RBW, based on RBW spec and ORR spec (dB)

where:

- $ORR_{mid\text{-}channel}$ (dB) is the maximum OSNR that could be measured with the instrument in the absence of noise (with only the limitation of the filter response); it approximates the first part of Equation 2:
- 10 x $_{log10}$((Pi+Ni)/Ni) at the given mid-channel spacing because Ni is relatively small compared to Pi and there is generally negligible error in approximating this value to the simpler: 10 X $_{log10}$(Pi/Ni), the ORR value specified by OSA manufacturers;
- RBW (nm) is the smallest specified resolution bandwidth (or noise equivalent bandwidth) for which the ORR is specified by OSA manufacturers for the given instrument;
- 0.1 nm is the reference bandwidth for comparison between instruments and since RBW is usually smaller than the reference 0.1 nm for the measurement, this part of the equation adds a negative offset in dB (less noise is measured in smaller RBW);
- 10 (dB) is a reasonable margin the instrument's ORR must display to avoid adding large uncertainty to the OSNR measurement.

For example, an OSA with a resolution bandwidth of 0.065 nm and a specified ORR of 45 dB at 50 GHz (mid-channel for 100 GHz channel spacing) would be capable of measuring:

$$OSNRcapability_{0.1nm\ RBW} = 45 + 10 \times log_{10}\ (0.065/0.1) - 10 + 33.1dB$$

without adding more than 0.42 dB uncertainty to the OSNR measurement.

To wrap up, the following table provides a sample of commercially available instruments with their respective specifications (published[xiv]) and the corresponding OSNR capability in 0.1 nm reference bandwidth for the given channel spacing (starting with the four OSAs used for the above experiments and the results measured in the practical tests above in brackets). Note that, in practice, the system requirements for OSNR are typically around 20 dB in a 0.1 nm RBW.

Instrument Description	RBW [nm]	ORR at 0.1 nm (Mid-Channel for 25 GHz Spacing) [dB]	Corresponding OSNR Measurement Capability in 0.1 nm Reference RBW [dB]	ORR at 0.2 nm (Mid-Channel for 50 GHz Spacing) [dB]	Corresponding OSNR Measurement Capability in 0.1 nm Reference RBW [dB]	ORR at 0.4 nm (Mid-Channel for 100 GHz Spacing) [dB]	Corresponding OSNR Measurement Capability in 0.1 nm Reference RBW [dB]
Field OSA – Sharp Filter [5]	0.065	- [~30]	- [18]	35	23.1	45	33.1
Field OSA – Sharp Filter [6]	0.035	35 [~45]	20.4 [30]	48	33.4	50	35.4
Lab/Field OSA – Classic Filter [7]	0.07	- [~17]	- [5]	-	-	58 (at 0.5 nm)	41.2
High-Resolution Lab OSA – Classic Filter [8]	0.01	- [~45]	- [25]	60	40	70	50
Lab/Field OSA – Classic Filter [9]	0.05	-	-	42	29	60	47
Field OSA – Sharp Filter [10]	0.075	-	-	33	21.8	40	28.8
Lab/Field OSA – Classic Filter [11]	0.06	-	-	40	27.8	55	42.8
Field/Lab OSA – Classic Filter [12]	0.05	-	-	40	27	55	42

Table 5. Summary table of OSNR measurement capability of commercial OSAs

References

[1] ITU-T Recommendation G.692: Optical interfaces for multichannel systems with optical amplifiers.
[2] ITU-T Recommendation G.959.1: Optical transport network physical-layer interfaces.
[3] IEC 61280-2-7 Fiber-optic communication subsystem test procedures – Part 2-7: Data analysis of bit error ratio versus received power for digital fiber-optic systems
[4] IEC 61280-2-9 Fiber-optic communication subsystem test procedures – Part 2-9: Digital systems – Optical signal-to-noise ratio measurement for dense wavelength-division multiplexed systems.
[5] EXFO FTB-5240S field OSA with fiber filter configuration and ~0.05 nm RBW.
[6] EXFO FTB-5240S-P field OSA with fiber filter configuration and ~0.03 nm RBW.
[7] Anritsu MS9710B Lab OSA also used in field applications; minimum ~0.07 nm RBW.
[8] Ando AQ6317 High-Resolution Lab OSA; with a minimum ~0.01 nm RBW.
[9] Anritsu MS9710C Lab OSA also used in field applications; minimum ~0.05 nm RBW.
[10] Acterna OSA 160, specification for RBW is typical.
[11] Agilent 8614xB family's best specifications.
[12] Ando AQ6331 Field/Lab OSA; minimum ~0.05 nm RBW.

Notes

i The desired number of channels being placed nominally on the grid defined by ITU Recommendation G.692[1] and at system-specific spacing on that grid.

ii Jitter as a direct effect on the relative sampling position within the bit while dispersion effects, namely polarization mode dispersion (PMD) and chromatic dispersion (CD), lead to variable delays that depend on the fiber properties and their environmental conditions for PMD, which can change the relative positions of consecutive bits enough to create inter-symbol interference and affect the BER of a given channel.

iii Other parameters like peak wavelength and peak power are secondary parameters. The ultimate effect of a wavelength drift for example is that the given channel slips near the edge of the multiplexer (MUX or DEMUX), thus decreasing the received power of that channel and, consequently, its OSNR, introducing polarization-dependent loss and delays. Another effect of such a drift is that this channel becomes “less rejected” by the MUX on the adjacent channel and it therefore contributes to a decreased OSNR of that neighboring channel. A wavelength drift is therefore an advance warning of an OSNR degradation. In the same manner, the peak power information is important as it is part of the OSNR equation. It is the OSNR that is usually adjusted at the commissioning of a system to optimize the performance of the system on all channels.

iv Note that the same can be said of a Q-factor measurement, which (although acquired at faster rates than the OSNR data from the spectrum) is generally performed at undersampled rates orders of magnitude below the actual transmitted bit rate.

v The noise-equivalent bandwidth (NEBW) of an instrument is the width of an ideal rectangular flat-top filter with summit at the peak and encompassing the same area under the curve as the instrument's response to a narrow peak (delta function). The value of the NEBW or resolution bandwidth (RBW) of an OSA is sometimes quoted as the full width at half maximum (FWHM or 3 dB width) as their values are generally close on OSAs.

vi When the noise level displays variations, as might be the case when signal channels travelling different routes with different span lengths and number of amplifiers have been combined or near the edge of an amplifier gain region, it may be useful to measure an average noise value over a number of points to increase the repeatability of the measurement. In the case of an even flat noise, such averaging does not improve the repeatability of the measurement, nor does it have a negative impact on the measurement, provided the width of measurement is adequately chosen. Typically, a measurement range of ~10 % of the measurement distance from the peak is an adequate choice of width.

Notes (cont'd)

vii That remains true because, provided that the ORR criterion mentioned in this document is met and the noise measurement is not influenced by the instrument's optical filter limitation, the broad noise level is approximately flat compared to the RBW and the noise level measured scales proportionally to the RBW.

viii Note that the draft standard did not specify the margin required, which would make this part of the recommendation coherent with the ORR requirement.

ix The standard uses the term dynamic range, which may lead to confusion with the instrument's maximum-to-minimum power measurement range. The term ORR is, therefore, more appropriate.

x Section 4.4.5 of the standard presents the following equation to evaluate the OSNR uncertainty introduced by ORR limitations at a given distance from the peak (mid-channel spacing):

$$\pm\partial OSNR = 10 \times \log\left(1+10^{-(ORR-OSNR)_{[GHz]}\,(dB)/10}\right)$$

where a 10 dB margin (ORR – OSNR = 10) yields a ±0.42 dB uncertainty on the measurement.

xi In practice, an unmodulated distributed-feedback (DFB) laser with a linewidth of a few MHz, orders of magnitude narrower than the OSA filter response, can be used as the source to observe the filter response of the OSA.

xii Grating-based OSAs had traditionally been used in the lab and have made their way to the field in the last few years. They offer the best performance for measuring OSNR of available OSAs in the field and in the lab.

xiii The central peak powers have been corrected to eliminate connector mating loss and absolute calibration errors. The fixed offset correction was < 0.5 dB and was applied to the entire curve.

xiv All specifications were valid at time of publication. For up-to-date specifications, please refer to respective manufacturers' websites.

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