White Paper

How to Measure the True OSNR in ROADM-Based Networks

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ROADM-Based Networks

Reconfigurable Optical Add Drop Multiplexers (ROADMs) are key elements for building a dynamically reconfigurable dense wavelength division multiplexing (DWDM) network or Agile Optical Network (AON). The AON accelerates triple-play service deployment and enables advanced wavelength applications at a much lower cost.

Figure 1. Agile optical network with ROADMs

While ROADM-based networks are more economical, they also present new measurement challenges for optical testing. The optical signal-to-noise ratio (OSNR) is the key performance parameter in optical networks for predicting the bit error rate (BER) of the system. An optical spectrum analyzer used to measure the OSNR fairly easily. Now, with ROADM-based networks new measurement methods must be deployed.

Executive Summary

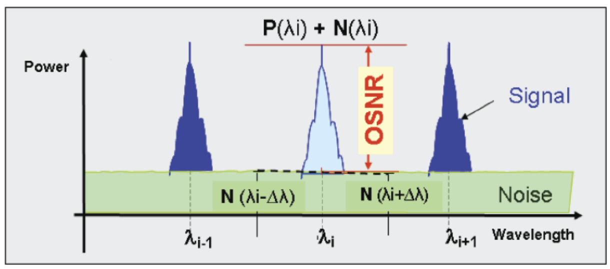
Several things are very clear about ROADM-based networks regarding the ability to measure the true OSNR:

- The typical signal shape is absent on a ROADM-based network.
- The OSNR measurement of one filter differs from that of a cascade of multiple ROADMs.
- A deployed ROADM-based network (typically 15 to 20 ROADMs cascaded) offers a wide variation of filter shapes and signals.
- Choosing an OSA to install, troubleshoot, and maintain a ROADM-based network requires getting the right answer.

The following discussion will show that the JDSU Optical Polarization Splitting (OPS) method, based on the Optical Polarization Nulling technique, is the only field method available to provide the true OSNR in all ROADM deployment scenarios.

OSNR Measurement Basics

IEC 61280-2-9 test procedure 2-9 defines the standard for measuring the OSNR. Figure 2 illustrates the linear interpolation method, which is based on the averaging of the noise levels to the left and right of the channel peak leading to the out-of-band OSNR result.

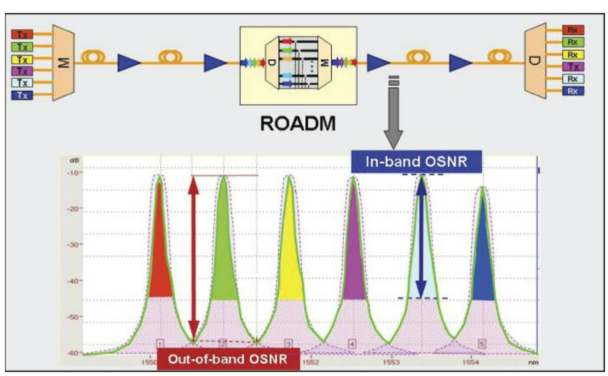


P = Signal power
N = Noise power
λi = Wavelength of channel i
N(λi) = ½ x [N(λi-Δλi) + N(λi+Δλi)]
OSNR = P(λi) / N(λi)

Figure 2. Linear Interpolation method (IEC 61280-2-9, Test Procedure 2-9

The ROADM-based Network Challenge

In high-speed optical networks based on ROADMs, each channel may traverse through different routes, optical amplifiers, and add-drop filters. As a result of these different paths, noise levels of adjacent channels may vary. In-line optical filters used for demultiplexing the channels inside the ROADMs also suppress the noise in between optical channels. Therefore, using the linear interpolation method (out-of-band measurement) gives no indication of the noise present at the actual channel wavelength, resulting in an incorrect OSNR value. Figure 3 shows that getting the true OSNR value requires an in-band OSNR measurement.



D = Demultiplexer
M = Multiplexer

Tx = Transmitter
Rx = Receiver

Figure 3. Comparison between out-of-band OSNR method and in-band OSNR method

OSNR Measurement Solutions

To measure the true OSNR, it is essential to gain access to the noise level inside the optical transmission band of the ROADM filters, or the in-band noise. Three approaches can be employed to perform "in-band" noise measurements:

1. Shoulder method software-based solution with conventional optical spectrum analyzer (OSA)
2. Polarization diversity detection limited polarization nulling technique
3. Polarization splitting method advanced polarization nulling technique

The following provides a closer look at the three solutions.

Shoulder Method

Theory:

Some test vendors may claim that even though the automatic OSNR measurement is wrong, one can manually measure OSNR with visual markers. This is the shoulder method. The "shoulder method" is based on the assumption that there will be a hump on either side of the peak indicating the noise shape of the optical filter, as shown in Figure 4. With the manual mode, the noise is measured at this hump.

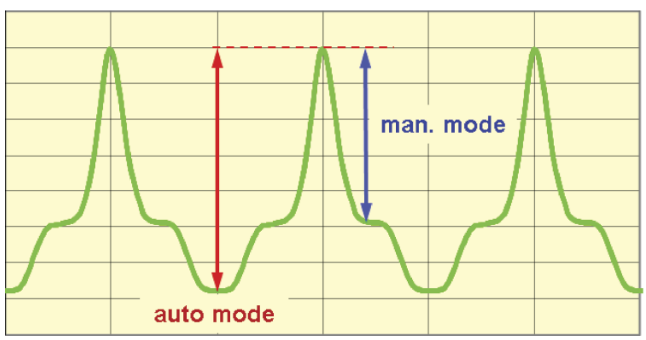


Figure 4. OSNR measurement based on shoulder method

Result:

In high-speed optical networks the bandwidth of the optical signal will almost be as large as the filter bandwidth leading to a very smooth transition between the noise and the signal.

Figure 5 shows the situation for 10 Gbps and 40 Gbps signals passing a single ROADM with 100 GHz filter (=100 GHz channel spacing).

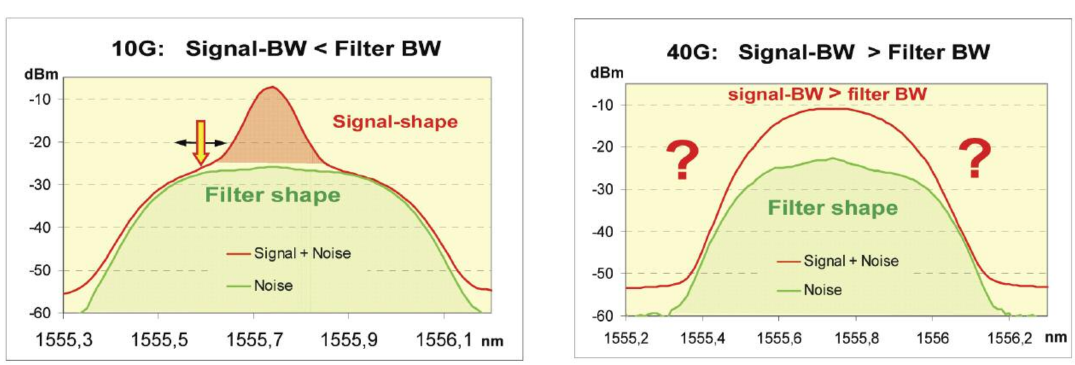


Figure 5. Optical spectrum of 10 Gbps and 40 Gbps after a ROADM (the red trace shows the measurement result of an OSA)

For better understanding, the noise floor inside the transmission band indicating the ROADM filter shape is indicated in green. A small hump is present for 10 Gbps signals but no hump is present at 40 Gbps. In ROADM-based networks, multiple ROADMs are cascaded leading to a narrowing of the filter shape making it almost impossible to detect a hump for accurate noise measurement even at 10 Gbps.

Conclusion:
The shoulder method makes it impossible to accurately measure the in-band noise floor in high-speed networks at data rates of 10 Gbps or higher (40/43 Gbps), which makes it impossible to measure the true OSNR.

Polarization Diversity Detection

Theory:
Polarization diversity detection is based on the polarization nulling principle supported by the fact that the optical transmission signal consists of arbitrary polarized light, whereas the amplified spontaneous emission noise (ASE) consists of only non-polarized light. Installing an optical polarizer in the light path will either block or pass the optical signal depending on the state of polarization (SOP) of the input signal. The block diagram in Figure 6 shows the polarization diversity detection technique.

The polarization splitter will separate the input signal in two orthogonal polarization states (SOP-1 and SOP-2) suppressing the polarized transmission signal and passing the non-polarized noise.

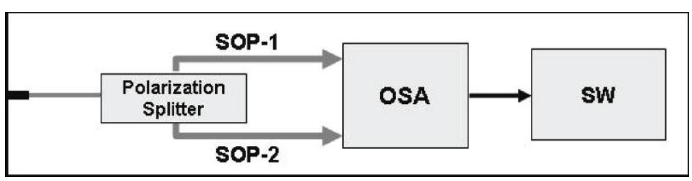


Figure 6. Block diagram polarization diversity detection

Though not common, some within the industry believe that by separating two orthogonal polarizations there is always a condition that shows the noise shoulders, which allows for direct measurement of in-band noise.

Result:
In ROADM-based systems the SOP of the optical transmission signal varies from channel to channel. The polarization splitter provides a fixed SOP. The suppression of the polarized transmission signal depends on the matching of the SOP between the input signal and the polarization splitter. The suppression can vary by 15 to 20 dB as shown in Figure 7.

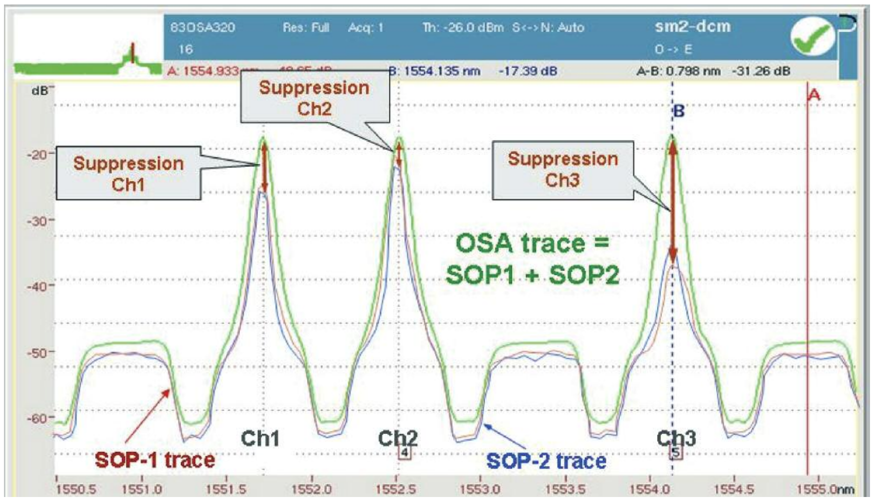


Figure 7. OSNR measurement without using a polarization controller

The screen shows three 10 Gbps channels passing a ROADM built with 100 GHz optical filters.

The green curve shows the original trace of the OSA. The blue and the red traces show the measurement result of the two SOPs achieved by polarization-diversity detection.

As shown, the suppression of the signal differs from channel to channel. Whereas Ch3 shows higher suppression of the polarized transmission signal to estimate the noise shoulder, it is not possible to access the noise shoulder in Ch1 and Ch2 as the suppression is too low, which leads to a high measurement uncertainty with this method.

Conclusion:
Using polarization diversity detection makes it impossible to reliably measure the in-band noise and, therefore, impossible to measure the true OSNR.

Optical Polarization Splitting Method

Theory:

The drawback of polarization diversity detection is that the suppression of the polarized transmission signal depends on the matching of the SOPs between the transmission signal and the polarization splitter. JDSU provides an improved solution using an integrated variable polarization controller to adjust the polarization of the input signal to match the polarization splitter. This method is called Optical Polarization Splitting (OPS) method.

A polarization controller is used to adapt the SOP of the input signal to the polarization splitter for a maximum suppression of the polarized signal. The polarization splitter will separate the SOP in two orthogonal states (SOP-1 and SOP-2). The polarization controller is adjusted individually for each optical channel. Using the measurement result from SOP-1 and SOP-2 simultaneously, it is possible to obtain the true OSNR.

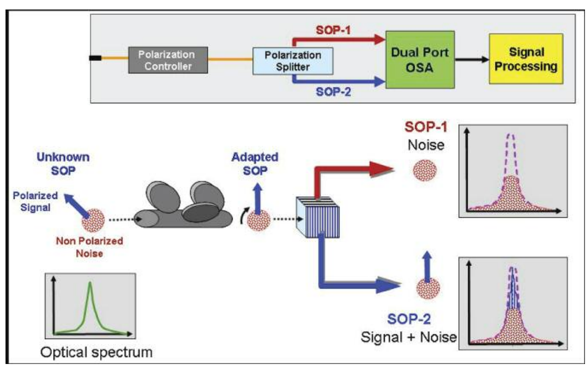


Figure 8. Block diagram of OPS method

Result:

Figure 9 shows the spectrum of a three-channel 10 Gbps system passing a ROADM built with 100 GHz optical filters.

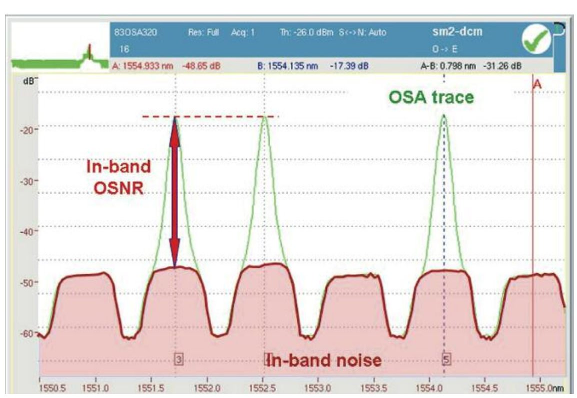


Figure 9. Measurement result of JDSU OPS method

The green trace shows the signal + noise measured with the OSA.

The red trace shows the suppression of the polarized transmission signal indicating the noise floor (in-band noise) measured using the OPS method thus leading to the true OSNR.

The OPS method will suppress the transmission signal individually for each channel providing access to the in-band noise floor. There is no limitation due to a missing shoulder or due to high bandwidth signals, for example, at 40 Gbps or 100 Gbps.

For further details, please refer to the JDSU technical note, "In-service measurements of the OSNR in ROADM-based Networks." Please contact the author, Wolfgang Moench, at wolfgang.moench@jdsu.com if you are interested in receiving a copy of the technical note.

Conclusion:
The OPS method makes it possible to measure the true OSNR of all optical channels with high accuracy under all conditions independent from data rate and modulation format.

Test Results

To verify the different methods used to measure the true OSNR in ROADM-based networks, use the following test setup with eight channels passing two ROADMs, as shown in Figure 10.

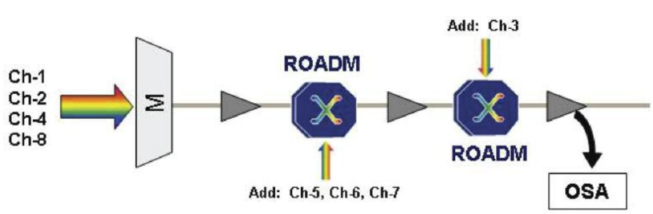


Figure 10. Test setup with eight channels

Channels 1, 2, 4, and 8 pass through the express route in the ROADMs.

Channels 3, 5, 6, and 7 were added in the ROADMs.

Figure 11 shows the results of using different methods to measure the OSNR.

Ch	Expected OSNR	Measured OSNR		
		S	E	JDSU
1	30,0 dB	28,3 dB	29,6 dB	29,5 dB
2	30,0 dB	23,2 dB	30,8 dB	29,6 dB
3	14,0 dB	18,0 dB	15,3 dB	13,9 dB
4	28,5 dB	15,6 dB	22,8 dB	28,1 dB
5	13,8 dB	12,2 dB	13,7 dB	13,4 dB
6	13,8 dB	16,4 dB	14,2 dB	13,6 dB
7	13,8 dB	26,4 dB	14,1 dB	13,5 dB
8	28,0 dB	28,8 dB	23,2 dB	28,5 dB

Figure 10. Test setup with eight channels

The results in Figure 11 show that the traditional, out-of-band OSNR measurements failed in five out of eight channels by 3-13 dB (red fields in column S). Measuring the OSNR based on the polarization diversity detection results in incorrect OSNR values for three out of eight channels (orange fields in column E). The only method providing accurate measurements for all channels is the JDSU OPS method (green fields in JDSU column).

Conclusion:
The JDSU OPS-method with integrated polarization controller is the ONLY method that provides accurate and reliable measurements of the true OSNR in all ROADM deployment scenarios.

References:

JDSU Technical Note: "Measuring the Optical Signal-to-Noise Ratio in Agile Optical Networks"
W. Moench, J. Larikova, "In-service measurements of the OSNR in ROADM-based Networks," ECOC 2007 P118

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