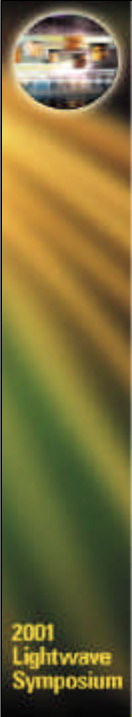


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Making OSNR Measurements
In a Modulated DWDM
Signal Environment



Jack Dupre
Jim Stimple

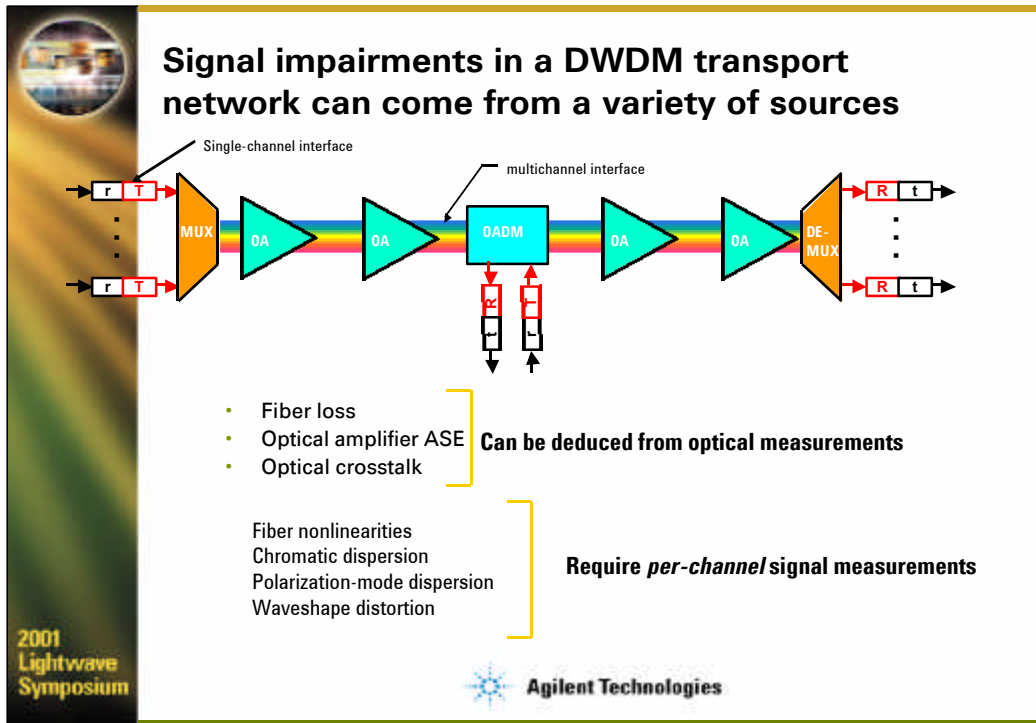
Making OSNR measurements in a modulated DWDM signal environment

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In a DWDM spectrum, it is desirable to measure the optical signal-to-noise ratio (OSNR) of each channel in order to gauge signal quality. A standardized definition and test method is described.

With higher modulation rates and narrower channel spacing, the modulation sidebands from adjacent channels interfere and limit the ability to measure the noise level between channels. Increasing the resolution of the optical spectrum analyzer does not affect this limitation. This paper provides simulations and actual measurements demonstrating the OSNR limit for 50-GHz channel spacing and modulation rates of 2.5 and 10 Gb/s.



In the unrelenting move toward all-optical networking, there are increasingly larger segments of the network in which there is no optical- to-electrical conversion. Here is shown an example of such a network section. Interfaces to this network section are standardized single-channel interfaces. As the DWDM signals propagate through the network, signal impairments that impact overall system quality can occur.

At the multichannel optical interfaces within such a network segment, it is desirable to measure parameters that provide information about signal quality. Such parameters are necessary in the *manufacture* of network elements, the *installation* of the network, and in *performance monitoring* of the operating network.

Ideally, such parameters would directly correspond to the bit error ratio (BER) of each channel of a multichannel carrier at the particular optical interface. Related parameters such as Q-factor or optical eye patterns would provide similar information and could be correlated to per-channel BER. However, it is difficult to obtain access to these parameters at a multichannel interface point. It is necessary to demultiplex the potentially large number of channels and make BER, Q-factor, or eye-diagram measurements on a per-channel basis.

In contrast, useful information about the optical properties of the multichannel carrier is readily obtained by measuring the optical spectrum. Wavelength-resolved signal and noise levels provide information on signal level, signal wavelength, and amplified spontaneous emission (ASE) for each channel.



OSNR in a transport network is dependent upon optical amplifier noise figure

single span

Span loss L (dB)

Signal-spontaneous noise figure* F (dB)

P_{out}

ASE(1)

$$OSNR = P_{out} - L - F - 10 \text{ Log} (h\nu B_r)$$

where h is Planck's constant
 ν is optical frequency
 B_r is the reference optical bandwidth

N spans

L (dB)

F (dB)

OA

L (dB)

F (dB)

OA

L (dB)

F (dB)

OA

P_{out}

ASE(N)

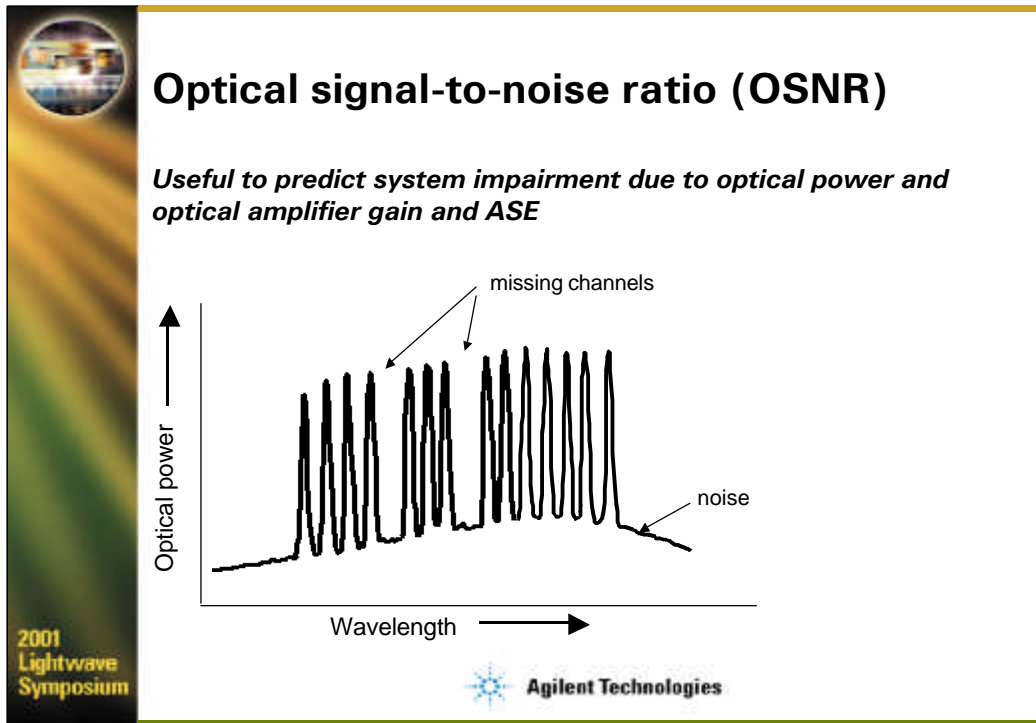
$$OSNR = P_{out} - L - F - 10 \text{ Log} (N) - 10 \text{ Log} (h\nu B_r)$$

* Signal-spontaneous noise figure is defined in IEC Publication 61290-3, Basic specification for optical fibre amplifiers test methods – Part 3: Test methods for noise figure parameters

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For a transport network, the OSNR can be calculated for given system parameters including span loss and optical amplifier gain and noise figure. It is therefore a useful parameter to determine if a system is performing to its designed performance.



A typical optical spectrum at a multichannel interface is shown here.

Important characteristics are:

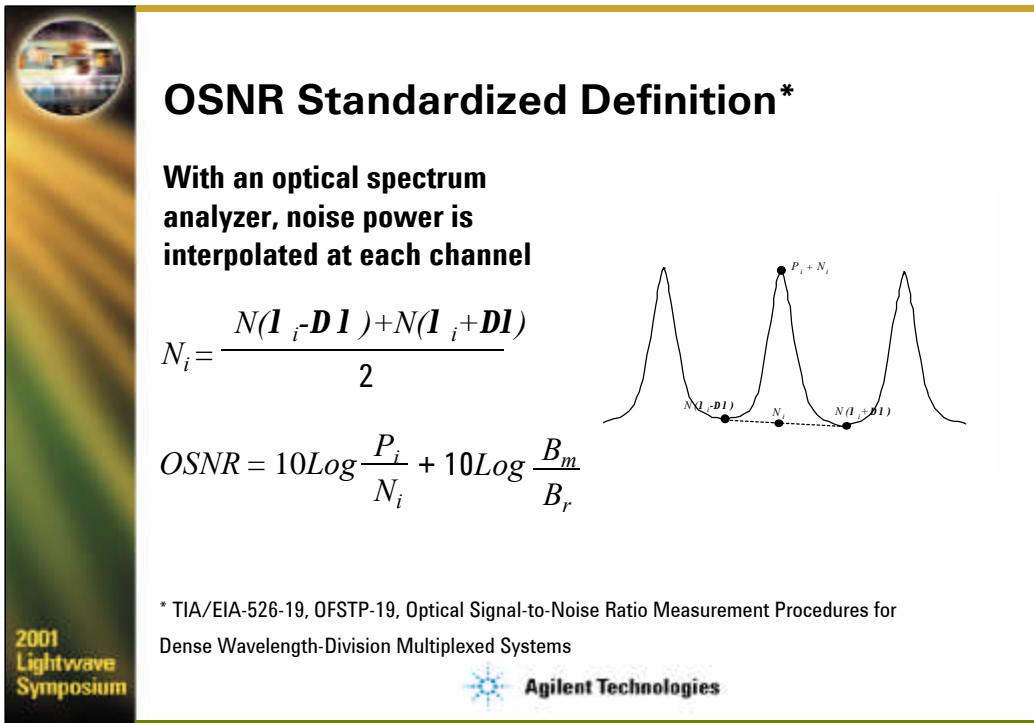
(a) The channels are placed nominally on the grid defined by ITU G.692.

(b) Individual channels may be non-existent because it is a network designed with optical add/drop demultiplexers or because particular channels are out of service.

(c) Both channel power and noise power are a function of wavelength.

For calculating OSNR, the most appropriate noise power value is that at the channel wavelength. However, with a direct spectral measurement, the noise power at the channel wavelength is included in signal power and is difficult to extract. An estimate of the channel noise power can be made by interpolating the noise power value between channels.

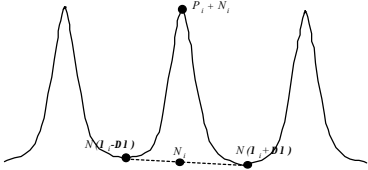




OSNR Standardized Definition*

With an optical spectrum analyzer, noise power is interpolated at each channel

$$N_i = \frac{N(I_i - DI) + N(I_i + DI)}{2}$$

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


* TIA/EIA-526-19, OFSTP-19, Optical Signal-to-Noise Ratio Measurement Procedures for Dense Wavelength-Division Multiplexed Systems

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In the figure:

P_i is the optical signal power in watts at the i -th channel.

N_i is the interpolated value of noise power in watts measured in noise equivalent bandwidth, B_m , at the i -th channel.

DI is the interpolation offset equal to or less than one-half the ITU grid spacing,

B_r is the reference optical bandwidth. (The units for B_m and B_r may be in frequency or wavelength but must be consistent.) Typically, the reference optical bandwidth is 0.1 nm.

Note that in the equation for OSNR, there is an adjustment to convert the OSA measured value of noise to that in the reference bandwidth. Also, the signal power is obtained by subtracting the the measured noise value.



Modulated source spectral width can cause an error in *signal* measurement

Power Envelope for 10 Gb/s 2⁷-1 PRBS

0.06 nm Resolution Bandwidth Shape

OSA resolution bandwidth set too narrow will not capture all source power

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The slide features a graph of the power envelope for a 10 Gb/s 2⁷-1 PRBS signal. The x-axis represents wavelength in nm, ranging from 1580 to 1620. The y-axis represents power in dBm, ranging from -20 to 20. The graph shows a series of peaks and valleys, with a smooth curve overlaid. A green arrow points to the curve, and another green arrow points to the peaks. To the right of the graph, a text box indicates '0.06 nm Resolution Bandwidth Shape'. Below the graph, the text 'OSA resolution bandwidth set too narrow will not capture all source power' is displayed in bold. The slide also includes the Agilent Technologies logo and the text '2001 Lightwave Symposium' in the bottom left corner.

The spectral width of each channel is broadened from that of the CW laser due to several causes:

- (a) laser chirp
- (b) intensity modulation for signal transmission
- (c) modulation to suppress stimulated Broullion scattering (SBS).
- (d) self-phase modulation (SPM)

For dense WDM systems in which external modulation is generally used, laser chirp is not a factor. Broadening due to SBS suppression and SPM are typically small compared to the broadening due to the signal modulation at 2.5-Gb/s and higher rates.

If the OSA resolution bandwidth is too narrow, the measured signal power will be lower than the true signal power.



Wide RBW required to avoid errors in signal measurement

2.5 Gbit/s NRZ Modulation¹

Amplitude Error dB

Resolution Bandwidth nm

~0.5 dB error with 50 pm RBW

10 Gbit/s NRZ Modulation²

Amplitude Error dB

Resolution Bandwidth nm

~2.5 dB error with 50 pm RBW

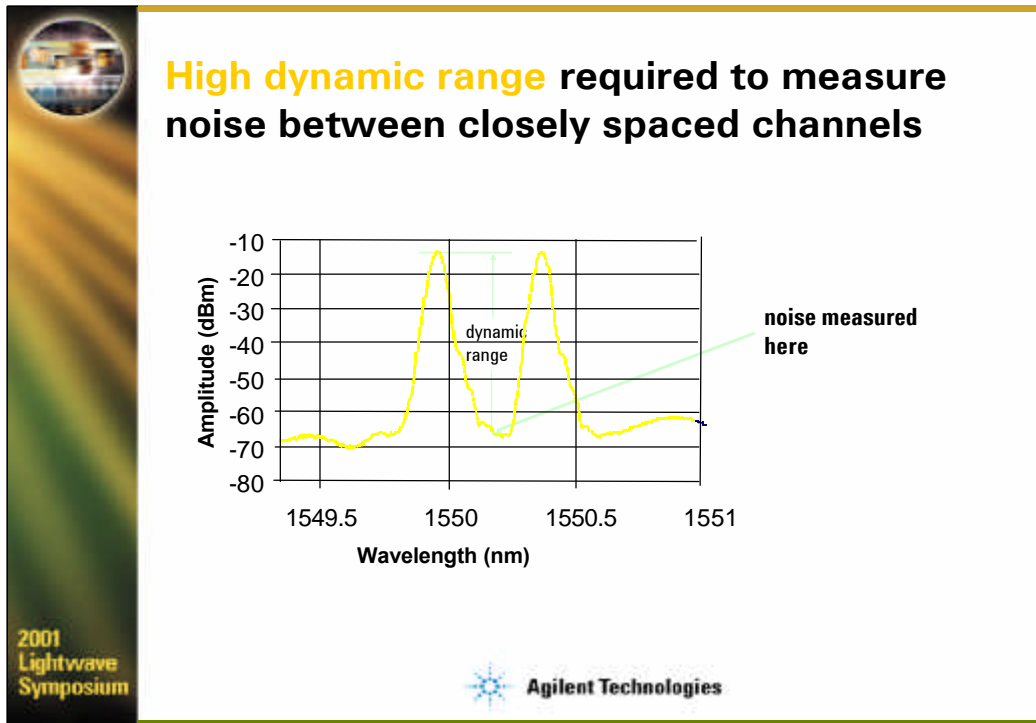
¹ Assumes 7.5-GHz electrical and 0.36-nm optical filtering with zero chirp.

² Assumes 30-GHz electrical and 0.64-nm optical filtering with zero chirp.

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Because a portion of the signal power is not captured by the OSA, an error in the measured signal power occurs. These charts show the magnitude of the error for 2.5-Gb/s and 10-Gb/s data rates respectively.

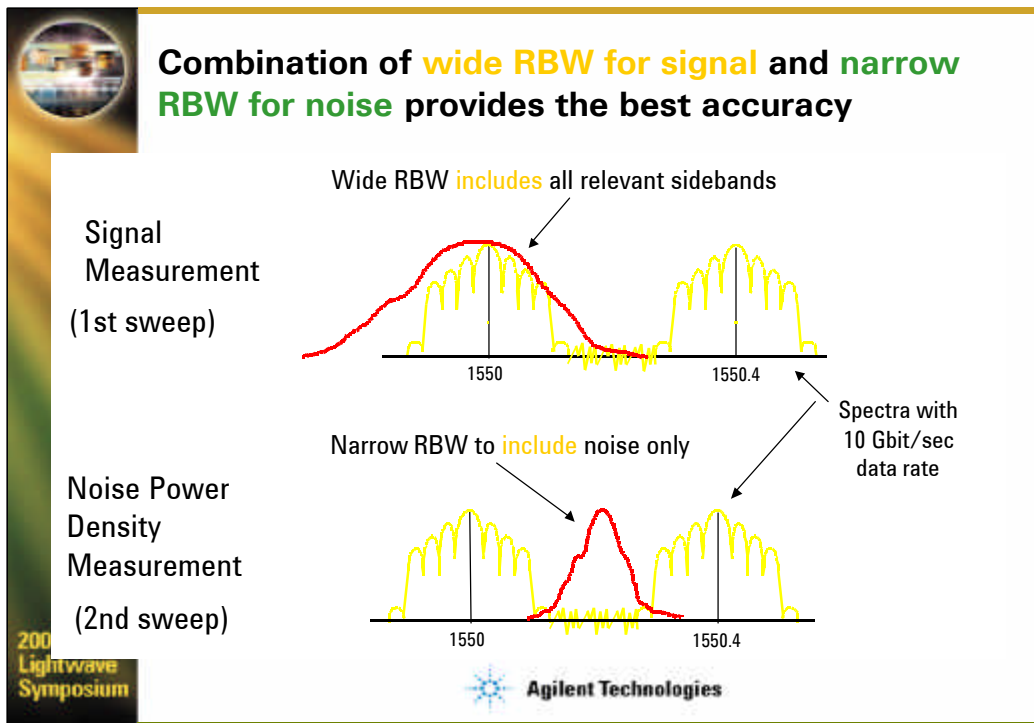
To minimize the error in the signal power measurement, a resolution bandwidth of sufficient width should be chosen. For less than 0.1-dB error and the modulated signal condition shown on the graphs, the RBW should be wider than 0.09 nm for 2.5 Gb/s and 0.2 nm for 10 Gb/s.



In order to accurately measure the noise between channels, the optical spectrum analyzer's dynamic range must be sufficiently high.

The dynamic range of an OSA is a measure of the OSA's ability to make measurements of low-level signals and noise that are close in wavelength to large signals. It is important to note that narrowing the RBW does not necessarily correlate to better dynamic range. RBW is a measure of the 3-dB bandwidth or noise equivalent bandwidth of its filter characteristic. Dynamic range, on the other hand, is a measure of the steepness of the filter characteristic and the OSA noise floor. Dynamic range is defined as the ratio, in dB, of the filter transmission characteristic at the center wavelength, f_c , and at one-half a grid spacing away, $f_c \pm D_1$.

The OSA's dynamic range must exceed the expected noise level by at least 10 dB. For example, if the grid spacing is 50 GHz, and the expected OSNR is 25-dB, the dynamic range must be at least 35-dB at ± 25 GHz for a 0.1-nm RBW setting. If the RBW is reduced to 0.05 nm, the OSNR requirement increases to 38 dB.




For narrow channel spacing, finding a single RBW setting that is optimum for both signal and noise measurement is difficult. As discussed, the signal measurement requires a setting that is sufficiently wide to accommodate the chirped modulated signal. The noise measurement requires high dynamic range that usually means a narrower RBW setting.

The solution is to take two consecutive sweeps of the OSA with different RBW settings. As shown, the first sweep measures the signal power at each channel and the second sweep measures the noise power between channels.



Agilent OSAs automatically measure OSNR in a DWDM signal environment



Each signal is marked and numbered

Easy to read table of:

- Channel number
- Channel Wavelength
- Channel Power
- Channel OSNR
- Span Tilt
- Peak to Peak Deviation

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Features of Agilent’s WDM Channel Analysis Application:

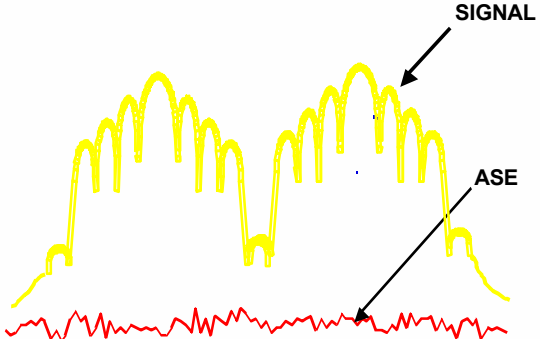
- Uses two sweeps to accurately measure both signal power and noise floor power density
- Uses “noise markers” that are corrected for OSA filter shape to more accurately measure noise floor power density
- Utilizes OSA’s 10 pm wavelength accuracy for an accurate center wavelength measurement
- Measures OSNR, center wavelength, peak to peak deviation, span tilt for signals spaced down to and including 50 GHz
- Remote control capable

Three choices for the position of the noise measurement are available:

1. Between channels - user inputs channel spacing and the application will measure noise halfway in between the channels (standardized definition).
2. Pit - the application will find the pit (lowest point) in between channels and use this as the noise measurement.
3. Specified offset- the user inputs an offset, noise is then measured at this offset away from the channel peak.



Modulation sidebands limit the measurement of the ASE level



"True" OSNR cannot be measured by conventional means

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As modulation rates have increased and channel spaces have narrowed a limitation is imposed on the measurement of the actual noise level. As shown here, the optical spectrum between channels is dominated by modulation sideband power. The ASE level is too low to be measured by conventional means.

An OSNR value can still be measured but its meaning has changed. It becomes a "signal-to-modulation sideband ratio". While it may still be a useful parameter, it does contain information about the build-up of ASE in a system.



Signal simulation methodology

1. Calculate spectral envelope for PRBS modulation
2. Bandpass filter the spectral envelope
3. Convolve with simulated OSA resolution bandwidth filter

$$P(f) = \left| \sin \left[\frac{(f-f_o)}{2\mathbf{P}f_m} \right] \right| / \left| \frac{(f-f_o)}{2\mathbf{P}f_m} \right|$$

where $f_m = \text{bit rate}/2$ for NRZ format
 $= \text{bit rate}$ for RZ format

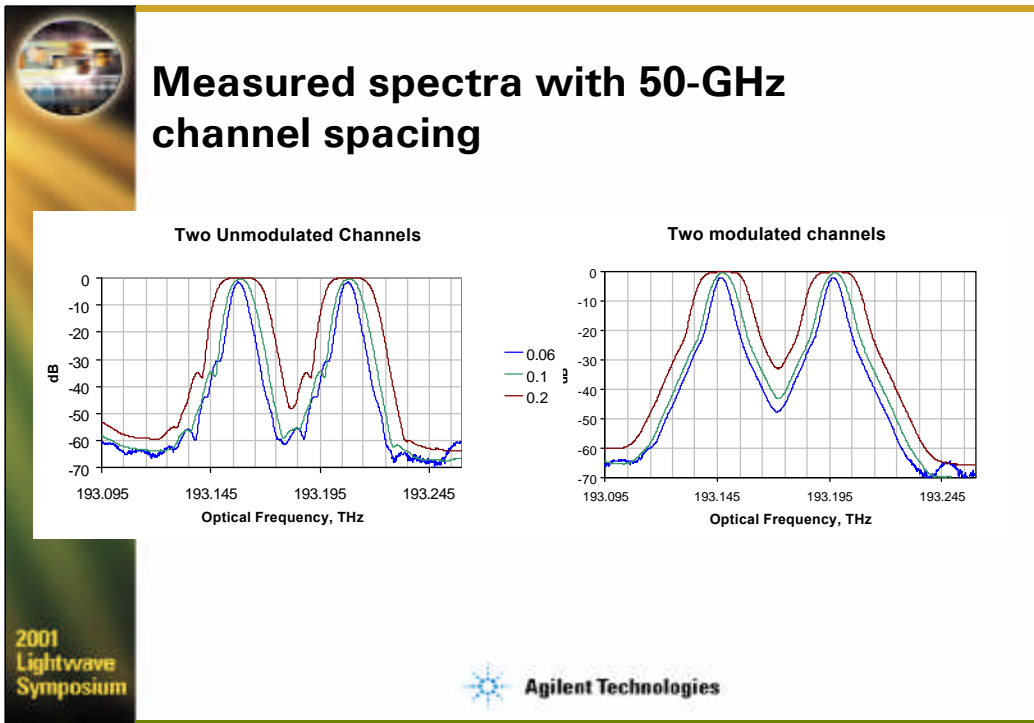
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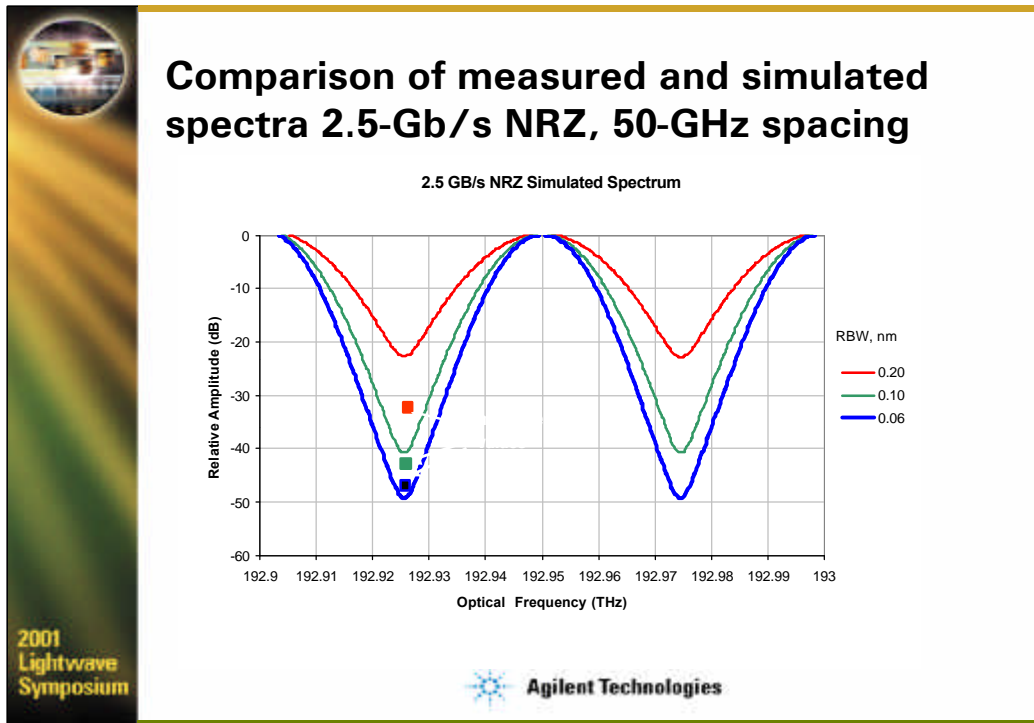
To determine noise measurement limitations imposed by modulation sidebands, a simple simulation is used. The spectral envelope for PRBS modulation is the familiar $\sin(x)/x$ function.

Because the signal envelope is filtered electrically in the modulation circuitry and optically in the demultiplexing filter, the simulation performs a bandpass filter function on the modulation envelope. Typical filter bandwidths are two to 5 times the bit rate.

An optical spectrum analyzer's resolution bandwidth filter characteristic is simulated by a Gaussian function

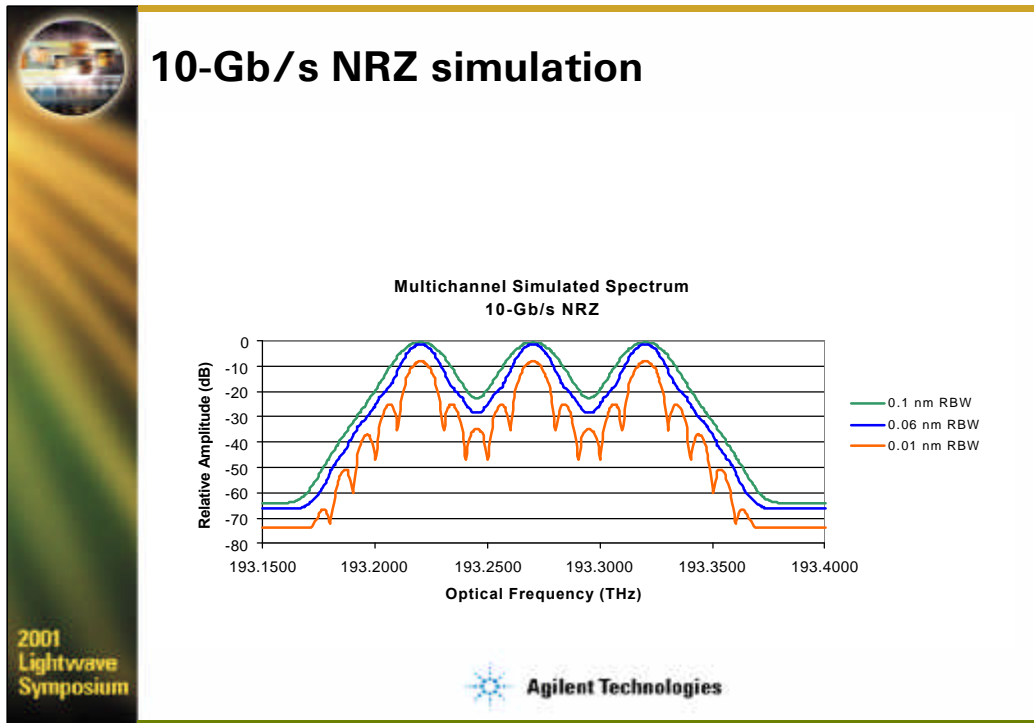


To validate the simulation, the spectrum of two laser sources separated by 50-GHz was observed on an OSA. The OSA's resolution was set to 0.06, 0.1, and 0.2 nm. Note that depth of the null between the signals is significantly less with the modulation turned on. In this case, the modulation was 2.5-Gb/s NRZ.

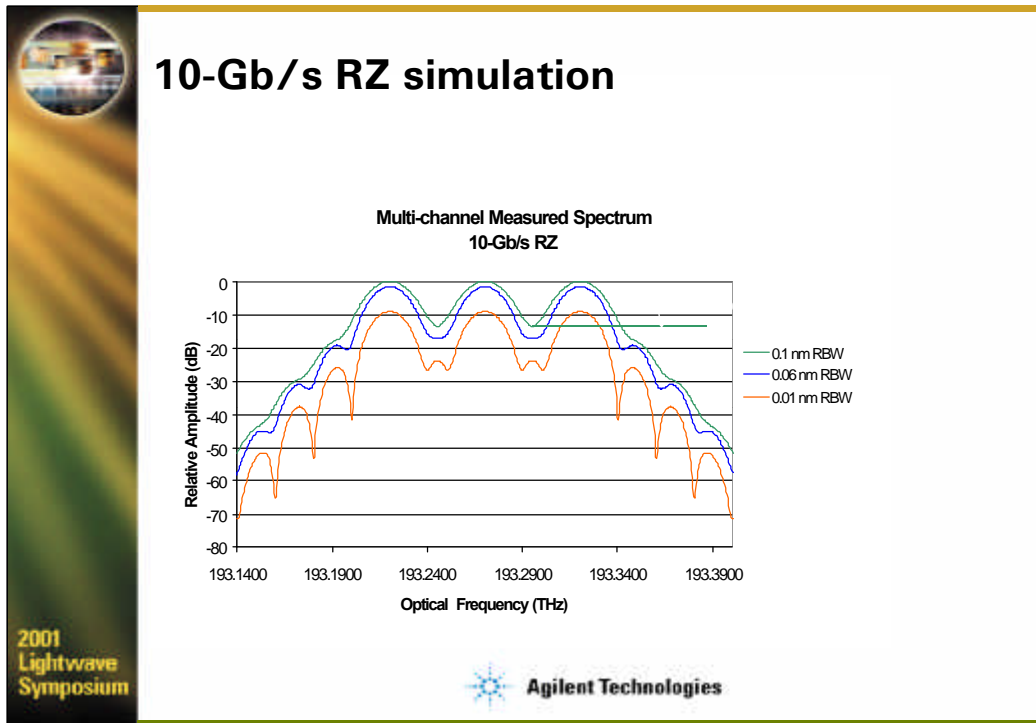


Here is the simulated data for the modulated spectra shown in the previous slide. The measured value of the minimum between signals is reasonable close to the simulation (< 2 dB) for the 0.06 and 0.1 nm resolution bandwidth settings. The 0.2-nm RBW, however, is considerably different. This can be explained by the fact that the OSA's wider RBW settings have filter characteristics that are more rectangular than Gaussian. An assumption of Gaussian shape was used in the simulation. The narrower RBW values tend to be more Gaussian in shape and give better agreement with the simulation.

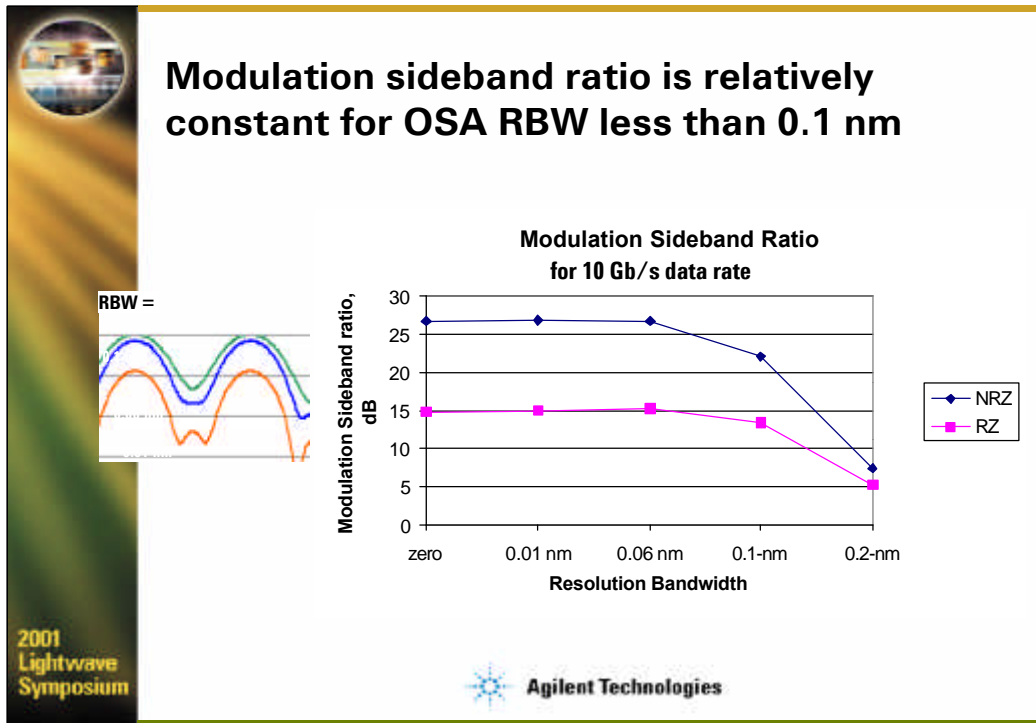
A bandwidth of four times the bit rate (10-GHz) was used which approximates the electrical bandwidth of the lasers modulation circuitry.




Now, we will look at simulations of 10-Gb/s modulation with three channels separated by 50 GHz. For the NRZ format a bandwidth of 2.5 times the clock rate or 25-GHz is assumed. Shown are the calculated spectra as would be observed on a optical spectrum analyzer for resolution bandwidth settings of 0.1, 0.06, and 0.01 nm. With the widest RBW, 0.1 nm, the signal peaks are identifiable and the modulation depth is only 22 dB. As the RBW is decreased to 0.06 and 0.01 nm, the depth of the modulation between signal peaks is increased. At 0.01-nm RBW, the spectral detail of the modulated carrier can be observed.



This is the same simulation but for RZ modulation. The bandwidth, still at 2.5 times the clock rate, has been increased to 50 GHz. We will define the ratio of the spectral amplitude at the signal peaks to the amplitude halfway between the signal peaks as the *modulation sideband ratio*. The modulation sideband ratio is less for RZ modulation due to the increased bandwidth requirement.



The modulation sideband ratio is charted here for resolution bandwidth setting of zero to 0.2 nm for NRZ and NRZ modulation formats. The important thing to note is that decreasing RBW below 0.06 nm does not change the measured value of the modulation sideband ratio. This has some interesting implications on the measurement of OSNR.

Implications on OSNR measurements

Procedure to obtain OSNR from 10-Gb/s data rate simulations:


1. Obtain the *signal* value from a wide (0.2 nm) RBW
2. Obtain the modulation-limited power spectral data halfway between channels for each RBW
3. Adjust the value in step 2 to convert to a 0.1-nm reference bandwidth.

OSNR Limit Imposed by 10-Gb/s Modulation, dB

	0.2-nm RBW*	0.1-nm RBW*	0.06-nm RBW*	0.01-nm RBW*
NRZ format	(11.1)	23.3	26.6	25.5
RZ format	(8.3)	14.8	16.1	15.3

Decreasing the OSA RBW below 0.06-nm does not significantly change OSNR value !

*For the noise measurement



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As discussed before, it is best to measure the OSNR by taking to OSA sweeps: one to obtain the signal power and the second the noise power. Because OSNR is defined for a particular reference optical bandwidth, usually 0.1 nm, the noise value needs to be corrected for the reference optical bandwidth.

Using this algorithm for the 10-Gb/s modulated signal as discussed, the OSNR limit due to modulation sidebands is calculated and summarized in the table.

A perhaps surprising result is that decreasing the OSA's RBW below 0.06 nm has minimal effect on the OSNR limit.



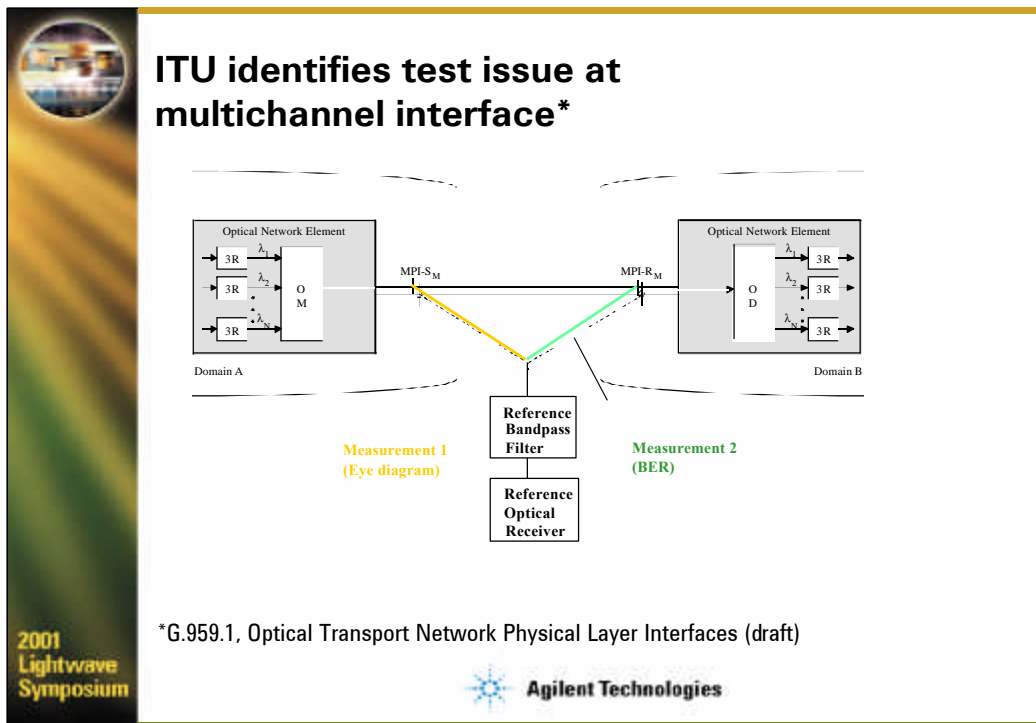
An alternative to OSNR when modulation-sideband-limited values are not sufficient to guarantee system performance

Filter a selected channel and route to *signal* measurement apparatus

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Earlier, it was mentioned that OSNR may be a useful parameter to measure the ASE build-up in a system. Clearly, with 10-Gb/s data rate and 50-GHz channel spacing, OSNR has limited utility. To achieve a better measure of signal quality, it may be necessary to filter each channel and route the selected channel to single channel measurement apparatus.



The ITU, in draft recommendation G.959.1, suggests that a meaningful multichannel interface performance measures require channel selection. Depending on whether the interface is at the transmit side or the receive side determines if an eye-diagram or a bit-error-ratio (BER) is more appropriate.

In either case, a reference filter followed by reference optical receiver is required.



Optical spectrum analyzer with filtered SMF output and DCA provide *spectrum* and *signal* measurements

multichannel input

Agilent 86141B H17 OSA
w/SMF filter mode

Agilent 86100 Infinium DCA

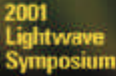
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An implementation of such a measurement system is an OSA with a filtered output capability such as the Agilent 86141B H17 followed by an Agilent 86100 Infinium Digital Communications Analyzer (DCA).

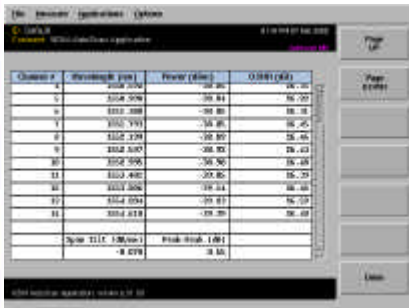

The OSA can perform OSNR, channel power and other spectral measurements. The DSA measures extinction ratio and eye-mask parameters with a standardized rate-specific reference receiver.






Key measurements

- Channel power
- Channel OSNR
- Tilt and peak-to-peak deviation
- Eye mask compliance
- Extinction ratio


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Using the built-in channel analysis application in the OSA, a tabular summary of wavelength, channel power, and OSNR is obtained. With the Infinium DCA, compliance to an optical eye-mask is tested.



Optical spectrum analyzer with filtered SMF output and DCA provide *spectrum* and *signal* measurements

multichannel input

Agilent 86141B H17 OSA
w/SMF filter mode


Agilent 83446A Lightwave Receiver

Agilent 86130A BitAnalyzer

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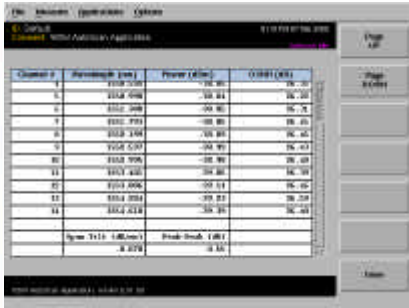
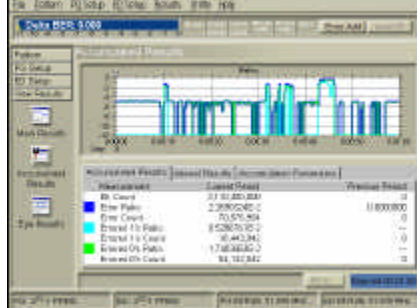



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Key measurements

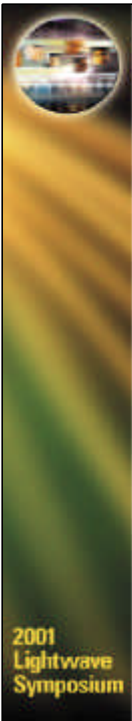
- Channel power
- Channel OSNR
- Tilt and peak-to-peak deviation

- Channel BER
- Channel Q-factor




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Summary

- OSNR is a valuable measure of system optical performance
- At 10-Gb/s and 50 GHz channel spacing, modulation spectra overlap putting a limit on the OSNR measured value that is not improved with narrower OSA RBW.
- A more-definitive measure of signal integrity is an optical eye-mask or BER measurement on each individual channel

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In summary, OSNR can be a useful measure of system optical performance but a combination of high data rate and narrow channel spacing limit OSNR as a measure of ASE build-up. The limit imposed by modulation sidebands is not improved by using a narrower OSA resolution bandwidth.

To obtain a more-definitive measure of signal integrity or quality at a multichannel interface, it is necessary to filter each channel and perform optical eye-diagram or BER measurements.