Spectral testing of active systems in lab and manufacturing environments

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1. INTRODUCTION

Any optical transmitter, whether it is a 100 Gbit/s line card or a pluggable, such as an SFP of QSFP28, includes optical subassemblies to generate the optical signal. The most basic component—the laser—gets integrated into increasingly more complex assemblies, up to forming the complete optical networking system (WDM or other). Each optical source, with its specific level of complexity, must be carefully tested and qualified. Spectral analysis, or the measurement of optical power as a function of wavelength and of related parameters, is a key part of a thorough optical source qualification. This document outlines the recommended tests in laboratory and manufacturing environments for each type of optical source.

This document has categorized the technical content in four sections. It is worth noting that each section is a key building block of the one.

1.1. Distributed feedback (DFB) lasers and Fabry-Perot (FP) lasers

These are the most basic optical sources, usually offered in a very small form factor. While Fabry-Perot lasers feature several side modes, DFB lasers present a more narrowband spectrum thanks to a Bragg grating that precisely selects the desired wavelength.

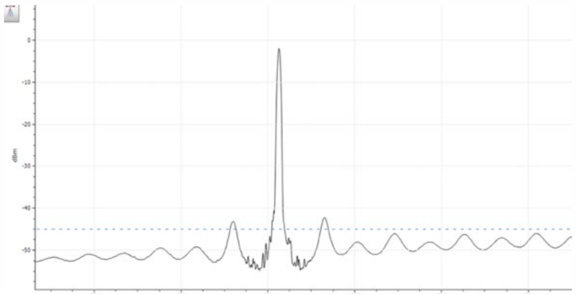


Figure 1. DFB optical spectrum

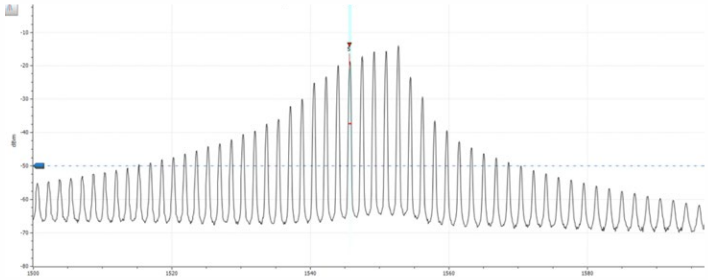


Figure 2. Fabry-Perot optical spectrum

1.2. Transmitter optical subassemblies (TOSAs)

TOSAs integrate one or many lasers, a multiplexer, and a laser driver in a metal or plastic housing. Depending on the application, they can also feature additional components, such as a photodiode monitor, cooling module, isolators, etc. TOSAs are used to couple the signal into an optical fiber.

1.3. Transmitters

Transmitters contain TOSAs as well as electronics to generate a meaningful optical data stream of a given protocol (OTN, Ethernet, etc.). These electronic components can condition and encode/decode the data into light pulses, manage the signal clock, etc.

1.4. Optical systems

A full optical system, usually based on wavelength division multiplexing (WDM) technology, features several passive components and a length of optical fiber transporting the signal between transceivers (a combination of transmitter and receivers). In some longhaul networks, the span of fiber is so long that the signal required amplifiers, often based on Erbium-doped fiber, to regenerate the signal without adding an excessive amount of optical noise to the system.

2. SPECTRAL TESTING OF LASERS

The spectral testing of DFB versus FP lasers share both similarities and differences. In both cases, critical measurements include central wavelength and optical power. For DFB lasers, the side mode suppression ratio (SMSR) is a key pass/fail criterion in manufacturing, since it qualifies how effectively the laser eliminates unnecessary side modes. SMSR can be obtained by computing the power difference between the main mode and first side mode (Figure 3). Figure 4 shows the measurements provided by EXFO's OSA in DFB mode.

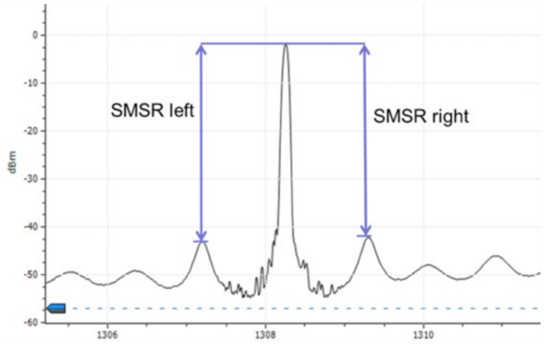
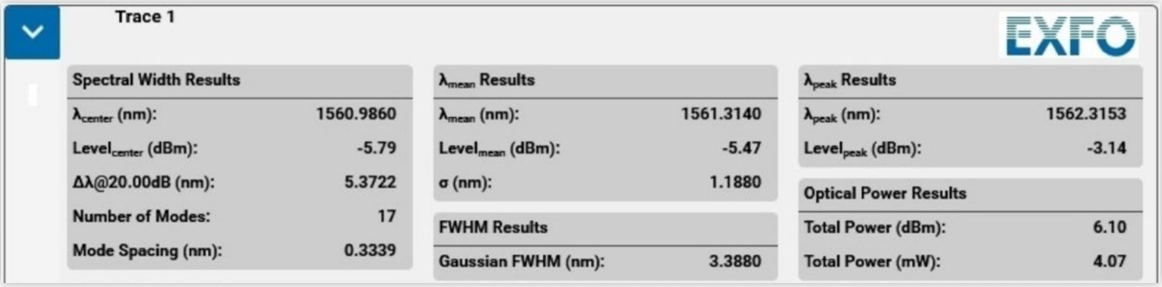


Figure 3. SMSR definition

Center wavelength:	1530,331 nm	Worst case SMSR:	51,45 dB
Peak power:	5,15 dBm	Worst case SMSR position:	1530,895 nm
Bandwidth at 3.00 dB:	0,031 nm	Left stopband:	0,443 nm
Bandwidth at 20.00 dB:	-	Right stopband:	0,564 nm
Left SMSR:	59,36 dB	Central offset:	-0,060 nm
Right SMSR:	51,45 dB	Fabry-Perot mode spacing:	0,675 nm

Figure 4. DFB mode display on EXFO's FTBx series of OSAs

In the case of FP lasers, the full width half maximum (the spectral width of the main mode 3 dB below the peak) is another common key performance indicator.



Spectral Width Results	
λ_{center} (nm):	1560.9860
$Level_{center}$ (dBm):	-5.79
$\Delta\lambda$@20.00dB (nm):	5.3722
Number of Modes:	17
Mode Spacing (nm):	0.3339

λ_{mean} Results	
λ_{mean} (nm):	1561.3140
$Level_{mean}$ (dBm):	-5.47
σ (nm):	1.1880

FWHM Results	
Gaussian FWHM (nm):	3.3880

λ_{peak} Results	
λ_{peak} (nm):	1562.3153
$Level_{peak}$ (dBm):	-3.14

Optical Power Results	
Total Power (dBm):	6.10
Total Power (mW):	4.07

Figure 5. FP mode display on EXFO's OSA20

3. SPECTRAL TESTING OF TOSAS

Best practices for characterizing TOSAs follow very closely the measurements discussed in the laser section. The relevant measurements are:

- Center wavelength
- Power
- SMSR

Since TOSAs often contain a cooling module, a measurement of central wavelength as a function of temperature is also often performed. The 20 dB linewidth, i.e. the spectral width of the main mode 20 dB down from the peak, can also be of interest in manufacturing.

4. SPECTRAL TESTING OF TRANSMITTERS

As we move closer to system level testing, optical characteristics become more relevant at the expense of opto-electrical parameters, such as the threshold current. At the transceiver level, most vendors will focus on measuring:

- Central wavelength
- Power
- 20 dB linewidth
- SMSR

In addition, other protocol layer tests would be carried out on transmitters, such as throughput, bit error rate or latency.

5. SPECTRAL TESTING OF AMPLIFIERS

The amplifier is a key item of long-haul transmission systems. As such most testing of amplifiers will be performed as part of the optical system ensemble, the details of which we provide in the next section. However, testing amplifiers can also be performed independently, allowing a much better characterization of the instrument itself. To that extent, amplifier vendors will look to measure the performance of their instruments through the following keys parameters:

- Amplifier's spectral coverage
- Amplifier gain & gain flatness as a function of the wavelength
- Noise figure

Indeed, the gain defines the amount of amplification achieved by the amplifier, whilst the noise figure provides information about the quality of that amplification by quantifying the deterioration of the original signal caused by the noise arising out of the amplified spontaneous emission (ASE). This background noise leads as consequence to degrade the OSNR and to increase the bit error rate (BER).

Start: 1250.000 nm
Stop: 1700.000 nm
Center: 1475.000 nm
Span: 450.000 nm
Sensitivity: -60 dBm (700 nm/s)
Resolution: Native
Mode: Continuous
Start: Manual
Progress: 100 %
Scan: 47

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Int. ASE_{out} (dBm): 1.57
Total P_{IN} (dBm): -24.33
G Flat. (dB): 3.84
Total P_{OUT} (dBm): 9.53
G Slope (dB/nm): 0.0749
G_{Avg} (dB): 31.47

Ch	λ_{Meas} (nm)	P_{IN} (dBm)	Res (nm)	$Noise_{Amp}$ (dBm)	Gain (dB)	NF (dB)	$OSNR_{Amp}$ (dB)	S (%)
-7	1558.0117	-30.13	0.0198	-28.06	32.86	4.15	22.90	99.92
3	1550.1152	-28.51	0.0197	-26.71	32.08	6.22	21.94	99.91
13	1542.3586	-31.57	0.0201	-29.64	29.02	6.19	23.24	99.81
23	1534.5066	-33.02	0.0200	-33.30	31.92	5.94	27.09	99.94

Figure 6. OFA (optical fiber amplifier) mode display in EXFO's OSA20

6. SPECTRAL TESTING OF OPTICAL SYSTEMS

This last level of optical source integration involves simulating in laboratory the behavior of the transceivers in an optical network that replicates the topology of real networks: long fiber spans, amplifiers, maybe some reconfigurable add drop multiplexers (ROADMs), a large number of channels, etc. As such, the spectral measurements carried out on optical systems in laboratories, usually by verification groups, are very similar to those made in the field, on actual networks.

Spectral testing at that level can be challenging and requires specific acquisition methods to be developed to provide meaningful results. For example, simulating long-haul network involves a spectral measurement setup through a recirculating loop configuration, while passive optical networks (PON) require spectral acquisition of bursts of data, typical of this type of system.

The relevant parameters when testing WDM networks are:

- Channel identification
- Channel central wavelength
- Channel power
- Optical signal-to-noise ratio (OSNR))

6.1. Optical signal to noise ratio (OSNR)

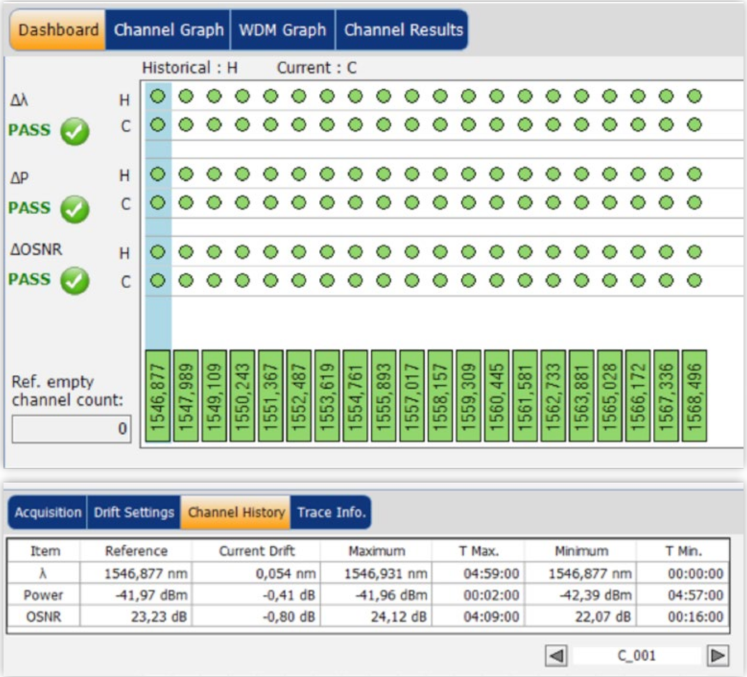
OSNR, due to its greater complexity, deserves to be addressed independently. OSNR is the ratio of signal power to amplified spontaneous noise power, the latter being produced by amplifiers and ROADMs. OSNR reveals signal quality since receivers require a minimum OSNR value in order to operate error-free. The receiver OSNR threshold will vary by vendor and model, but it is generally speaking between 15 and 18 dB for 10G systems, between 12 and 15 dB for 100G QPSK-based systems, and around 19-20 dB for 16-QAM-based systems. It should be highlighted that selecting the right OSNR methods, which depends on the data rate and the presence or not of ROADMs, is critical to obtain an accurate OSNR reading (Figure 6).

Data rate	ROADM	Modulation format	Baud rate	OSNR method
≤ 10 Gbit/s	No	OOK	10 GBd	IEC
≤ 10 Gbit/s	Yes	OOK	10 GBd	In-band
40 Gbit/s non-coherent	Yes or no	DPQSK or other	20 GBd	In-band
40 Gbit/s coherent	Yes or no	DP-QPSK or DP-BPSK	10 GBd or 20 GBd	Pol Mux / In-service Pol Mux
100+ Gbit/s coherent	Yes or no	DP-QPSK, DP-16-QAM	28 GBd	Pol Mux / In-service Pol Mux

Figure 7. The right OSNR methods for different situations

For an in-depth discussion of OSNR methods, please read OSAs in next-generation networks (www.exfo.com/umbraco/surface/file/download/?ni=12838&cn=en-US), 40G/100G/200G OSNR measurements with a pol-mux OSA (www.exfo.com/umbraco/surface/file/download/?ni=13240&cn=en-US) and In-service Pol Mux OSNR measurements with an FTBx-5255 optical spectrum analyzer (www.exfo.com/umbraco/surface/file/download/?ni=13020&cn=en-US).

Also, verification engineers generally run spectral tests at different locations in the network. Tests at the receiver are of paramount importance, because they provide the complete picture of the network behavior. If all spectral tests at the receiver pass, then tests elsewhere in the network become less critical. Spectral analysis at the transmitter or between the Tx and Rx also provides useful information about system performance, in particular if they are done over time to assess system stability. The drift mode in EXFO's OSA, which samples the signal at specific times for a duration specified by the user, is the ideal tool to undertake this task (Figure 8).



Item	Reference	Current Drift	Maximum	T Max.	Minimum	T Min.
λ	1546,877 nm	0,054 nm	1546,931 nm	04:59:00	1546,877 nm	00:00:00
Power	-41,97 dBm	-0,41 dB	-41,96 dBm	00:02:00	-42,39 dBm	04:57:00
OSNR	23,23 dB	-0,80 dB	24,12 dB	04:09:00	22,07 dB	00:16:00

Figure 8. Drift mode in EXFO's OSA to evaluate the long-term spectral performance of an optical system

7. EXFO PORTFOLIO FOR SPECTRAL TESTING

EXFO offers a full range of high-performance OSAs for spectral testing in laboratory and manufacturing environments. The EXFO portfolio for spectral testing can be summarized as follows:

OSA model	Platform	Suitable environment	FB, DFB, EDFA, transmittance	OSNR measurement method for non-coherent DWDM (10G, 40G)	OSNR measurement method for coherent DWDM (40G, 100G, 200G, 400G)	Special acquisition (RLT & burst)
FTBx-5243-HWA	FTB-4 Pro LTB-8	Manufacturing	✓	----	----	----
FTBx-5245	FTB-2/FTB-2 Pro FTB-4 Pro LTB-8 *	Field and manufacturing	✓	IEC interpolation	----	----
FTBx-5245-P			✓	IEC interpolation and in-band	Pol-Mux	----
FTBx-5255			✓	IEC interpolation and in-band	Pol-Mux and in-service Pol-Mux	----
OSA20	Benchtop instrument	Manufacturig and R&D labs	✓	IEC interpolation	on/off	✓


FTBx-5243-HWA


FTBx-5245
FTBx-5245-P
FTBx-5255


OSA20


FTB-4 Pro


LTB-8 *

** The LTB-8 can host up to 8 modules including optical power meters, variable optical attenuators and switches. In addition, the EXFO Multilink feature connects multiple users to EXFO modules and LTB-8 platforms remotely through any web browser.*

Abbreviations: FB=Fabry-Perot laser, DFB=Distributed FeedBack laser, EDFA=Erbium-Doped Fiber Amplifier, RLT=Recirculating Transmission Loop, INSPM=In-service Pol-Mux.

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