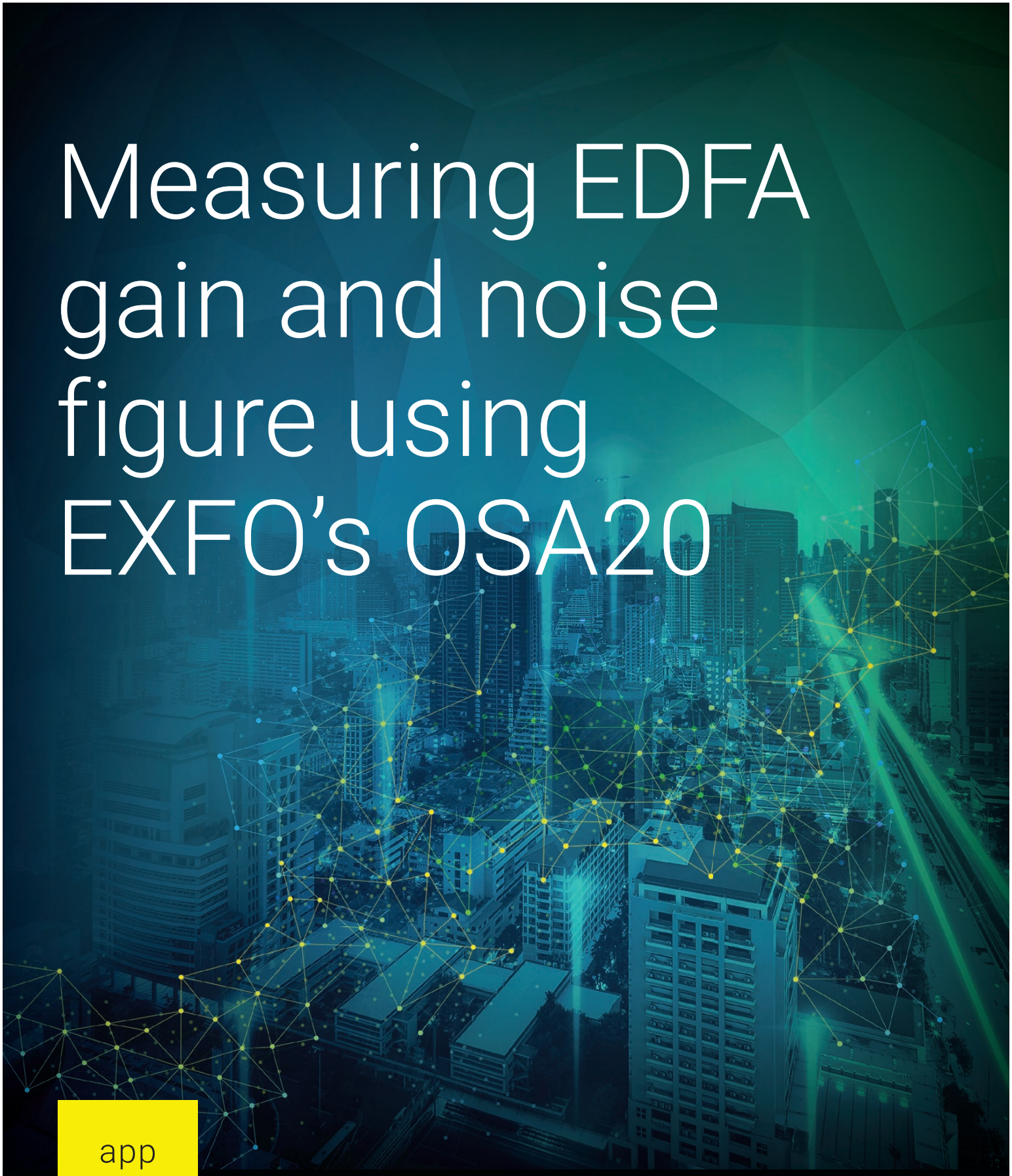
Measuring EDFA gain and noise figure using EXFO's OSA20



app note

EXFO

Measuring EDFA gain and noise figure using EXFO's OSA20

app note

In the early 1990s, the low-noise erbium-doped fiber amplifier boosted the development of long-haul fiber optic telecommunication systems.

Introduction

EXFO's optical spectrum analyzer, the **OSA20**, includes an **OFA mode** with a range of analysis tools for accurate, quick and easy characterization of optical fiber amplifier parameters. In this application note, the performance of different erbium-doped fiber amplifiers (EDFAs) is assessed by measuring the gain and noise figure in the amplification of two optical sources: a tunable laser (**T100S-HP**) and a DWDM laser source composed of several **OSICS DFB modules**.

Erbium-doped fiber amplifiers

In the early 1990s, the low-noise erbium-doped fiber amplifier boosted the development of long-haul fiber optic telecommunication systems. The low noise and high efficiency of these amplifiers around the c-band (c=conventional: 1525–1565 nm), a region of minimal absorption loss for optical singlemode fiber, meant EDFAs rapidly became the driving power for the migration of operational telecommunication systems towards this spectral range.

There are two key parameters used to characterize an optical amplifier: (1) *Gain*, which defines the amount of amplification achieved by the amplifier in a particular configuration, and (2) *noise figure*, which provides information about the quality of that amplification.

An amplifier's optical gain depends on the input signal's optical wavelength, which must be optimized so that the EDFA provides efficient amplification over a limited band (typically the c-band). The gain, which is a function of the wavelength, can be defined as the ratio of the output signal power (P_{out}) to input signal power (P_{in}). It is conventional to specify gain in the logarithmic dB unit, and it can be expressed as follows:

$$G(\lambda) = 10 \log_{10} \frac{P_{out}}{P_{in}} \quad \ldots (1)$$

Now, source spontaneous emission (SSE) from the input laser source will also be amplified and will combine with amplified spontaneous emission (ASE) from the amplifier itself to produce background noise that will degrade the optical signal-to-noise ratio (OSNR) and increase the bit error rate (BER) at the receiving end of the transmission path. In the case of cascaded optical amplifiers used for long-haul transmission applications, the ASE power contribution of each EDFA is amplified by subsequent amplifiers, hence further impacting system performance. The noise figure quantifies this deterioration. When measurements are performed by using an optical spectrum analyzer (OSA), a simplified expression of noise figure[1] is determined by the quantum noise as follows:

$$NF = \frac{P_{ASE}}{hv \times Gain \times \Delta v} \quad \ldots (2)$$

1. Becker, P.C., N.A. Olsson and J.R. Simpson. *Erbium-Doped Fiber Amplifiers: Fundamentals and Technology*. San Diego: Academic Press Inc.,1997.

© 2018 EXFO Inc. All rights reserved.

Here P_{ASE} is the power of an amplifier's ASE, *h* is the Planck constant, *v* is the center frequency of the output signal and Δv is the frequency resolution of the OSA measured on the P_{in} signal.

Figure 1 illustrates the amplifier gain, along with its ASE and OSNR, as measured by an OSA. Note that the peak power measured by an OSA is actually the sum of the signal power, as defined above, with the noise coming from source spontaneous emission. The gain calculation is therefore modified as follows:

$$G(\lambda) = 10 \log_{10} \frac{P_{out}^{OSA} - Noise_{out}^{OSA}}{P_{in}^{OSA} - Noise_{out}^{OSA}}$$

Here P_{in}^{OSA} and P_{out}^{OSA} represent the peak power detected by the OSA before and after amplification, respectively, and $Noise_{in}^{OSA}$ and $Noise_{out}^{OSA}$ represent the noise measured by the OSA before and after amplification, respectively.

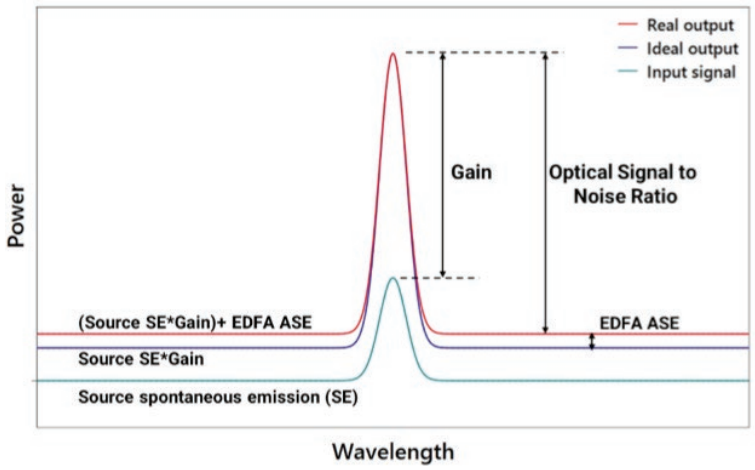


Figure 1. Key parameters of an EDFA measured using an OSA

© 2018 EXFO Inc. All rights reserved.

Three conventional techniques are commonly employed for measuring the ASE level in optical amplifiers. These techniques rely on a reference measurement (where the input spectrum of the signal going into the device is measured) and a device-under-test (DUT) measurement (where the output spectrum is measured).

I. Interpolation measurement technique

Sometimes called the *source subtraction technique*, the interpolation measurement technique relies on the fact that the output ASE can be measured directly by the OSA while the EDFA is operating. This is done by measuring the ASE level on either side of the amplified signal spectrum (e.g., 1 nm away from the peak), then interpolating the ASE level at the signal wavelength. The **OSA20** uses this method in **OFA mode**.

As indicated in Figure 2, although the method is simple to implement, the technique requires a stable laser signal and, more importantly, good noise interpolation. The measurement strongly depends on the spectral shape of the noise (for example, if a WDM filter is used in the system). Under such conditions, the following two techniques should be considered:

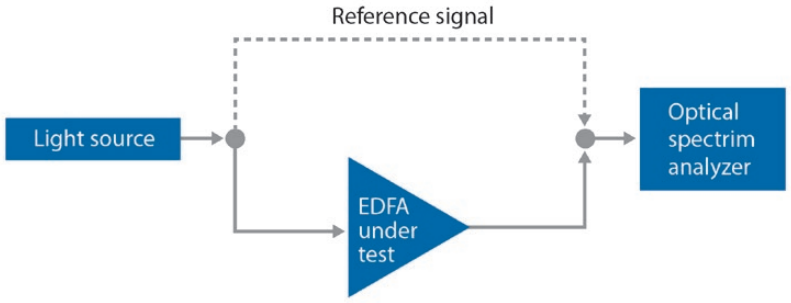


Figure 2. Block diagram for ASE level measurement using the interpolation technique

II. Polarization extinction ratio technique

As mentioned earlier, the polarization extinction technique is used mainly when the ASE level at the signal wavelength cannot be easily interpolated. The method requires additional polarization-control equipment and relies on the fact that, even though an optical signal can have a large degree of polarization, the ASE generated by the optical amplifier is non-polarized. Therefore, if a spectrum is measured in an orthogonal polarization to the signal's polarization, the ASE level can be determined, then the gain and noise figure calculated.

III. Time domain extinction technique

Another way to remove the optical signal to directly measure the amplifier's ASE is via the time domain extinction technique. This method takes advantage of the slow gain dynamics of the EDFA to reduce the effect of SSE. Considering that the metastable erbium ions in the EDFA require a relatively long time to return to the ground state, and assuming that the on/off switching cycle of the optical input to the EDFA is sufficiently shorter than the recovery time, the ASE level can be obtained directly by measuring the output of the EDFA while the optical signal is temporally switched off.

This method is more complex to implement since it requires additional equipment for synchronous detection of the ASE signal onto the OSA.

© 2018 EXFO Inc. All rights reserved.

Note that with all these techniques, the power level detected by the OSA may differ from the actual power level detected at the amplifier's input and output. This could be caused by additional couplers or switches in the system's optical path used to speed up the acquisition process. These additional losses need to be taken into account when computing gain and noise figure characteristics.

The OSA20's OFA mode provides a complete set of analysis tools for in-depth EDFA performance testing. The next section presents experimental setups using different laser source configurations for EDFA testing and methods for speeding up the measurement process using LabVIEW.

The OFA mode automatically calculates the gain, noise figure and OSNR after amplification by comparing a reference trace with the amplified signal.

Experimental setup

The **OSA20** uses the interpolation measurement technique described above to evaluate the performance of an EDFA. The full analysis and results are available via the **OSA20**'s firmware. The sections below cover technical implementation, programming and automation.

Hardware

Evaluation of EDFA performance in two configurations:

1. Using a single source, where the gain and noise figure are calculated at a single wavelength

2. Using a multichannel setup with a DWDM comb as the input signal to measure and calculate gain and noise figure at several wavelengths at once

The equipment required for both measurements is described below.

Optical spectrum analyzer: OSA20

The **OSA20** is a diffraction-grating-based optical spectrum analyzer with a scanning speed of up to 2000 nm/s, a resolution of 20 pm, and a noise floor as low at -80 dBm. It withstands up to +20 dBm input power per channel and a total input power of +25 dBm.

The **OSA20**'s OFA mode features an extensive suite of built-in analysis functions for measuring optical amplification and calculating essential parameters in the amplification process, including amplifier gain and noise figure. Furthermore, the OFA mode features supplementary analysis tools such as the OSNR calculation or channel detection tools for cases where the spectral input trace is composed of several WDM channels.

The OFA mode automatically calculates the gain, noise figure and OSNR after amplification by comparing a reference trace with the amplified signal. As shown in Figure 3, the blue trace corresponds to the reference signal, whereas the red trace represents the amplified signal. The analysis results per channel are summarized in the table, in addition to the gain and the noise figure, which are plotted in light blue and orange, respectively.

© 2018 EXFO Inc. All rights reserved.

Figure 3. Evaluating amplified signals with OSA20 in OFA mode

Laser sources: OSICS DFB module and T100S-HP

EXFO's **OSICS DFB** modules and **T100S-HP** are laser sources that provide excellent wavelength and power repeatability and stability, which makes them ideal for EDFA characterization. The T100S-HP features ultra-low SSE.

The **OSICS DFB** modules are part of the OSICS Multifunction Platform and are based on high-performance distributed feedback laser diodes, offering more than +13 dBm of optical power coupled in a polarization-maintaining fiber with a remarkable ±5 pm wavelength stability over one hour. The internal wavelength calibration yields a ±30 pm accuracy, and the wavelength can be finely tuned within 1.8 nm. These characteristics guarantee exceptional performance and great flexibility (grid setting) for DWDM setups.

The **T100S-HP** delivers fast, high-power measurements over a large wavelength range. Several models exist to cover all major telecom bands, ranging from 1240 nm to 1680 nm, with up to 200 nm sweeping span at a power of +8 dBm with no mode-hop and a precision of +/-20 pm. These lasers are mainly aimed at swept-wavelength applications and stepped measurements with 1 pm sampling resolution.

Attenuator: OSICS ATN-HP module

To simulate losses in the transmission line, the input signal must be attenuated to avoid high-gain emissions (>20 dBm) in the EDFA output. The **ATN-HP** module, also part of the OSICS platform, was chosen because it combines a 60 dB attenuation range and operates throughout a large wavelength range (1250–1650 nm). Additionally, the **ATN** module is used in this WDM application to achieve low power levels without modifying the source signal-to-noise ratio.

© 2018 EXFO Inc. All rights reserved.

EDFA

For this application note, two EDFAs were tested.

- EDFA 1 is a gain-flattened amplifier operating over the range of 1530–1565 nm, delivering an amplification around 35 dB with a noise figure of 4 dB.
- EDFA 2 delivers up to 40 dB of amplification in the range of 1528–1565 nm and noise figure levels lower than 6 dB.

Setup

The performance of optical fiber amplifiers can be characterized in two test-case conditions:

Multichannel EDFA characterization: In this case, a DWDM signal covering the c-band and composed of 40 multiplexed **OSICS DFB** modules with 100 GHz of spacing from 1529.5 to 1561.4 nm is used to qualify the amplifier's performance. Prior to the measurement, the optical power of each WDM channel is adjusted to provide the same optical power in all channels. It is then attenuated by the **OSICS ATN-HP** module and sent through an optical switch (**OSICS SWT** module). The switch enables automated measurements of the input signal (i.e., the non-amplified signal [CH1]), which is sent to the OSA20 as reference signal) and the output signal (i.e., the EDFA signal [CH2]). Finally, the amplified signal is calculated using the **OSA20** and a "per-channel" analysis is performed. This setup, shown in Figure 4, is strongly recommended for testing EDFA in WDM applications.

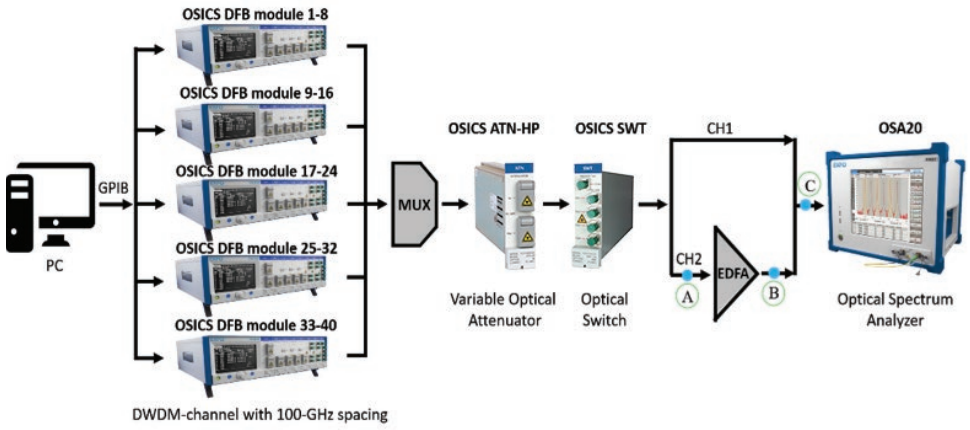


Figure 4. Experimental setup for multiwavelength EDFA characterization recommended for WDM applications

© 2018 EXFO Inc. All rights reserved.

Single-wavelength EDFA characterization using a tunable laser: As in the previous method, a switch allows for automated measurement of the reference signal (input) and the amplified signal (output). However, here the laser source is a tunable laser (**T100S-HP**). The full characterization hence requires repeated, stepped measurements that record the analysis of the amplification process at each wavelength, making it longer to complete the measurement process. Figure 5 shows this experimental setup.

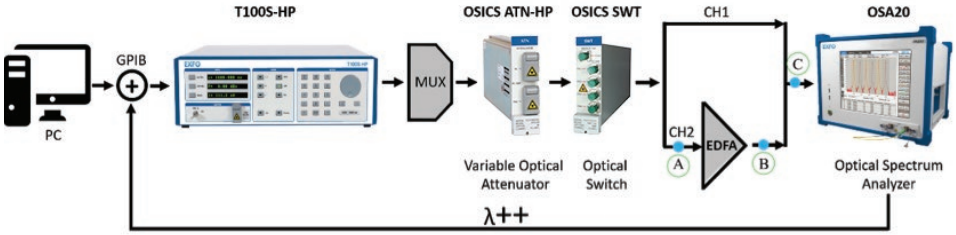


Figure 5. Experimental setup for single-wavelength EDFA characterization spectrally sweeping the tunable laser emission

By using a tunable laser with a wide tuning range and a high spectral resolution in this experimental setup, characterization of the amplification process can be extended beyond the c-band or with high sampling resolution, allowing characterization of the flatness gain in the complete range of operation of an EDFA.

As shown in Figures 4 and 5, the OSA20 displays the optical power at point C, while the input and output optical power of the EDFA are measured at points A and B. To address this difference in power, the input and output attenuation can be entered as parameters in the OSA20 analysis.

© 2018 EXFO Inc. All rights reserved.

Software

The instruments presented in Figures 4 and 5 feature USB or GPIB remote control access ports. Remote control programs in LabVIEW (Figures 5 and 6) have been developed for automated EDFA amplification measurement and analysis using the setups described above. These LabVIEW codes allow users to control the instruments (lasers, attenuators and switches) and data acquisition (gain, noise figure, OSNR, etc.) from the OSA20. As a final step, the results of the gain and noise figure are plotted as a function of optical frequency (see Figures 6 and 7).

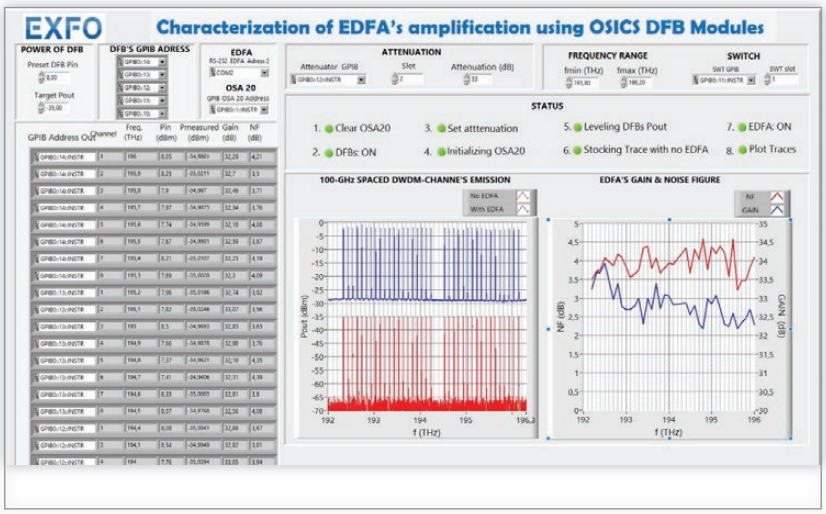


Figure 6. Remote control of the experimental setup for multichannel EDFA characterization via LabVIEW.

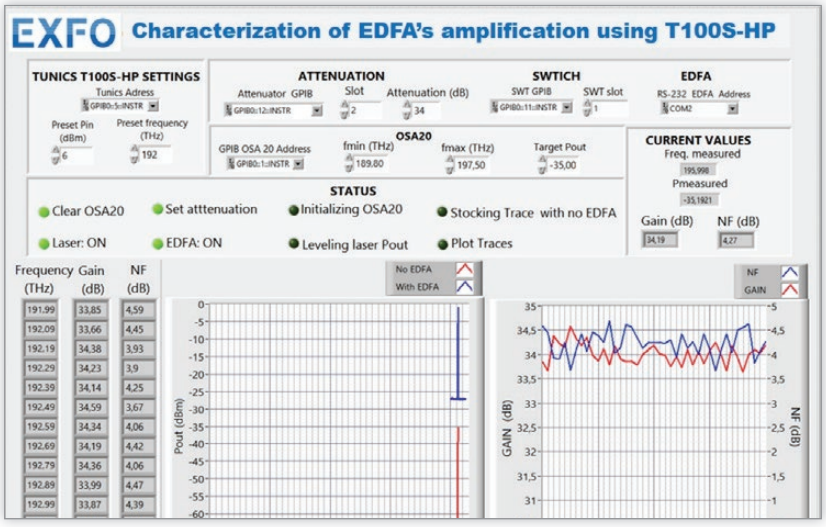


Figure 7. Remote control of the experimental setup for single-wavelength EDFA characterization spectrally sweeping a tunable laser's emission via LabVIEW

© 2018 EXFO Inc. All rights reserved.

The algorithms applied to evaluate optical amplifiers using the two setups previously introduced are further detailed in Figure 8.

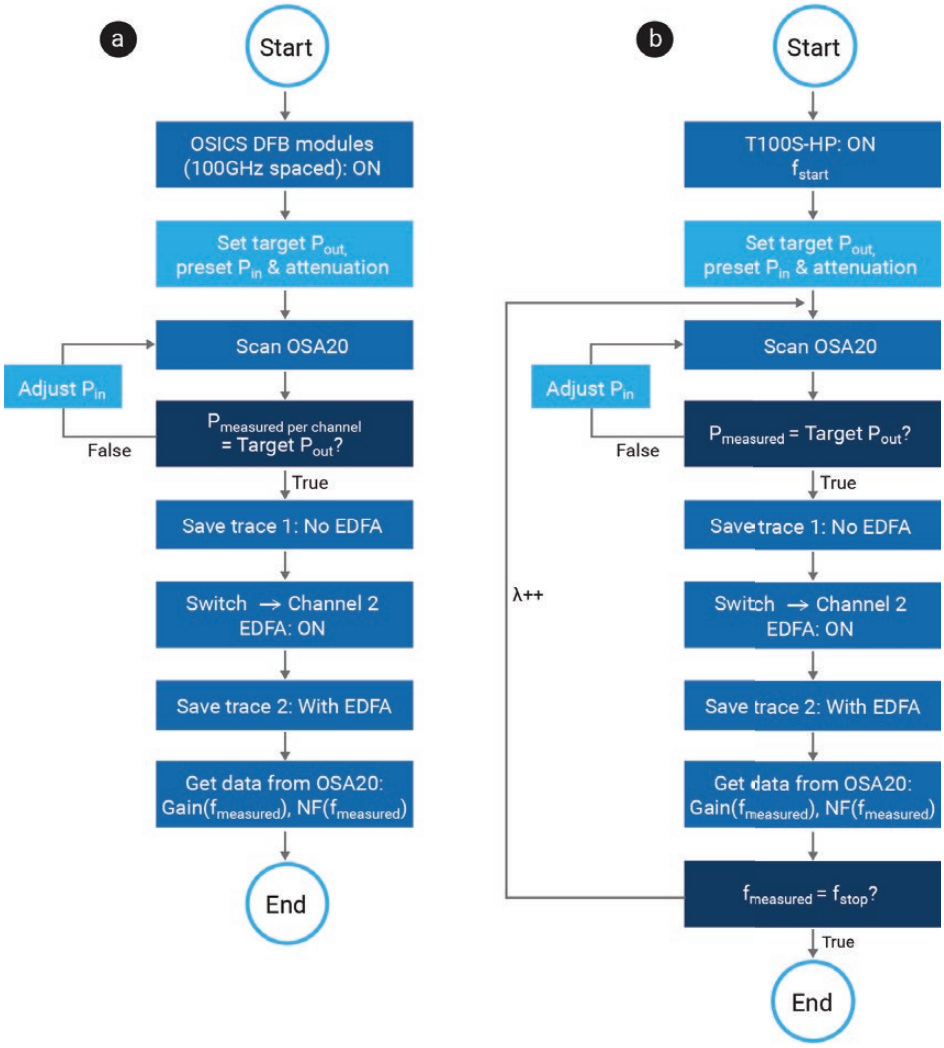


Fig. 8. Block diagram to characterize an EDFA using (a) multichannel measurement and (b) single-wavelength measurement.

© 2018 EXFO Inc. All rights reserved.

Experimental results

Multichannel vs. single wavelength

EDFA 1's gain and noise figure were automatically measured as a function of the frequency, in the range of 192–196 THz, by executing the LabVIEW programs in multichannel and single wavelength configurations as described above. An input signal optical power level of -20 dBm was used in all the measurements. The results are plotted in Figure 8.

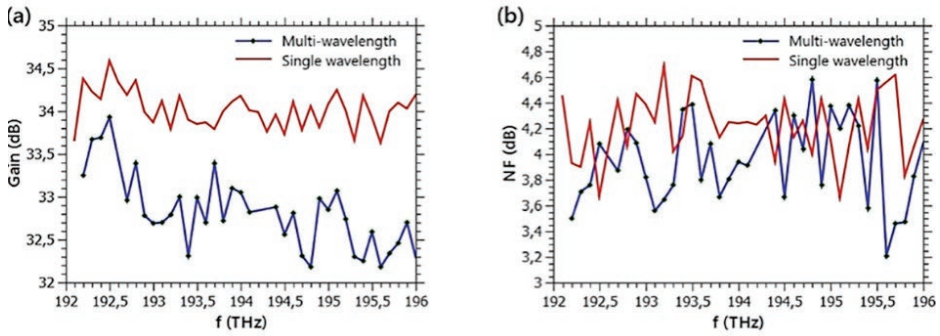


Fig. 9. Evolution of the EDFA 1's
(a) gain and (b) noise figure as a function of the frequency in two different configurations

The gain values obtained in single wavelength and multichannel setups were (34.2 ± 0.5) dB and (33 ± 0.9) dB, respectively (Figure 8 [a]), close to the specified value of 35 dB amplification. A slight slope of -0.25 dB/THz and a decrease in gain value were observed in the multichannel configuration due to pumping of several channels at once. The gain flatness was more uniform within the measured spectral range when a single laser was amplified.

However, noise figure measurements were observed to be very close for both setups (Figure 8 [b]), presenting values of (4.1 ± 0.5) dB and (3.9 ± 0.5) dB for single and multiwavelength emission respectively, once again very close to the specified value of 4 dB.

Out-of-band gain measurement

As described above, the key advantage of the single wavelength setup is that the tunable laser source offers the possibility of measuring gain and noise figure outside the typical spectral range covered by DWDM DFB lasers. Figure 9 shows the results obtained when probing the spectral range of 188–198 THz (λ=1514–1594 nm) for EDFA 1 and EDFA 2, with a sampling resolution of 100 GHz.

EDFA 1 is a gain-flattened amplifier with the well-defined flat amplification level over the c-band, already observed in Figure 8. As expected, the gain value drops sharply on either side of that spectral region. However, the noise figure remains lower than 5 dB in that spectral range.

© 2018 EXFO Inc. All rights reserved.

EDFA 2 is a generic c-band amplifier without a gain-flattened output. This amplifier achieves gains as high as 40 dB over a somewhat limited bandwidth when compared to EDFA 1 (Figure 9 [a]). The noise figure for EDFA 2 is lower than 6 dB over the whole frequency range in the amplification, as the specifications announce, with a larger wavelength dependence that EDFA 1.

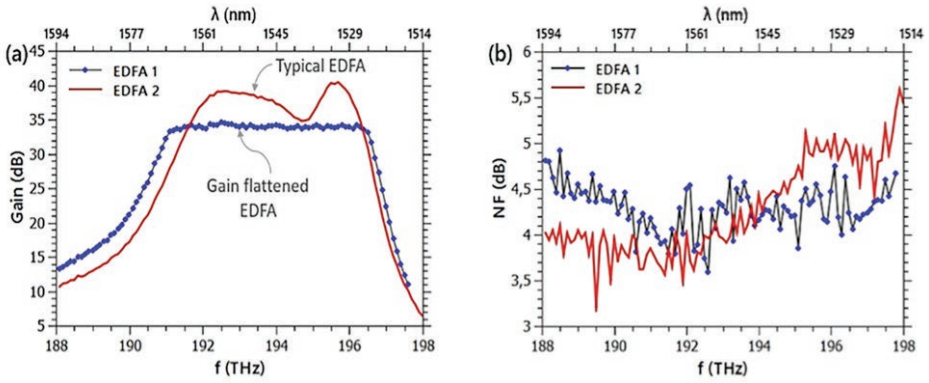


Fig. 10. Output signal function of DWDM laser source with 100-GHz spacing in the c-band. (a) Flat function

The OSA20 delivers fast, reliable and easy-to-implement amplifier testing in both multichannel and single-wavelength configurations, which is ideal for demanding applications such as gain slope measurement on gain-flattened EDFAs.

Summary

The **OSA20**'s OFA mode is a high-performance embedded analysis suite providing a variety of tools to measure optical amplifier performance using the interpolation measurement technique. The OSA20 delivers fast, reliable and easy-to-implement amplifier testing in both multichannel and single-wavelength configurations, which is ideal for demanding applications such as gain slope measurement on gain-flattened EDFAs.

EXFO serves over 2000 customers in more than 100 countries.
To find your local office contact details, please go to **www.EXFO.com/contact.**

© 2018 EXFO Inc. All rights reserved.