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APPLICATION NOTE

TUNABLE DFB LASER SOURCES: THE RIGHT CHOICE FOR EDFA AND SYSTEM-LEVEL TESTING

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This article will review the critical parameters of tunable laser sources (TLS) applicable to EDFA and system testing. With the objective of increasing confidence in EDFA testing as well as system qualification and manufacturing, we will also examine the performance characteristics of a tunable DFB laser source and present its principal advantages.

Controlling monochromatic laser central wavelength has been a hot R&D topic for the past 20 years. From probing atmospheric gases to solid-state materials, the narrow emission linewidth and relatively high power characteristics of TLSs has been essential to spectroscopy and interferometry measurements. It is a unique tool, which triggered the development and industrialization of new technologies. The tunable laser sources used in the 1980s to characterize erbium-doped and specialized fibers or bulk materials are becoming today's revolutionary instrument for testing all-optical wavelength-division multiplexing (WDM) networks. The use of tunable lasers as part of transmitter units is not far behind.

Benefits of Multiple-Wavelength Testing

Companies investing in DWDM long-haul networks, integrating optical amplifiers, are requiring system manufacturers to provide them with test results showing amplification and noise at every WDM tone throughout one or multiple EDFA stages. Single-wavelength tests do not emphasize inhomogeneous gain, inter-channel gain and power shifts, crosstalk due to non-linearities, or effects from dispersion-compensated fiber and components. All these parameters must be characterized during all phases, from production to installation, and this can only be achieved through multiple-wavelength testing. The cost of the test source, the power produced by each tone, as well as the spontaneous emission contribution to the amplifier's noise, are key elements in elaborating relevant test setups for EDFA and system testing.

Optical fiber amplifier (OFA) manufacturers must carefully choose the right combination of sources and instruments in order to demonstrate to customers that transmitting 32 tones through a costly amplifier is possible under all circumstances.

A tunable DFB laser source is an interesting alternative for OFA and system-level testing. With its 2 nm tuning range around the central wavelength on which the tunable DFB laser diodes are set, the configuration of tunable DFB laser sources will cover the requested spectral range over which the tests are conducted.

How Does a Tunable DFB Laser Diode Work?

A distributed Bragg grating etched onto the active layer of a semiconductor laser naturally locks central wavelength within the gain band, and only a single longitudinal mode profits from the available energy. This optical structure is sensitive to refractive index variations due to carrier density (more or less proportional to the current applied at the junction) and temperature.

When laser current and laser temperature are accurately controlled, the peak wavelength can be tuned along an acceptable range. The control through current is fast, but the sensitivity on central frequency is weak, on the order of 0.01 nm/mA. This sensitivity is weak for a large tuning, but is strong enough that it should be taken into account to obtain a flat output power while tuning wavelength through temperature. Thermal stabilization time for a standard DFB module is rather slow, on the order of a few seconds, which makes this type of controlled source more appropriate for fixed-point applications.

Controlling wavelength and power can become rather complex when both are functions of forward current and laser temperature, as shown in the following equations:

$\lambda = f\ (T_{sub}, I_F)$

$P = f\ (T_{sub}, I_F)$

where T_{sub} represents module submount temperature and I_F represents the forward laser current.

Through specialized algorithms and calibration of both parameters, a setting resolution of 0.01 nm and a range of ± 1 nm can be obtained from standard WDM DFB lasers. The extremely high reliability and ruggedness of this type of module make it the perfect choice for long-term or environmental tests, where source stability (wavelength and power) usually contributes to errors in measurements.

Tunable DFBs at System-Level Testing

At the system level, tunable sources are used as laboratory reference sources. Therefore, stability in wavelength and power is at least one order of magnitude better than the stability of the WDM transmitter. Before going to the final BER testing stage, the constant wave (CW) reference source(s) can be used to simulate the effects of different field conditions such as

- a power drop of a few dB in one channel and the effect of this drop on other tones
- varying total input power in its specified range
- varying tone wavelengths in their respective specified limits
- changing comb flatness within its specified limits
- input power polarization state
- input signal(s) SSE (a DFB laser diode spontaneous emission can be changed through the drive bias current applied at its junction)
- dithering the tones in frequency through small kHz modulations over the laser diode bias current (controlled linewidth widening of each tone signal helps reduce non-linear scattering and high loss, as well as coherent signal interference in low-chirp, high-power applications)

Tunable DFBs in Amplifier Testing

Optical amplifiers have a dynamic response time on the order of 1 ms due to rare-earth ions, which have a relatively low spontaneous emission rate. Gain or output power reaction time, due to a change of input power level, can only be seen after a time period of, typically, 1 ms. If a laser source's amplitude is modulated (ON or OFF type) so that the OFF (or no light) period is short enough to maintain the amplifier's saturation regime, then measurements such as amplified spontaneous emission (ASE) power in relation to wavelength can be taken. The modulation frequency required to obtain such a steady state gain should exceed 50 kHz at a 50 % duty cycle, but may depend on the doped fibers used. For amplifier materials having faster decay time, this method is rather impractical, as it requires fast synchronization measurement tools. Semiconductor amplifiers (SOAs) are a good example of a faster decay-time material. Using the method shown above requires gating measurement capabilities, triggered by a reference voltage signal. This method can be used to measure gain, noise figure and ASE levels as a function of wavelength, without contribution of the saturating source's spontaneous emission. With a single saturating source, one can directly modulate at the source level through laser and current direct modulation. Modulation is applied where all tones are combined in order to avoid synchronization problems and jitter between sources. Figure 1 above illustrates amplifier testing using the so-called time-domain extinction technique.

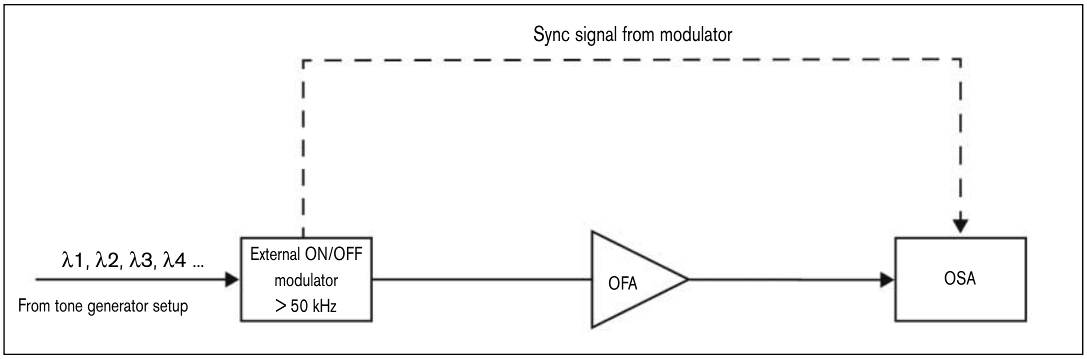

Figure 1. Time-domain extinction technique using multiple-tone generators as a saturating signal

Measuring WDM Subsystem Crosstalk with the IQS-2400 WDM Laser Source

During manufacturing, as well as during pre-shipment testing of 8-, 16- or 32-channel WDM links, many passive optical characteristics need to be measured: loss, polarization sensitivity, crosstalk and the influence of launching tones at different power levels with controlled linewidth. Figure 2 illustrates a simplified setup where a WDM "black box" filters and routes wavelengths to different points, which can be kilometers away from the launch point.

Crosstalk and isolation are typical measurements that can be performed with a standard optical spectrum analyzer (OSA). Each input can be set at its channel limits and the following measurements can be performed:

- Drop port λ1: Crosstalk of λ2 in channel 1
- Add port λ2: Directivity
- Output port λ1, λ2: Total channel loss
- Add port λ1: Directivity
- Drop port λ2: Crosstalk of λ1 in channel 2
- Launch port λ2: Tone launch anywhere ± 1 nm around the central wavelength of channel 2. Directivity of channel 1 into this launch port can also be measured.

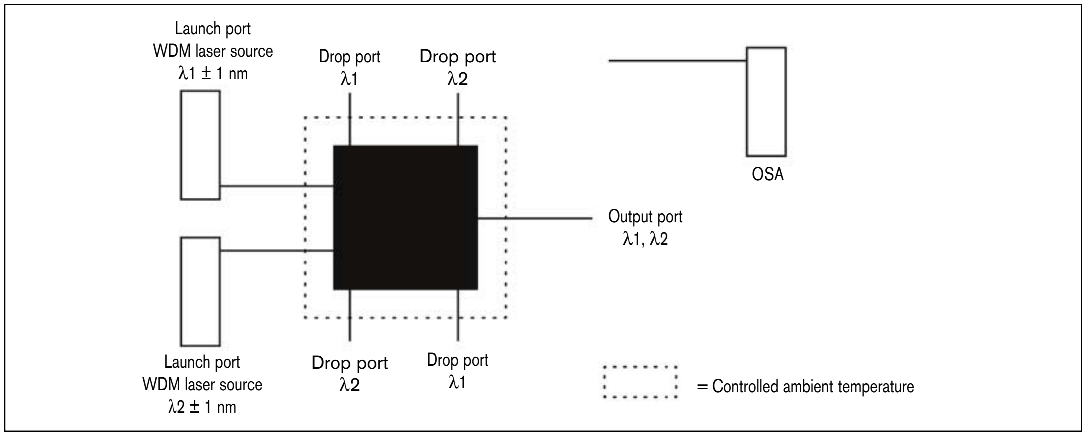

Figure 2. Dual ITU-grid tunable sources for WDM spectral insertion loss measurement

Using the IQS-2400 WDM Laser Source for WDM Tone Generator with Polarization Control

The input tone comb generated by a configuration of multiple tunable DFB laser sources is linearly polarized but its state of polarization (SOP) will change after passing through different fiber sections (test jumpers, DUT pigtails, erbium-doped fiber and others). Injection of a known and constant SOP will lead to a clearer interpretation of test results.

A change in the input-signal SOP generally induces a change in loss levels through the different passive components of the amplifier unit. Sudden and fixed change in the SOP, before the doped fiber core, will affect the input power level actually being sent through the amplifier. Changes in input power lead to linear or non-linear variations in output power and gain (in a compressed gain situation). The doped fiber section can also induce polarization-dependent gain (PDG), where the two orthogonal signals can profit from the available gain differently. It is important to qualify a fiber amplifier's gain, flatness and output power according to the input SOP. Testing the effects of polarization requires an output power detection instrument with low-PDL sensitivity. Obviously, an OSA with low-PDL detection is an essential tool to accurately measure the effects of input signal polarization.

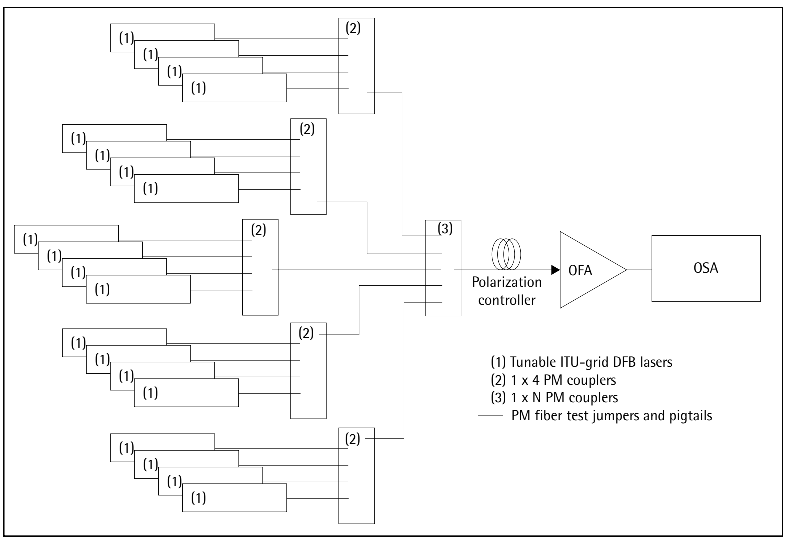

Figure 3. WDM tone generator with polarization control

The IQS-2400 WDM Laser Source emits polarized light signals. In a multiple-wavelength test situation, one polarization controller per source–in order to set their respective SOP at the entrance of the amplifier unit–would be an ideal setup. Mechanical and thermal stability of the total fiber link between the source and the amplifier unit is usually not good enough to maintain a preset state for the total period of a measurement. The use of polarization-maintaining pigtailed sources, test jumpers (fusion-spliced) and couplers would provide satisfactory SOP stability. A polarization controller can be used in the common segment, just before the amplifier unit, to specifically set one tone SOP (by disconnecting or shuttering-off the others) or, more simply, to randomly scan SOP and search for minima and maxima on each signal after the amplifier under test (see Figure 3).

Performance Review

It is well known that for DFB structures slow-rate central wavelength stability is directly related to temperature stability. Obtaining the desired stability requires thermoelectric cooling and temperature control with sufficient heat conduction from the laser chip location to the ambient air. EXFO's IQS-2400 WDM Laser Source allows temperature control parameters to be adapted to device-specific properties. A 40-hour test using EXFO's IQS-5320 Multi-Wavelength Meter, providing 1 pm resolution, showed that the peak-to-peak variation on the central wavelength was ± 0.001 nm (see Figure 4). This measurement was performed at a constant ambient temperature of ± 0.5 °C. The first hour clearly indicates the one-hour thermal stabilization time of the assembly. When the ambient temperature variation is greater, which is the case in an uncontrolled environment, most DFB modules show a wavelength sensitivity with respect to a temperature of about 2 pm/ °C.

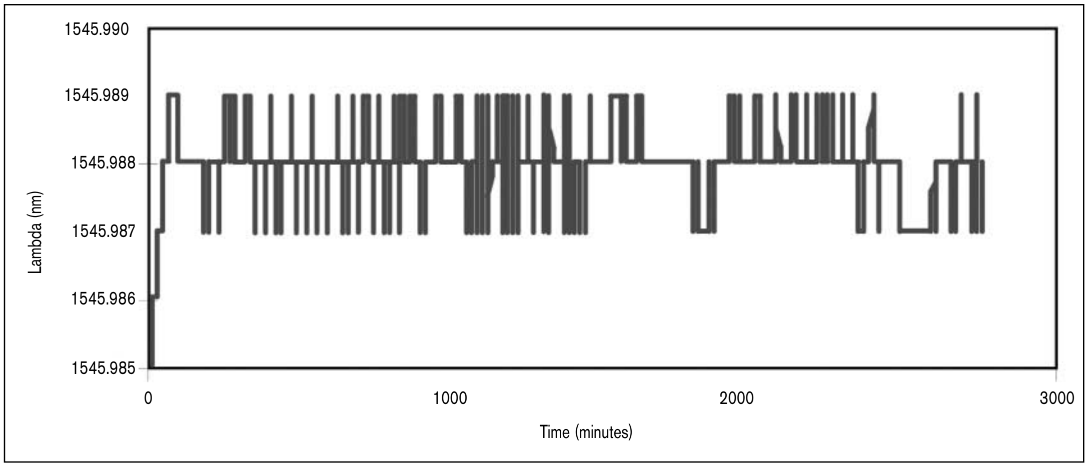

Figure 4. IQS-2400 WDM Laser Source 40-hour wavelength stability test

With such stability, we have been able to prove that an absolute accuracy of ± 0.01 nm is possible from a factory calibration of the IQS-2400 WDM Laser Source. How this accuracy is maintained throughout the ± 1 nm range and throughout the 10 dB attenuation range is the most important performance factor in a tunable DFB.

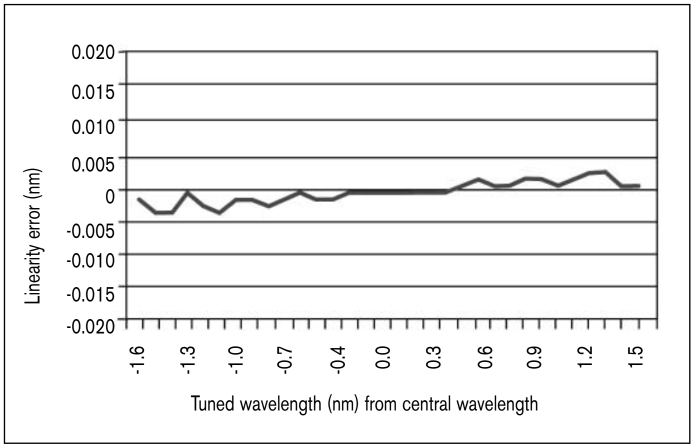

Figure 5. Results of the set wavelength accuracy while tuning both sides of an ITU-T grid set point.

The wavelength error remains well within a ± 0.003 nm window and is small enough for most applications. It should also be noted that this particular source, when used with an OSA, provides better wavelength accuracy than the instrument calibration, usually 5 to 10 times better!

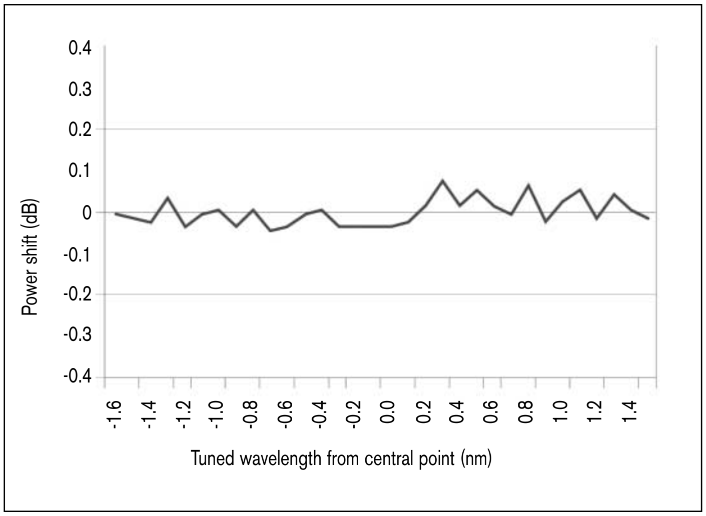

Figure 6. Output power flatness across the tuning range

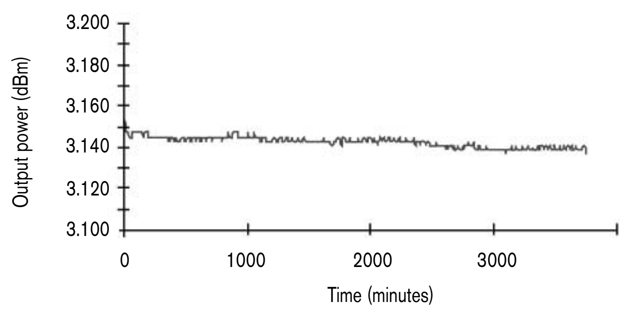

Figure 7. WDM laser source output power typical drift

Because tuning mechanisms based on temperature control affect output power, feedback control from a monitor photodetector is required. Also, temperature is the parameter that most affects wavelength and the device's quantum efficiency. It turns out, once again, that nature cannot be overcome; applying a correction factor to laser current to maintain power at a fairly stable level throughout the range also shifts wavelength.

The carrier density must also be taken into account, since a change in laser current at the semiconductor junction affects the thermal equilibrium of the material. Fortunately, the impacts of temperature and carrier density on central wavelength differ by one order of magnitude. Figure 6 opposite shows that efficient numerical control of these parameters leads to acceptable power flatness.

A DFB in a butterfly package is a standard industry off-the-shelf laser module. New manufacturing techniques, with the help of automated alignment systems, for example, have made these devices extremely reliable, providing very stable output power. With adequate temperature control, the power can be maintained at ± 0.005 dB for 60 hours as shown in Figure 7.

Such stability provides the ideal source for long-term environmental testing in which referencing the power can cause other loss factors such as connection and reconnection, PDL or optical switch repeatability. The fact that these sources can now provide an output power of more than +13 dBm with such excellent power stability is a great advantage.

In EXFO's IQS-500 Intelligent Test System, take advantage of the qualities of tunable DFS, and take control of multiple IQS-2400, using the multi-module application. This integrated application allows to easily and very fastly, change the setting of an individual source or of multiple sources at the same time, either changing the central wavelength, attenuating the power or simply tuning it "on" or "off". Figure 8 provides an example of the control panel available within an IQS System.

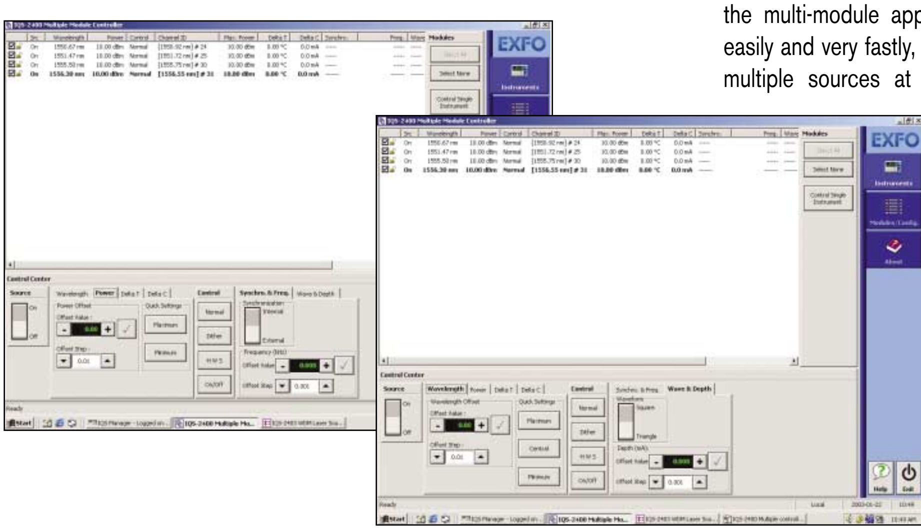

Figure 8.

Conclusion

The ideal test tool for EDFA characterization and system-level testing should be able to measure the entire WDM range (1528 nm to 1606 nm) while offering the most stable wavelength and power possible. Other wavelength of interest are also available such as 1308 nm, 1470 nm and 1490 nm used for CWDM applications. The absolute wavelength accuracy of the test unit should be as accurate as possible so that its measurement, and not the reference measurement taken with an OSA or a wavelength meter, could be used.

This article explained the many reasons for choosing a test source laser based on a tunable DFB laser and the IQS-2400 WDM Laser Source has been presented as an interesting option for EDFA and system-level testing. The user can precisely control the temperature and power parameters of the integrated DFB laser, thanks to the laser source's ingenious design.

Specialized algorithms for these parameters allow the transmission wavelength of the DFB laser to be tuned over a 2 nm range, while maintaining a high degree of wavelength and power stability. The IQS-2400 offers wavelength stability of ± 0.002 nm and power stability of ± 0.005 dB over long periods; combining several modules allows the user to cover the entire selected WDM range. Further, the absolute accuracy of the DFB laser (± 0.01 nm), being five to ten times more reliable than a standard OSA, overcomes the need to verify the transmission wavelength with an external reference unit, as is required when using an external cavity laser (ECL).

The large number of DFB lasers available on the market today guarantees a ready supply of affordable and reliable products. Choosing a test source laser based on a tunable DFB laser is the best option for EDFA characterization and system-level testing.

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