Application Note 075

The Need for Testing Low PMD Values in DWDM Components

Alain Pham, Product Manager, Industrial and Scientific Division

The continuous increase in both data-rate-per-channel and wavelength channel count serves only one purpose: to fulfill the telecommunications industry's hunger for optical bandwidth. However, the total number of wavelength-division-multiplexed (WDM) channels that can be accommodated in a system depends on many factors, ranging from cost and component-wavelength selectivity to loss and dispersion budgets, as well as non-linear effects. Among these, polarization mode dispersion (PMD) is particularly troublesome for high data-transmission speed, mostly because of its random nature.

The PMD coefficient of today's fiber is 0.1 to 0.5 $\text{ps}/\sqrt{\text{km}}$, whereas unofficial announcements of next-generation fiber boast a PMD coefficient of less than 0.05 $\text{ps}/\sqrt{\text{km}}$. Yet many other inline components will induce additional PMD with erbium-doped fiber amplifiers (EDFAs) standing out as the major contributor.

In light of these facts, the need to measure PMD values to the femtosecond range is inevitable. To achieve this, manufacturers need to perform complete analysis of polarization states; they also need PMD test systems that use fully polarimetric techniques to measure all Stokes parameters. Moreover, in 40 Gb/s systems, second-order PMD is becoming the key optical parameter. Enter the **FPMD-5600 Femtosecond PMD Analyzer**, EXFO's answer to measuring ever-lower first- and second-order PMD values.

FPMD-5600: State of the Art in Fully Polarimetric Interferometry

The fully polarimetric interferometry (FPI) approach using Generalized Poincaré Sphere Analysis (GPSA) has been recognized by the TIA, the ITU and the IEC as the equivalent of the Jones Matrix Eigenanalysis (JME).

Measuring PMD in the femtosecond range is best achieved using FPI because of its speed and accuracy. One can obtain unbiased results with a minimal risk of error, while avoiding the tedious data acquisition required by the JME method.

In FPI, a high-precision polarization controller determines the three input states of polarization. Thanks to an input amplified-spontaneous-emission (ASE) broadband light source combined with a polarimetric interferometer, all wavelengths are available simultaneously within the spectrum range in use. This means the system only needs a few seconds to accurately acquire data for the next PMD analysis. The result: fast, accurate and repeatable PMD measurements.

Second-order PMD is related to the variations of the principal state of polarization (PSP) as a function of wavelength. Optical component manufacturers who supply fiber networks must test their products at the design and manufacturing stages to ensure that first- and second-order PMD are within acceptable ranges for quality transmission on optical networks.

EXFO's FPMD-5600 enables optical component manufacturers to perform both first- and second-order PMD measurements, quickly and easily.

Measuring PMD with the FPMD-5600

Measuring PMD of passive broadband devices

Passive broadband devices can be divided into two major families:

- Cable and fiber
- Broadband components (couplers, variable optical attenuators, isolators, etc.)

Figure 1 depicts the connection scheme that should be used for such devices when testing with the FPMD-5600.

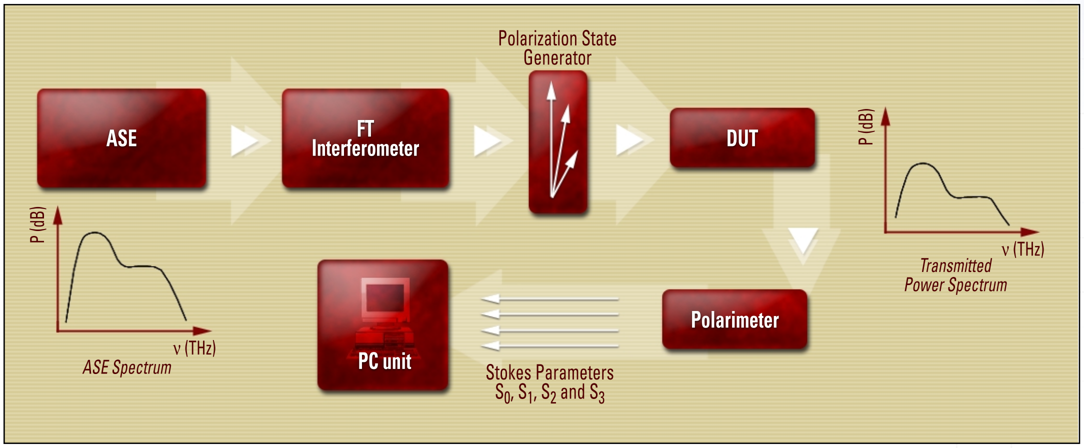

Figure 1. Connection scheme for passive broadband devices in the FPMD-5600.

A Fourier spectrum of the input ASE source, provided by the interferometer, undergoes three successive polarization states provided by the polarization-state generator (PSG). The three successive polarized Fourier spectra then propagate through the device under test (DUT) and are analyzed by the polarimeter. The data package is sent to the computer and the test results are displayed on the screen after data processing. PMD is defined as the root-mean-square (RMS) value of the measured differential group delay (DGD).

Testing 10-ps PMD emulators (random coupling)

In this example, a 10-ps fiber emulator is used as a passive device under test (DUT). Figure 2 shows the envelope of the DUT's time-domain interferogram, while Figure 3 shows its DGD and Stokes vector variations, respectively. One can recognize the typical behavior of a device exhibiting random coupling properties. As the interferogram spreads up to ± 25 ps over the whole scan capability, which covers ± 133 ps, a ± 30-ps filter can be applied to the interferogram to minimize the effect of noise. The signal can be thoroughly characterized according to the Nyquist sampling theorem.

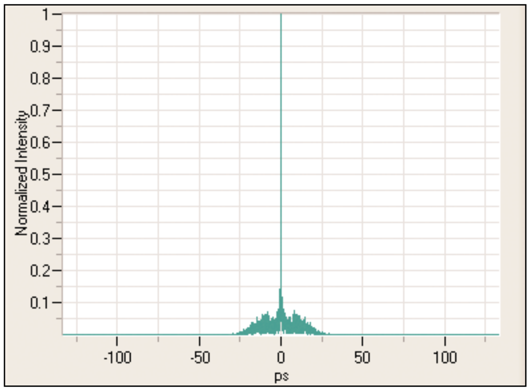

Figure 2. The envelope of the time-domain interferogram shows Gaussian behavior, typical of the random coupling mode.

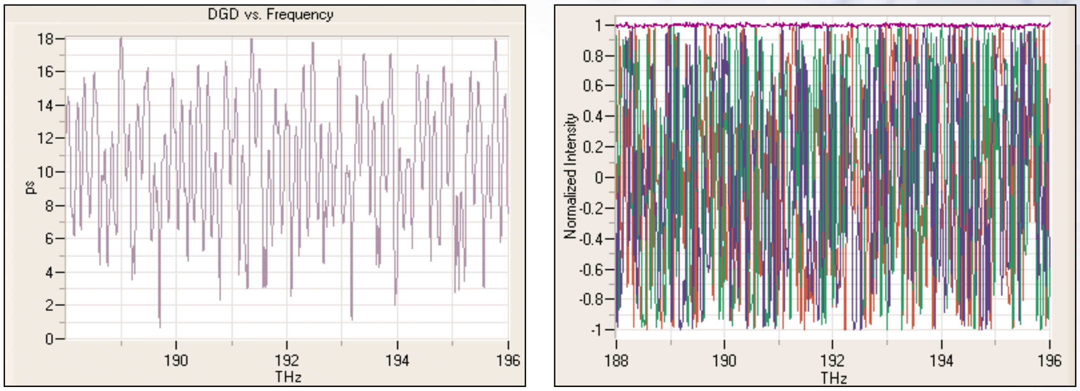

Figure 3. The DGD (a) and the Stokes vectors (b) show random behavior, typical of the random coupling regime.

Testing 1-ps PMD emulators (random coupling)

Next, the PMD of a 1-ps passive emulator is measured. The emulator is a passive broadband device that belongs to the random coupling family. However, due to its low-average PMD value, its interferogram appears as a sharp narrow peak centered on zero. If zoomed in on the signal area, one can choose a filter width of ± 5 ps in the Fourier space. This filter will remove the noise contribution to measured data and generates the DGD and Stokes vectors illustrated in Figures 5a and 5b.The measured PMD is equal to 0.975 ps.

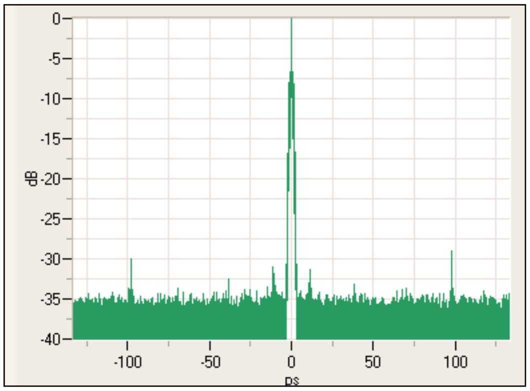

Figure 4. Time-domain interferogram of a 1-ps PMD emulator.

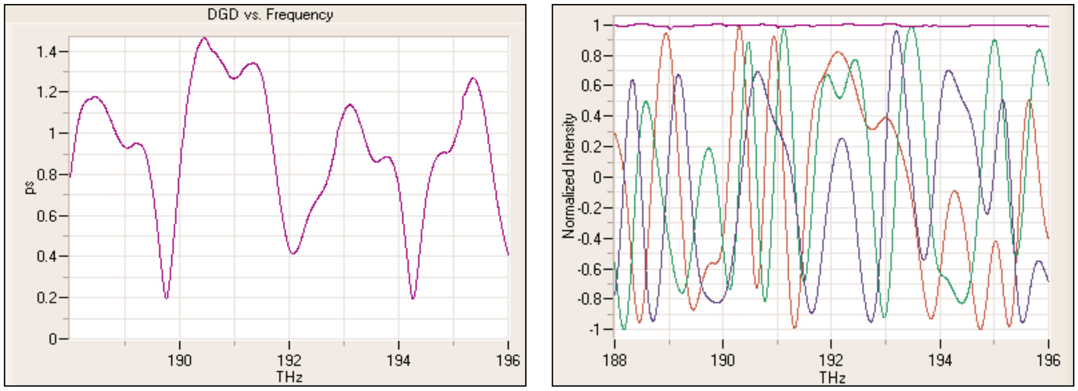

Figure 5. 1-ps PMD emulator: the differential group delay (a) and the Stokes vectors (b) show random behavior, typical of the random coupling regime.

Testing a 20-meter section of polarization-maintained fiber (negligible coupling)

Polarization-maintaining fibers (PMF) belong to a popular family of optical devices used in component manufacturing. Their high-birefringence properties make them ideal for using with various devices including optical modulators, pigtailed lasers and low-cost dispersion compensators.

The measurements yield PMD values of 12.035 ps. Figure 6 shows a central peak corresponding to the auto-correlation of the signal surrounded by symmetrical peaks, which in turn correspond to the constant delay induced by the 20-m PMF. In this particular case, the interferogram can be filtered using a ± 40-ps filter. The PMF differential group delay fluctuates slightly around its RMS value (12.935 ps) while the Stokes traces show perfect sine wave traces. If these Stokes vectors are projected on the Poincaré Sphere, they will describe perfect circles—an illustration of the polarization dispersion vector (PDV) movement around the principal state of polarization (PSP).

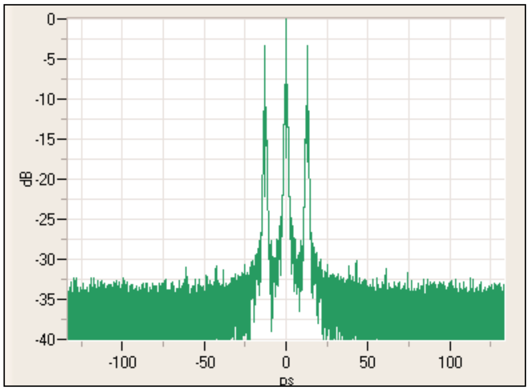

Figure 6. Time-domain interferogram of a 20-m polarization-maintained fiber (PMF).

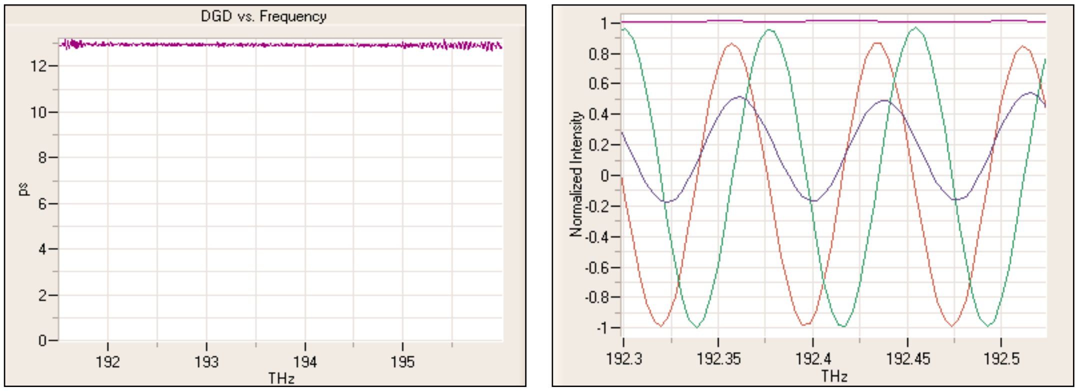

Figure 7. The DGD (a) of a PM fiber shows a constant behavior around its PMD value. Stokes vectors (b) show typical sine wave behavior. Projected on a sphere, these sine waves become circles.

Measuring PMD of Narrowband Devices

All DWDM systems consist of the following components: precise-wavelength optical transmitters (lasers), optical multiplexers (MUX) and demultiplexers (DEMUX), and broadband optical receivers. They can also feature optical add/drop multiplexers (OADM) and optical amplifiers.

Optical multiplexers combine the transmission signals from different wavelengths onto a single optical fiber. Optical demultiplexers separate the combined signals into their component wavelengths at the receiving end. Thin-film dielectric filters and optical gratings constitute the main types of multiplexers and demultiplexers. DWDM multiplexers are typically passive devices, which means they do not require electrical input. They behave like high-precision prisms to separate the individual colors of the DWDM signal.

Testing 100-GHz bandwidth multiplexers

In this example, a test is performed on a 100-GHz MUX, using a 5-dB power criterion to eliminate highly attenuated wavelengths, in order to only measure PMD in the clear window region. The valid window is demonstrated by the white area, while the gray region is the part that is not taken into account (see Figure 10). The channel under test exhibits a 0.8 ps PMD, which can be considered a high value. Having information such as the interferogram, Stokes vectors and second-order PMD value can help specialists optimize their MUX design.

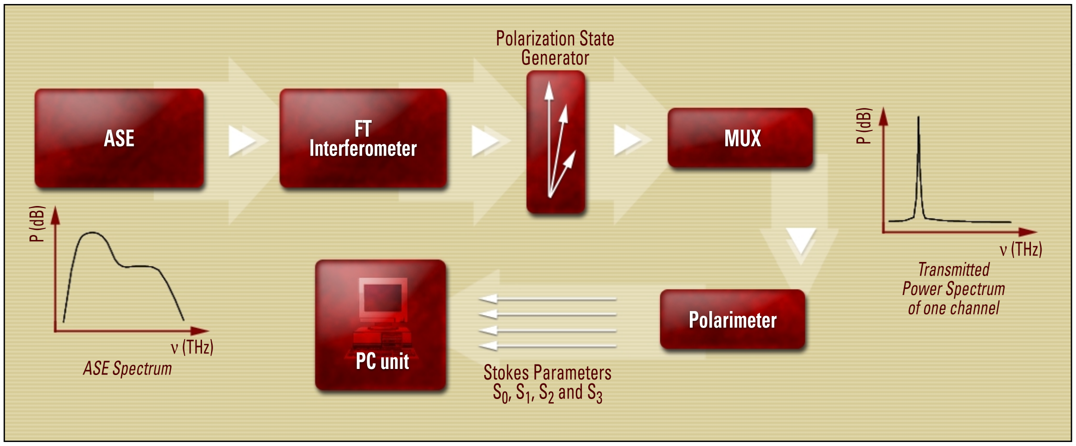

Figure 8. Connection scheme for a passive narrowband device (MUX) functioning in transmission.

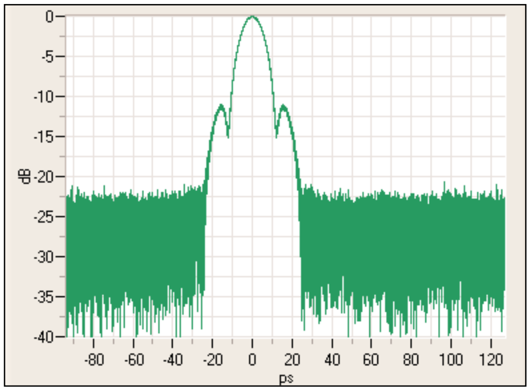

Figure 9. The interferogram of the tested 100-GHz MUX is completed and characterized within the scanning range of the FPMD-5600. A 40-ps filter can be applied to remove noise effects.

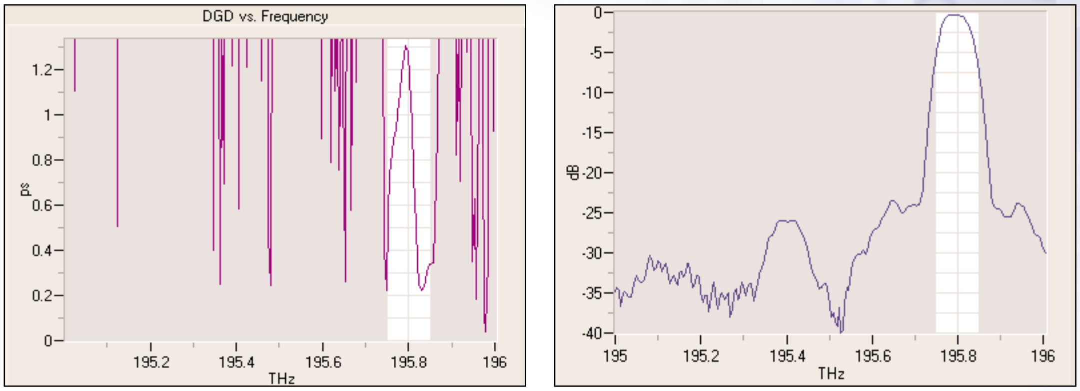

Figure 10. DGD (a) and transmission spectrum (b) of the 100-GHz MUX under test. The white area corresponds to the clear window of the MUX—the only region where PMD is calculated.

Measuring PMD in fiber Bragg gratings

Fiber Bragg gratings have become critical to today's dense wavelength-division multiplexing (DWDM) systems. Few technologies can compete with the performance and large spectral slopes that can be achieved by FBGs in filtering, multiplexing and dispersion-compensation management.

A fiber Bragg grating is a short length of photosensitive optical fiber that has been slightly modified. The fiber core has been exposed to ultraviolet radiation in a regular pattern, which has also caused the refractive index of the fiber core to be altered in a regular pattern. The result is that light traveling through these refractive index changes is reflected back slightly, but the maximum reflection usually only occurs at one particular wavelength. The reflected wavelength—known as the Bragg wavelength—depends on the amount of refractive index change that has been applied, as well as on the distance between the changes.

FBGs are designed to work in reflection. However, their PMD can be measured in either transmission or reflection (see Figures 11 and 12).

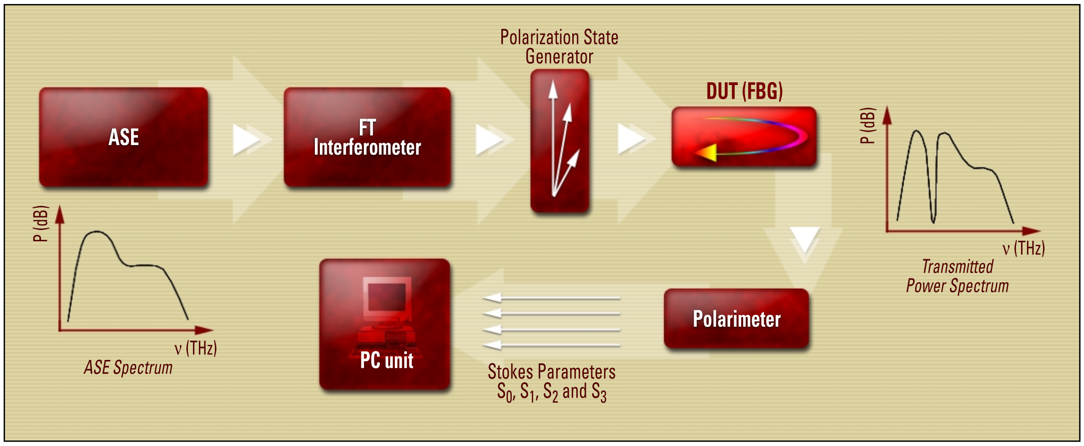

Figure 11. Connection scheme for a fiber Bragg grating tested in transmission.

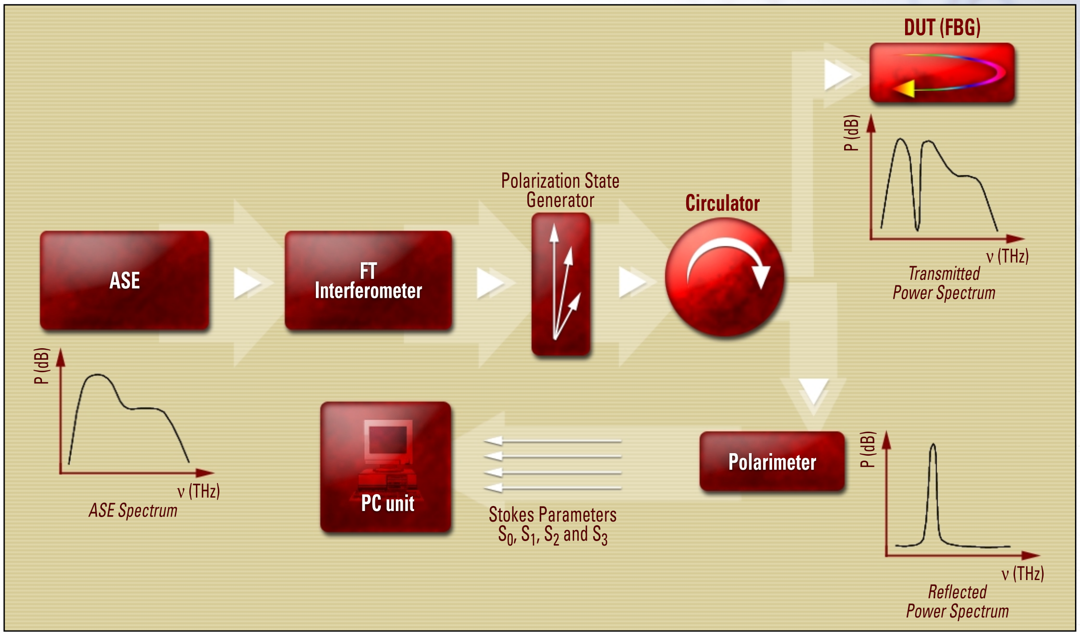

Figure 12. Testing a fiber Bragg grating in reflection regime requires the use of an optical circulator.

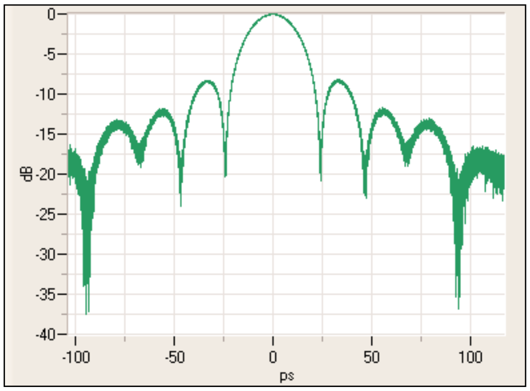

Figure 13. Time-domain interferogram of a 25-GHz chromatic dispersion FBG.

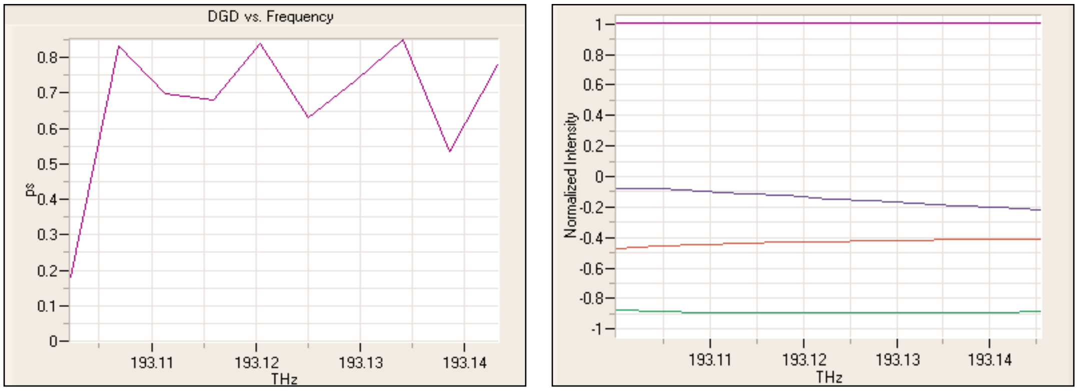

Figure 14. DGD (a) and Stokes vectors (b) of the 25-GHz fiber Bragg grating.

Figure 13 shows the time-domain interferogram of the tested FBG in logarithmic scale. Due to the way they are manufactured, FBGs are characterized by gratings with very square profiles. The Fourier spectra corresponding to such profiles will be given by the mathematical function sin(t)/t, which spans from -∞ to +∞. In this case, the coherence-time filter must be kept to its maximum of ± 133 ps. Choosing a smaller coherence time can lead to erroneous results as the interferogram would be truncated.

Testing 60-GHz Interleavers

An interleaver/de-interleaver is essentially an optical router that allows existing DWDM filters designed for operations with wide channel spacing to be extended to system designs with narrow channel spacing in the range of 50 GHz or even less. In the simplest case, an interleaver combines two sets of channels into one densely packed set with half the channel spacing. In reverse, the de-interleaver routes the single input set of channels into two output streams with twice the channel spacing. Interleavers/de-interleavers can be cascaded to match the desired channel combination or routing.

Naturally, these devices should be tested for PMD. The FPMD-5600 is the ideal instrument for this kind of test.

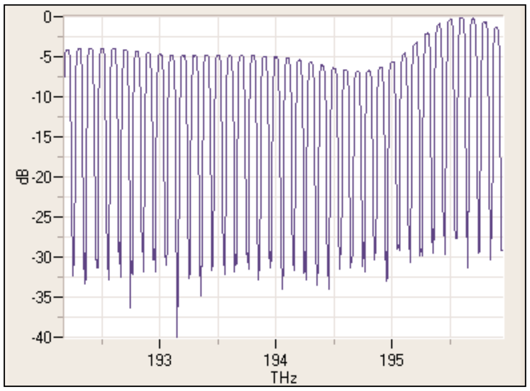

Figure 15. Transmission spectrum of a 60-GHz interleaver over the C-band.

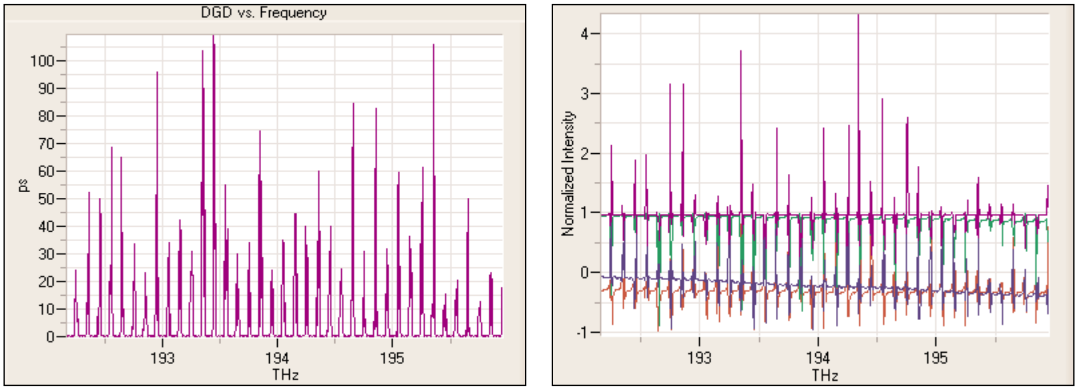

Figure 16. DGD curve (a) and Stokes traces (b) of the interleaver. Clear windows (transmission windows) show very low PMD values.

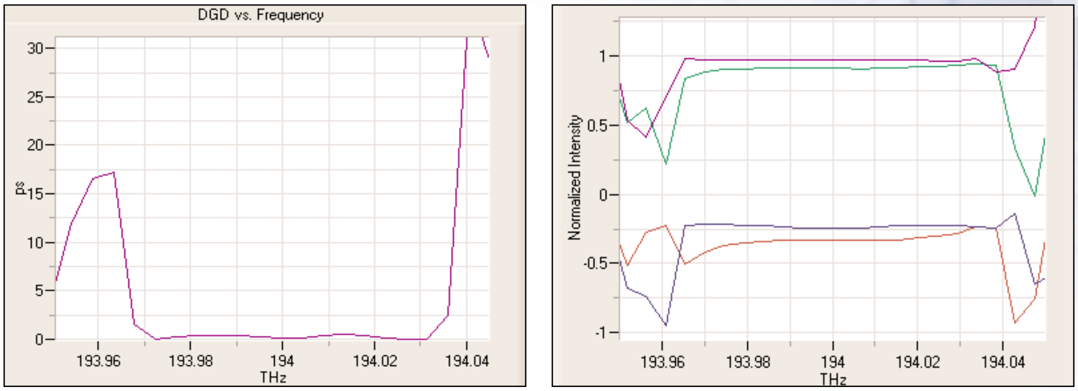

Figure 17. DGD curve (a) and Stokes traces (b) of the interleaver between 193.97 THz and 194.03 THz. Clear windows (transmission windows) show very low PMD values.

In one push of a button, the user can perform complete C+L-band characterization of an interleaver's first- and second-order PMD properties, (see Figures 15, 16 and 17).

Measuring PMD of Active Devices Such As Erbium-Doped Fiber Amplifiers

The discovery of erbium's photonic abilities and its effect on wavelengths in the 1550 nm range prompted the creation of erbium-doped fiber amplifiers (EDFA). EDFAs use pump lasers to excite the erbium atoms buried in the amplification fiber, which transfer energy to target wavelengths propagating through the fiber amplifier. The result is the ability to optically strengthen the signal's power—already weakened by attenuation—without all the equipment usually required for receiving, processing and retransmitting the bit stream. EDFAs enable longer links, as they amplify entire wavelength bands.

EDFAs constitute one of the most important applications in optical networks. Using the FPMD-5600, one can test them either as passive devices (when turned off) or as active devices. In the following example, we have tested an EDFA turned on, which is its normal functioning mode (see Figure 18).

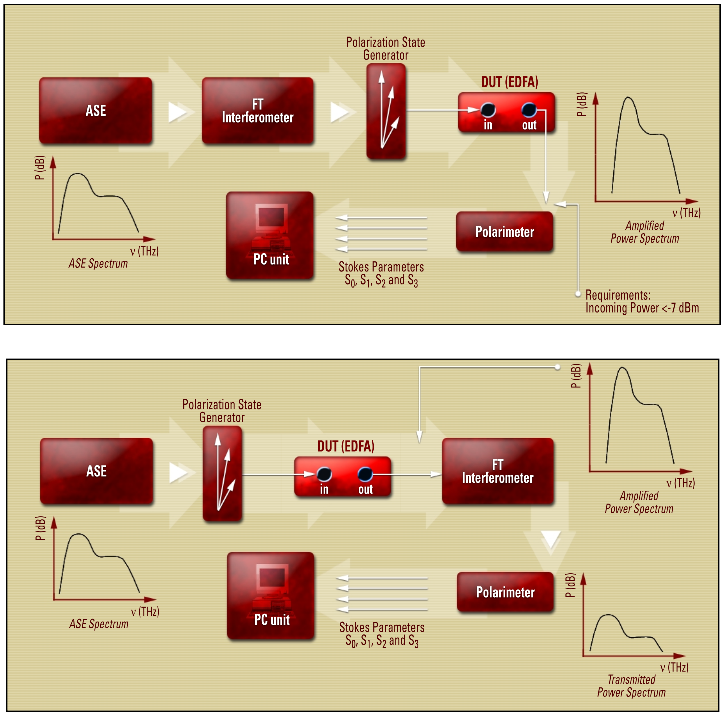

Figure 18 (a). The FPMD-5600 allows testing EDFAs in low-gain regime (a) as well as in high-gain or saturation modes (b).

Figure 19 shows the PMD measurement results of an EDFA functioning in the low-pump power regime. The interferogram uses a 20-ps filter to eliminate the noise contribution to the final result. The average PMD is approximately 0.1 ps. On the second EDFA, made by another manufacturer, the average measured PMD is approximately 0.4 ps.

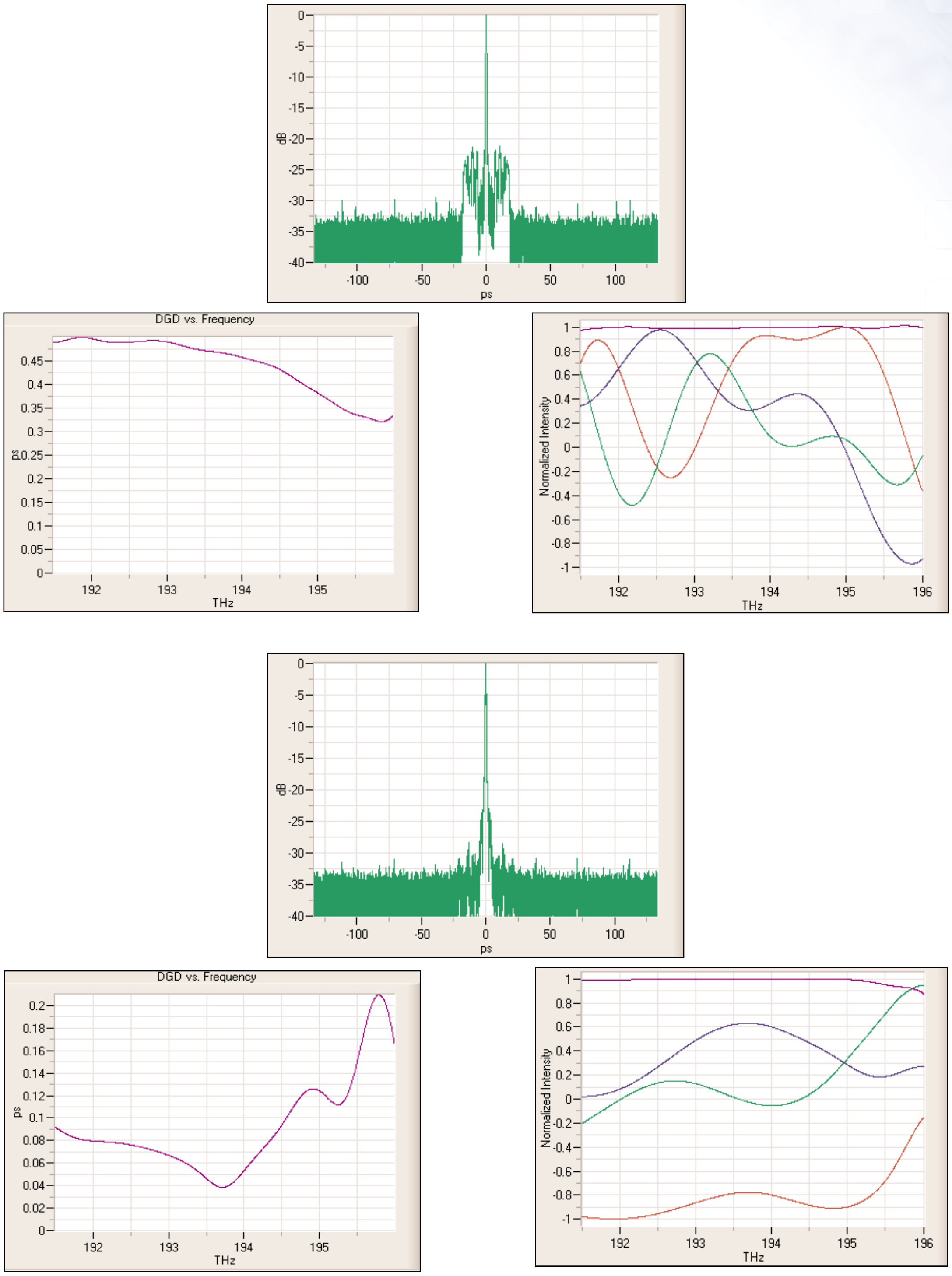

Figure 19. PMD tested on 2 different EDFAs working in the low-pump power regime.

As shown in Figure 21, both active and passive devices can be incorporated into the test procedures. If the ASE source's signal is excessively attenuated by a DUT, it can be boosted with an EDFA. The ASE/EDFA combo is equivalent to a high-power broadband source that goes through a highly attenuating device. This setup is also recommended for long links of fiber networks.

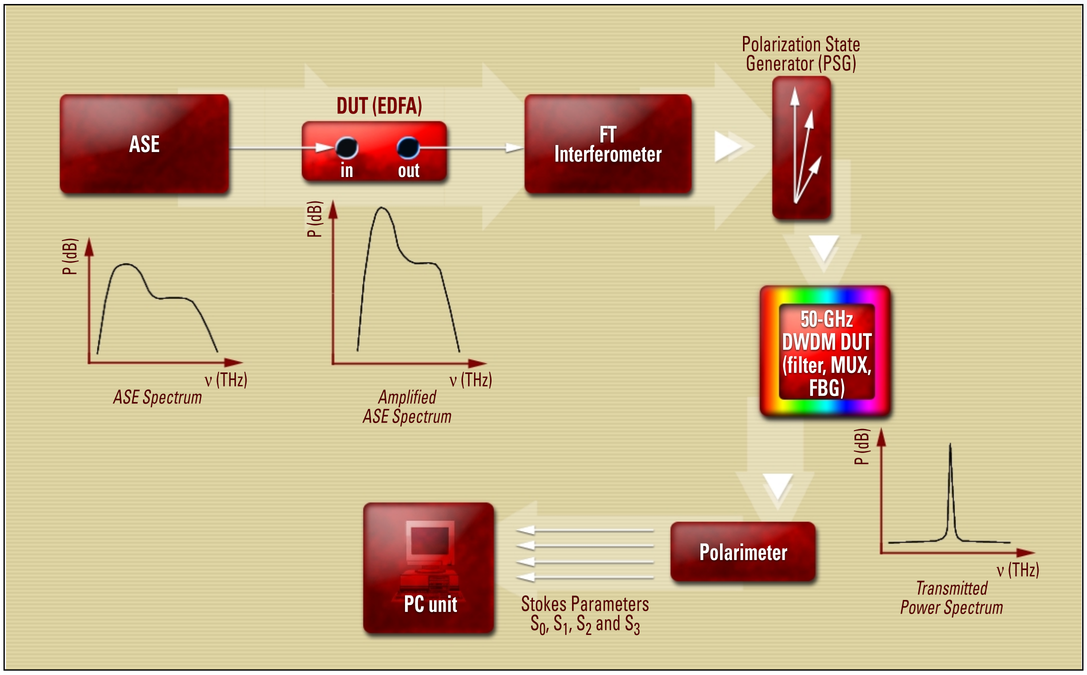

Figure 21. Schematic diagram of a PMD test setup incorporating both active and passive devices.

Add it all up—femtosecond PMD technology gives broadband and narrowband DWDM component manufacturers highly productive solutions to meet even their most stringent requirements.

CORPORATE HEADQUARTERS	465 Godin Avenue	Vanier (Quebec) G1M 3G7 CANADA	Tel.: 1 418 683-0211 . Fax: 1 418 683-2170
EXFO AMERICA	1201 Richardson Drive, Suite 260	Richardson TX 75080 USA	Tel.: 1 800 663-3936 . Fax: 1 972 907-2297
EXFO EUROPE	Le Dynasteur 10/12, rue Andras Beck	92366 Meudon la Forêt Cedex FRANCE	Tel.: +33.1.40.83.85.85 . Fax: +33.1.40.83.04.42
EXFO ASIA-PACIFIC	151 Chin Swee Road, #03-29, Manhattan House	SINGAPORE 169876	Tel.: +65 333 8241 . Fax: +65 333 8242
TOLL-FREE (USA and Canada)	Tel.: 1 800 663-3936	www.exfo.com • info@exfo.com	

www.exfo.com

ANOTE075.1an