

CHARACTERIZING POLARIZATION-DEPENDENT WAVELENGTH IN AWGs AND PLCs

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APPLICATION NOTE

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The spectral features of wavelength-dependent passive optical components can significantly vary according to the input state of polarization (SOP). This is the polarization-dependent wavelength (PDW) phenomenon-sometimes referred to as polarization-dependent center wavelength (PDCW) or polarization-dependent bandwidth (PDBW). The severity of this dependence is closely related to device technology and, in many devices, namely planar lightguide circuits (PLCs), it must be characterized so that compensation techniques can be evaluated and implemented.

Measuring IL, PDL, ORL and PDW with EXFO's IQS-12004B

The IQS-12004B DWDM Passive Component Test System measures insertion loss (IL), polarization-dependent loss (PDL) and optical return loss (ORL) as a function of wavelength, and now incorporates polarization-dependent wavelength (PDW) characterization. The system is based on a fast-sweeping, continuously tunable laser source, an integrated swept-wavelength reference, a monitor module, multichannel optical power meters and an optional polarization-state adjuster (PSA).

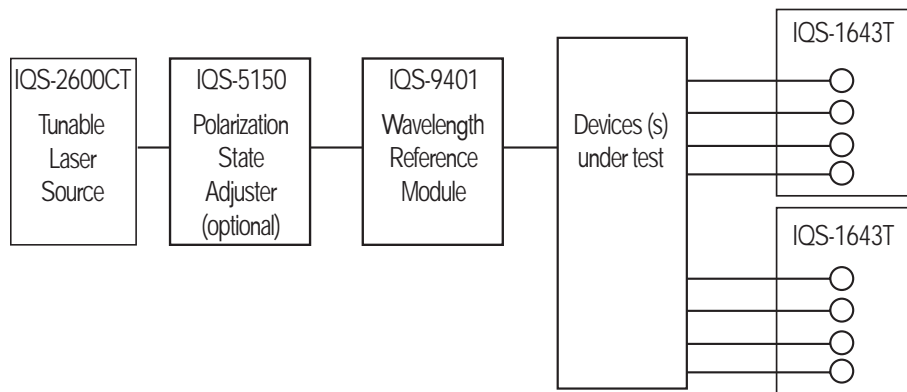


Figure 1: Block diagram of EXFO's IQS-12004B DWDM Passive Component Test System.

The polarization state adjuster generates the four input SOPs (in this case, linear horizontal, linear diagonal, linear vertical and right-hand circular) needed for performing Mueller Matrix PDL measurements. The two-step procedure consists of a power reference at the four SOPs (performed periodically) followed by a power measurement with the device under test (DUT) inserted. The four-state reference accounts for the power variations when going from one SOP to the other. The first-row elements of the Mueller Matrix representing the DUT are computed using these IL measurements. Then, other essential device characteristics, such as maximum and minimum transmittance with respect to input SOP (T_{MAX} and T_{MIN}) and hence PDL, are inferred for each wavelength in the scan.

Computing the first row of a DUT's Mueller Matrix as a function of wavelength-using data acquired by a swept-wavelength system featuring a PDL option like the IQS-12004B-is a well-known technique, although not always properly implemented or calibrated. Up to very recently, first-row elements were used exclusively for PDL measurements. However, when advising customers on the best ways of evaluating polarization and wavelength-dependent parameters, EXFO specialists realized that much more than just PDL can be deduced from the four first-row elements. In fact, knowing the first row of the DUT's Mueller Matrix as a function of wavelength allows its transmission curve $T(\lambda)$ (output power/input power) to be known for any given input SOP. Here's a generic equation for calculating $T(\lambda)$ for different SOPs:

$$T(\lambda, S) = m_{00}(\lambda) + (m_{01}(\lambda)S_1 + m_{02}(\lambda)S_2 + m_{03}(\lambda)S_3)$$

PDCW: Definition and Computation

The DUT's transmission curves are computed for input SOPs forming a grid that covers the Poincaré sphere. For example, one such transmission curve, obtained with one given input SOP, is shown in Figure 2. For each input SOP (ϕ_i, ψ_i) of the grid, the center wavelength ($CW_{i,j}$) is deduced from the transmission curve according to a standard definition, where λ_R and λ_L are the two wavelengths at the -3 dB level with respect to peak (maximum) transmission:

$$CW = (\lambda_R + \lambda_L) / 2$$

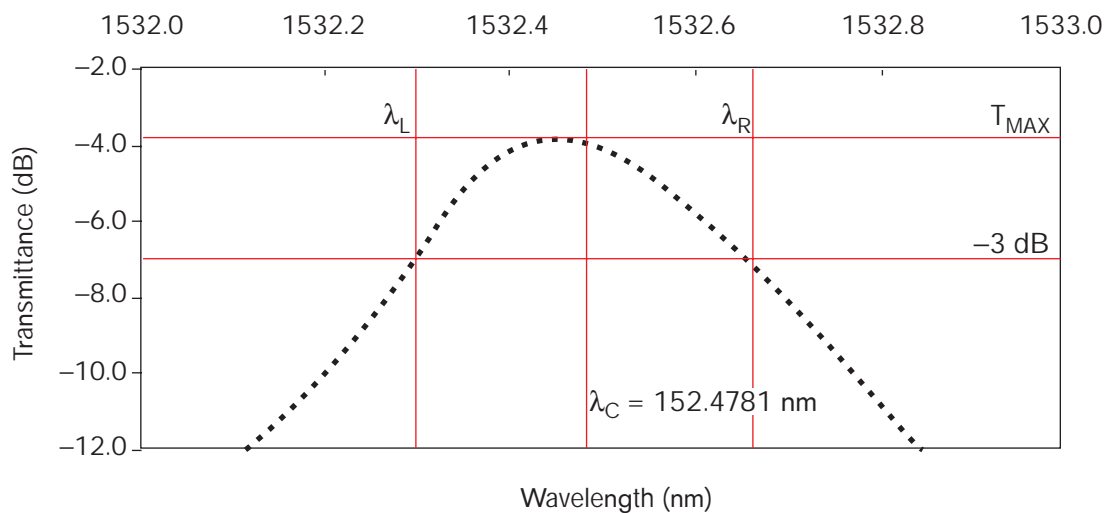


Figure 2: Transmission curve, as computed from the first row of the Mueller Matrix, for one given input SOP. Center wavelength is indicated by the solid vertical line.

The PDCW phenomenon is easily visualized through a 3D surface plot, with $(\phi_i, \psi_j, CW_{i,j})$ as the coordinates. Such a plot is shown in Figure 3. For devices exhibiting PDCW, the surface plot will show clear minimum and maximum center wavelengths for two distinct input SOPs.

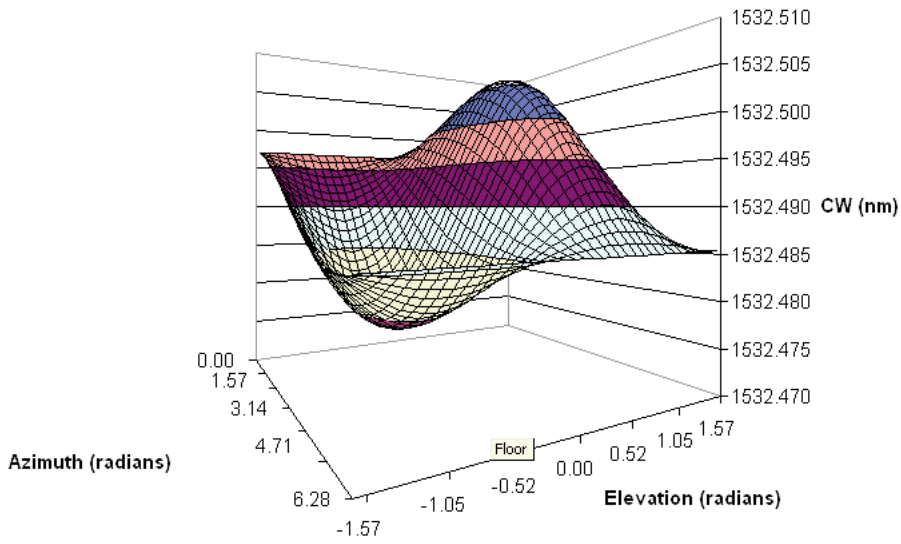


Figure 3: Visualization of the PDCW phenomenon through a 3-D surface plot.

The minimum and maximum center wavelengths are found as the minimum and maximum of this surface. The two PDCW axes (SOPs for which minimum and maximum occur) can also be determined from these plots. PDCW is given by:

$$\text{PDCW} = \text{CW}_{\text{MAX}} - \text{CW}_{\text{MIN}}$$

The two transmission curves obtained when the input SOP is aligned with one of the two PDCW axes are plotted side by side in Figure 4. For many devices, these two (2) transmission curves are an excellent approximation of the TE and TM response of the DUT.

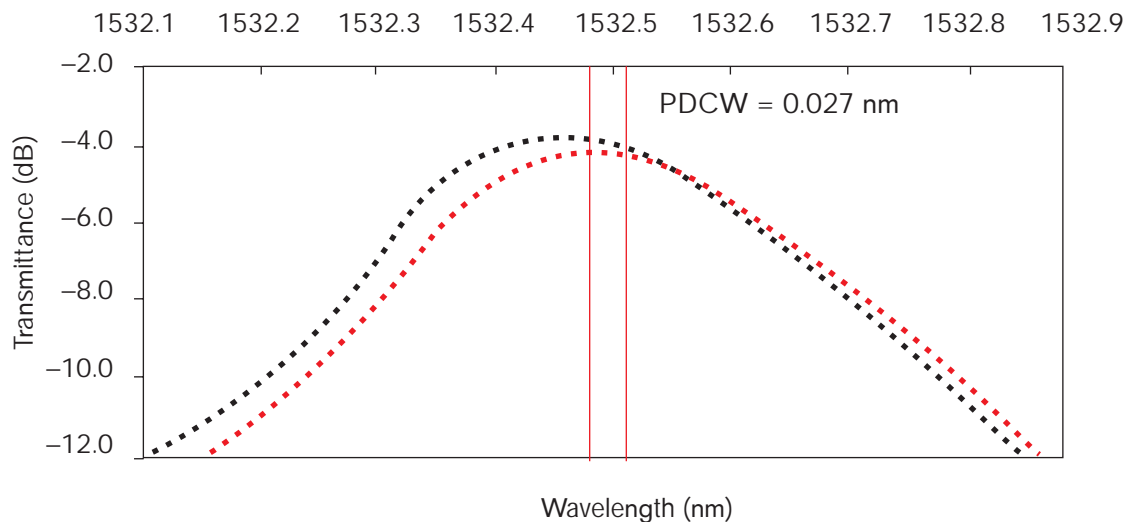


Figure 4: Transmission curves for input SOP aligned with PDCW axes (input SOPs where center wavelength is minimum or maximum). In this example, PDCW equals 0.027 nm.

Calculation of PDBW

Polarization-dependent bandwidth (PDBW) is computed in the same way as PDCW. For each transmission curve, the bandwidth, as well as the center wavelength, can be computed. In the case of the 3 dB bandwidth, it results in:

$$BW_{3dB} = (\lambda_R - \lambda_L)$$

A surface similar to the one shown in Figure 3 is obtained, except that the vertical axis is the bandwidth instead of the center wavelength. Minimum and maximum bandwidths are determined. Therefore, the PDBW is:

$$PDBW = BW_{MAX} - BW_{MIN}$$

TE/TM Alignment vs. Mueller Matrix

During the R&D phase, designers of arrayed waveguide gratings (AWG) and other planar light guide circuits (PLC) often evaluate the performance of a component by looking at its amplitude response for both the transverse electric (TE) and the transverse magnetic (TM) polarization states. Although the TE/TM alignment requires only two scans across the wavelength range of interest, the absolute state of polarization needs to be controlled and/or measured, and this makes the TE/TM method complicated, time-consuming, costly and unlikely to produce high-accuracy measurements.

Using the Mueller Matrix computations described in this article and integrated into EXFO's IQS-12004B DWDM Passive Component Test System, it is possible to obtain the same data quickly, accurately and automatically. In addition to the PDL, PDCW and PDBW, the algorithms can provide:

- Transmission as a function of wavelength for any SOP
- PDL axes, as well as the axes of minimum and maximum transmission
- Maximum and minimum IL at each wavelength

Maximum IL is very useful for determining the worst-case loss for a DWDM channel, while minimum IL is important for measuring the worst-case device isolation and crosstalk. With this additional data now available, component or system engineers benefit from complete information regarding the polarization dependence of a device.

In Figure 5, the data-part of the IQS-12004B's internal PDW computations-shows the polarization dependence of the center wavelength for an AWG channel. Figure 6 presents the transmission data for the corresponding minimum and maximum center wavelengths, assumed to be the TE and TM responses of the packaged AWG.

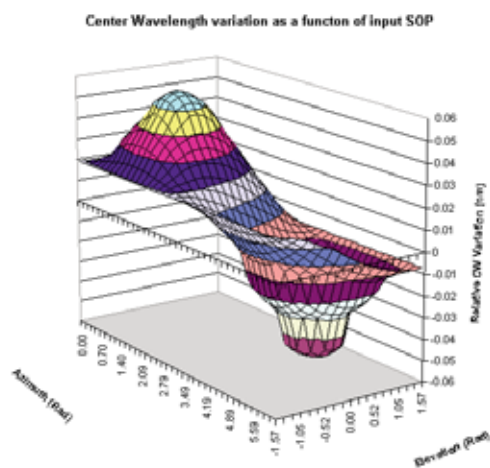


Figure 5: Center-wavelength variation as a function of input SOP for AWG device.

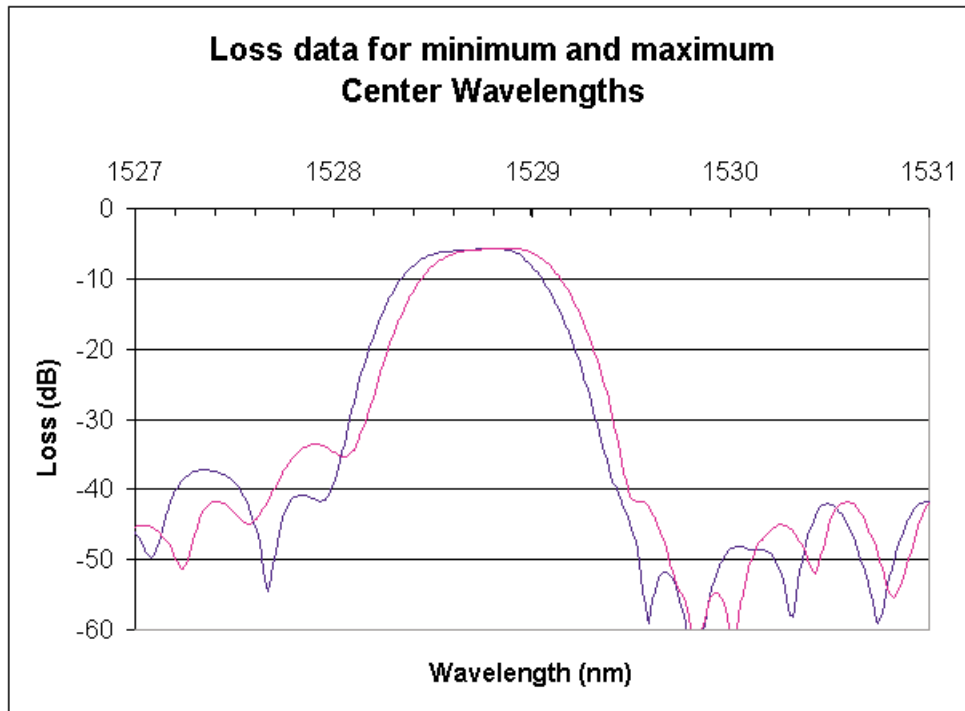


Figure 6: Computed TE and TM responses of AWG channel, as measured with EXFO's IQS-12004B DWDM Passive Component Test System.

Conclusion

The PDW-parameter evaluation method, based on the first-row elements of the Mueller Matrix and described in this article, is both fast and efficient. Unlike traditional methods for evaluating PDW, this approach is fully automated and hands-free.

This measurement principle and the associated algorithms have been integrated into EXFO's IQS-12004B DWDM Passive Component Test System and are currently available with the PDL measurement option of the system. By simply selecting a PDW checkbox from the software interface, the user can measure the PDCW and PDBW of any DWDM bandpass filter, notch filter or multichannel demultiplexer.

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