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IL and PDL spectra with the N7786B Polarization Synthesizer and the N7700A Photonic Application Suite

Application Note

Introduction

The spectral measurement of optical insertion loss (IL) and polarization dependent loss (PDL) as well as the related parameter for reflected light, return loss (RL), provides the primary performance data for verifying passive fiberoptic components including couplers and splitters.

The spectral dependence of these parameters is especially important for testing components designed to route signals based on their wavelength, such as wavelength multiplexers, demultiplexers and add/drop filters used in dense wavelength division multiplexed (DWDM) networks, coarse WDM (CWDM) networks and passive optical networks (PON) used for fiber-to-the-home installations. The demands on such tests have increased for configurable and dynamic network components for which the spectra can be adjusted and may need calibration, such as wavelength selective switches and



other forms of reconfigurable optical add/drop multiplexers (ROADM) as well as dynamic gain equalizers and other components using variable attenuation.

The N7786B polarization synthesizer enables a new implementation of the industry standard Mueller Matrix method for measuring IL and PDL spectra, based on its fast polarization-state switching and synchronized logging of output power and state of polarization (SOP logging). New software in the N7700A Photonic

Application Suite for this implementation provides valuable improvements in measurement throughput by reducing sensitivity to environmental disturbance such as vibration and drift for excellent reproducibility and accuracy as well as ease of setup. The measurement itself is very fast, especially useful for testing components with multiple ports like multiplexers and switches, measuring all ports at the same time using the fast data throughput and quick connectivity of the N7745A multiport power meter.



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Mueller Matrix Method

The measurement of PDL with the Mueller Matrix method involves determining the insertion loss of the component at a set of at least 4 input SOP with known orientation to another. The insertion loss itself is the ratio of output optical power to input power and the input power is usually established with a reference power measurement of the source before connecting it to the component input fiber. From the set of IL values, the Mueller Matrix calculation allows determination of the maximum and minimum IL for any input SOP (References 1 and 2). This method has been adopted in the international standard IEC 61300-3-2. This method also provides the polarization averaged IL, the IL that would be measured using an unpolarized light source.

The power of the Mueller Matrix method, vs. simply measuring the output power while the polarization is scanned over a sufficient sampling of all possible SOP, becomes apparent when it is necessary to measure the

wavelength spectra of IL and PDL together. DWDM components must typically be measured with a wavelength resolution of 10 pm or less and over a range of 50 nm or more. Spectra with so many points would require prohibitively long duration with the all-states polarization scanning method. Instead the Mueller Matrix method allows the IL and PDL spectra to be measured by continuously sweeping the wavelength of a tunable laser and synchronously sampling the output power with a power meter. This can be performed over 4 such sweeps at different input SOP. Using sweep rates like 80 nm/s, the IL and PDL spectra can be quickly obtained (Reference 3). This method has been standardized for DWDM components in IEC 61300-3-29. The Mueller Matrix data can also be used to find the IL spectra at selected SOP such as those where the optical electromagnetic field is oriented with a planar component, transverse electric or magnetic (TE or TM), without needing a measurement with the signal exactly in that orientation (Reference 4).

However even with such sweep rates, several seconds can pass between the measurements of the SOP set at any particular wavelength. Unfortunately the SOP of a signal passing through optical fiber, like used to connect the component and the instruments, is typically sensitive to temperature drift, mechanical movement and pressure and vibration. If such effects change the input SOP to the component between the samples in the SOP set, then the accuracy of the Mueller Matrix calculation is degraded. Anything that causes a change in optical power among the wavelength sweeps can also disturb the measurement. Addressing these concerns generally requires special care in fiber placement and fixing and workplace stability and encourages the use of additional real-time power monitoring of the signal input to the component. In addition, the instrumentation used to control the SOP generally has dependence on wavelength that needs to be corrected by the software for highest accuracy.

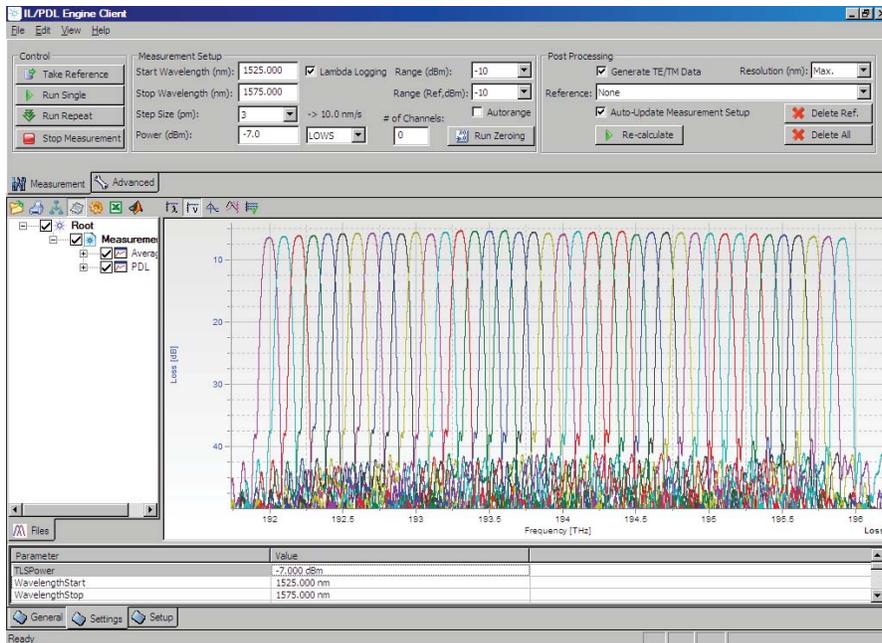


Figure 1. Example measurement of a 40 channel array waveguide multiplexer.

Fast-Switching PDL Method

The concerns just mentioned can now be alleviated by implementing the Mueller Matrix measurement with the fast SOP-switching N7786B. This instrument allows the optical signal to be switched through the selected set of SOP during a single wavelength sweep of the tunable laser. The samples are taken with a small wavelength spacing, so that with interpolation an accurate determination of the IL at each SOP for a point on the spectrum is quickly obtained. In a standard configuration, the SOP set is obtained in less than 1 ms, so the measurement results are almost immune to normal fiber movement and temperature drift.

For each sample, the SOP is switched and when the new SOP is reached the N7786B electrically triggers the power measurement of the output from the component by the power meters. At the same time it also measures and logs the SOP and power of the signal to the component, providing correction for any input changes since the reference power measurement and any dependence of the output SOP on wavelength. The wavelength itself is measured and logged by the tunable laser, synchronized with electrical triggers to the other instruments.

The fast-switching single-sweep style of measurement was introduced in the Adaptif A2000, which is now updated as the Agilent N7788B, for the Jones Matrix Eigenanalysis method to obtain PMD, PDL and IL for single-port measurements. Now the N7786B supports multichannel IL and PDL measurements with the Mueller Matrix method, with an algorithm incorporated in the N7700A Photonic Application Suite.

A sample multichannel measurement, displaying the IL spectrum for a set of multiplexer ports is shown in Figure 1 and a single IL channel is shown in Figure 2. The data were measured and displayed in the N7700A software.

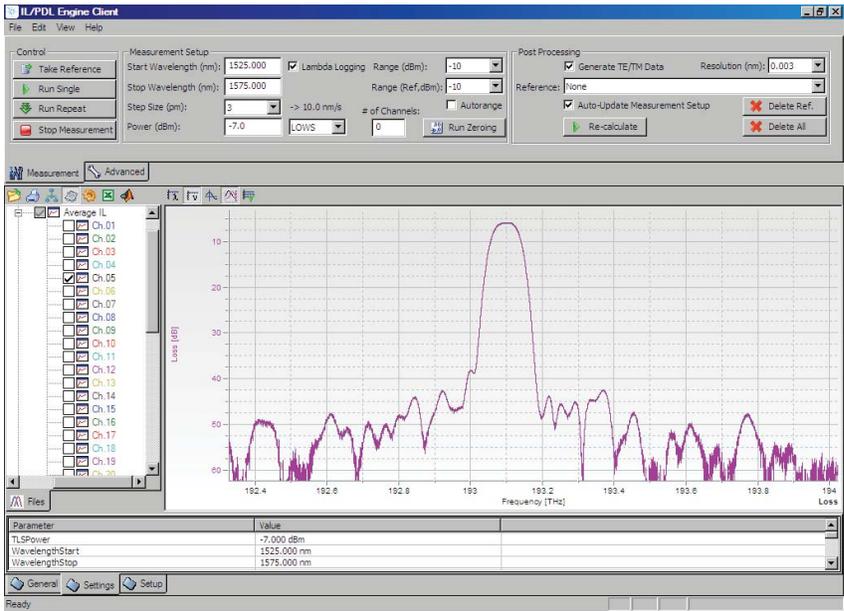


Figure 2. Insertion loss measurement for a selected AWG channel with about 60 dB measurement dynamic range.

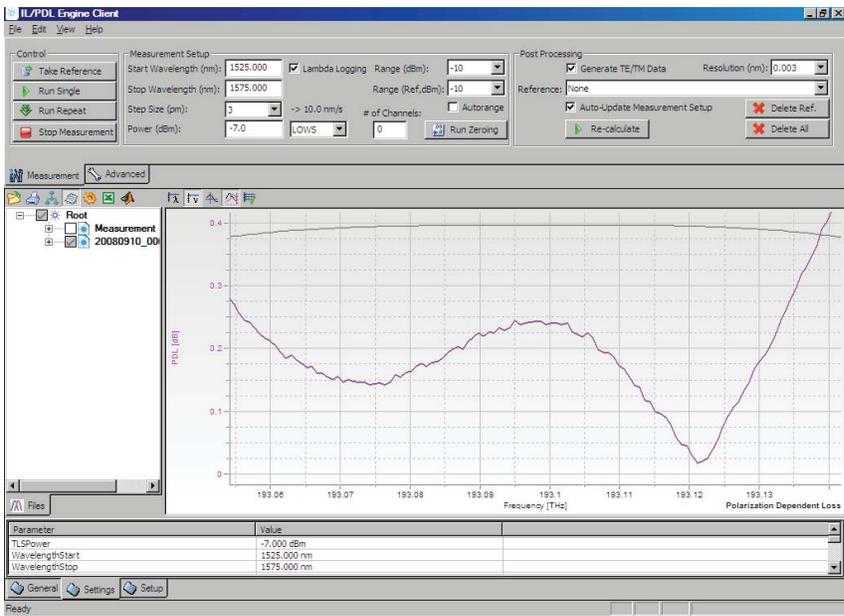


Figure 3. PDL measurement in the passband of a selected AWG channel.

In Figure 3 the details of the channel for PDL are shown.

Configuration

Figure 4 shows the setup schematically for making multichannel fast-switching IL and PDL measurements. The tunable laser should be selected for the required wavelength range and other performance parameters, as detailed in the next section. The optical output from the laser is connected to the input of the polarization synthesizer. The trigger output from the tunable laser mainframe is connected with a BNC cable to the trigger input of the synthesizer. The laser can be conveniently controlled over the GPIB connection from the N7786B, or directly from the controller PC.

The optical connections to the tunable laser and polarization synthesizer can be flexibly configured for different types of fiberoptic connectors, like FC, SC, LC, etc. with the 81000xl connector interface system. Usually the instruments will be selected with the options for angled-face fiber connections to avoid power fluctuations due to interference from multiple reflections.

The optical output from the synthesizer can be connected to the input of the device under test (DUT). It is usually a good idea to attach a patchcord to the synthesizer that can then be connected to the component or used to connect directly to the power meter for reference measurements. This reduces the frequency and corresponding wear from reconnections at the instrument.

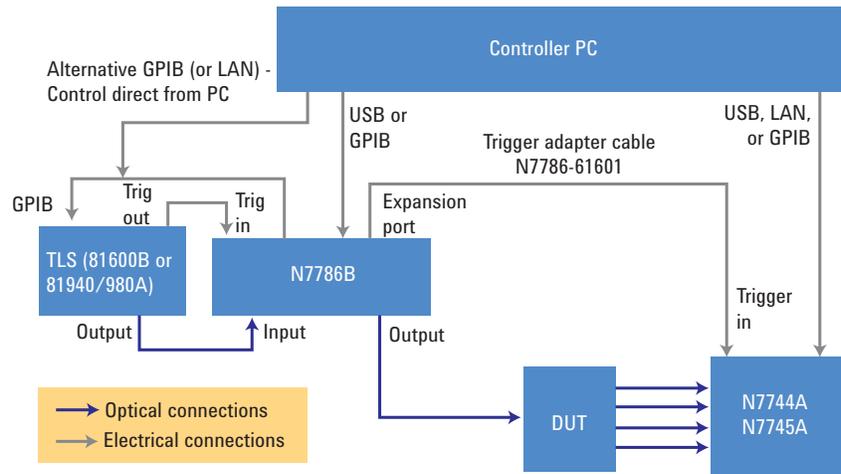


Figure 4. Schematic diagram of the instrument setup for single-sweep PDL measurement.

The special trigger cable included with the N7786B, (part number N7786-61601) is used to connect from the expansion connector of the synthesizer to the trigger input of the power meter instrument. When more than one power meter instrument is used for measuring more ports, then the output trigger from the first unit can be connected by BNC cable to the input of the next unit and the trigger can be connected similarly for each successive instrument. The power meter trigger ports are configured by the software to “pass through” for this daisy-chain arrangement. The N7786B is usually controlled via a USB cable to the PC. Alternatively, a GPIB cable can be used, but results in slower data transfer.

The optical output ports of the component are connected to the N7744A 4-port or N7745A 8-port power meters using the special quad-adapters corresponding to the connector type, for example the N7740FI for FC connectors. These quad-adapters provide snap-on attachment of 4 fibers at once and speed the complete measurement procedure. For efficient instrument use in production test, the adapters can be connected to one component while the previous component is still attached to and measured by the instruments. The power meters are connected to the PC with USB or LAN for data transfer. The USB 2.0 connection provides the fastest transfer. If desired GPIB connection is also available.

The PC runs the measurements using the Agilent N7700A photonic application suite software, running the IL/PDL measurement engine from either the N7700A user interface program or automated with customized user software. The IL/PDL measurement engine is provided under the product option N7700A-100.

Choice of instruments and parameters

The primary hardware variations involve the choice of tunable laser and the number of power meter channels. The number of channels usually corresponds to the output ports of the components. Other variations could include optical switches for reference measurements or a 2x1 coupler between the synthesizer and component for measuring the reflected power with another power meter channel.

For measuring DWDM components used to separate wavelength channels with spacing of 100 GHz or less, the tunable laser source of choice is the 81600B, used with the 8164B mainframe. The 81600B provides the required relative and absolute wavelength accuracy for such measurements and the accuracy is specified during the wavelength sweeps of up to 80 nm/s. This is achieved by the built-in wavelength monitoring and logging. The available wavelength range can be chosen, based on the product option, throughout the single-mode fiber wavelength bands.

Especially for accurately measuring the wavelength isolation (which determines channel crosstalk in the networks) of narrow band-pass filters, where the IL on the steep flanks of the filter must be determined, wavelength resolution of 10 pm or less is advisable, requiring high relative wavelength accuracy. Another reason for requiring high wavelength accuracy results from modern networks passing signals through multiple

wavelength-switching elements with reconfigurable wavelength routing. Each filter reduces the width of the combined channel and design network bandwidth values are not much higher than 20 GHz (about 160 pm at DWDM wavelengths) so offsets in the center wavelength of one of the filters with respect to the others must be kept small, requiring absolute wavelength accuracy better than about 10 pm.

Another requirement in measuring wavelength filtering components also favors choice of the 81600B tunable laser for low source spontaneous emission optical output. Such filters are characterized for wavelength isolation, requiring high dynamic range in the spectrum between the signal inside and outside the pass-band. Measuring very low power out of band requires that the laser have very low broadband spontaneous emission (Reference 5). Otherwise, spontaneous emission can typically limit the measured dynamic range to 50 dB or less, depending on the laser and on the width of the pass-band. This width dependence makes the spontaneous emission even more critical for CWDM filters that are several nanometers wide.

In other cases where the needs for wavelength accuracy or dynamic range are not quite so demanding, the 81940A or 81980A compact tunable lasers provide a smaller and lower cost option with very good performance. The compact tunable laser

can be used in the smaller 8163B mainframe as well as the 8164B. Especially for broadband components like splitter and couplers, this is a perfect fit.

Only a few setup parameters are needed to make the measurement, from which the software determines other instrument parameters. The start and stop wavelengths for the measurement should be chosen as required for the device under test, considering that filter components often also need specification for the out-of-pass-band range used by other channels too. Either the low-SSE or "high-power" optical output of the 81600B should be chosen as required. The wavelength resolution (step) and number of spectral points are tied to the sweep speed. In the standard realization, a speed of 10 nm/s is used for 3 pm resolution and 20 nm/s for 6 pm step.

The power levels of the instruments can be selected for maximum measurement dynamic range when this is needed. The power range of the power meters can be adjusted in steps of 10 dB. In the -10 dBm range using 25 μ s averaging time, the dynamic range is 57 dB and the maximum measurable power is -7 dBm. If at least 3 dB insertion loss are expected between laser and power meter, then the tunable laser can be set to -4 dBm, allowing IL measurements from 0 to 57 dB. This is a good power level for the low-SSE output of the 81600B Option 160 over the C and L wavelength bands, for example.

Measurement Procedure

The measurement procedure consists of steps like the following. Some of the steps do not need to be repeated for each measurement, as described.

- 1. Zeroing.** If low power levels need to be measured, as for high-dynamic filters, then the zeroing function of the power meters should be used to measure the electrical signal under dark conditions to avoid this offset. Often this can be done while fibers are attached to the power meter if the light source at the input is off. Or the N7740ZI zeroing adapter provides very high attenuation of any background light and can be used as well. Zeroing should be performed after the unit has warmed up to operating temperature. The N7744A and N7745A power meters have very low drift of the zero level under stable operating temperature so under stable conditions the zeroing does not need to be used often. The stored zeroing values are also saved when the unit is turned off, so that after turning it on and allowing it to reach the same operating temperature, the zero values will usually be very good.
- 2. Reference measurement.** After selecting the desired measurement parameters, the fiber from the synthesizer should be connected to the power meter. The reference can be made at any one port for use by all channels or measured individually at each port. For best PDL results this fiber should have a straight-faced connector at the power meter, since this is an open connection to air and an angled-face connector will introduce some PDL into the system (about 0.02 dB). Since the orientation of this PDL to the polarization of the light output from the component

is unknown, it is not generally possible to correct for this system PDL. (In general, reference measurements can remove polarization dependence of the system located before the DUT but not after the DUT, because of the unknown polarization change due to the DUT.) Then the reference measurement is started from the software.

- Insertion loss measurements using a reference measurement from the same port are accurate to the relative power uncertainty of the power meter, disregarding connection uncertainty. If the reference measurement is made at only one channel, the measurements at other ports compared to this reference have additional IL uncertainty due to interport variations within the higher absolute power uncertainty of the ports and the differing wavelength dependence. Higher IL accuracy is obtained by performing a reference measurement at each port.
- The power monitoring of the N7786B and stability of the laser help to keep the reference data valid for extended periods in a stable working environment, so that many measurement repetitions or components can be measured without repeating the reference. To verify this, the fiber can be reattached as for the reference measurement and an IL & PDL measurement performed to check for any changes from zero IL and PDL. Such a test, including repositioning of the fiber to simulate the change in SOP that a component would cause, is also a good way to estimate the IL and PDL measurement uncertainty of the system under the setup conditions.

3. Component connection. The fiber from the synthesizer should be connected to the component input, making sure to use a straight or angled connector to match the component. The output connectors, which may be previously attached to quad-adapters are connected to the power meter ports.

- If the quality of the components output connectors should be included in the IL, then these connectors should be connected to fiber cables with “reference” grade connectors and these cables should then be attached to the power meters.

4. Data review. Then the measurement can be started from the software. The resulting data can be inspected from the user interface software, and saved for further analysis and documentation. As one example of analysis, Figure 5 shows the resolution of a thin film filter measurement into TE and TM polarized spectra. Note that the crossing point at the peak results in a point of minimum PDL.

Measurement Procedure, Continued

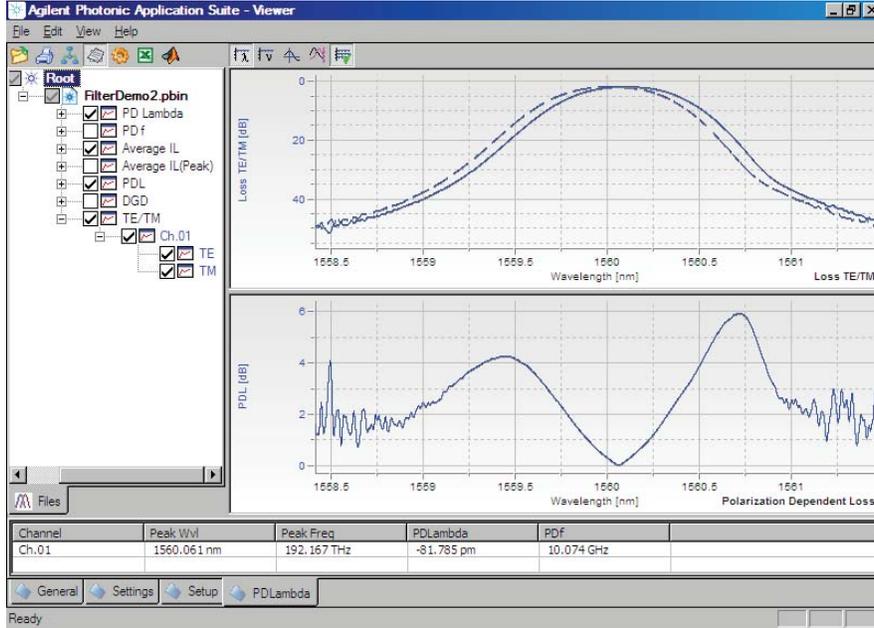


Figure 4. TE/TM analysis of a thin-film filter for the determination of PDL.

Measurement Speed and Performance

The time required for these measurements depends primarily on the number of points and thus on the sweep speed and range. Increasing the number of channels only slightly increases the measurement time. As an example, measuring 40 channels over 50 nm with 12 pm resolution can be repeated in about 10 seconds. With points every 3 pm, the repeated measurement time is about 20 seconds. Such measurements are able to show IL dynamic range beyond 57 dB using the 81600B low-SSE tunable laser and PDL uncertainty below ± 0.04 dB.

References

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- [3] Agilent P/N 5988-7325EN: "Photonic Foundation Library Fast Sweep PDL: A Getting Started Guide to perform PDL measurements in Fast Sweep Mode".
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- [5] Agilent P/N 5980-1454E: "State of the Art characterization of optical components for DWDM applications".



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