Abstract
This application note describes an approach to significantly reduce the measurement time associated with polarization dependent loss (PDL) measurements. The method described combines the Mueller method technique for measuring PDL with the Fast Sweep measurement function provided by the Photonic Foundation Library. The paper describes the implementation and discusses and compares measurement results, measurement times and accuracy qualitatively.
Introduction

This application note discusses an easy way of reducing the time needed to perform polarization-dependent loss (PDL) measurements based on the Mueller method. The Fast Sweep PDL measurement approach introduced here leverages the existing functionality of the Photonic Foundation Library (PFL). Therefore, the implementation of the discussed approach does not require any changes in hardware from a typical PDL measurement setup based on Mueller method.

The approach being discussed combines the implemented functionality and measurement setup of a standard Mueller method PDL measurement with the Fast Sweep (or Real Time) functions of PFL. The implementation of the Fast Sweep PDL measurement is carried out in the PFL software layer.

In this application note, we briefly review the PDL measurement principle based on the Mueller method and the Fast Sweep functionality provided by the PFL. Then, it is described in great detail how the Fast Sweep capability can be combined with the Mueller method PDL measurement technique to yield significant improvements in measurement time. We discuss and compare measurement results and measurement times obtained by a standard PDL measurement using Mueller method, and the Fast Sweep PDL measurement.

Polarization Dependent Loss Measurement

The insertion loss of optical components, and hence higher order filter parameters, depend on the polarization of the incident light signal. Because polarization is not constrained in optical networks, i.e. it changes randomly, it became mandatory to measure the influence of polarization on the component’s loss performance, denoted as the polarization dependent loss (PDL). Most higher-order parameters of optical filters, such as Crosstalk, Bandwidth or Ripple are polarization dependent as well. For a thorough analysis of these, the polarization influence must be included.

A well known method for measuring PDL is the Mueller method [1] [2]. The Mueller method determines the PDL by exposing the device under test (DUT) to only four but well-known states of polarization. The PDL of the device is derived from the

transmission measurement at these four states of polarizations.

The Mueller method is especially advantageous if the PDL needs to be measured over wavelength, with high resolution. The Mueller method can be incorporated with swept wavelength measurement techniques, where, at each of the four polarization states, the transmission over wavelength is recorded using a tunable laser source and power meter configuration. In such a setup, the tunable laser should be capable of continuously tuning across the wavelength range. Consequently, for a large number of wavelength points the Mueller method obtains accurate measurement results in a short period of time.

The Photonic Foundation Library (PFL) uses the Mueller method to measure PDL properties of optical components. Therefore, the Mueller Algorithm together with the swept wavelength measurement capabilities are embedded into the PFL to perform PDL measurements over wide wavelength ranges with high accuracy and resolution. The typical PDL measurement techniques using the Mueller method are shown in Figure 1.

![Figure 1: Principle of polarization loss measurement. The setup is similar to the setup for insertion loss measurement, but in this case a polarization controller has also been included to measure loss at four predefined polarization states.](image-url)

The principle of the Mueller method and the test environment for PDL measurements is not new and has been well described in earlier publications [1] [2]. However, ease of system development, predefined specification, and error correction cannot all be integrated into the test without the PFL.
Real Time Measurement

Real time (or fast sweep) measurement is a new feature that the PFL makes available for Agilent Swept Wavelength test systems [3] [4]. It allows users to continuously perform swept wavelength measurements without needing to individually stop and restart each sweep. The real time measurement capability is optimized for fast measurement and processing speed and is therefore an ideal tool for all tests that require short measurement times and high update rates. A good example is the continuous measurement of the spectral transfer function of thin film filters while adjusting or aligning them automatically.

The capability to monitor the spectra of multiple channels and update data within short measurement times is achievable using the PFL’s enhanced technology, working in combination with Agilent’s tunable laser sources, mainframes and optical power meters. We will show in this application note how the Fast Sweep PDL measurement could be implemented for PDL measurements to reduce test time.

Fast Sweep PDL Measurement

The Mueller method is the most commonly used method of Polarization Dependent Loss (PDL) measurement in test environments for passive optical devices. With the Real Time measurement capabilities provided by PFL, PDL measurement time can be significantly reduced, which directly translates into a major contribution to decreasing the cost of test.

The complexity of the Mueller method PDL measurement algorithm lies in the calculations that must be performed to obtain accurate measurement results. PFL contains the calculations to obtain the PDL and average insertion loss values over wavelength as well as post processing algorithms to enhance the accuracy of the measurements [3]. The defined polarized states are already programmed in the VXI Plug & Play driver of the PFL and are ready to use.

In contrast to the measurement setup for Real Time measurements, the PDL measurement setup adds a polarization controller in order to generate the four states of polarization that are applied to the DUT. The tunable laser source and multiple power meters are common to both setups.

Both the Mueller method PDL measurement and the Real Time measurement setups are implemented using the PFL. The PFL provides functions to perform swept wavelength PDL measurements based on Mueller method, and functions to perform real time spectral loss measurements.

The fundamental idea of the Fast Sweep PDL measurements is to combine the Mueller method PDL measurement with the Real Time capabilities provided by PFL. The integration of the Fast Sweep PDL measurements is carried out in the software layer of PFL, taking advantage of the building block approach taken by the PFL function libraries [Ref]. The measurement setup is the same as for a regular Mueller method PDL measurement, Figure 1.

Before describing how a Fast Sweep PDL measurement can be implemented, let’s have a look at the PFL functions used to perform a Mueller method PDL measurement, and a real time sweep.

A standard Mueller method PDL measurement is performed using the following PFL commands:

- pfl_FindMaxPolPosition: This function adjusts the polarizer at the input of the 8169A polarization controller so that maximum transmission through the polarizer (and thus the least impact on the overall dynamic range) is obtained.
- pfl_prepareMFlambdascan: This function sets the parameters for swept-wavelength loss measurements, such as: output power, optical output port, wavelength range defined by start and stop wavelength as well as step size, sweep speed, dynamic range and selection of used power meter channels.
- Pfl_executeMFlambdaPolScan: This function executes a swept-wavelength multi-channel insertion loss measurement at a specific input state of polarization. The state of polarization is generated by adjusting the wave plates of the 8169A polarization controller to a specific angle, independent of the selected wavelength range.
- pfl_getMFlambdaScanResults: This function returns power and wavelength arrays for the chosen channel.
• **pfl_calcPDLMueller8169A**: This analysis function calculates the PDL over wavelength according to the Mueller algorithm. The average insertion loss and the maximum and minimum transmission are additional output parameters. The function requires the reference and DUT transmission measurement data over wavelength, at the well defined four states of polarization. All together, eight arrays of power data are required as input. The function corrects any wavelength-dependent error that occurs while generating the four polarization states.

A real time measurement can be implemented using the following functions of PFL:

• **pfl_prepareFastSweep**: This function is used to set standard sweep parameters, such as wavelength range, step size, TLS optical output, output power and the number of used channels. In addition, the range of the power meters can be set.

• **pfl_executeFastSweep**: Surrounded by a program loop, this function performs the wavelength sweep.

• **pfl_getFastSweepResults**: This function receives the measurement data from the test system. This function is also located in the program loop.

• **pfl_closeFastSweep**: This function terminates the real-time mode of the measurement system.

The approach for the Fast Sweep PDL measurement appropriately combines the functionality used to a Mueller Method PDL measurement and the Real Time sweep.

The basic idea is as follows:

As mentioned above, a real time sweep is typically performed in a loop, repeating the swept measurement n times with the same parameter settings, or until a user defined break occurs. Using the plug and play driver functionality of the 8169A, the quarter and half wave plates can be set in order to generate the desired states of polarization. The setting of the retarders occurs before a swept measurement is performed, within the loop. As only four states of polarizations must be generated for the Mueller method PDL measurement, the loop is abandoned after the fourth sweep. After each sweep, the power readings from the power meters are retrieved. Together with the calibration data recorded before a DUT measurement, the Mueller matrix calculation can be carried out to yield the desired values.

Figure 2 shows a flow diagram of the Fast Sweep PDL measurement.
As can be seen in the flow diagram, the algorithm makes use of some functions typically used for standard Mueller method PDL measurements, such as\texttt{pfl\_FindMaxPolPosition} or \texttt{pfl\_calcPDLMueller8169A}. The core routines for the actual measurement consist mostly of functions used for the real time application of PFL, together with some VXI Plug and Play driver functions of the 8169A polarization controller to set the quarter and half wave plates.

Taking a closer look at the algorithm, the first step is to initialize the measurement parameters, such as start and stop wavelength and step size, and to initialize all instruments required to perform the measurement, as shown in Figure 3. After the initialization, the optimum polarizer position is searched for, in order to minimize the loss through the polarization controller.
In Figure 4, the core routine of the Fast Sweep PDL measurement is shown. First, the measurement setup is prepared for swept wavelength measurements, using the `pfl_prepareFastSweep` function. The user settings for start and stop wavelength, step size and others are transferred to the system.

Then, the fast sweep is performed four times in a loop. In each loop, the quarter and half wave plates are set using VXI plug and play driver commands for the 8169A polarization controller. Then, with the command `pfl_executeFastSweep` a swept wavelength measurement is performed across the user defined wavelength range with the given resolution. The power readings from the power meters are retrieved to the PC with the `pfl_getFastSweepResults` function. This is repeated four times to measure the transmission through the DUT at the four states of polarization.

The calculation of the PDL and insertion loss values is done using the `pfl_calcPDLMueller8169` function. The reference and DUT measurement values are given as input values. After the measurement has been finished, the session is closed, as shown in Figure 6.

As can be seen, the implementation of the Fast Sweep PDL measurement requires no changes in the hardware configuration of a standard PDL measurement setup, and only software related adaption of the appropriate functionality. However, as will be shown in the next section, the Fast Sweep approach offers several advantages, especially in terms of measurement time.

Figure 3: Flow Chart of the initialization routine.
Set Values

FastSweep_PDL Algorithm

Set Values
- Get tls_Power
- Get tls_Output
- Get start_wavelength
- Get stop_wavelength
- Get step_wavelength

DO 4 times (4 states of polarization)

No → Close

Yes → hp8169_setLambdaHalfPos
hp8169_setLambdaQuartPos

pfl_doFastSweet

pfl_getFastSweepResult

Set Number of data Points

These functions need to be within the DO loop in order to move the Quarter and Half plates to their desired orthogonal position relative to the polarizer (maximum output power of polarizer)

Get Values
- Set Wavelength_Array
- Set Power_Array

Set Values

Key

Get Values
Set Values
Data Structure

Figure 4: Fast Sweep PDL core routine.
**Measurement Results**

In the following section, we will be comparing measurement results obtained by a standard Mueller method PDL measurement, and the Fast Sweep PDL measurement. We are comparing the PDL baseline, the measurement times, and measurement results of a DWDM channel using both techniques.

In this first part we will concentrate on the baseline measurements.

The baseline measurement is a technique to evaluate the system performance without the presence of a DUT. A simple patchcord is used for both the reference and the DUT measurement. If the setup does not experience any change, and the fiber is not disconnected at any point, then ideally the loss and PDL values should be zero. The deviation from the ideal is an indication of the uncertainty present in the measurement setup.

The methodology of describing the measurement is as follows:

- **Measurement Picture** - The actual measurement results in image format.
- **Description** – A discussion of the results.
- **Comparison (Optional)** – A brief comparison statement between the two techniques.

![Figure 7: Baseline measurement performed with regular Mueller method PDL measurement.](image)
Figure 7 is a baseline measurement using the regular PDL Algorithm across 80nm (1540 to 1620nm), which took approximately 61.2 s / measurement. Using the same setup, the baseline measurement was repeated using the Fast Sweep PDL measurement approach.

Figure 8: Baseline measurement result obtained with the Fast Sweep PDL measurement routine.

Figure 8 is also a baseline measurement, but has been taken with the Fast Sweep PDL measurement principle. In comparison to the regular approach, the Fast sweep PDL Algorithm accomplished a measurement time of 23.2 s/measurement across the same wavelength span. The reduction in measurement time is as much as 60%. However, from the baseline measurement it is also obvious that the noise level increases. For the regular PDL measurement, the noise level over the entire wavelength band does not exceed 5mDB. In comparison, the peak noise of the Fast Sweep PDL measurement is around 10mDB. Nevertheless, these results indicate that the Fast Sweep PDL algorithm yields significant improvements in measurement time while not degrading the measurement accuracy too much. The level of noise is still acceptable in most measurement applications for DWDM components.

Comparing measurement results obtained at equal sweep speeds, the noise levels get very comparable to each other. In Figure 9, the measurement result obtained from a regular PDL measurement at 40nm/s is shown. The measurement time was 41s for the same measurement conditions as above.

Figure 9: Baseline Measurement performed with the regular Mueller matrix PDL measurement routine at 40nm/sec.

The peak noise level is close to 10mDB. Noting that the Fast Sweep is also performed at this sweep speed, it can be concluded that the Fast Sweep PDL measurement reduced the measurement time while not degrading measurement accuracy for equal test conditions.

Let’s now consider the measurement of a typical DWDM filter, as shown in Figure 10.

The regular and Fast Sweep Mueller method PDL measurements were performed with the following parameters: 1530nm to 1535nm and 1pm step, -8dBm power. The Agilent 81635A was used as the optical detector. The sweep speed for the Fast sweep routine was run at 5nm/s, whereas for the regular PDL routine the sweep speed was automatically selected to 20nm/s in Auto mode. Even when using a lower sweep speed, the measurement time in Fast Sweep PDL was only 18.6 s/measurement, compared to 28.6 s/measurement for the regular PDL measurement.
Figure 10: Measurement of a DWDM filter with the Regular and Fast Sweep PDL measurement routines.

Figure 11: Zooming into the PDL of the filter passband, comparing measurement results of both PDL measurement methods.

Let’s now have a closer look at how well the measurements agree, or if significant deviations in the measurement results can be observed. From Figure 10 it can already be seen that the filter shapes don’t differ from each other. Zooming into the PDL of the filter passband, Figure 11, it can be observed that the measurement results match quite well.

The measurement shown in Figure 12 was performed using all the same settings as above with the exception of the Fast Sweep PDL which was run @ 40nm/s with a step size of 1.1 pm with the Fast Power Meter (81637B) as the detector. In the passband region there is not much difference between running at 5 nm/s or 40 nm/s.

Figure 12: Fast Sweep measurement taken at 40nm/s.
Figure 13: Repeated measurement of the passband PDL using the Fast Sweep PDL algorithm.

Figure 13 shows 10 consecutive measurements of the passband PDL using the Fast Sweep PDL approach. The 10 consecutive measurements were done with the same reference measurement taken before the 10 measurements. The measurement time per update is 10.4 seconds.

Plot 8 is a narrow slice of the measured passband PDL values around the center wavelength (1543.73nm) of the selected DWDM channel. The graph shows the deviation between the 10 measurements, and depicts <5mDB variance between the runs.

Measurement Time Improvements.

It has already been mentioned in the previous section that the measurement time can be significantly improved by implementing the Fast Sweep PDL approach, without degradation of the measurement accuracy. The reduction of measurement time should be more visibly demonstrated in a more detailed investigation. For that matter, the measurement times of a regular and the Fast Sweep PDL measurement over a 50nm wavelength range with different resolutions and number of channels are compared. All measurements were done with the maximum allowable sweep speed, depending on the required resolution. For the measurements, the following hardware was used:

- Agilent 81640B Tunable Laser Source
- Agilent 8164B / 8166B mainframe
- Agilent 81637B Fast Power Meters
- 8169A Polarisation Controller
- Photonic Foundation Library Revision 1.1.3

The following Table 1 shows the obtained measurement times.

Figure 14: The Fast Sweep PDL measurement shows very good repeatability of approximately 5mDB.
Table 1: Typical Measurement Times of Fast Sweep and Standard PDL measurement at different resolutions, sweep speeds and number of channels.

<table>
<thead>
<tr>
<th>Channels</th>
<th>5pm @40nm/s</th>
<th>1pm@20nm/s</th>
<th>0.5pm (1520-1569) @10nm/s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fast Sweep PDL</td>
<td>Standard PFL</td>
<td>Fast Sweep PDL</td>
</tr>
<tr>
<td>1</td>
<td>14.47</td>
<td>26.75</td>
<td>33.86</td>
</tr>
<tr>
<td>2</td>
<td>14.87</td>
<td>32.16</td>
<td>35.48</td>
</tr>
<tr>
<td>4</td>
<td>17.69</td>
<td>42.52</td>
<td>42.33</td>
</tr>
<tr>
<td>8</td>
<td>24.74</td>
<td>72.76</td>
<td>60.65</td>
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<tr>
<td>20</td>
<td>44.56</td>
<td>122.4</td>
<td>101.8</td>
</tr>
</tbody>
</table>

Please note that the measurement times observed represent only typical values. Absolute numbers may differ depending on computer processing speed, firmware of instruments and if instruments other than the specified above are used.

Summary

An approach to significantly reduce measurement times of PDL measurements has been introduced: the Fast Sweep PDL measurement. The approach is a combination of the standard swept wavelength Mueller method approach for measuring PDL and the Fast Sweep capability provided by the Photonic Foundation Library. The implementation of the Fast Sweep PDL measurement is done in the PFL software layer, where extensive use can be made of existing PFL functions. It has been shown that, while maintaining a very acceptable level of measurement accuracy, the measurement time could be drastically reduced, in some cases by more than 60% compared to the standard PDL Mueller measurement using PFL functions.
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