Application Note for PDL Measurement

Introduction:

Polarization-dependent-loss (PDL) measurement is extremely sensitive to unwanted variations in the measurement system, including light source instability, connector back reflections, and even the layout of the test fiber cables. Large measurement inaccuracies or fluctuations may occur if the test setup is not properly arranged, even if a high accuracy measurement instrument is used. This application note describes precautions for accurate PDL measurements in general and ways to minimize measurement inaccuracies using General Photonics' PDL multimeter (PDL-201).

PDL is defined as:

$$PDL = 10\ Log\ \frac{P_{max}}{P_{max}} \qquad (1)$$

where Pmax and Pmin are the maximum and minimum output optical power passing through a device under test (DUT) when the input light is scanned over all possible polarization states, as shown in Fig. 1.

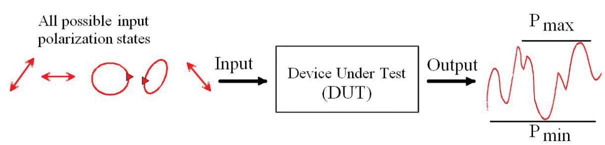

Figure 1 Illustration of PDL definition

Several possible errors or uncertainties may be introduced during measurements, including:

1. Error caused by light source fluctuation

As indicated in Eq. (1), if the power from the light source fluctuates with time, the measured Pmax and Pmin also fluctuate, resulting in measurement inaccuracies. Therefore, a light source used for PDL measurement must be highly stable.

Even if the light source itself is highly stable, small back reflections from various positions in the measurement system may feed back to the laser, disturbing its operation and causing output instabilities. Therefore, it is highly recommended that an isolator be used at the input of the PDL measurement instrument to minimize back reflections, even though the laser source may already have an isolator at its output. In addition, all of the connectors between the light source and the PDL meter must be APC type to minimize connector back reflection.

2. Error caused by double reflections

There may be small reflections from some components used in the measurement setup, including the connectors and the DUT itself. As shown in Fig. 2, reflected light from a component may be reflected again by another component. The double-reflected light travels in the same direction as the main input light and can therefore interfere with it. The total output optical power is thus:

$$P = P_{in} + P_{dr} + 2\sqrt{P_{in} P_{dr} \hat{e}_{in} \cdot \hat{e}_{dr}} \cos\phi \qquad (2)$$

where P_{in} and P_{dr} are the powers of the main and double reflected light beams, $\hat{e}_{in}$ and $\hat{e}_{dr}$ are the unit complex vectors of the states of polarization (SOP) of the main and double reflected light beams, and $\emptyset$ is the relative phase between them.

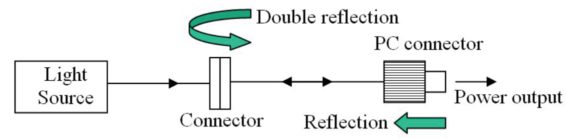

Figure 2 Illustration of double reflection

Because the relative phase and the SOPs of both the double-reflected light and the main light beam change when the fiber is disturbed, their interference causes the total output power to fluctuate. The magnitude of the relative fluctuation, in dB, from Eq. (2) is:

$$\Delta = 10\log[2\sqrt{P_{in}P_{dr}}/(P_{in}+P_{dr})] \approx 10\log(2\sqrt{P_{dr}/P_{in}} \qquad (3)$$

Although the double-reflected light is very weak, its contribution cannot be ignored because it interferes with a strong light signal (the input). For example, if a light beam is first reflected by an open PC connector with the typical 4% reflectivity, and is then reflected again by a mated PC connector with a reflectivity of 0.01% (a return loss of 40 dB), the detected power fluctuation can be as large as 0.017 dB. This power fluctuation will cause a PDL measurement fluctuation of 0.017 dB. Such a value cannot be ignored when measuring DUTs with similar PDL values. If an APC connector with a return loss of 60 dB is used instead of the mated PC connector in the previous example, the PDL fluctuation is reduced to 0.0017 dB, which can be ignored in most cases.

To minimize the contributions from double reflections, APC type connectors with low reflections should be used, if possible. Alternatively, a light source with a short coherence length (shorter than the optical path difference between the double reflected light and the main light beam) can also be used. This way, the interference described in Eq. (2) cannot take place; therefore, the resultant interference fluctuations described in Eq. (3) do not occur.

3. Error from connector and cable contributions

In addition to the DUT, the fiber cables and/or connectors used in the PDL measurement also have small PDL values. For example, optical cable itself may have a PDL value on the order of 0.01 dB, and this value may increase when it is bent with a small radius of curvature. Connectorized fiber jumpers may also have a small amount of PDL, on the order of 0.01-0.02 dB. Poorly connectorized jumpers can have even higher PDL values, probably caused by excess stress on the fiber during connectorization. Angle polished connectors (APC) generally have high PDL, especially when not mated with another APC connector. Therefore, it is possible that a connectorized fiber jumper used in the measurement can contribute a PDL error of 0.02 dB or higher to the PDL measurement of a DUT.

4. Variation caused by PDL vector summation

PDL can be viewed as a vector in a 3D space, because Pmax and Pmin in Eq.(1) correspond to two orthogonal states of polarization of the input light, which can be represented on a

Poincaré Sphere. Therefore, when two or more components in the measurement setup have non-zero PDL values, the total PDL is the vector summation of the PDL values of all of the components. For example, for the setup shown in Fig. 3, the total measured value of PDL is the vector summation of the PDLs of fiber connectors A, B, C, D, and the DUT (assuming for simplicity 's sake that the fiber cables have zero PDL):

$$PDL_T\hat{e}_T = PDL_a\hat{e}_a + PDL_b\hat{e}_b + PDL_c\hat{e}_c + PDL_d\hat{e}_d + PDL_{DUT}\hat{e}_{DUT} \quad (4)$$

where PDL_T and $\hat{e}_T$ are the value and complex unit vector of the total PDL; PDL_a, PDL_b, PDL_c, PDL_d, and PDL_{DUT} are the PDL values; and $\hat{e}_a$, $\hat{e}_b$, $\hat{e}_c$, $\hat{e}_d$, and $\hat{e}_{DUT}$ are the complex PDL unit vectors of connectors A, B, C, D, and the DUT, respectively. Fig. 4 shows graphically how the PDL vectors add up. The maximum PDL results if the PDL vectors of all of the components are parallel:

$$PDL_{T\max} = PDL_a + PDL_b + PDL_c + PDL_d + PDL_{DUT} \quad (5)$$

The minimum PDL results if the PDL vectors of all connectors are aligned, but are counter-parallel with the PDL vector of the DUT, assuming that the DUT's PDL value is larger than the sum of the connector PDL values:

$$PDL_{T\min} = PDL_{DUT} - (PDL_a + PDL_b + PDL_c + PDL_d) \quad (6)$$

The direction of each component's PDL vector relates to the orientation of the component and to the stress induced birefringence of the fiber cable. When the fiber between two components is disturbed, the relative directions of the PDL vectors are also changed, resulting in measurement variations. The maximum PDL value variation is therefore:

$$\Delta PDL_T = PDL_{T\max} - PDL_{T\min} = 2(PDL_a + PDL_b + PDL_c + PDL_d) \quad (7)$$

If the PDL value of the DUT is much larger than those of the connectors, the relative measurement error is small. A large relative error will result if the DUT has a PDL value similar to those of the connectors. Therefore, for accurate characterization of DUTs with small PDL values (such as fused couplers), the PDL values of any connectors and cables connecting to the DUT must be extremely small. The limiting factor for measurement accuracy is often not the accuracy of the instrument itself, but the residual PDL of the connectors and cables connecting to the DUT.

Table I: Typical PDL values of common optical components:

Component	Typical PDL value
1 meter single mode fiber	<0.02 dB
10 km single mode fiber	<0.05 dB
PC type connector	0.005 ~ 0.02 dB
APC type connector	0.02 ~ 0.06 dB
50% fused coupler, single window	0.1 ~ 0.2 dB
50% fused coupler, dual window	0.15 ~ 0.3 dB
90/10 fused coupler, through path	0.02 dB
90/10 fused coupler, -10 dB path	0.1 dB
Isolator	0.05 ~ 0.3 dB
3-port circulator	0.1 ~ 0.2 dB
DWDM	0.05 ~ 0.15 dB
Polarizer	30 ~ 50 dB

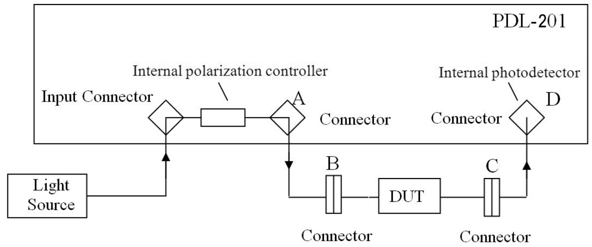

Figure 3 PDL measurement setup using the PDL-201 with 4 connectors: A, B, C, and D

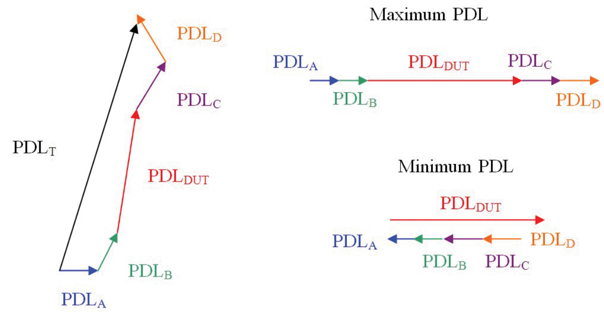

Figure 4 Illustration of the vector summation of PDL contributions from all connectors and DUT. The measured PDL fluctuates between a maximum value and a minimum value, depending on the relative orientations of each PDL vector.

Summary of good practices for minimizing PDL measurement errors

Keeping in mind the sources of PDL measurement errors described above, here is a summary of good practices for PDL measurement, using General Photonics' PDL-201 multimeter as an example. A typical measurement setup is shown in Fig. 5.

1. The light source used for PDL measurement must be highly stabilized, with a short-term stability similar to the intended PDL measurement accuracy. For example, if a PDL accuracy of 0.02 dB is to be achieved, the laser source's short-term power stability must be better than 0.02 dB.

2. An isolator at the input of the PDL-201 is recommended for minimizing the amount of back-reflected light from the downstream connectors and DUT that goes back into the light source. General Photonics' NoTail isolator, which has no fiber pigtails, is preferred.

3. Only APC connectors should be used between the light source and the PDL-201 input, in order to minimize back reflection to the light source, and consequently to minimize back-reflection induced instability of the light source. The NoTail isolator described in step 2 should therefore be APC connectorized.

4. The polarization of the light source should be relatively stable. Lasers with fast polarization fluctuation will cause measurement fluctuations.

5. The wavelength of the light source should be relatively stable, because fast wavelength fluctuation of the light source will cause fast polarization fluctuation due to the birefringence of the fiber cable connecting the laser and the instrument.

6. Fiber jumpers with low PDL should be used for connecting to the DUT.

7. To minimize the error contribution from double reflection, APC connectors should be used for inputting light into the instrument and to the DUT. The PDL-201 has APC bulkhead connectors (input connector and connector A in Figs. 5 and 6) mounted on the front panel for this purpose. For accurate measurement of low-PDL DUTs (less than 0.1 dB), index matching gel can be used at connectors B and C to reduce back reflection and residual PDL.

8. To minimize connector PDL contributions, a PC type connector should be used to send the output light from the DUT into the instrument (connector D in Figs. 5 and 6). Light from the PC connector will be directly incident onto a free space photodetector inside the instrument. If an APC connector were used here, a PDL error contribution of 0.03 ~ 0.04 dB would result.

9. There should be no sharp bending or tight coiling of the fiber cable between connectors A and D, because bending can introduce non-negligible PDL in the fiber cable.

10. For pre-connectorization measurement of pigtailed components on the production floor, the setup shown in Fig. 6 should be used. In this setup, a fiber pigtail with an APC connector at one end is connected to bulkhead connector A. The other end is left free for fusion splicing. The operator may fusion splice the free pigtail to that of the DUT input, and use a removable PC type bare fiber adapter at the DUT output to connect to bulk-connector D. Index matching gel may be used with APC connector A to minimize its PDL contribution.

Note: Connector A in Figs. 5 and 6 will also contribute a slight background PDL. Therefore, for pre-connectorization measurement of pigtailed components (especially low-PDL components), it can be replaced with a fiber pigtail which can be fusion spliced to the DUT input (Fig. 7). Please contact General Photonics for desired configuration before ordering.

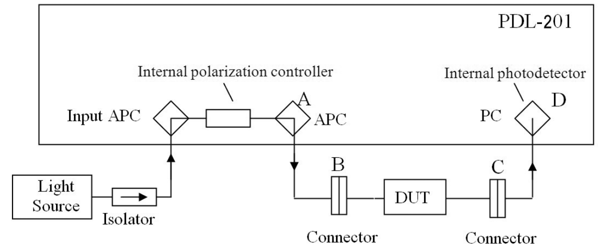

Figure 5 Typical setup for measurement of a connectorized DUT with the PDL-201.

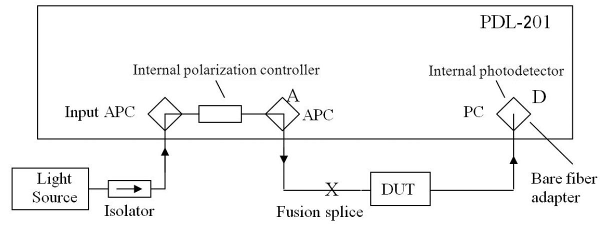

Figure 6 Production floor setup to measure an unconnectorized, pigtailed DUT using fusion splice to a free pigtail and bare fiber adapter to connect to the PDL-201.

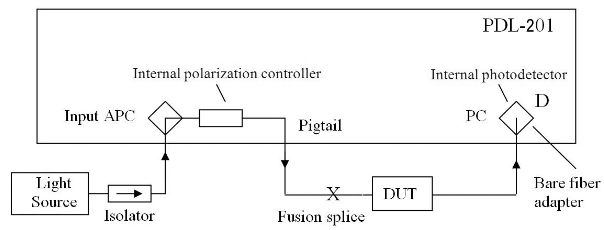

Figure 7 Production floor setup to measure an unconnectorized, pigtailed DUT using only fusion splice and bare fiber adapter to connect to the PDL-201.