MEASURING POLARIZATION DEPENDENCE OF DWDM PASSIVE DEVICES WITH THE IQS-12004B DWDM PASSIVE COMPONENT TEST SYSTEM

061

APPLICATION NOTE

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When discussing polarization sensitivity of passive components, the first thing that comes to mind is polarization-dependent loss (PDL). Although PDL is very important, there are other parameters, such as central wavelength, bandwidth and isolation that are also sensitive to the state of polarization (SOP). Often, some of these measurements are overlooked. This application note presents some experimental data derived from tests taken with EXFO's IQS-12004B system and will illustrate three important concepts related to polarization:

- Polarization-dependent loss measurements
- Polarization-dependent wavelength measurements
- Depolarized and average loss measurements

IQS-12004B DWDM Passive Component Test System–A Brief Introduction

The IQS-12004B DWDM Passive Component Test System is an innovative approach to DWDM component characterization. The system sweeps a very-low-noise tunable laser source across the spectral band of the device under test (DUT), and simultaneously measures power on multiple channels, thus providing a quick testing time that is practically independent of the number of device ports. Because of the low source spontaneous emissions (SSE) of the IQS-2600 and the IQS-2600B Tunable Laser Source, a dynamic range of 60 dB, or more, is easily attained. The wavelength reference module ensures accuracy by providing a fast and continuous wavelength reference across the sweep range.

The modularity of the IQS-200 Optical Test System and the flexibility of the software enables the user to easily expand to a higher number of channels. Start with a single-channel system for measuring filters or gratings and expand to 32, 64 or more channels simply by adding the necessary plug-in modules.

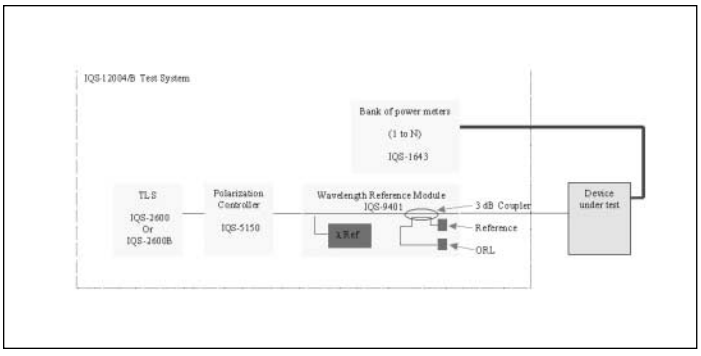


Figure 1: IQS-12004B functional diagram

Integrated software (developed at EXFO in Visual Basic) controls all instrument functions from start to finish. The step-by-step approach, similar to other integrated applications, offers a systematic test procedure that ensures accurate and repeatable results. Numerous features–including automatic pass/fail detection, filter masks and a part number database–simplify DWDM component characterization.

Remote control of the IQS-12004B system is available through either a GPIB interface or a high-speed DLL/COM interface. The GPIB and DLL interfaces offer high-level commands that greatly simplify customer application development.

Polarization-Dependent Loss

As mentioned in the introduction, one of the most critical requirements for characterizing DWDM passive components (filters, MUX, DEMUX, gain flattening filters, OADMs, FBGs, attenuators, etc.) is the ability to measure polarization-dependent loss as a function of wavelength. When configured with the optional IQS-5150 Polarization State Adjuster, the IQS-12004B system performs this task exceptionally well. PDL measurements with the IQS-12004B system are taken using the Mueller Matrix method and provide PDL vs. wavelength across the complete range.

Polarization Scanning vs. Matrix Calculation Method

Optical engineers often ask the question, how does the Mueller Matrix method compare with traditional polarization scanning techniques for measuring PDL as a function of wavelength? This is an important question and is best answered by first explaining each test configuration. There are essentially two practical methods for measuring PDL: the polarization scanning method (TIA/EIA-455-157) and the Matrix calculation method (proposed by TIA/EIA-455-198).

Polarization Scanning

In the polarization scanning method, we cover practically all states of polarization and monitor the variation in transmission properties, where the PDL is the difference between the minimum and maximum transmission. If we do this with a tunable laser source over a series of wavelengths, then we can arrive at a profile of PDL vs. wavelength.

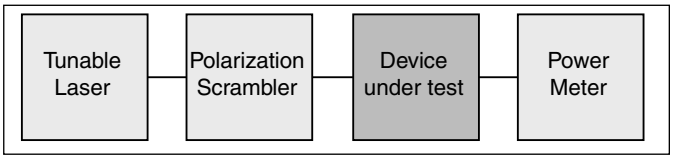


Figure 2: PDL measurement using polarization scanning method

In this configuration, it is important that the polarization scrambler cover as many states of polarization as possible in the shortest time. The polarization scrambler must also have low activation loss[1]. If not, additional precautions must be taken to compensate. Further, the power meter detectors should have very low polarization-dependent sensitivity. The IQS-5100B Polarization Controller and IQS-3400B PDL Meter have been specifically designed for this type of measurement.

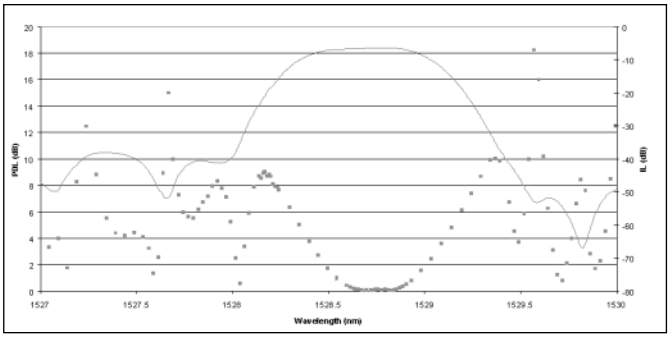


Figure 3: PDL measurement results using polarization scanning method

The measurements depicted in Figure 3 were taken on an arrayed waveguide (AWG) grating. The illustration shows the insertion loss curve, along with a series of PDL measurements taken at discrete wavelengths. As expected, the PDL is very low in the device passband and is much higher in most other regions.

Mueller Matrix Method

In the matrix calculation method, transmission measurements are performed at four orthogonal states of polarization and the DUT's maximum, minimum and average transmission properties are calculated t using the Mueller and/or Jones matrix. Normally 0-, 45- and 90-degree linear states are used along with a right-hand circular state.

[1] *Activation loss is the variation in power measured at the ouput of the polarization scrambler as the instrument covers the Poincaré Sphere.*

In the simplified diagram shown in figure 4, it is very important that the polarization controller be able to accurately generate the required SOPs; this normally requires a waveplate-based polarization controller. The IQS-12004B system uses the Mueller Matrix method; a typical test sequence (after reference and calibration) would consist of four sweeps of the tunable laser across the specific wavelength range at different states of polarization. Based on the transmission characteristics of the device at each state of polarization and on the calibration/reference data, PDL is calculated for each wavelength.

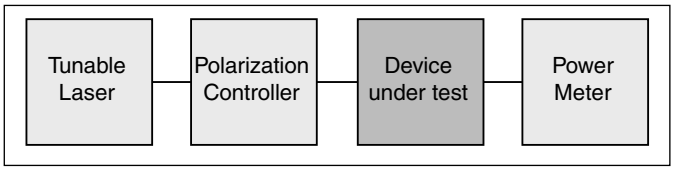


Figure 4: Mueller Matrix PDL measurement setup

The data shown in figure 5 is for the same device as in Figure 3 and we can clearly see that the PDL response is very similar. The real test, of course, is to overlay the results from both methods and to see just how good the correlation is.

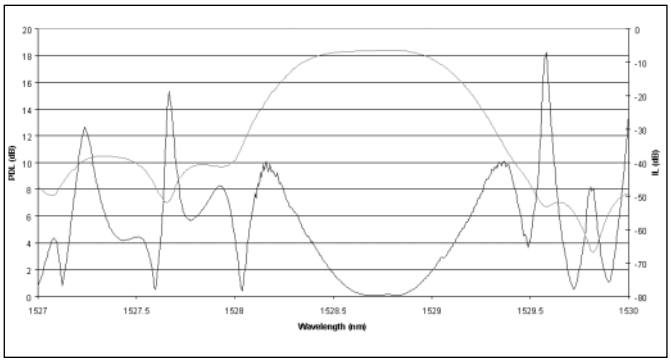


Figure 5: PDL measurement using the Mueller Matrix method

It can be observed that the correlation is very good for all PDL values, even where it is close to 20 dB at ~1529.6 nm. The only area where there appears to be a significant difference between the two sets of measurements is in the transition zone at ~1528.2 nm. At this wavelength, the data obtained using the polarization scanning method is more accurate. Why?

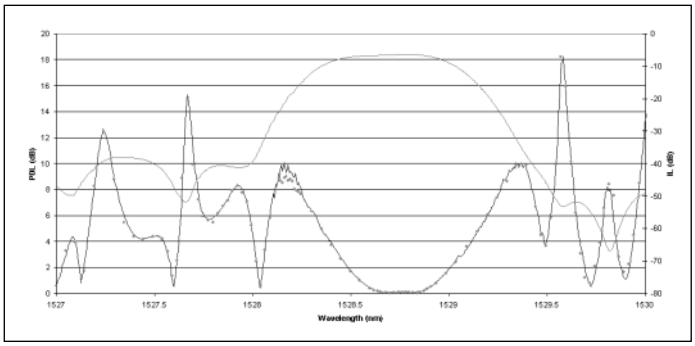


Figure 6: PDL measurement using both techniques (Mueller Matrix and Polarization Scanning)

The answer is not related to which PDL measurement method is used, but rather to the way the measurement is performed. To recap, the polarization scanning method steps the source and takes a PDL measurement at each wavelength. Thus, the source stays at the same wavelength and does not move until sufficient data is accumulated to give a PDL value. The swept Mueller Matrix measurement sweeps the laser four times across the wavelength range and then calculates the PDL at each wavelength. It is impossible to guarantee that each of the four measurements is taken at the exact same wavelength. When we have a steep filter slope, any error in wavelength (however small) will generate a significant loss-measurement error and will have a tendency to calculate a higher-than-expected PDL value.

We could always step the laser and, at each step, measure the loss at four states of polarization, as required by the Mueller Matrix method. This would remove any measurement error due to wavelength error, but would unfortunately increase the testing time significantly.

Let's have a closer look at the most important area of the filter shown: the passband region, where the PDL is typically very small. Again, we can see that the two sets of data essentially coincide. There is a small difference of approximately 0.02 dB that is well within the error expectations for each measurement.

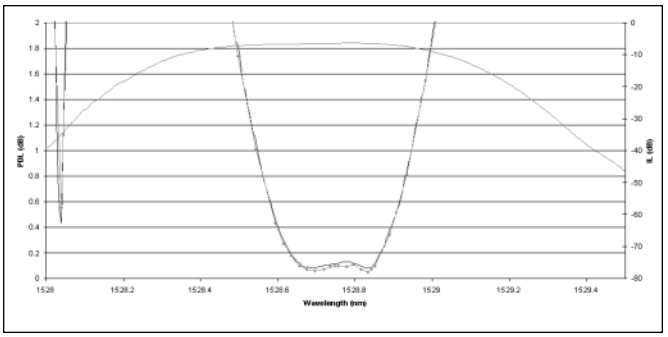


Figure 7: Polarization-dependent loss in the passband of an AWG device

The data is convincing, but it should be pointed out that implementing accurate swept Mueller Matrix PDL measurements is a very complicated project, in which there are many considerations and variables.

- The polarization controller must be accurate and repeatable; this becomes more important when the PDL values are high.
- The reference detector and the measurement detector should have as low a polarization sensitivity as possible–the importance of having detectors with low PDL should not be underestimated. The PDL measurement error (assuming all other sources of error are controlled) will be ± 2 x PDL Detector.
- The power meter electronics must be very linear over a high dynamic range–non-linearities contribute considerably to measurement error and that is why, with some systems, PDL error gets very high as the device loss increases. This, of course, is unacceptable when measuring the PDL of an attenuator at 20 dB attenuation, or when trying to measure polarization-dependent isolation, for example.
- The power meter must have high resolution and very low noise–a measurement resolution of 0.001 dB or better is required if small variations in PDL are to be observed.
- The polarization must not drift between the polarization controller and the reference detector. Because of the PDL and the polarization-dependent coupling ratio (PDCR) of the reference coupler, any movement of this interconnection cable will have a major effect on the quality of the measurement. EXFO solves this problem by using rigid cables.
- Include considerations for wavelength corrections based on the type and wavelength of the waveplates in the polarization controller.
- Coherence interference should be avoided as much as possible–using a medium-coherence tunable laser helps to avoid interference from parasitic etalons.

The matrix calculation method for measuring PDL as a function of wavelength is very reliable, as long as it is implemented correctly. It is much faster than the polarization scanning method for spectral characterization and provides data at high resolution over a wide wavelength range.

Polarization-Dependent Wavelength

The spectral properties of a filter or device channel depend, to some degree, on the state of polarization. That means that if we were to measure the device at different SOPs then we could see either a shift in the central wavelength, different bandwidth characteristics, or a combination of both. The severity of this dependence is closely related to the device technology. For example, planar waveguide AWG devices are more troublesome than thin-film devices. No matter what technology is used, this polarization dependency must be characterized so that compensation techniques can be evaluated and implemented.

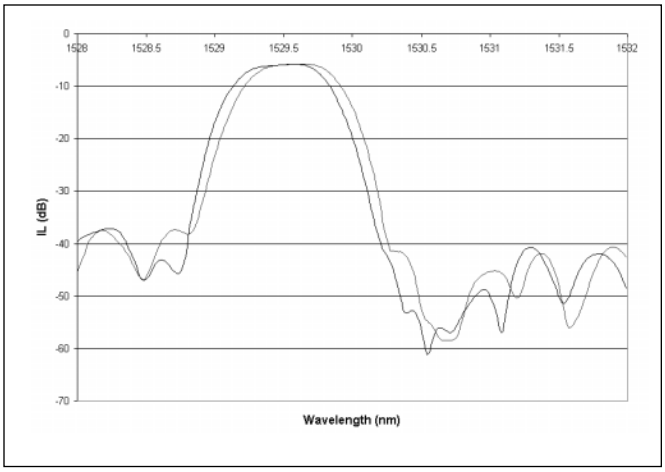


Figure 8: Spectral characteristics of an AWG device at two different SOPs

Data at two states of polarization for an early-prototype AWG device is shown above. Clearly, there is a significant shift in the central wavelength as well as a shape change; we can also observe that the isolation structure has changed. What if we were to measure at more SOPs?

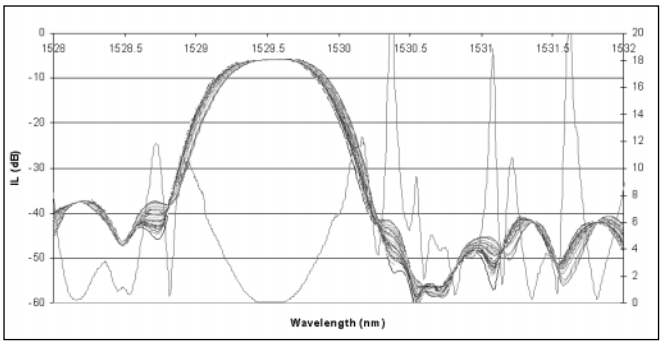


Figure 9: Spectral characteristics of an AWG device at 40 different SOPs

The illustration above depicts the spectral characteristics of the same device as in Figure 8, using the same channel. We can see that, in Figure 9, there is a concentration of values within the same range. If the SOPs are reasonably well distributed, we can find a minimum and maximum value for the central wavelength and thus arrive at the polarization-dependent central wavelength (PDCW). We can also clearly see the relationship between the PDL and the various measurements at different SOPs. Where the concentration of values is more spread out, the PDL is high, and where all the curves converge, the PDL is low.

In Table 1, below, we have measured four channels of the device at 40 different SOPs and have found the PDCW to be ~ 80 pm. This is quite high for a 100 GHz device in which the inter-channel spacing is approximately 800 pm or about 0.8 nm.

	Central Wavelengths (nm)				
SOP	**Channel 1**	**Channel 2**	**Channel 3**	**Channel 4**	
1	1528.751	1529.532	1530.32	1531.102	
2	1528.788	1529.572	1530.356	1531.138	
3	1528.743	1529.527	1530.31	1531.094	
4	1528.777	1529.567	1530.344	1531.13	
5	1528.757	1529.543	1530.326	1531.113	
6	1528.76	1529.54	1530.326	1531.108	
7	1528.784	1529.569	1530.353	1531.139	
8	1528.789	1529.577	1530.36	1531.141	
9	1528.747	1529.531	1530.319	1531.103	
10	1528.741	1529.523	1530.308	1531.09	
11	1528.74	1529.521	1530.31	1531.088	
12	1528.716	1529.502	1530.288	1531.069	
13	1528.725	1529.507	1530.29	1531.077	
14	1528.716	1529.502	1530.285	1531.067	
15	1528.747	1529.531	1530.318	1531.096	
16	1528.757	1529.539	1530.32	1531.101	
17	1528.762	1529.546	1530.329	1531.111	
18	1528.739	1529.524	1530.312	1531.093	
19	1528.755	1529.54	1530.323	1531.102	
20	1528.77	1529.551	1530.337	1531.12	
21	1528.725	1529.507	1530.291	1531.074	
22	1528.715	1529.498	1530.284	1531.066	
23	1528.736	1529.519	1530.301	1531.089	
24	1528.727	1529.506	1530.295	1531.069	
25	1528.726	1529.51	1530.294	1531.078	
26	1528.729	1529.509	1530.297	1531.077	
27	1528.723	1529.508	1530.296	1531.076	
28	1528.716	1529.501	1530.287	1531.07	
29	1528.749	1529.531	1530.318	1531.101	
30	1528.737	1529.517	1530.298	1531.082	
31	1528.728	1529.505	1530.295	1531.076	
32	1528.712	1529.498	1530.282	1531.065	
33	1528.713	1529.5	1530.285	1531.069	
34	1528.727	1529.509	1530.296	1531.077	
35	1528.765	1529.546	1530.336	1531.117	
36	1528.767	1529.545	1530.333	1531.109	
37	1528.716	1529.5	1530.289	1531.069	
38	1528.773	1529.559	1530.341	1531.128	
39	1528.76	1529.545	1530.334	1531.116	
40	1528.734	1529.518	1530.302	1531.084	
Average	**1528.7436**	**1529.5269**	**1530.3122**	**1531.0944**	nm
Min	**1528.712**	**1529.498**	**1530.282**	**1531.065**	nm
Max	**1528.789**	**1529.577**	**1530.36**	**1531.141**	nm
PDCW	**0.077**	**0.079**	**0.078**	**0.076**	nm

Table 1: PDWC data results of a four-channel device at different SOPs

Non-Polarized Loss Measurements

Having established that the spectral characteristics of a DWDM device may vary considerably according to polarization, the obvious question is, how can we test or interpret the device based on a single measurement? The standardization bodies are not yet in complete agreement as to how this is best done, but one of the more common ways is to use non-polarized measurements. This allows customers and suppliers to test and interpret data that is independent of polarization sensitivity. Interesting options are available when using the EXFO IQS-12004B system; but first, let's examine certain fundamental concepts.

Tunable lasers are highly polarized, whereas amplified spontaneous emission (ASE) broadband sources are generally non-polarized. Therefore, the easiest way to perform non-polarized measurements is to use an ASE source with an optical spectrum analyzer. This is one of the classic methods for performing spectral loss characterization of passive devices. The main disadvantage of the ASE/OSA method is the fact that PDL measurements are inaccurate and that it is not properly adapted for the characterization of multichannel components.

So how can we perform non-polarized measurements with a tunable laser? If we can depolarize the laser, then our problem is solved. If not, then we have to rely on average loss measurement techniques.

Depolarizing a Tunable Laser Source

Essentially, there are two techniques used to depolarize a tunable laser source: active depolarization and passive depolarization. The active depolarization technique relies on a fast electro-optic polarization scrambler that produces the effects of depolarization by averaging measurements over a period of time. The disadvantage of this technique is that it is unsuitable for fast swept measurement systems like the IQ-12004B; it would simply slow the measurement down unacceptably.

The EXFO IQS-9700 and M9700 Passive Depolarizers perform the same depolarization function but are based on passive optical components, so the depolarization is extremely fast. With the passive depolarizer in the optical path, the system can scan at full speed. In addition, our tests show a residual polarization of approximately 5 % to 8 %.

Like everything else, the passive depolarizer has its limitations:

1. Since a passive depolarizer can effectively depolarize a source with a short- or medium- coherence length, an ECL laser cannot be depolarized. However, the EXFO line of medium-coherence tunable lasers used in the IQS-12004B can.

2. The depolarizer degrades power stability, so it is necessary to tap and monitor the power for referencing. This is not a problem in the IQS-12004B as the reference is built in.

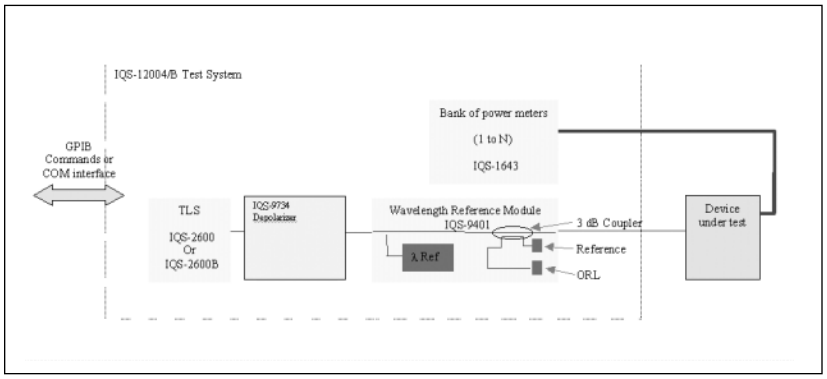


Figure 10: Detailed diagram of IQS-12004B test setup

The depolarizer can replace the polarization controller as shown above.

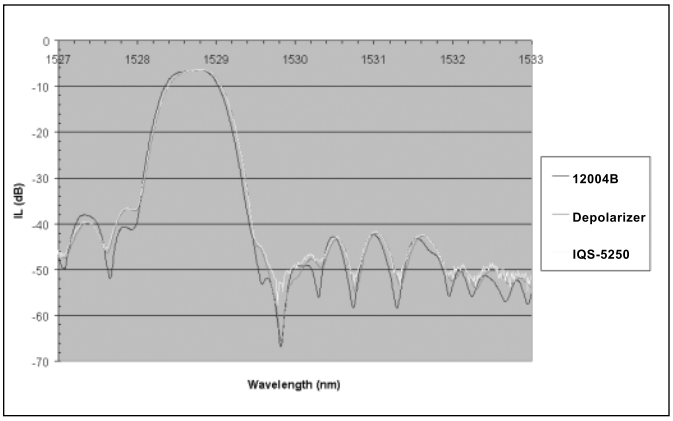


Figure 11: Test performed on an IQS-12004B, an M9700 and on an IQS-5250

The illustration above shows three sets of results. One is a measurement with the IQS-12004B in the standard configuration with the normally polarized TLS. The second is a data series taken with an ASE source and an OSA, and the third is the IQS-12004B system configured with the passive depolarizer. It is clear that the ASE/OSA trace and the depolarized IQS-12004B trace follow each other very closely. The OSA trace starts to get noisy at around 60 dB loss but the trend is very clear. This is the expected result and simply confirms that the depolarizer is doing its job.

As explained earlier in this document, the data obtained from the scans at four SOPs are used to calculate minimum loss, maximum loss, average loss, and polarization-dependent loss. It is interesting to compare how the average loss (which is the average of the horizontal and vertical SOP measurements) compares to the non-polarized measurements.

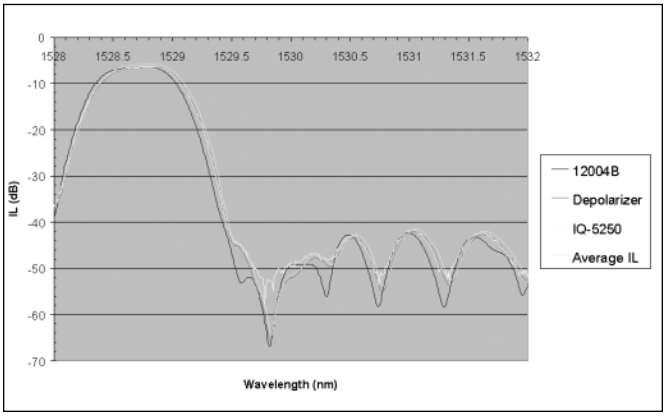


Figure 12: Comparison between average loss measurements and non-polarized measurements taken with the IQS-12004B.

Again, we see that the data is very similar. None of the overlays are perfect but it is clear that the average insertion loss calculated from the Mueller matrix, the ASE/OSA trace and the depolarized IQS-12004B are all showing similar spectral structure. The advantage of the depolarized measurement over the Mueller matrix measurement is that it takes one scan instead of four.

Conclusion

In short, three main ideas should be retained about the IQS-12004B DWDM Passive Component Test System. First, its polarization-dependent loss measurements correlate well with the polarization scanning method. Second, it can measure polarization-dependent central wavelength; and last but not least, used with a depolarizer, the system can also perform average loss measurements.

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