HOW OFDR IS REDEFINING OPTICAL COMPONENT CHARACTERIZATION

HOW OPTICAL FREQUENCY-DOMAIN REFLECTOMETRY (OFDR) DELIVERS NEW LEVELS OF PERFORMANCE AND CAPABILITY FOR TESTING MODERN OPTICAL COMPONENTS

INTRODUCTION
TESTING PASSIVE OPTICAL COMPONENTS
INSERTION LOSS AND RETURN LOSS
MEASURING IL AND RL
OFDR-BASED MEASUREMENT AND ANALYSIS
LUNA 6415 LIGHTWAVE COMPONENT ANALYZER
DUAL-DOMAIN ANALYSIS
- TIME/LENGTH DOMAIN
- PATH LENGTH MEASUREMENT IN TIME DOMAIN
- SPECTRAL DOMAIN ANALYSIS

LEARN MORE

LUNA

Introduction

The demand for communications capacity and bandwidth is growing exponentially, driven by the needs of a more connected world and the adoption of technologies such as 5G, the internet of things (IoT) and massive cloud computing. Optical communications technology is growing and evolving rapidly to meet this demand. From inside the data center to metro/edge networks and core, long-haul networks, optical communications is the key enabling technology to global interconnectedness.

Modern optical networks require ever higher-speeds and the associated optical and electronic systems must be smaller and less power hungry. This need has driven major investment in new component technologies that leverage semiconductor technology, resulting in ever smaller and more integrated photonic devices. And new component technologies demand higher performance test solutions that enable better designs, ensure optimum component performance, minimize costs and maximize throughput.

New measurement solutions based on OFDR technology provide a more comprehensive approach to passive optical component characterization that

- delivers unprecedented insight into optical component performance for enhancing design and
- provides unmatched speed of test maximizing throughput in manufacturing.

Testing Passive Optical Components

Passive optical components are critical building blocks in optical networks and systems, which are used to route, filter or combine light in an optical network. Common passive components include devices such as connectors, switches, couplers, splitters, waveguides, filters, multiplexers and demultiplexers.

For optical networks and integrated devices to function optimally, it is critical to ensure that the optical component building blocks are operating

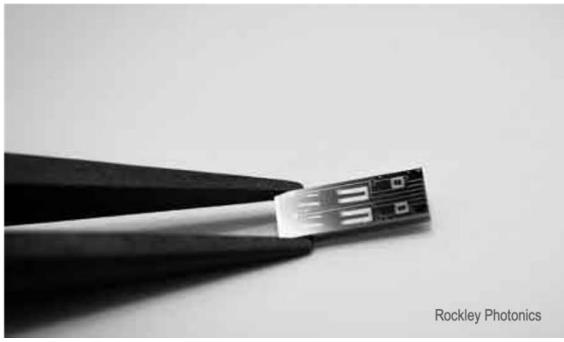


Figure 1. Lower cost, lower power and integration with electronics are driving the development and adoption of integrated silicon photonic devices

properly, transmitting light as intended and have sufficient bandwidth to transmit at speed.

One of the most basic tests is the measurement of the overall amount of optical power transmitted through as well as reflected from the component. Further characterization typically involves measuring the reflection or transmission of light as a function of wavelength. A further step up in complexity is to also measure the DUT's polarization-dependent response as a function of wavelength.

More and more, passive components are combined into advanced photonic integrated circuits (PICs) based on silicon photonics or other developing technologies. As these technologies evolve to pack more functionality into smaller packages with tighter spectral features, optimizing the propagation of light becomes even more important.

More accurate and higher resolution measurements become increasingly critical when optical functionality is integrated into waveguide platforms. Because integrated devices combine multiple components without direct access to individual components for testing, engineers have needed to

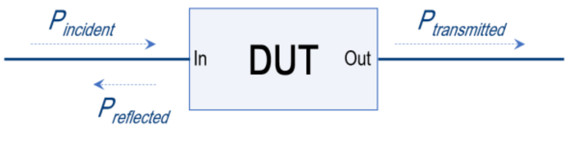


Figure 2. Transmission and reflection of light in a DUT

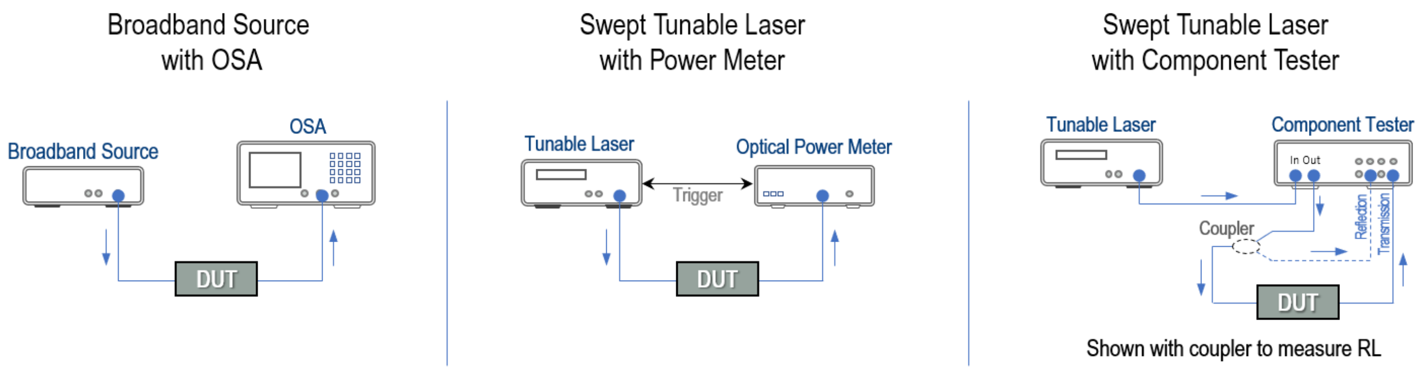


Figure 3. Traditional approaches to measuring component IL and RL with respect to wavelength

settle for validating only the overall response of the integrated device and making assumptions about the behavior of each individual component. Only with very high-resolution reflectometer technology are they able to essentially see inside an integrated component and map optical loss along the light path for a more complete picture of the integrated device's performance.

Additionally, understanding the sensitivity of higher performance components has become increasingly important. While the OFDR technology discussed in this document also provides polarization and dispersion measurements, this document will focus on the measurement of insertion loss and return loss.

Insertion Loss and Return Loss

Two fundamental parameters in the characterization of optical components and how well they transmit optical signals are insertion loss (IL) and return loss (RL). IL is the basic measurement that represents the optical loss of an optical path and is calculated as:

$$IL(dB) = 10\log\frac{P_{transmitted}}{P_{incident}}$$

where $P_{incident}$ is the amount of light into a device and $P_{transmitted}$ is the amount of light transmitted out of the DUT (see Figure 2). IL is often measured as a function of wavelength.

RL represents the relative amount of light reflected from the DUT and is calculated as:

$$RL(dB) = 10\log\frac{P_{reflecion}}{P_{incident}}$$

Measuring IL and RL

At a basic level, measuring IL and RL consists of injecting a known quantity of light into a DUT and measuring the resulting amount of transmitted light and reflected light. Because characterization of the loss across a range of wavelengths is usually required, either a broadband light source or tunable laser is utilized.

Three traditional approaches to characterizing IL and RL are illustrated in Figure 3. A relatively simple approach is to use a broadband light source combined with an optical spectrum analyzer (OSA) to measure the transmitted light across a wide wavelength range. Alternatively, for generally better dynamic range and resolution, a swept tunable laser can be used with an optical power meter. By synchronizing the wavelength sweep of the laser with the power meter, a continuous measurement of optical power versus wavelength can be obtained.

Finally, a more specialized instrument, commonly referred to as a component tester, may be substituted for the power meter. Compared to a power meter, component testers typically integrate additional functionality, including synchronizing the optical power acquisition with the swept tunable laser, often through a direct trigger signal

Figure 4. The OCA-1000 is a component analyzer that simultaneously measures IL and PDL on multiple channels

connection, multiple measurement ports, and provisions for measuring polarization dependent loss (PDL) by incorporating the capability to modify the polarization state of light sent to the DUT.

In order to measure RL with these types of test systems, you must insert an optical 2x1 coupler or circulator to isolate and route the reflected signal to a power meter or component tester. In Figure 3, this configuration is shown with the component tester.

One example of a multiport component tester is the OCA-1000. The OCA-1000 component analyzer, shown in Figure 4, simultaneously measures IL and polarization dependent loss (PDL) on multiple paths. The base model includes 8 channels and is expandable to 40 channels, making it ideal for manufacturing test of components with multiple outputs, such as DWDMs, ROADMs and AWGs.

OFDR-Based Measurement and Analysis

The traditional test configurations illustrated in Figure 3 are able to measure the overall loss performance of the DUT with varying degrees of accuracy, precision and resolution. An alternative test approach based on optical frequency-domain reflectometry (OFDR), however, delivers superior performance and resolution and can provide unprecedented insight on the inner workings of the DUT with its dual-domain capability.

OFDR is an interferometer-based measurement that utilizes a swept wavelength laser source to interrogate a DUT which is placed in one arm of an interferometer. OFDR-based testers and analyzers are able to provide fast characterization of optical devices.

IL and RL characterization as a function of wavelength using the OFDR technique has the advantage of superior speed and a combination of very high dynamic range and wavelength resolution.

However, in addition to superior wavelength characterization of devices, OFDR has the added benefit of time-domain capability. An OFDR system can function as a very high-resolution reflectometer – similar to an OTDR but with a much higher resolution that is more suitable for component and short network analysis. When scanning a DUT in reflection, OFDR-based systems can map the optical loss as a function of optical delay or distance along the entire optical path with very high resolution. This time (or length) domain measurement allows a level of analysis not available with the traditional component test systems.

Luna Innovations offers a variety of instruments based on OFDR for analyzing components and fiber optic networks. The Optical Backscatter Reflectometer (OBR) family includes ultra-high resolution reflectometers that offer sampling resolution as high as 10 µm in the time delay/length domain and the sensitivity to analyze Rayleigh backscatter. The Optical Vector Analyzer (OVA) is a comprehensive analyzer that provides complete wavelength characterization of a component in a single scan, including polarization and phase. The newest addition to the Luna family of OFDR-based instruments is the 6414 Lightwave Component Analyzer.

Luna 6415
Lightwave Component Analyzer

The Luna 6415 Lightwave Component Analyzer (LCA) is a new analyzer that utilizes OFDR technology to deliver an optimized combination of performance, speed and value for testing in development or in manufacturing. The 6415 is an integrated analyzer, requiring no external light source or additional components for complete and fast analysis of optical component IL and RL. The Luna 6415 can analyze a DUT connected in reflection or in transmission. When analyzing a DUT in reflection, the Luna 6415 measures optical reflection (and analyzes IL and RL) with a spatial resolution of 20 µm.

Because its measurements are based on OFDR technology, the 6415 LCA can connect to a DUT in reflection and directly measure and locate IL (via analysis of Rayleigh scatter) and RL events through a single port. The 6415 can also measure a DUT in transmission mode.

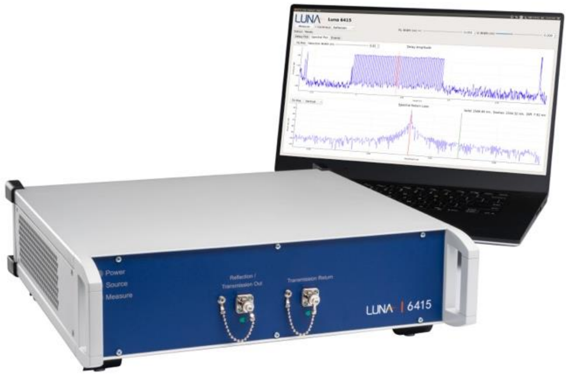


Figure 5. The Luna 6415 Lightwave Component Analyzer uses OFDR for comprehensive component testing and analysis

Dual Domain Analysis

As components and integrated devices become more complex with higher performance requirements, the ability to analyze a DUT both spectrally and spatially can be very valuable. With OFDR, instruments such as the Luna 6415 can analyze the loss (IL and RL) in the spectral domain, as well as in the time (or length) domain.

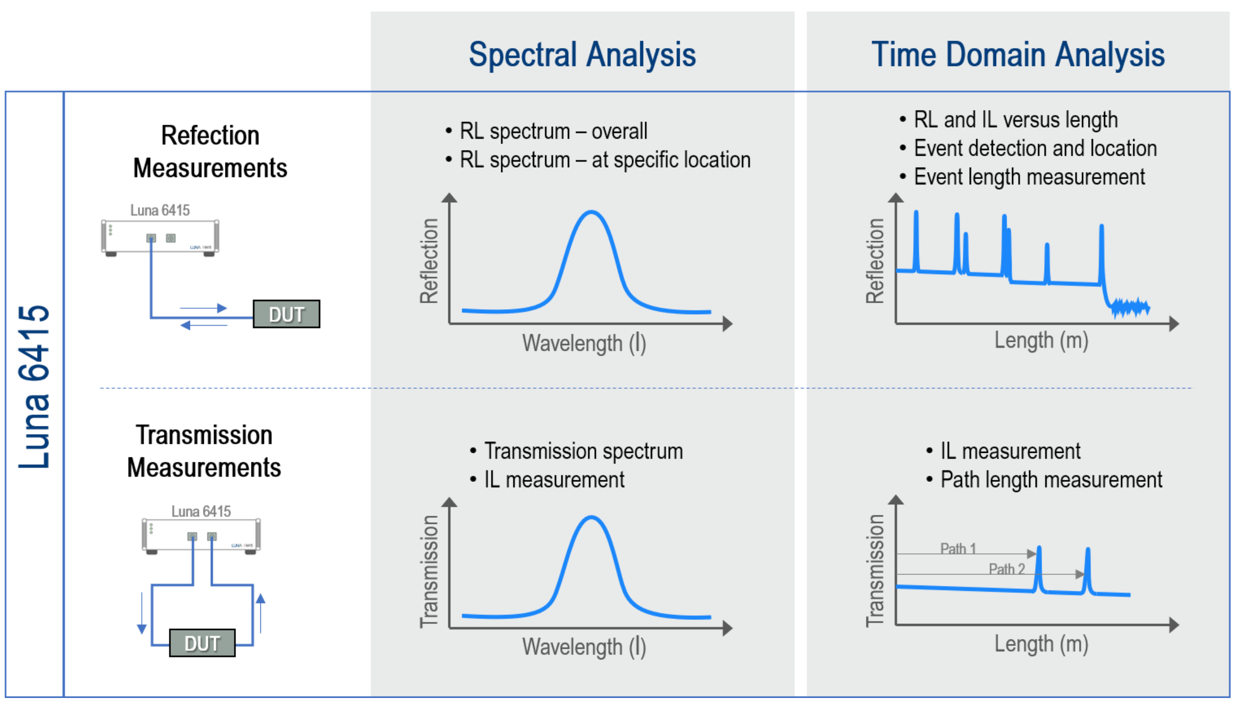


Figure 6. The Luna 6415 provides both traditional spectral analysis and time/length domain analysis of passive optical components; and is able to measure the loss of a DUT connected in reflection or in transmission

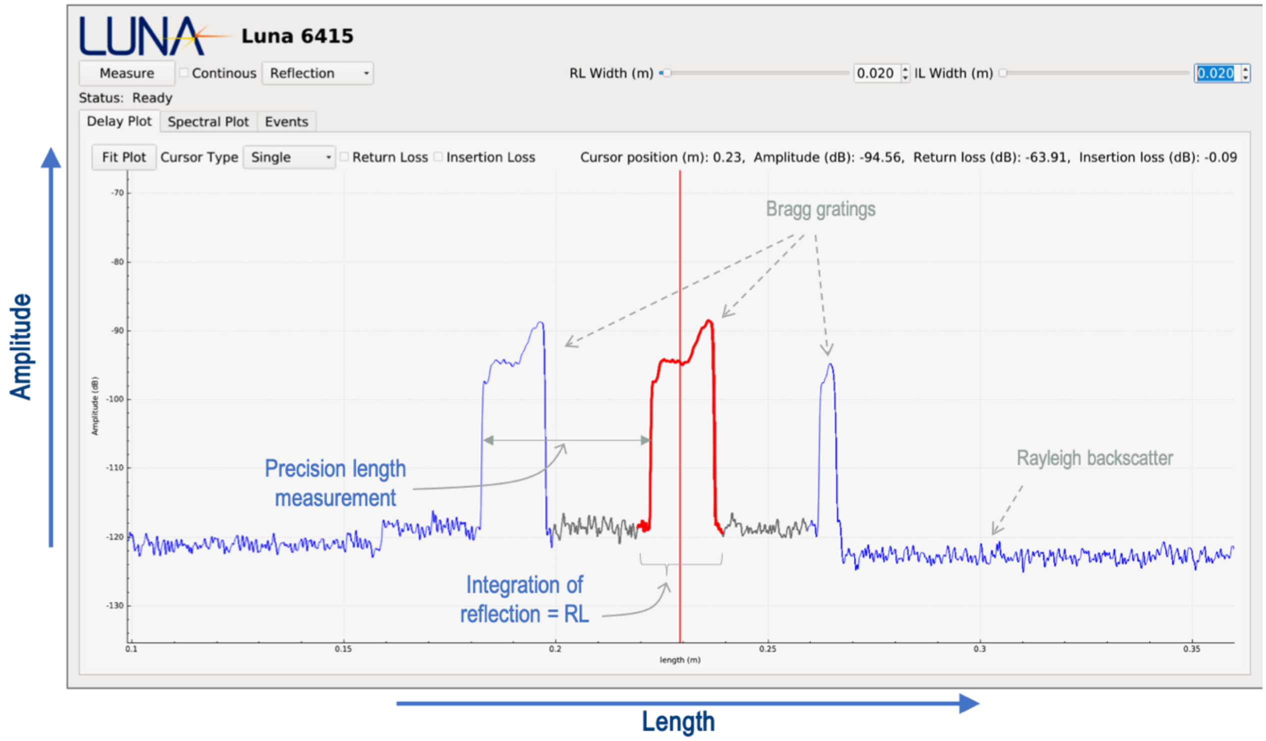


Figure 7. A scan of a Bragg gating string with a Luna 6415, connected in reflection, illustrates the high-resolution map of reflectance versus length, allowing high-precision measurement of RL, IL and path lengths

Time/Length Domain

By scanning a DUT in reflection, the Luna 6415 is able to measure the reflectance as a function of length along the optical path. This measurement data is similar to what is obtained with optical time-domain reflectometers (OTDRs) but with a spatial resolution that is orders of magnitude higher.

Figure 7 shows a 6415 scan of a short string of Bragg gratings. The OFDR plot of reflection amplitude versus length clearly shows two gratings, which are each 10 mm wide, and a third, which is about 3 mm wide, all spaced at 40 mm center to center. By integrating the reflection of a single grating or any reflective event, we can calculate the exact RL attributed to that reflection.

In between reflection events from gratings, connectors or other components, the measured signal indicates the Rayleigh backscatter present in the optical fiber or waveguide. Insertion loss can be measured along the path by calculating the average change in Rayleigh backscatter. The Luna 6415 includes tools to measure and calculate RL and IL along the light path interactively or automatically with preset parameters.

Path Length Measurement in Time Domain

The length, or the time delay, of the optical path or the precise location of reflection events can be easily extracted from the time-domain scan of a DUT in reflection. For example, as shown in Figure 7, you can easily measure the grating spacings or the length of any segment of the light path.

When the Luna 6415 is connected to a DUT in transmission mode, you do not see a map of distributed reflectance versus length as you do when measuring in reflection mode. However, the 6415 can still precisely measure the length of the overall path with a spatial sampling resolution of 20 µm. If the DUT does include multiple paths through the device, then the 6415 can simultaneously measure the length of each independent optical path.

Spectral Domain Analysis

For components or systems with wavelength-dependent functionality, such as DWDM filters or multiplexers, the ability to measure and characterize loss or transmission as a function of wavelength is a basic requirement. With the dual-domain capability of OFDR and the Luna 6415, you can examine the reflected signal at any specific location along the path and isolate the spectral response of a specific feature or detail. This allows you to see how different elements of the component or system are contributing to the overall transfer function.

For example, Figure 8 shows the spectral return loss of the second grating in the string, highlighted in red by the selection cursor. The spectral response of the single grating, centered at 1556.97 nm, is displayed in the lower plot.

The Luna 6415 LCA can also measure the input-to-output transfer function of a component. By connecting the component in transmission mode, the Luna 6415 can spectrally characterize the transmission, as shown in Figure 9, for a typical add-drop filter. When measuring a DUT in transmission mode, the time-domain plot can be used to measure the length of optical paths from input to output. If the DUT includes multiple paths, the length of each can be measured. Detailed mapping of loss versus length is not included in measurements made in transmission mode.

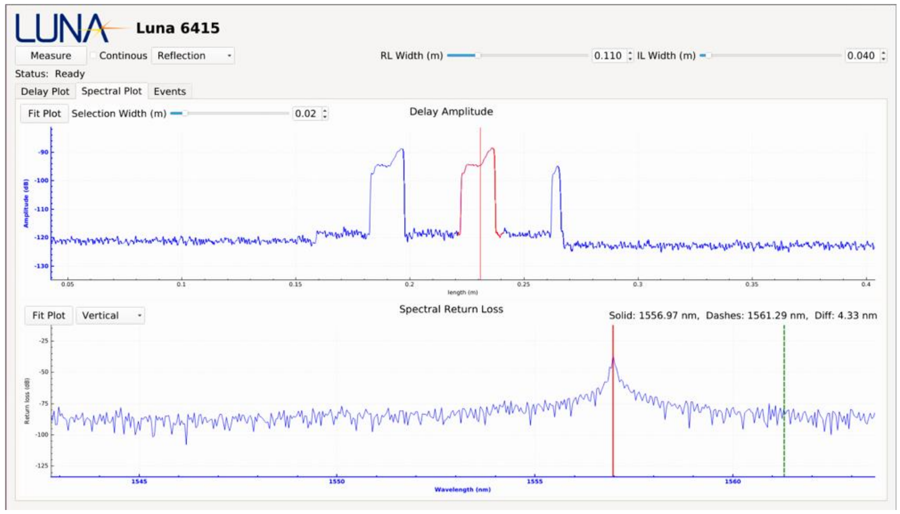


Figure 8. In the lower plot, the reflection spectrum of the second Bragg grating (selected and highlighted in red in the upper plot) is displayed

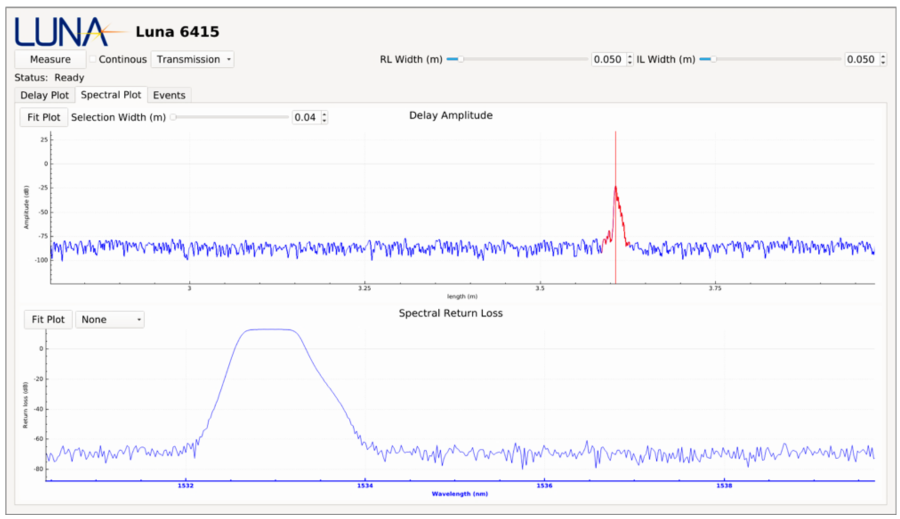


Figure 9. The transmission spectrum of an add-drop filter scanned by a Luna 6415 Lightwave Component Analyzer

Learn More

The fast, efficient and accurate testing of optical components and integrated devices is becoming increasingly important. As summarized in Figure 10, OFDR-based systems such as the new Luna 6415 provide an alternative and more comprehensive approach to testing IL and RL in these components.

- Luna 6415 Product Information
- Optical Device Test and Characterization - Applications

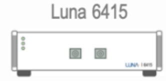
		Traditional Approach	OFDR-Based Component Analyzer (Luna 6415)
Test Configuration	Light Source	Tunable Laser or Broadband Source	Single Integrated System Luna 6415 
	Optical Power Measurement	Optical Power Meter Or Spectrum Analyzer	
IL – Spectral Response		✓	✓
	Dynamic Range	typ. 45-55 dB	70 dB
	Wavelength resolution	1 - 20 pm	~0.1 pm
	Wavelength accuracy	~5 pm	1.5 pm
	Single scan speed	>1 s	160 ms
Distributed RL and IL (IL/RL versus length)		*n/a*	✓ (reflection measurement)
Length Measurement		*n/a*	✓

Figure 10. Comparison of OFDR-based 6415 Lightwave Component Analyzer with more traditional approaches to testing optical components