Luna OVA CT*e*/ST*e* Data Sheet

OVERVIEW

See the "*e*"
Enhanced OVA

Optical Vector Analyzer

Product highlights

- **All-parameter analysis** - Complete spectral characterization of all optical device parameters over the C and L bands in a single laser sweep.
- **Reduced test cycles** - All optical parameters measured in <5 seconds over a 40 nm scan.
- **Real-time mode** - Update rate of up to 4 Hz allows dynamic alignment of components to optimize all parameters.
- **Minimal setup time** - Full calibration takes ~1 minute for the entire wavelength range of the system.
- **NIST-traceable wavelength accuracy** - Internal gas cell wavelength reference accurate to ±1.5 pm.
- **Exclusive linear transfer function measurement** - Allowing optical phase error characterization and direct component modeling.
- **Look inside devices** - Diagnose faults, determine how to eliminate undesirable characteristics with impulse response windowing.

NEW! **Automatic internal calibration** - Automatically maintain calibration despite changing environmental conditions.

NEW! **Auxilliary port** - Configurable third port allows the OVA*e* to be custom tailored for automatic testing environments.

Applications

For all passive optical component testing needs:

- Design and development
- Assembly and manufacturing
- Quality assurance and regression testing
- Production engineering and failure analysis
- Incoming inspection and product qualification

The new Luna OVA*e* is based on a swept laser interferometric technique that provides unparalleled measurement of component loss, dispersion, and polarization characteristics. The dramatically decreased measurement time offered by the OVA*e* results in increased efficiency in final acceptance tests of passive optical devices. The Luna OVA*e* reduces time and cost to make state of the art optical devices, leading to robust optical systems, and resulting in revenue generating optical networks.

Specifications (after one hour warm-up at 20 °C)

Parameter	Specification	Units
Model CT Measurement Performance		
Wavelength range:		
Option CC	1525-1565	nm
Option LL	1565-1605	nm
Option CL	1525-1605	nm
Wavelength:		
Standard Resolution	3.2	pm
High Resolution	1.6	pm
Accuracy[1]	± 1.5	pm
Repeatability	± 0.1	pm
Optical phase error[2]	0.0075	radians
Insertion loss[3]:		
Dynamic range	60	dB
Ripple	± 0.01	dB
Resolution	± 0.002	dB
Accuracy	± 0.05	dB
Chromatic dispersion[3]:		
Accuracy	± 5	ps/nm
Group delay:		
Range[4]	3 or 6	ns
Accuracy[3,5]	± 0.05	ps
PMD:		
Range[4]	3 or 6	ns
Accuracy[3,5]	± 0.05	ps
PDL:		
Extinction ratio	40	dB
Accuracy[3]	± 0.03	dB
Measurement Timing:		
Laser sweep rate	70	nm/s
All-parameter measurement rate[6]	150	ms/nm
Typical measurement time[7]	15	s
Real-time mode update rate[8]	5.0	Hz
Maximum device length (including leads)	30	meters

Parameter	Specification	Units
Model ST Measurement Performance		
Wavelength range:		
Option CC	1525-1565	nm
Option LL	1565-1605	nm
Option CL	1525-1605	nm
Wavelength:		
Standard Resolution	3.2	pm
High Resolution	1.6	pm
Accuracy[1]	± 1.5	pm
Repeatability	± 0.1	pm
Optical phase error[2]	0.0075	radians
Insertion loss[3]:		
Dynamic range	60	dB
Ripple	± 0.01	dB
Resolution	± 0.002	dB
Accuracy	± 0.05	dB
Chromatic dispersion[3]:		
Accuracy	± 5	ps/nm
Group delay:		
Range[4]	3 or 6	ns
Accuracy[3,5]	± 0.10	ps
PMD:		
Range[4]	3 or 6	ns
Accuracy[3,5]	± 0.05	ps
PDL:		
Extinction ratio	40	dB
Accuracy[3]	± 0.03	dB
Measurement Timing:		
Laser sweep rate	35	nm/s
All-parameter measurement rate[6]	150	ms/nm
Typical measurement time[7]	20	s
Real-time mode update rate[8]	4.0	Hz
Maximum device length (including leads)	70	meters

Parameter	Specification	Units
Processor I/O		
Input/Output devices	• IEEE-488/GPIB • Ethernet port • 3.5-inch HDD • CDRW drive • Printer port • Keyboard/Mouse • Display	
Electrical		
Input voltage range	90-250	VAC
Input frequency range	47-63	Hz
Operating power	80	VA
Environmental		
Operating temperature range	10-35	ºC
Storage temperature range	0-40	ºC
Relative humidity (non-condensing)	< 80	%
Physical		
Weight (processor not included)	20.5 45	kg lbs
Case size (W X D X H)	452 X 430 X 178 17.75 X 17.0 X 7.0	mm inches

[1] Accuracy maintained by an internal NIST traceable HCN gas cell.

[2] See Figure 1 for more detail.

[3] Measured using 20 averaged calibration scans, 64 averaged measurement scans, and 30 pm resolution bandwidth.

[4] Specifies the total device impulse-response duration that may be captured.

[5] See Figure 2 for more detail.

[6] Combined laser sweep and analysis time per scan.

[7] Measurement with full specification (see Note 3) over 2 nm range. Excludes calibration time.

[8] For 1 nm scan range.

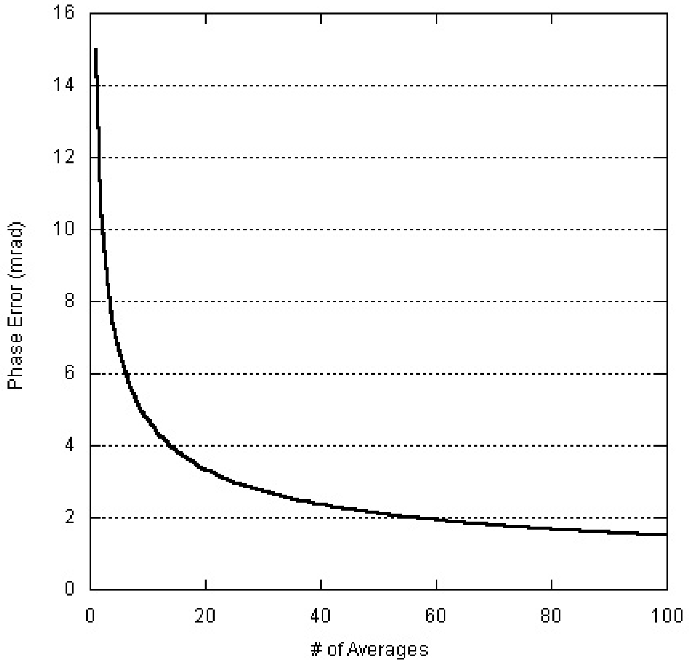

Figure 1. Phase Error

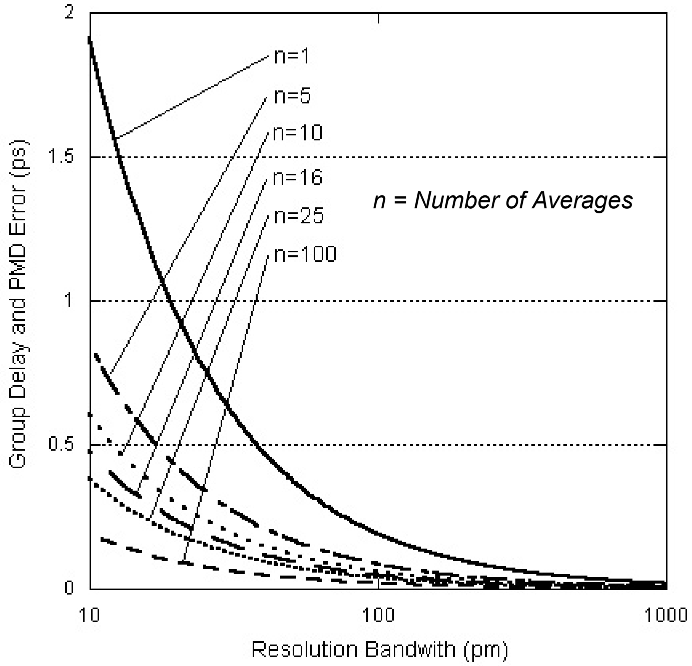

Figure 2. Group Delay and PMD Noise

Theory of Operation

Introduction

The OVA is the first instrument to use a rigorous linear systems approach to optical fiber components. This approach reduces the current multi-parameter characterization of fiber optic components to a single Optical Transfer Function (OTF) characterization. Any linear parameter can then be calculated from the OTF.

The Jones matrix

Fiber optic systems generally support two polarization modes. As a result, a simple fiber optic component having a single input fiber and a single output fiber must be modeled as a four port device: two polarization modes in and two polarization modes out. Generally, light may couple from any input mode to any output mode, giving rise to four complex transfer functions. These functions describe how the device affects the amplitude, phase and polarization state of the light when it passes from the input to the output of the component.

These four transfer functions can be placed into a matrix that serves as a useful tool for both analysis and modeling. This method of representing the effect of an optical component on the polarization state of light was first described by R. C. Jones in 1941. Therefore, within the optical community, this linear transfer function for a two-input two-output optical system is referred to as the *Jones matrix*[1].

Most measurement systems conduct a direct measurement of device parameters such as insertion loss, group delay, PDL, etc. This collection of parameters is an incomplete description of the device under test. The OVA directly measures the amplitude and **phase** of the Jones matrix elements, yielding a complete mathematical description of the device under test:

$$\mathbf{J}(\omega) = e^{i\phi(\omega)}\begin{bmatrix} a(\omega) & b(\omega) \\ c(\omega) & d(\omega) \end{bmatrix}$$

An example of a measured Jones matrix appears in Fig. 3.

The OVA is the only instrument capable of capturing the complete Jones matrix with all relative phase information. This matrix can then be used in its raw form for device modeling, or it can be used to construct the

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[1] Note that Luna Technologies uses the term “Jones matrix” to refer to the fully rigorous optical transfer function of the device under test; thus “Jones matrix” and “OTF” are used interchangably within this document. Elsewhere, the term “Jones matrix” is often used to refer to a matrix that describes only the change in polarization state as light passes through the device.

standard set of device characteristics (insertion loss, group delay, PDL, PMD, etc.). Instead of arriving at the individual parameters through multiple separate measurements as is the current industry practice, the OVA uses a single interferometric characterization to determine all optical parameters.

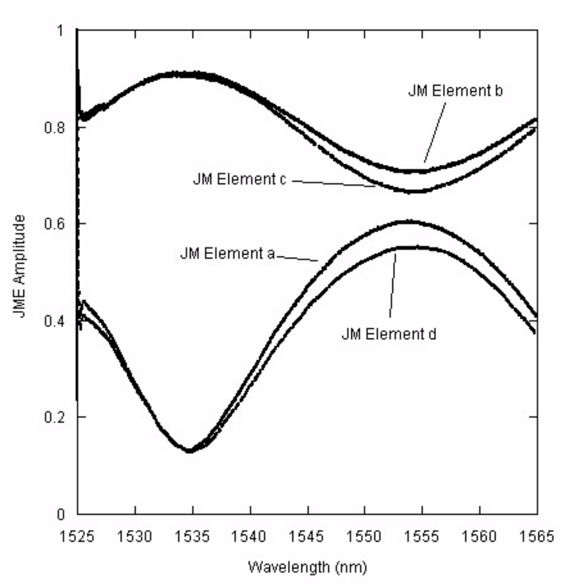


Figure 3. JME amplitudes for a single stage isolator.

Parameter Calculations

With a system that can accurately measure the complete OTF of a component, it is necessary to define familiar parameters such as insertion loss in terms of the OTF matrix entries. The following definitions are written in terms of the OTF $\mathbf{J}(\omega)$, defined as

$$\mathbf{J}(\omega) = \begin{bmatrix} a(\omega) & b(\omega) \\ c(\omega) & d(\omega) \end{bmatrix} \qquad (1)$$

These definitions provide results that agree with those obtained using current standard measurement techniques.

Insertion loss

The insertion loss is defined in terms of the OTF to be

$$IL = 10\log\left(\frac{|a|^2 + |b|^2 + |c|^2 + |d|^2}{2}\right) \quad . \qquad (2)$$

This definition of insertion loss produces a value that is equal to the average insertion loss when measured over all polarization states (for example, a polarizer would measure as -3 dB). The measured insertion loss for a fiber Bragg grating appears in Fig. 4.

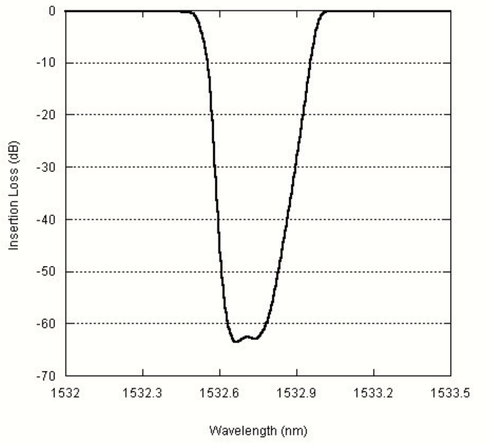


Figure 4. Insertion loss measurement of a fiber Bragg grating in transmission mode.

Polarization dependent loss

Polarization Dependent Loss (PDL) is the maximum difference in the transmitted power when measured over all polarization states. A concise mathematical formula for obtaining this value from the complete Jones matrix is available in B.L. Heffner, “Deterministic, analytically complete measurement of polarization-dependent transmission through optical devices,” *IEEE Photonics Tech. Lett.,* vol. 4, pp. 451-454, 1992. Example PDL measurements made with an OVA are shown in Fig. 5.

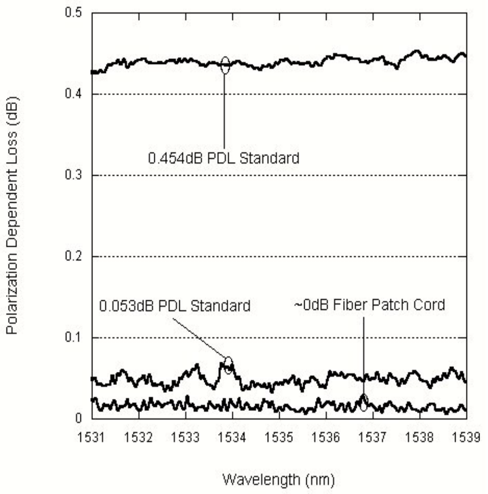


Figure 5. Polarization dependent loss of a 0.454 dB PDL artifact and a ~0 dB fiber patch cord.

Group delay

Group Delay is defined to be the rate of change of phase as a function of frequency. Physically, this property is seen as the delay with which a sinusoidal modulation envelope will propagate through the device.

The OVA measures the OTF interferomterically, and calculates the group delay using the formula

$$GD = \frac{\angle(a_{n+1}a_n{}^* + b_{n+1}b_n{}^* + c_{n+1}c_n{}^* + d_{n+1}d_n{}^*)}{\Delta\omega} \qquad (3)$$

where x^* denotes the complex conjugate of a complex number, and $\angle x$ denotes the argument (phase) of a complex number. The optical frequency increment between points is given by $\Delta\omega$. This definition provides a weighted average group delay over polarization states, where the weighting factor is the amplitude response for each state. An example group delay measurement appears in Fig. 6.

The OTF measurement is always performed at the finest resolution of the system, and the step size for the derivative in the group delay calculation may be changed at any time following the measurement. In this way results for various step sizes may be obtained without the need to repeat the measurement.

This is in contrast to the popular Modulation Phase Shift method of group delay measurement, which measures group delay by modulating the output of a tunable laser, and then measuring the shift in the phase of the modulation envelope as it propagates through the device under test. In this method the step size is equal to twice the moduation frequency, so results for various step sizes would require multiple measurements. Also

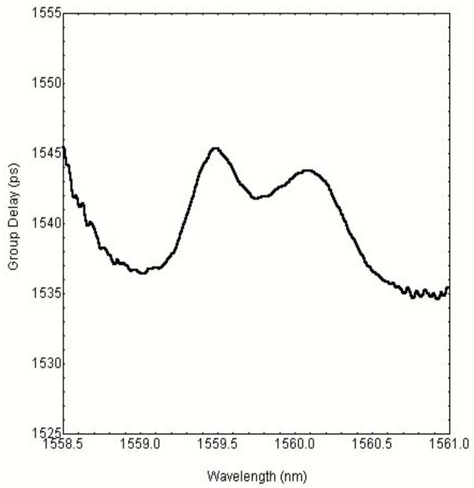


Figure 6. Group delay measurement for a single channel of a 16-channel AWG.

note that the modulation phase shift measurement is made at a particular input polarization, and that amplitude or wavelength dependent phase shifts in the detector or electronics will produce an error.

Chromatic dispersion

The OVA can provide a fast and accurate measurement of the chromatic dispersion of a component by taking the numerical derivative of the group delay. Note, however, that chromatic dispersion is a useful construct only when it remains relatively constant over the bandwidth of the communication channel (as is the case for long lengths of optical fiber). Because chromatic dispersion often varies over the channel bandwidth for DWDM components, it can be a poor predictor of component performance in an optical communications system. By making a direct measurement of optical phase, the OVA provides a better means by which to qualify component performance.

See Fig. 7 for chromatic dispersion data measured using an OVA.

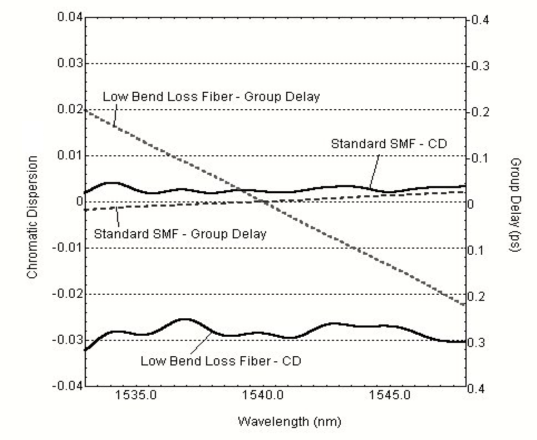


Figure 7. Chromatic dispersion and group delay for ~3 m lengths of both standard SMF and low bend loss fiber.

Optical phase error

Because the OVA measures the complete OTF, it is the first instrument capable of providing optical phase measurements for fiber-optic component response. The availability of optical phase makes the characterization of the dispersive effects of components significantly less complicated. Without optical phase information, group delay and chromatic dispersion measurements must be carefully interpreted to predict the effects of an optical device on a transmission system.

Basic filter theory dictates the effects of phase error in a transmission system; a system with strictly linear phase response will delay a signal without distorting it. Any deviation from linear phase within the signal bandwidth will begin to cause distortion. If this deviation from linearity exceeds 90 degrees, the signal will become unrecognizable. The

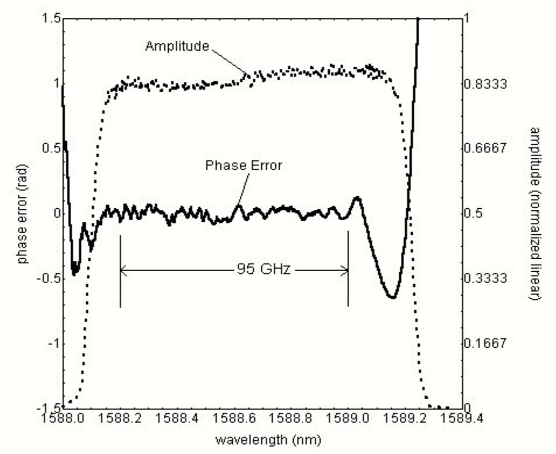


Figure 8. Optical phase error for a dispersion compensation grating.

acceptable phase distortion does not change with bit rate (i.e., the noise penalty for a 0.1 radian phase error is the same for a 2.5 Gb/s and a 40 Gb/s system). The only parameter that changes between systems is the bandwidth over which the phase error must be maintained.

It is therefore possible to specify a single tolerance on the phase (e.g., 0.1 radians) and then pass or fail components based upon this single limit. A further advantage is that the component may be evaluated for performance at any bit rate based on this single measurement. In other words, the process, equipment, and tolerances for qualifying a part for 40 Gb/s operation will be identical to the process for qualification at 10 Gb/s. Thus, as component quality is increased, component characterization can remain the same, realizing a tremendous benefit for documentation and process control.

A dispersion compensating device is expected to have a group delay that varies linearly with optical frequency, and an optical phase that is parabolic. Therefore, a parabolic curve fit would be used on such a device instead of the linear fit for nominally nondispersive components. See Fig. 8 for a phase error plot for a dispersion compensation grating.

Polarization mode dispersion

To successfully receive a data signal, all of the spectral components of a single channel must be received in the same polarization state (except in exotic formats such as polarization modulation). Transmission systems that support high bit rates are sensitive to polarization mode dispersion, which causes the polarization state to vary across the signal spectrum.

Polarization Mode Dispersion (PMD) is a measure of the maximum rate of change of the polarization state at a particular wavelength. Equivalently, one can think of PMD as the maximum differential group delay between two principal polarization states at a given wavelength. PMD measurement can be an indicator that there will be an operational problem with the

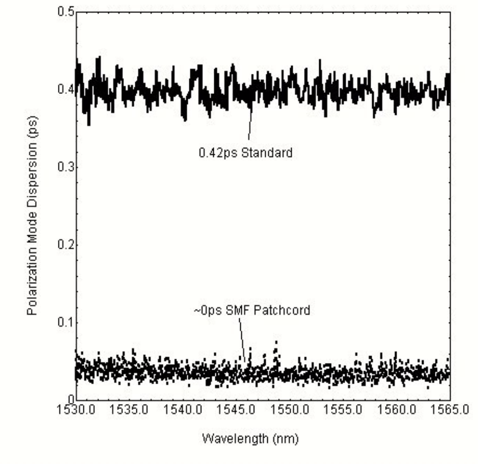


Figure 9. PMD measurements for a 0.42 ps standard and a ~0 ps SMF patch cord.

component under test, but, it does not necessarily yield a definitive description of the component's performance in an optical communications system.

PMD is calculated by finding an angular error between two Jones matrices taken at two closely spaced optical frequencies (wavelengths). This error is then divided by the difference in the optical frequencies to form a numerical derivative. The convention is to take the absolute value of calculated PMD. (See B. L. Heffner, "Automated Measurement of Polarization Mode Dispersion Using Jones Matrix Eigenanalysis," *IEEE Photonics Tech. Lett.*, vol. 4, pp 1066-1069, 1992.) Figure 9 shows OVA PMD measurements for a known PMD standard and for a fiber patchcord. As with the group delay calculation, the step size for the PMD calculation may be changed without repeating the measurement.

Polarization error

A more accurate description of the component's impact on system performance can be obtained by measuring the absolute polarization error measured relative to the center wavelength of the filter. The "effective loss" due to the change in the polarization state across the signal spectrum will vary as the cosine squared of this angle. See Fig. 10 for an example of a polarization error measurement.

The computation of the polarization error is similar to the Jones matrix Eigenanalysis technique with the exception that the change in angle is computed with respect to the complete Jones matrix at the center wavelength, and the resulting angular difference is not divided by the increment. The units of the measurement are radians, and the same evaluation criteria apply to the polarization error as apply to the deviation from linear optical phase.

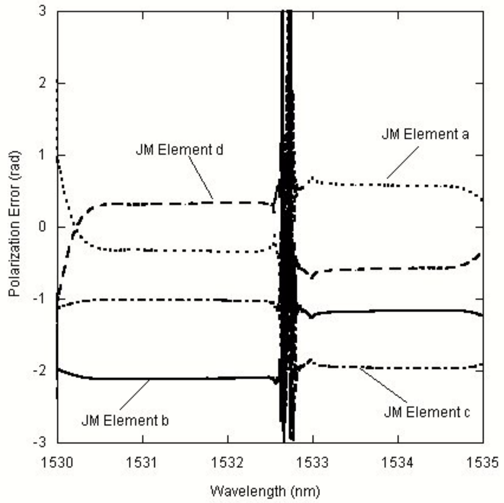


Figure 10. Polarization error, in radians, for a fiber Bragg grating in transmission mode.

As with the optical phase, the maximum allowed polarization error will remain the same for all bit rates and only the range over which the tolerance must be maintained will change. Thus, the same benefits of a consistent component characterization that does not become obsolete as technology advances applies to polarization error as well.

Time domain information

Because the complete OTF measured by the OVA contains relative phase information between wavelengths, a numerical Fourier transform of the matrix will produce the impulse response of the system in the time domain. The amplitude of the impulse response for a fiber Bragg grating is shown in Fig. 11. The OVA control software provides windowing cursors that enable the user to look inside the optical device or subsystem for fault analysis.

In the frequency (spectral) domain, transfer functions are multiplied by the input spectrum to find the response of the system. Because the inputs (electric field) and outputs (electric field) of optical components have the same units, the transfer function is dimensionless. The amplitude response, or insertion loss, can then be described in decibels.

In the time domain, responses are calculated in terms of convolutions, and this requires that the impulse response have units of inverse time or Hertz. The OVA displays the amplitude of the impulse response in terms of Gigawatts per Joule (which reduces to Hertz) because the response is theoretically the system response to an infinitely short, 1 Joule, pulse (Dirac delta).

The time domain information also has a phase associated with it, and a phase derivative can be applied in this domain as well. The derivative is taken with respect to time, so the units are in radians per second. The

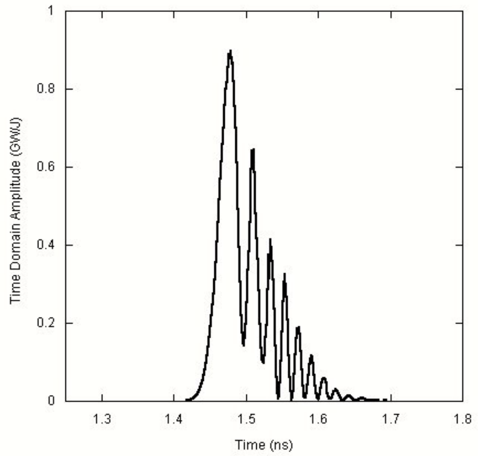


Figure 11. Amplitude of the impulse response in the time domain for a fiber Bragg grating in reflection mode.

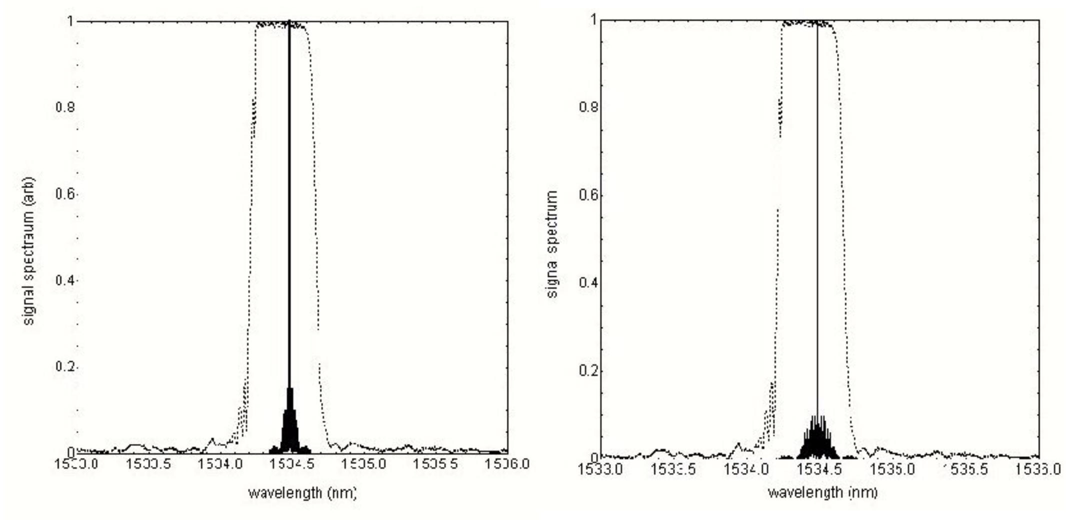
phase derivative in the time domain gives the optical frequency of the impulse response at that particular instant in time. The OVA converts this optical frequency to the equivalent vacuum wavelength in nanometers. This data is particularly useful for examining the spatial chirp of a fiber Bragg grating.

Analogous time domain parameters for PDL and PMD can also be calculated, but are not currently part of the OVA standard software set.

Component modeling with the OVA

Because the OVA uses the formalism of linear systems and matrix algebra in the construction and representation of the component characterization, the effects of the component on optical signals are easily calculated. Given an input electric field, $\mathbf{E}_{in}$, the output electric field can be readily computed using a simple matrix multiplication in the frequency domain.

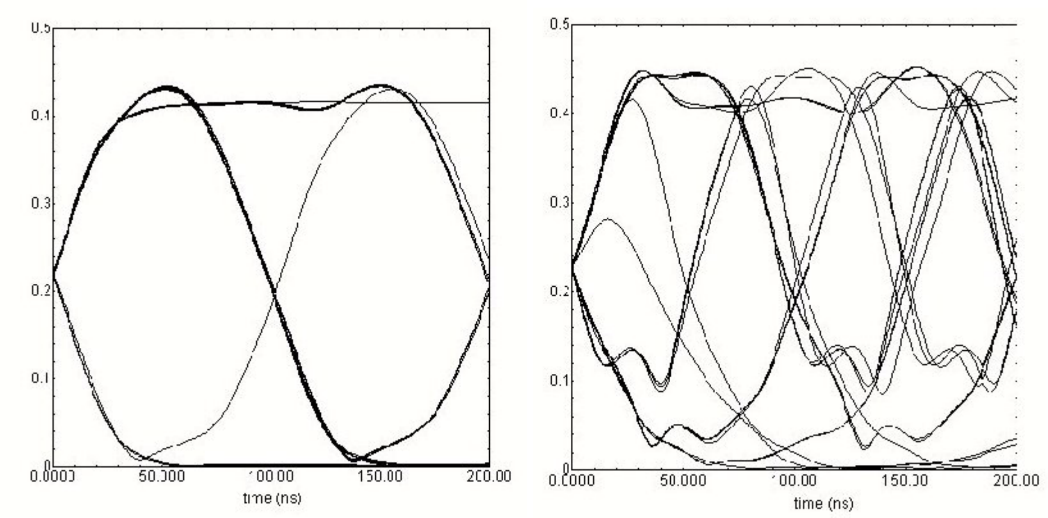
Figure 12 shows the spectrum for 10 and 20 Gb/s signals. Overlaid on these plots is the amplitude response of an optical filter. Multiplying the electric field by the measured OTF of the component produces the output electric field. This output field can then be transformed back to the time domain and used to find the detected optical power as a function of time. Figure 13 shows the computed eye diagram for the 10 and 20 Gb/s signals. If other optical signals are present in the adjacent bands, the effects of cross-talk can also be modeled simply by adding these signals to the input. states of the connecting fiber can be checked for acceptable operation. Thus, the OVA is an extremely useful tool in the modeling of the overall performance of an optical communications system.



10 Gb/s

20 Gb/s

Figure 12. Signal and grating spectra.



10 Gb/s

20 Gb/s

Figure 13. Eye diagrams computed for the grating in Figure 12.

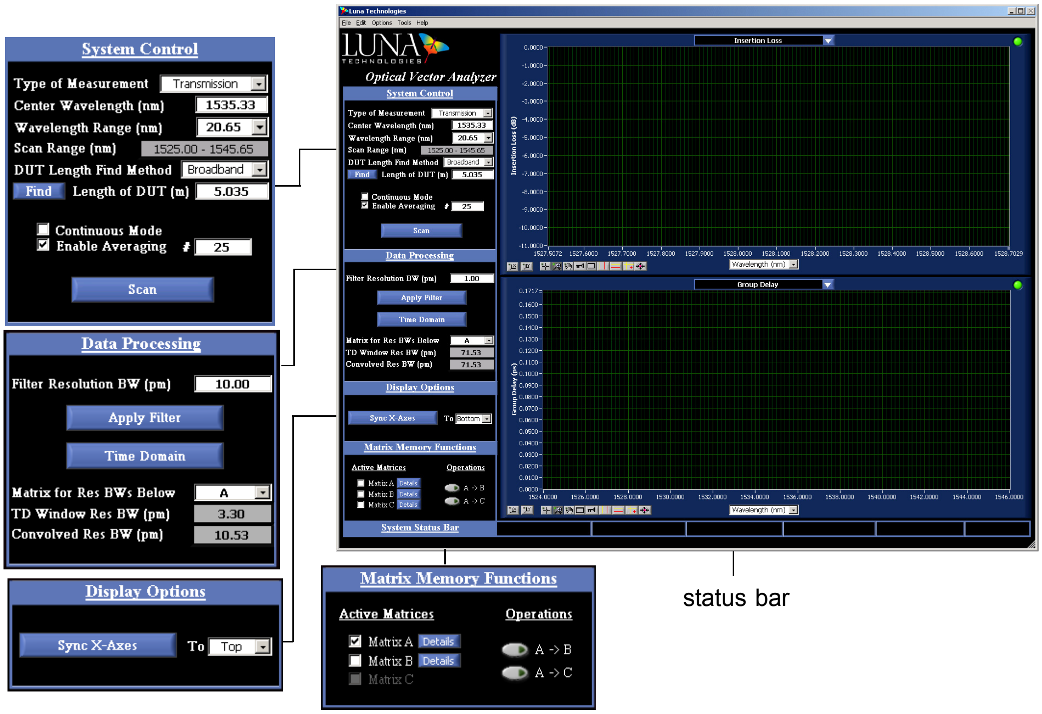
Software Features

The Luna OVA measurement software uses the measured Optical Transfer Function (OTF) to compute and display parameters familiar to most users.

Luna OVA software interface is easy to use, with graphical controls and options easily accessible from the single main window or the menu bar.

Main window features

The main window is composed of 6 functional areas:



System Control

Type of Measurement: Transmission
Center Wavelength (nm): 1535.33
Wavelength Range (nm): 20.65
Scan Range (nm): 1525.00 - 1545.65
DUT Length Find Method: Broadband
Length of DUT (m): 5.035
☐ Continuous Mode
☑ Enable Averaging # 25

Data Processing

Filter Resolution BW (pm): 10.00
Matrix for Res BWs Below: A
TD Window Res BW (pm): 3.30
Convolved Res BW (pm): 10.53

Display Options

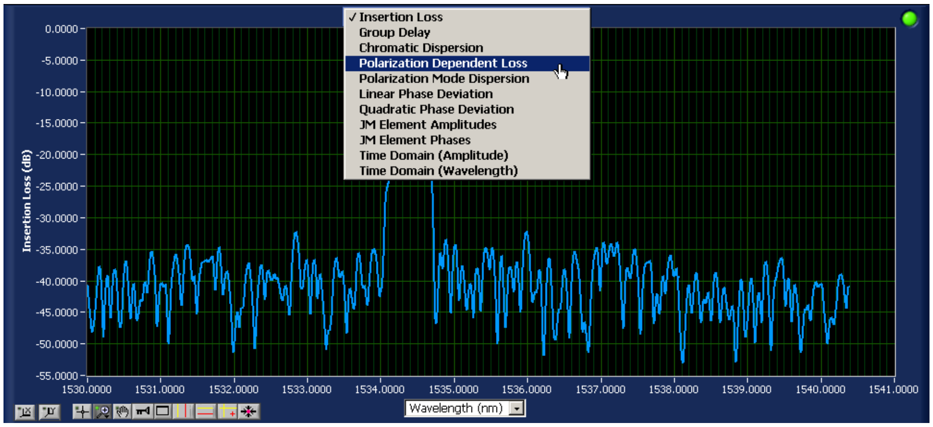
Sync X-Axes To: Top

Matrix Memory Functions

Active Matrices
☑ Matrix A
☐ Matrix B
☐ Matrix C

- **System Control** contains controls that set test parameters, select measurement modes, and perform measurements.
- **Data Processing** contains controls for filtering measured data. Filter settings can be based directly on the impulse response of the device under test.
- **Display Options** contains a control that synchronizes the horizontal axes of the two plot windows.
- **Matrix Memory Functions** contains controls for storing and displaying multiple data sets.
- The **System Status Bar** displays system messages such as laser status, calibration status, and system errors. The status bar also indicates when the Luna OVA is ready to test.
- The graph area contains two plots of test data.

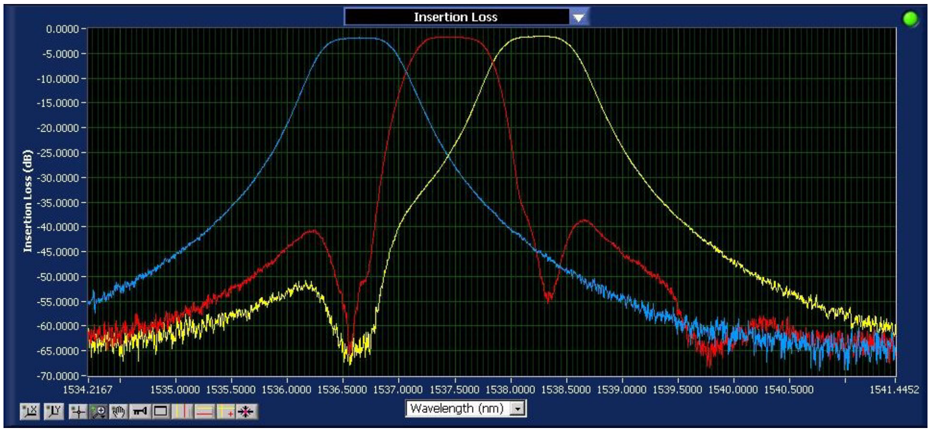
A pull-down menu at the top of each plot window selects any of 11 different parameters to display.



Buttons on each graph control how a plot appears in the window, including multiple click-and-drag zoom features as well as manual scaling options.

Display Multiple Data Sets

The Matrix Memory Functions area of the main window contains controls that allow the user to save data from three scans and display the current scan and saved scans in various combinations. When multiple plots are selected, they are superimposed in a single graph window, and each plot is color coded.

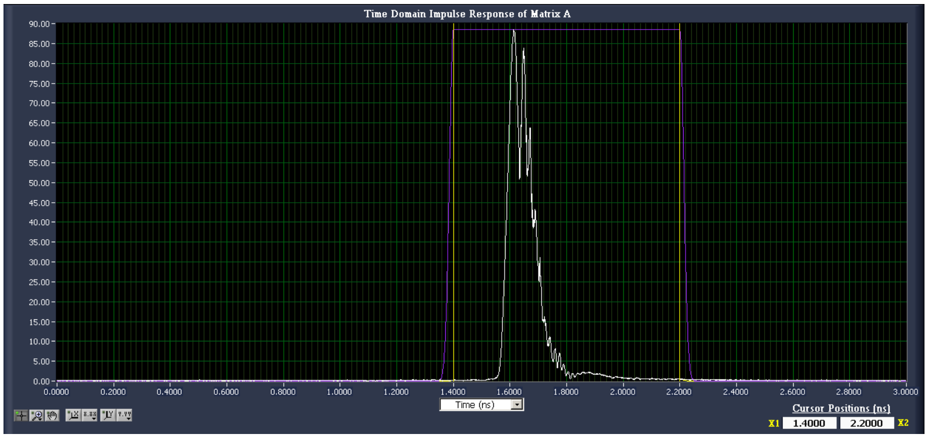


Real-Time Mode

Real-Time mode allows multiple measurements to be made in rapid succession — up to a 4 Hz update rate for the OVA CT. This allows active monitoring of measurement parameters during alignment of optical devices. Optimize alignment for all parameters, not just loss. With the OVA Real-Time mode, alignment and testing are no longer two separate steps in the manufacturing process. Real-Time mode is also an invaluable tool for evaluating the perfomance of tunable devices.

Impulse Response Filtering

The duration of a device's impulse response can be used to determine the appropriate resolution bandwidth for frequency domain measurements. This is accomplished quickly and easily using the OVA's time domain windowing function. This feature can also be used in reflection mode to independently characterize the properties of muliple reflective devices or interfaces within an optical subassembly.



Future-Proof Data Archiving

The OVA measurement of the OTF provides the complete mathematical description of the device under test, and includes all device parameters. Therefore, when saving data it is only necessary to save the OTF data to a single compact file, rather than save a bulky data set for each of the many parameters of interest. Furthermore, the OTF can be used to calculate other parameters that are not required now, but may become important in the future (such as 2nd order PMD). There would be no need to perform a new measurement on a device; simply calculate the new parameter from the OTF.

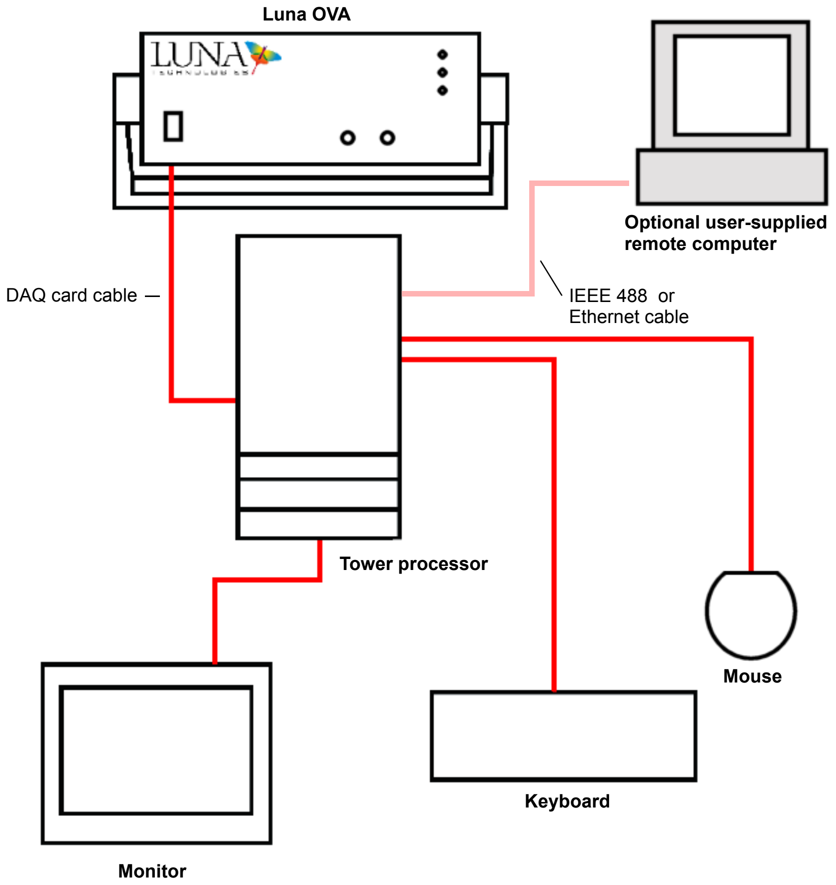
Desktop Analysis Software

Free up the OVA for use by multiple users by performing data analysis using Luna's Desktop Analysis Software. This software provides all of the analysis funtionality of the OVA control software, without the need for the instrument itself. This software package allows the user to load the raw OTF data from a file for careful inspection and analysis. It displays plots of all parameters just like the OVA control software, and includes all data manipulation tools and filters.

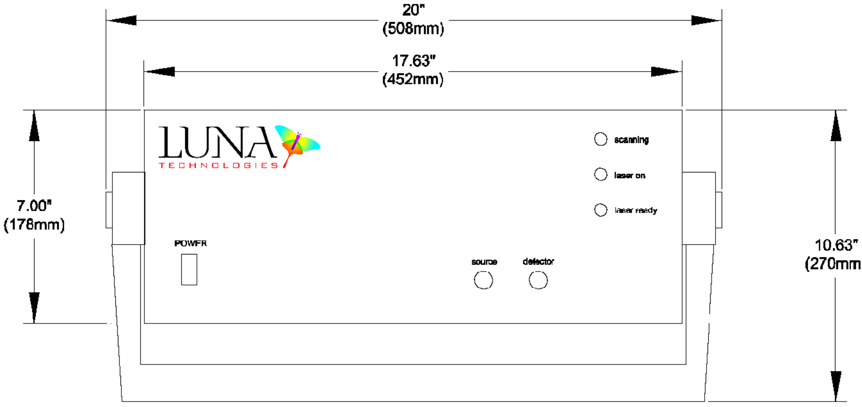
Configuration

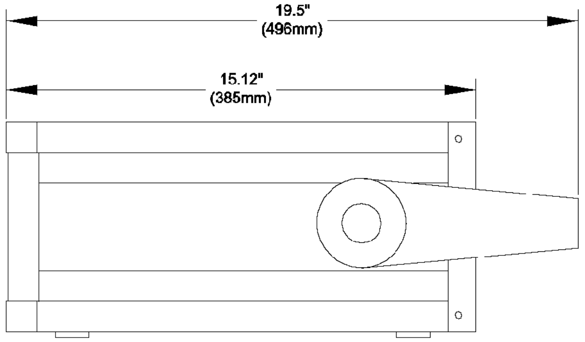
The OVA includes:

- Luna OVA benchtop instrument
- Model 52 processor in a tower case
- Keyboard, mouse, and mouse pad
- IEEE-488 standard interface and parallel printer port for connecting a remote computer and printer
- Ethernet interface
- 17-inch flat panel display



OVA Dimensions





Ordering

For ordering and pricing information contact:

Ed Valigursky

Vice President of Sales

770-634-6765

sales@lunatechnologies.com

Luna Technologies Incorporated

Redefining the Economics of Optical Test

2020 Kraft Drive, Suite 2000
Blacksburg VA 24060
Toll free sales and support: 866.LUNAOVA (866.586.2682)
Fax: 540.961.5191
E-mail: solutions@lunatechnologies.com
Web: www.lunatechnologies.com