Optical Vector Analyzer

User Guide

CLASS 1 LASER PRODUCT
IEC 60825-1, 2007
AND 21CFR1040.10

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IEC 60825-1, 2001
AND 21CFR1040.10

Many regions prohibit the disposal of WEEE (Waste Electrical and Electronic Equipment) in the normal waste stream, to comply with the Restriction of Hazardous Substances (RoHS) released into the environment. Please contact your local waste authority for instructions on proper recycling of the electronic product(s) described in this *User Guide*.

Contents

Chapter 1

System Overview

The Optical Vector Analyzer (OVA) fully analyzes the optical properties of fiber optic components, modules, and subsystems, providing comprehensive characterization based on a complete transfer function measurement. The OVA software uses a complete vector model of the optical field, including polarization state and optical phase, to characterize the device under test. The OVA's optical phase measurements make the characterization of the dispersive effects of components significantly less complicated than it has been in the past.

When equipped with all options, the instrument will measure the complete matrix transfer function (Jones matrix) of the device under test. From this measurement, any linear parameter can be extracted and graphed, including insertion loss, polarization dependent loss (PDL), group delay, chromatic dispersion, optical phase, and polarization mode dispersion (PMD) as a function of wavelength. The full measurement, including all parameter calculations, is accomplished using a single sweep of the internal tunable laser.

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The OVA may also be operated as an Optical Frequency Domain Reflectometer (OFDR), if the user purchases this option. By reconfiguring the hardware and data processing algorithms, the OVA can be utilized to measure the full scalar response of an optical system, including both phase and amplitude information in terms of the system transfer function. This allows the data to be presented for both the time domain and the frequency domain. For a complete discussion of how the OFDR measures these values, see Chapter 7, "Optical Frequency Domain Reflectometer," on page 95.

Overview of Operation

The vast majority of fiber optic systems and components support two polarization modes, and in general each input polarization mode can couple into either one of the output modes. Therefore fiber optic devices are best characterized using a 2 x 2 complex matrix, generally referred to as a Jones matrix,[1] which fully describes all of the linear characteristics of the device:

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

The quantities a, b, c and d are the four scalar transfer functions, and ω represents optical frequency. The Jones matrix represents the complete mathematical description of the propagation of light through the device. It is equivalent to the transfer function of linear systems theory.[2] The Jones matrix contains all of the typical parameters such as insertion loss, group delay, polarization dependent loss, and polarization mode dispersion, as well as more subtle effects such as a second order PMD that may exist in the device. The Jones matrix encapsulates all optical properties in a single compact matrix that is fundamentally rigorous, making it an

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[1] For detailed information about the Jones matrix, see Swindell, W. ed. Polarized Light, (Dowden, Hutchington & Ross, Inc., Stroudsburg PA, 1975, pp. 187-233), where the original papers by R.C. Jones have been reprinted.

[2] The term "Jones matrix" has been used to describe the matrix optical transfer function, as well as a normalized matrix that describes only the evolution of the polarization state. In the context of this manual and the OVA, the term is used to refer to the former, as the Jones matrix measured by the instrument contains all amplitude, phase and polarization information.

ideal tool for modeling and understanding fiber optic systems. A more detailed discussion of the Jones matrix appears in Chapter 9.

The Control Software

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The OVA control software uses the measured Jones matrix to compute and display a variety of parameters, including all industry standard parameters for characterizing optical components.
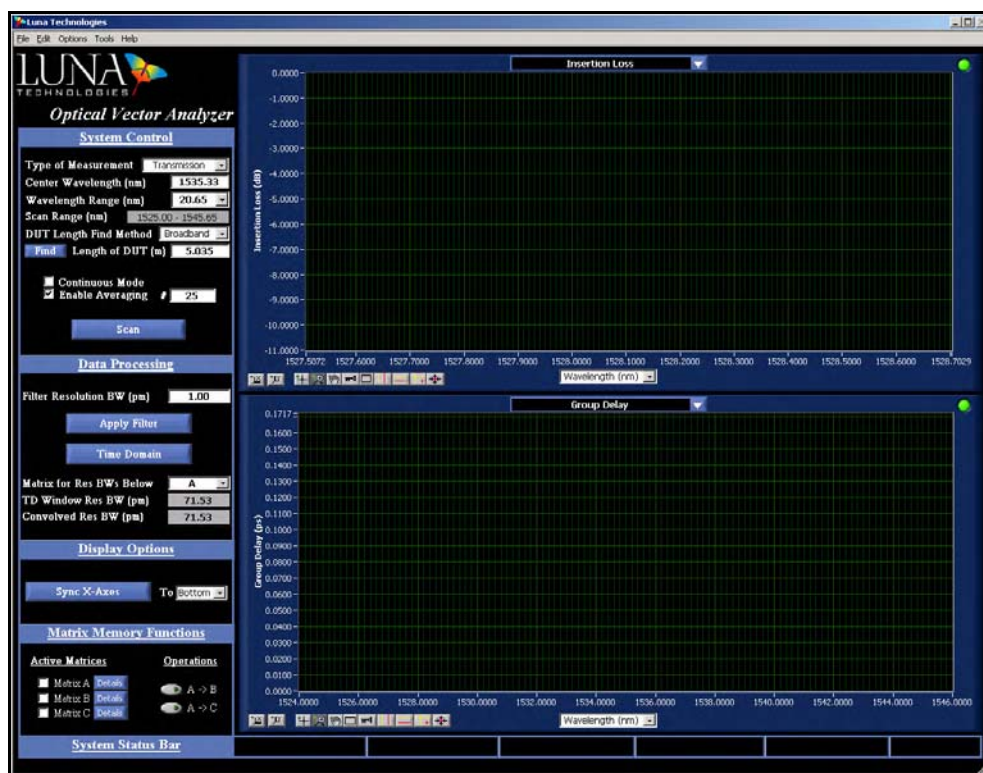
Figure 1-1. OVA control software main window.

The control software plots various curves depending on the parameter selected from the pull-down menu at the top of a plot window. Please see "Parameter Calculations" on page 217 for complete parameter definitions.

1
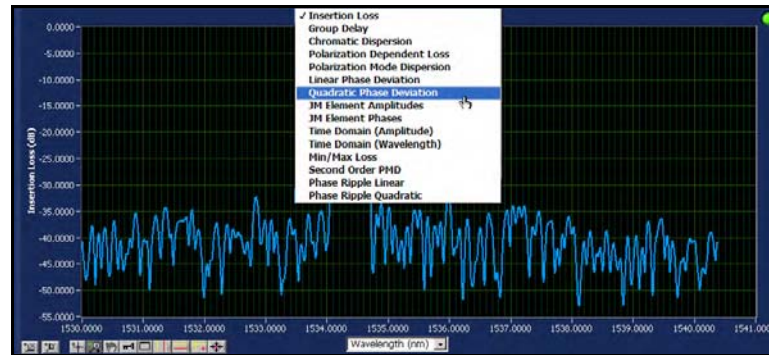
Figure 1-2. Graph area with the Title Bar pulled down for selecting the parameter to plot.

The following parameters are calculated and displayed by the OVA control software:

- Insertion Loss (For a complete definition, see "Insertion loss" on page 217).
- Group Delay (See page 218).
- Chromatic Dispersion (See page 219).
- Polarization Dependent Loss (See page 220).
- Polarization Mode Dispersion (See page 220).
- Linear Phase Deviation (See page 223).
- Quadratic Phase Deviation (See page 224).
- Jones Matrix Element Amplitudes (See page 225).
- Jones Matrix Element Phases (See page 225).
- Time Domain (Amplitude), (See page 225).
- Time Domain (Wavelength), (See page 226).
- Min/Max Loss (See page 227).
- Second Order Polarization Mode Dispersion, (See page 221).
- Phase Ripple Linear (See page 228).
- Phase Ripple Quadratic (See page 229).

The control software also provides many tools for data acquisition, manipulation, and display. Data acquisition modes include single scan, multiple scan (averaging), continuous scan, and real-time mode. There are also two different filtering methods for reducing measurement noise. Postprocessing allows the user to change the

resolution bandwidth without the need to redo the measurement. Graph windows support the display of up to three different data sets simultaneously, and include powerful zoom and cursor features.

1

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Chapter 2

Assembly and Startup

2

The Optical Vector Analyzer is shipped with everything needed to conduct device characterizations, including the measurement instrument and all supporting hardware, software, documentation, and cables.

Read and follow all assembly and startup instructions before attempting to operate the Optical Vector Analyzer.

Warning

The protection provided by the equipment may be impaired if the equipment is used in a manner not specified by the manufacturer, resulting in serious injury or death.

Components List

All models of the Optical Vector Analyzer are shipped with these components:

Optical Vector Analyzer instrument

One (1) USB cable to connect the OVA instrument to the PC

2

One (1) power cord for the OVA instrument (Plus two (2) more, if you ordered the PC and monitor)

OVA laptop PC (or desktop PC, shown below)

Laptop power supply

OVA desktop PC (or laptop PC, shown above)

2

17-inch flat panel monitor (with desktop only)

Monitor-PC interface cable (with desktop only)

Keyboard (with desktop only)

Mouse (with desktop only)

Fiber polarization controller

Gold reflector

2

Luna Technologies mouse pad
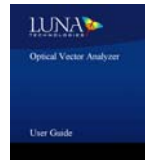
OVA User Guide

Software recovery CD-ROM

Optical fiber connector cleaner

Optical fiber bulkhead connector cleaners

If components are missing or damaged, contact Luna Technologies toll free at 866-586-2682 or by e-mail at support@lunatechnologies.com.

Assembling the OVA

> **Important** ✓
>
> The instrument should always be fully assembled before turning power on to any of its components.

2

To assemble the OVA

1 Remove all the OVA components from the shipping containers and verify that no components are missing. (See "Components List" on page 7.)

2 Place the OVA on a stable surface free of excessive vibrations and capable of supporting the weight of the entire unit. For the weight and dimensions of the unit, see Appendix A, "Specifications," on page 275.

> **Important** ✓
>
> Place the OVA away from walls or objects that will restrict the air flow through the fan duct on the back of the unit.

3 Unpack and set up the desktop or laptop PC according the manufacturer's instructions provided. If you purchased a desktop PC, connect the monitor, keyboard, and mouse to the PC, using the cables provided. For user-supplied PCs, see "Minimum PC Requirements" on page 276.

> **Important** ✓
>
> Do not turn the power on to the PC yet.
> Do not connect the instrument to the PC until instructed.
> ***Do not place the laptop on top of the instrument.***

4 If printouts are desired, connect a local printer to a printer port (parallel or USB) on the back panel of the PC using the proper cable for the printer. For information on printing, see "Printing" on page 82.

5 If necessary, install the drivers for local or network printers that will be used for printing data sheets.

| Important | Do not install any software on the OVA PC other than a printer driver or software supplied by Luna Technologies. Third-party software installed on the PC may impair the proper function of the OVA. |

2

6 Optional: To connect the OVA to a network, attach a network cable (not provided) to the ethernet port on the back panel of the PC.

7 *Do not connect* the OVA instrument to the PC with the USB cable until instructed in the next section.

8 On the front of the instrument, there are plastic caps installed to protect the ports. Leave these caps on when the instrument is not in use. To remove the cap for measurements, turn it counterclockwise.

9 Attach the power cords provided to the instrument and to the laptop (or PC and monitor). To ensure safe operation, place the instruments to allow easy disconnection of the power cord. Note that the OVA requires surge-protected, grounded outlets.

The OVA is now fully assembled.

Startup

1 Once the OVA instrument is fully assembled (except for the USB cable connecting the instrument to the PC), allow the equipment to stabilize at room temperature, between 10–35 ºC.

2 Turn on the PC, allowing it to fully load up Microsoft® Windows® XP.

3 If you purchased a PC from Luna Technologies, it comes with the OVA control software already installed. If not, install the OVA software now. (From the Luna Technologies CD provided, open the OVA folder and run setup.exe, following on-screen instructions.)

4 Ensure that the OVA is powered **OFF**.

5 Connect the OVA to the PC using a standard USB cable (provided).

6 Turn on the OVA using the power switch on the front panel.

7 The PC will automatically detect the device and display the "Found New Hardware Wizard" dialog window:

2

8 Select the "**No, not this time**" option and click the "**Next**" button to continue. A new window, similar to the one below, will be displayed:
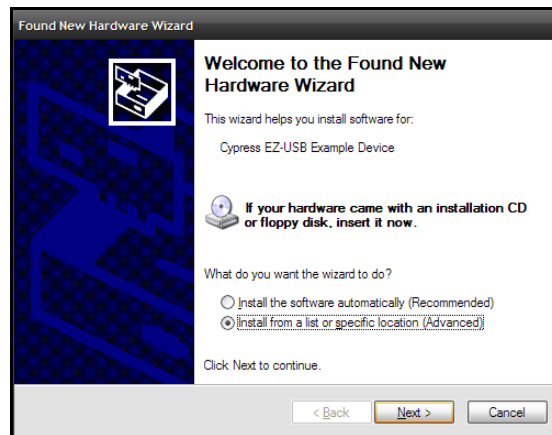
9 Select the "**Install from a list or specific location (Advanced)**" option and click the "**Next**" button.

10 A new window, similar to the one below, is displayed:

2
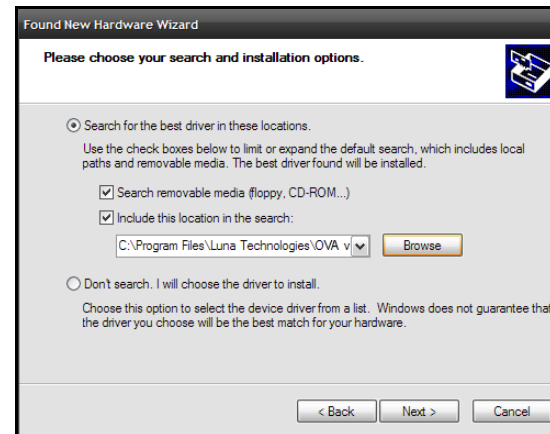
11 Select the "**Search for the best driver in these locations**" option and check the "**Include this location in the search**" checkbox. Click the "**Browse**" button to select the location of the driver.

12 Browse to the location where the instrument software was installed (e.g. *C:\Program Files\Luna Technologies\OVA v#.#*) and then into the "USB_Drivers" sub-directory. Click "**OK**".

13 Another dialog box will alert the user to wait while the Wizard searches. When it becomes available, click the "**Next**" button to continue.

14 An alert dialog similar to the one below will be displayed:

> **Hardware Installation**
>
> ⚠ The software you are installing for this hardware:
>
> Luna Technologies OVA
>
> has not passed Windows Logo testing to verify its compatibility with Windows XP. (Tell me why this testing is important.)
>
> **Continuing your installation of this software may impair or destabilize the correct operation of your system either immediately or in the future. Microsoft strongly recommends that you stop this installation now and contact the hardware vendor for software that has passed Windows Logo testing.**
>
> [Continue Anyway]   [STOP Installation]

2

15 Click the "**Continue Anyway**" button to proceed. A new window will be displayed:

> **Hardware Update Wizard**
>
> **Completing the Hardware Update Wizard**
>
> The wizard has finished installing the software for:
>
> ⟜ Luna Technologies OVA
>
> Click Finish to close the wizard.
>
> [< Back]   [Finish]   [Cancel]
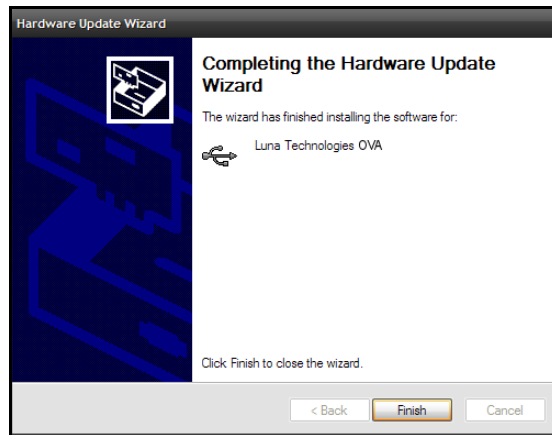
16 Click the "**Finish**" button to complete installation of the driver.

Important ☑ It is helpful to make a note of which USB port you used for the OVA instrument. If the instrument is ever connected to a different USB port, it may require that this driver installation procedure be completed again.

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17 Double-click the **OVA** desktop icon or select **OVA Software** from the **Luna Technologies** program group in the Windows® Start menu. An initial window will appear for a few moments while the user interface is initialized.

Important

If the control software is started when the instrument is not powered on, a communication failure error message opens. However, the software can be used in desktop analysis mode when the instrument is not powered by clicking **OK** in the message box.

To operate in normal mode, turn on the instrument. The software automatically detects the instrument and displays a message. The system can then be used normally.

Once the control software is running, the OVA is ready for alignment and calibration. (See "Aligning the OVA Optics" on page 33 and "Calibrating the System" on page 34.) Do not attempt to perform measurements before aligning and calibrating.

Chapter 3

Software Guide

The control software is the primary interface between the user and the instrument. It provides all of the necessary tools to calibrate and align the system and to perform complete, all-parameter measurements of fiber-coupled optical devices. It also contains a variety of powerful features for data manipulation and display.

3

This chapter provides an overview of the location and function of all controls and indicators included in the control software. Chapter 4, "Performing Measurements," on page 33 provides greater detail on how to use the OVA to perform specific measurement tasks. Chapter 5, "Data Processing and Display," on page 55 more fully describes how to process the data and manipulate plots.

Important

If the control software is started when the instrument is not powered on, a communication failure error message opens. However, the software can be used in desktop analysis mode when the instrument is not powered by clicking **OK** in the message box.

To operate in normal mode, turn on the instrument. The software automatically detects the instrument and displays a message. The system can then be used normally.

Window Features

3
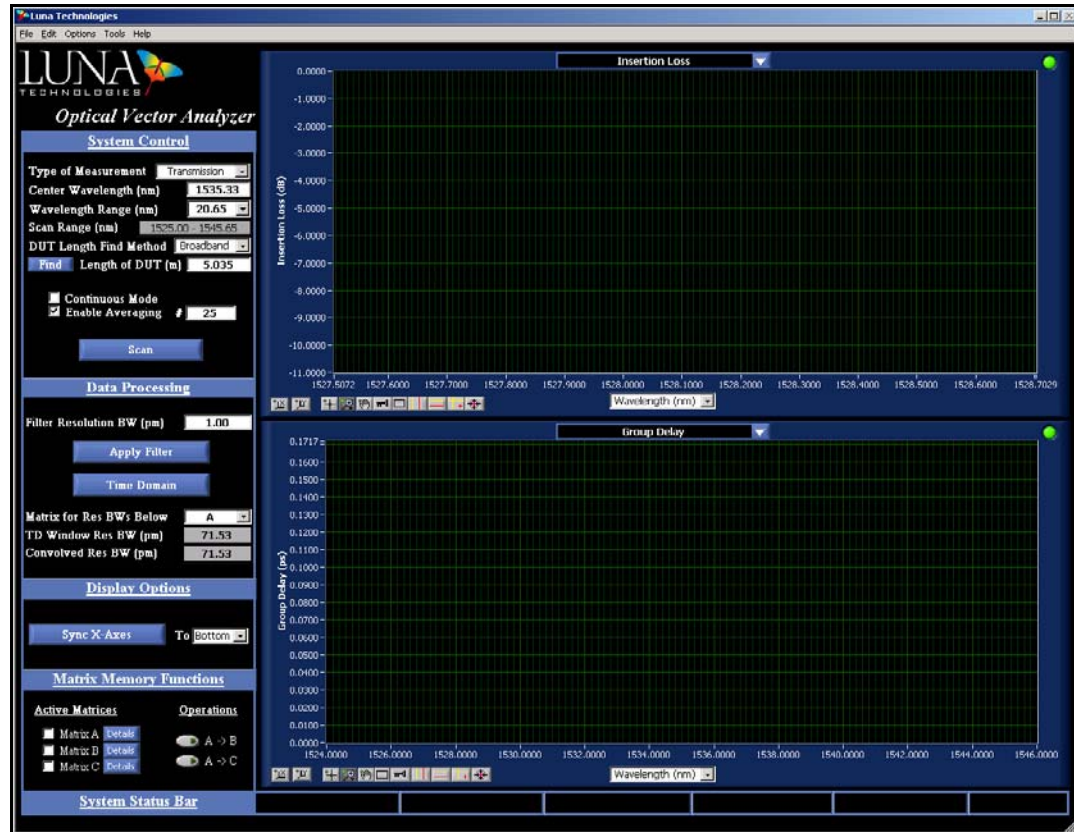
Figure 3-1. OVA control software main window. The figure above shows most of the buttons and fields active. However, when the software starts, most buttons and fields are unavailable because no data is in active memory yet.

The main window is composed of 7 functional areas:

1 The **System Control** area contains fields and menus that control the OVA instrument and set test parameters.

2 The **Data Processing** area contains controls for setting the resolution of filters and buttons for applying filters to the acquired data.

3 The **Display Options** area allows the user to synchronize the horizontal axes and X-axis cursors of both graphs.

4 The **Matrix Memory Functions** area contains controls that allow the user to work with up to three data sets simultaneously.

5 The **System Status Bar** at the bottom of the screen displays system messages such as error, laser status, and calibration status information.

6 The two **Graph** areas contain plots of test data. The pull-down menu at the top of each graph allows the user to select which parameter is displayed. Buttons to the lower left of each graph adjust plot axes, cursors, legend, and zoom. The lower center pull-down menu controls X-axis units.

7 The **Menu Bar** contains additional commands for loading and saving data files, printing, controlling calibration and alignment, and for setting various measurement and display options.

System Control

The **System Control** area of the main window contains fields and menus that control the OVA instrument and set test parameters.
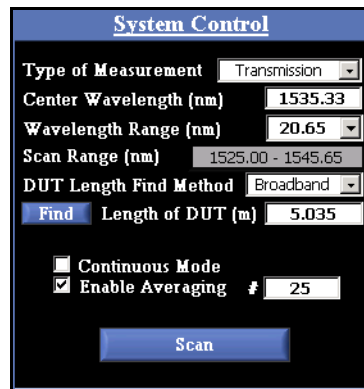
Figure 3-2. The System Control area in the main OVA software window.

- The **Type of Measurement** pull-down menu allows the user to choose the type of measurement: reflection or transmission. The

3

proper hardware configurations for these measurements will be described in Chapter 4, "Performing Measurements," on page 33.

- The **Center Wavelength (nm)** field allows the user to set the center wavelength of a scan. To set this parameter, type in a number within the wavelength range of the instrument. If the user enters values outside the range of the instrument, the software replaces them with values within the instrument's range. (See the specifications given on our website at www.lunatechnologies.com. for standard instrument wavelength ranges.)

- The **Wavelength Range (nm)** field allows the user to set the range of the scan. The wavelength range determines the number of nanometers that will be analyzed during the next measurement. A drop-down list contains the range options available for the OVA model in use.

- The **Scan Range (nm)** field shows the starting and ending wavelengths that will be scanned, as determined by the center wavelength and wavelength range entered by the user in the two fields above this field.

- The **DUT Length Find Method** pull-down menu allows the user to choose either the **Narrowband** or **Broadband** method of determining DUT length. The two length-finding methods are described under "Finding the DUT Length" on page 44.

- The **Length of DUT (m)** field shows the length of the device under test. It is automatically updated by the software when the user clicks **Find**, or the user can enter it manually. If the user selects **Options > Automatically Find DUT Length**, this field will be automatically updated each time a normal or averaging scan is performed.

- **Continuous Scan Mode**, when checked, causes the OVA to repeatedly make another measurement upon the completion of the previous measurement. The graph displays are continuously updated after each measurement. Note that this mode will operate more quickly if one of the graph areas is turned off. (See Figure 3-8 on page 25.) This mode is started and stopped by pressing the **Scan** button.

- **Enable Averaging**, when checked, causes the OVA to acquire multiple measurements of the Jones matrix and use the average result to

compute the displayed parameters. The number of measurements that will be acquired and averaged is set by the user in the field labeled #.

- The **Scan** button starts the measurement of the device under test. This same button is used to stop scanning when operating in **Continuous** or **Real-Time Mode**. The user may scan either before or after setting up filters.

Data Processing

The **Data Processing** area of the OVA main window contains controls for setting the resolution bandwidth of filters and buttons for applying filters to the acquired data.

3
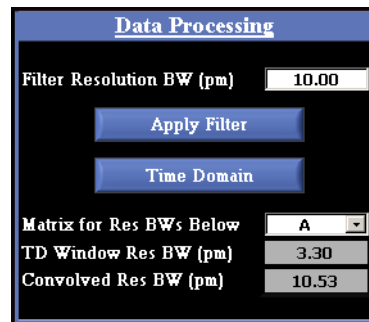
Figure 3-3. The Data Processing area in the main OVA software window.

- In the **Filter Resolution BW (pm** or **GHz)** field, the user can define the bandwidth of an acausal Gaussian filter (described under "The Smoothing Filter" on page 79) that can be applied to the data. The filter is applied to the measurement when the **Options > Always Apply Filter** menu item is checked or when the user clicks **Apply Filter** in the **Data Processing** area.

Note

By default, the **Filter Resolution BW**, the **TD Window Res BW**, and the **Convolved Res BW** are all displayed in units of picometers. To change the units to gigahertz, select **Options** > **Resolution BW Units** > **Gigahertz (GHz)**.

- Clicking the **Apply Filter** button applies the acausal Gaussian smoothing filter discussed immediately above to all active matrices.

- Clicking the **Time Domain** button opens a window displaying the impulse response of the selected matrix in the time domain. The window provides fields and cursors for adjusting this filter. For more information, see "The Time Domain Filter" on page 70.

- The **Matrix for Res BWs Below** pull-down menu allows the user to select which of the active memory locations will be used for the following two data fields.

- The **TD Window Res BW (pm** or **GHz)** field indicates the resolution bandwidth set by the time domain filter applied in the **Time Domain Window**. See "The Time Domain Filter" on page 70 for a detailed description of this filter.

- The **Convolved Res BW (pm** or **GHz)** field indicates the overall wavelength (or frequency) resolution of the data in the memory location selected by **Matrix for Res BWs Below**, taking into account both the smoothing and the time domain filters, if applied. It is calculated by taking the square root of the sum of the squares of the **Filter Resolution BW** and the **TD Window Res BW**. More details are given under "The Convolved Resolution Bandwidth" on page 81.

Display Options
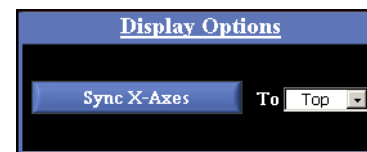
Figure 3-4. Display Options area in the main OVA software window.

- Clicking the **Sync X-Axes** button synchronizes the X-axes of both graphs displayed. This feature adjusts only the X-axis scale. The Y-axis scale is not affected. If both graphs have X or cross-hair cursors on when **Sync X-Axes** is clicked, the cursor style and location will also synchronize to the selected graph.

- The **To** field is used to specify whether the software will synchro-nize to the top or bottom graph.

Matrix Memory Functions

The **Matrix Memory Functions** allow the user to work with up to three data sets concurrently in local memory.
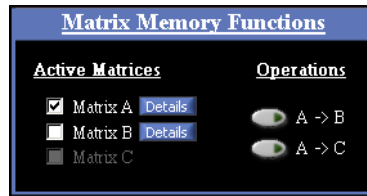
Figure 3-5. Matrix Memory Functions area in the main OVA software window.

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- Checkboxes under **Active Matrices** show which of the three data sets in local memory are superimposed in each graph window. Matrix names and **Details** buttons are grayed out when no data is stored in that location. In the example above, data is loaded in Matrices A and B, but only A is selected and graphed; Matrix C has no data in it.
- Clicking the **Details** buttons shows the user the measurement con-ditions for the data loaded in that matrix.
- The **Operations** lines allow the user to copy data from matrix A to B or C. The original data in Matrix A remains in A until new data is acquired.

Important

✓

New scans are automatically loaded into Matrix A, overwriting any data there. To avoid losing data, copy data to Matrix B or C, or save it to a file, before performing a new scan.

Note that scans already in Matrix B and C memory cannot be swapped.

Graphs

Each **Graph** area contains controls for selecting the content of the graph and for manipulating how the graph is displayed.

3
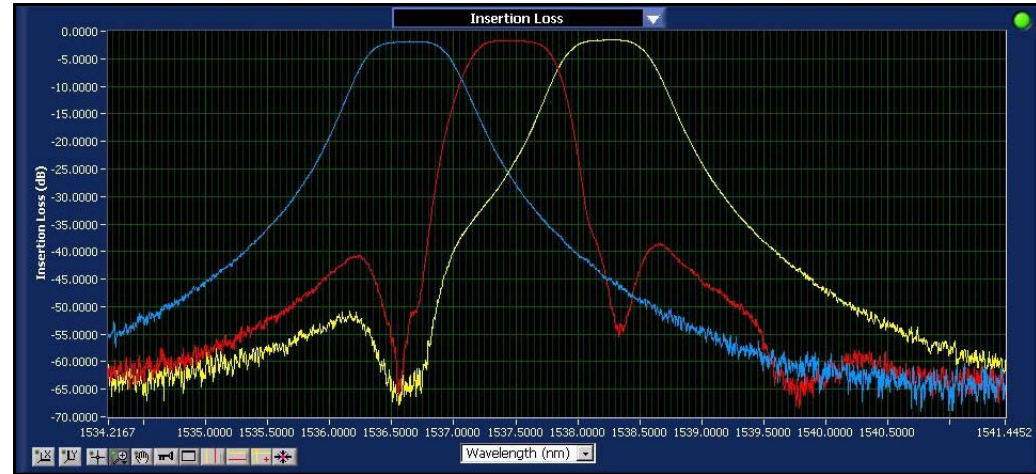
Figure 3-6. One of two graph areas in the main OVA software window. By default, Matrix A is shown in blue, Matrix B red, and Matrix C yellow.

- The **Title Bar** at the top of each graph is a pull-down menu allowing the user to select which parameter is graphed. These parameters are defined under "Parameter Calculations" on page 217.
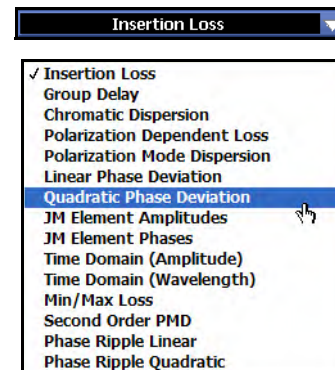
Figure 3-7. The Title Bar, or parameter selection pull-down menu, at the top of each graph area, before (above) and during selection.

- The **Graph On/Off Control** in the upper right hand corner of each graph allows the user to turn off the graphs. When a graph window

is turned off, newly scanned data will not be updated in that graph window. Turning one graph off allows **Continuous Mode** and **Real-Time Mode** to operate more quickly.

Figure 3-8. Graph On/Off Control: graph on (left) and graph off (right).

- The **X-Axis Label** below each graph is a pull-down menu that allows the user to select the X-axis units.

3
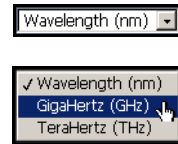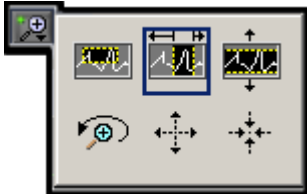
Figure 3-9. X-axis units pull-down menu, before and during selection.

- **Buttons** to the lower left on each graph allow the user to adjust plot axes, cursors, and zoom, and to show or hide a legend. Table 3-1 describes the function of each button and gives a page number for further explanation.

Table 3-1: Graph area buttons and their function.

Button	Description	Page
	Sets the scale of the X-axis to display the full range of the data set.	63
	Sets the scale of the Y-axis to display the full range of the data set.	63

3
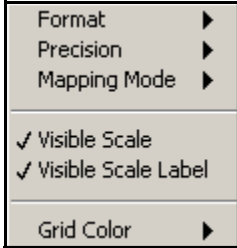
Button	Description	Page
	Sets the mouse cursor to a cross-hair that allows the user to move graph cursors.	66
	Allows the user to select from the following zoom tools that appear in a pop-up menu. A blue border surrounds the selected tool. Allows the user to click and drag to define a "zoom window" in both the X and Y dimensions. Allows the user to click and drag a zoom area in the X-axis only. This is the default tool active in each graph. Allows the user to click and drag a zoom area in the Y-axis only. Returns the graph to the full scale of all data. Zooms in (magnifies) from the point where the cursor is located. Zooms out from the point where the cursor is located.	64
	Lets the user pan around the data in a graph window by clicking on the graph and dragging the cursor.	66

Button	Description	Page
	Toggles the plot legend on or off. The color, style, and width of a line may be changed in a menu accessed by clicking within the legend. (See "Changing graph style and color" on page 68.)	68
	Opens a graph in a full-screen window. (This button does not appear in OFDR software.)	68
	Toggles two vertical cursor lines on or off. (Note that in optional OFDR software, upper graph vertical cursors control the data displayed in the lower graph. See "Updating Lower Graph" on page 120.)	67
	Toggles two horizontal cursor lines on or off.	67
	Toggles twin locked cursor on and off. Regardless of where these cursors are dragged, they will intersect the first graph at a data point.	67
	Brings cursors into the viewed portion of the graph. By default, cursors appear at 10% and 90% of the X- or Y-axis range. They may be dragged by selecting the cross-hair cursor, ⊹ .	67
	Recalculates the linear and quadratic phase deviation plots. Because cursors are attached to the first matrix plotted, only the plot of the first matrix displayed is valid. To calculate the phase deviation of **Matrix C**, for example, deselect **Matrices A** and **B** in the checkboxes in the **Matrix Memory Functions** area. Then set the cursors to the appropriate positions and press the recalculate button. *Note that this button only appears when either linear or quadratic phase deviation is displayed.*	68

3

3

Button	Description	Page
	Allows the user to select from the pop-up menu shown below to adjust the appearance of the X-axis scale and grid. *Note that this button only appears in the **Time Domain Window** or when one graph is viewed in the full screen view.*	69
	Allows the user to select from the pop-up menu shown above to adjust the appearance of the Y-axis scale and grid. *Note that this button only appears in the **Time Domain Window** or when one graph is viewed in the full screen view.*	69
	Moves the vertical cursors to the peak of the regions highlighted. This button is available in the OFDR software ("Optical Frequency Domain Reflectometer" on page 95), but not the OVA software.	67
	The center button recalculates the data in the lower graph area based on the data in the upper graph highlighted by the yellow (left) or orange (right) vertical cursor. These buttons appear in the upper left of the lower graph only when the vertical cursors are on in the upper graph. Clicking the left button will automatically recalculate the lower graph based on the yellow cursor in the upper graph *if* **Options > Display Options > Auto-Update Lower Graph** is checked. Otherwise, the user must click either the yellow or the orange button and then hit the recalculate (center) button. Words to the left of these buttons show which trace is being displayed in the lower graph. This button is available in the OFDR software ("Optical Frequency Domain Reflectometer" on page 95), but not the OVA software.	120

The Menu Bar

The menu bar contains additional commands for controlling calibration, alignment, and for setting various measurement and display options. Menu bar commands are organized into five menus.

The File menu

- **Load Data File** loads a binary Jones matrix data file previously saved by the OVA. A dialog box appears allowing the user to select the file, followed by a second dialog box which is used to select which of the three matrix memory locations will store the data. (See "Loading Saved Data" on page 60 for more information.)

- **Specify Device Descriptor** allows the user to enter information about the device under test. This information will appear in the upper right heading of printouts. It will also appear in the header of spreadsheet files. (See "Printing" on page 82 for more information.)

- **Select Data Save Options** calls up a dialog box allowing the user to specify which parameters should be included in any saved spreadsheet file, and whether or not a binary Jones matrix file should be saved as well. The user may select the file extensions for both the spreadsheet and binary files. Also in this window, the user selects whether or not to apply the current smoothing filter to the spreadsheet output. (See "Saving Data" on page 58 for more information.)

- **Save Data Files** saves measurement data according to the selections in the **Select Data Save Options** dialog box. (See "To save data" on page 59 for more information.)

- **Save Software Settings** saves user-selected settings from the **Options** menu and the **System Control** area; these settings are retained the next time the software is run.

- **Print Data Sheet** prints the two graphs as they are displayed. (For more information, see "Printing" on page 82.)

- **Exit** exits the OVA control software.

The Edit menu

- **Cut** may be used to cut user-selected numbers in fields and axes and paste them to the clipboard.

- **Copy** copies selected numbers from a field or axis to the clipboard.

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- **Paste** pastes numbers from the clipboard to a field or axis value.
- **Clear** removes selected data from a field or axis value without copying it to the clipboard.

The Options menu

- **Enable High Dynamic Range Averaging**, when checked, uses the high dynamic range. When unchecked, the normal range is used. If this option is grayed out in the menu, it means the higher dynamic range was not purchased with the instrument. For more information on dynamic range averaging, see page 248.
- **Resolution BW Units** toggles the units of the resolution bandwidth displays between picometers (pm) and gigahertz (GHz). The default setting is picometers.
- **Auto Calibration Settings** calls up a dialog box where the user may toggle automatic calibration on and off, as well as specify the time interval for automatic calibration. (For more information, see "Automatic Calibration" on page 42.)
- **Enable Real-Time Mode** or **Disable Real-Time Mode** turns on or off Real-Time Mode. (For more information, see "Real-Time Mode" on page 52.)
- **Apply Time Domain Window**, when checked, applies the **Time Domain Window** settings from **Matrix A** to newly acquired data. For this to function properly, the user must first adjust the **Time Domain Window** and check the **Retain Settings** box. (See "Applying the time domain filter" on page 74.)

  Turning **Apply Time Domain Window** on (checked) and off also updates the data currently displayed. If the **Apply Time Domain Window** is not checked (turned off), the **Time Domain Resolution Bandwidth** will equal the minimum resolution of the data.

- **Apply Time Domain Hanning Window** allows the user to toggle the frequency domain Hanning window on (checked) and off. (See "Time Domain Hanning Window" on page 246 for more information.)
- **Always Apply Smoothing Filter**, when checked, automatically applies the smoothing filter specified by **Filter Resolution BW** in the **Data Processing** area to current and newly acquired data. When

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this option is not selected, the **Apply Filter** button must be clicked to apply the filter. (For more information, see "The Smoothing Filter" on page 79.)

- **Autoscale Plot Axes**. When this option is selected, the plot axes automatically scale to include the entire data set in a graph window when a new measurement is performed. This option is ignored during operation in **Real-Time Mode**.

- **Automatically Find DUT Length**. When this option is selected, the length of the DUT is automatically found when the **Scan** button is pressed in normal and averaging mode. However, the OVA will *not* automatically find the DUT length in **Continuous** or **Real-Time Mode** operation. For these modes, the user must click **Find** or enter a DUT length manually in the **System Control** area. (See "Finding the DUT Length" on page 44 for more information.)

- **Remote Interface Setup** opens a dialog box allowing the user to select a GPIB or TCP/IP interface. It also allows the user to set the interface address. The default setting is 1. (For more information on remote operation, see "Remote Control Setup Configuration" on page 136.)

- **Specify Compression Settings** is only available as a purchased option. Otherwise it will not appear in the **Options** menu. For more information, see "Pulse Compression" on page 53.

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The Tools menu

- **Turn Laser ON** or **Turn Laser OFF** allows the user to turn the laser on and off. Note that turning on the OVA hardware automatically turns on the laser.

- **Use OVA as Light Source** performs a sweep of the laser through the wavelengths specified in the **System Control** area, without performing a scan. This command allows the OVA to function as a tunable light source. Depending on the wavelength range setting, this command can take up to 15 seconds to complete.

- **Internal Calibration** initiates an instrument calibration that does not require the user to connect a reference fiber or polarization controller. A dialog box allows the user to specify calibration parameters. (For more information, see "To perform an internal calibration" on page 40.)

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- **Full Calibration** fully calibrates the system. This requires the user to connect either a reference patchcord or polarization controller. A dialog box allows the user to specify calibration parameters. (For more information, see "To perform a full calibration" on page 37.)
- **Reload Cal Data File** allows the user to reload a calibration file into memory, should an attempted calibration fail. The OVA software looks for an appropriate calibration file based on the **Type of Measurement** specified in the **System Control** area.
- **Align Optics** performs an alignment of the internal optics of the OVA. (See "Aligning the OVA Optics" on page 33 for more information.)
- **Last Calibration Information** calls up a dialog box showing the conditions and time of the most recent full and internal calibrations. (For more information, see "Information on the Last Calibration" on page 44.)
- **Check Warm-Up Time** displays a timer which counts down one hour from the time the OVA hardware was powered on. For optimal measurement accuracy and calibration stability, the OVA should be allowed to warm up for one hour prior to performing measurements, even though the laser ready LED will come on before one hour has elapsed.
- **Reset Hardware** allows the user to reset the OVA hardware without having to turn off the device. This should only be used in the rare event that the device becomes non-responsive. This is useful for reestablishing a link to the OVA unit without turning the laser off and back on, which would require the laser to warm up again. This command will close the software and thus requires the user to restart the OVA software.

The Help menu

- **About OVA** displays information about the current software version and contact information for Luna Technologies.

Chapter 4

Performing Measurements

Setting Up

The front panel of the Optical Vector Analyzer contains the power switch and the optical connectors necessary to perform reflection and transmission measurements. The third connector (marked "aux") is available for Luna Technologies to customize the system at the purchaser's request.

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Four LEDs on the front panel indicate the state of the instrument:

- The **Power** LED lights when the power is on.
- **Laser On** lights after the laser has been turned on.
- **Scanning** lights whenever the laser is scanning.
- **USB** lights after a scan, while the OVA unit is sending data to the PC.

Aligning the OVA Optics

In order to perform accurate measurements, the internal optics of the OVA must be properly aligned. The three conditions that require an alignment to be performed are listed below.

Alignment must be performed...

1   When the instrument is initially set up for the first time.

2   Whenever the OVA is physically moved from one location to another.

3   Whenever the   **Out of Alignment**   indicator in the **System Status Bar** is visible.

Important ✓	Immediately following alignment, the OVA will tend to drift out of calibration as the internal mechanical components settle. It is highly recommended that the automatic calibration interval be set to 0.25 hours for at least one hour following alignment (see "To configure automatic calibration" on page 42).

To align the OVA optics

1   Ensure that the OVA unit is powered on and that the laser is on and ready.

2   Select **Tools > Align Optics**.

A dialog box appears instructing the user to disconnect devices. The user may opt to **Cancel** or click **OK** to continue.

If **OK** is selected, alignment begins. A status bar shows the progress of the alignment. When the alignment is complete, the software returns to the main window.

3   When the alignment is complete, the software will prompt the user to perform an internal calibration. It is strongly recommended to select "yes" after this prompt. The conditions for this internal calibration are determined by the settings previously entered under **Tools > Internal Calibration**. (For more information, see "To perform an internal calibration" on page 40.)

Calibrating the System

The OVA system must be calibrated prior to performing measurements. The OVA calibration removes the effects of the measurement network to ensure that the measured Jones matrix represents only the device under test.

Calibration Files

Transmission and reflection measurements each require an independent calibration. The most recent calibrations for each measurement type are stored in files, which are loaded by the control software upon start-up. If the software is unable to locate at least one calibration file, a dialog box will appear to alert the user that a calibration

must be performed before a measurement can take place. In this event, the **Scan** button will be unavailable until a calibration has been performed.

Calibration files are saved to the same directory as the OVA.exe file. The default directory for OVA.exe is "*C:\Program Files\Luna Technologies\OVA*"

Calibration Types

The OVA has two types of calibration. One is a complete transfer function measurement, that will remove all instrument network effects from the measurement, up to and including the connectors on the front panel. This requires an external reference device, and is termed a "full calibration." In addition to the full calibration, there is also an "internal calibration." An internal calibration is only possible once a full calibration has been performed. The internal calibration process corrects for any internal drift in the system that has occurred since the last full calibration. It will not calibrate out the front panel connector effects if they have been disconnected and reconnected since the last full calibration.

The OVA control software can be configured to execute internal calibrations automatically at a user-specified time interval. For further information on this feature, see "Automatic Calibration" on page 42.

When performing a full calibration, the user has the option of whether or not to calibrate for polarization dependent loss. Calibration for PDL requires the use of the supplied polarization controller as a reference device, and the user must move the polarization controller paddles at prescribed points in the calibration process. If the system is not to be calibrated for PDL, the polarization controller is not necessary and the calibration process takes less time.

For instructions on selecting these calibration options, see "The Calibration Procedure" on page 37.

Conditions that Require Calibration

In a typical laboratory or manufacturing environment, a full calibration should be performed at least once every 72 hours. It is also recommended that an internal calibration be performed every 1 to 4 hours. This is easily accomplished by turning on the automatic calibration and setting the time interval appropriately (see "To configure automatic calibration" on page 42).

The need to recalibrate is largely determined by the surrounding environmental conditions. If the temperature is fluctuating rapidly, it may be necessary to set the

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automatic calibration interval to something less than one hour. If the surrounding temperature is very stable, a longer interval may suffice.

A full calibration must be performed whenever the surrounding temperature has changed by more than ±5 degrees C, or whenever an internal calibration fails to bring the instrument back into calibration (see "To check the calibration" on page 42).

Following an alignment, the software will prompt the user to perform an internal calibration. It is strongly recommended to select "yes" after this prompt.

In certain cases the control software will detect that the internal optics of the instrument have drifted, and it will alert the user via the **System Status Bar** indicator **Out of Calibration**. When this occurs an internal calibration will typically suffice.

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Considerations Prior to Calibrating

Take the following considerations into account when calibrating to ensure that the calibration is appropriate for the device or devices to be measured, and that the subsequent measurements are as accurate as possible.

1 For devices with a narrow pass band (< 5 nm), choose a calibration range that is at least twice as wide as the device passband.

2 Effects due to the front panel connectors on the OVA can be removed from the measurement by cutting the calibration fiber and splicing the device under test into the measurement path, rather than connecting the device to the OVA directly.

   By connecting a device to the OVA directly, loss measurements are limited by the connector repeatability, which can be ±0.3 dB or greater for both insertion loss and PDL.

3 Calibration is most accurate if the length of the reference fiber (in the polarization controller) is close to the same length as the device under test, to within ±2 m. For long devices, cut the reference fiber and splice in a section of standard fiber (Corning SMF 28 or equivalent) that is equal to the device length for calibration. Then remove the section when performing measurements, and splice the device under test in its place.

The Calibration Procedure

To perform a full calibration

1 Ensure that the OVA unit is powered on and that the laser is on and ready. Select **Tools > Check Warm-Up Timer** to make sure the instrument is ready.

2 If the laser is not already on, select **Tools > Turn Laser ON**.

By default, the laser comes on when the OVA hardware is turned on. If the laser was off, it may take a few minutes to warm up. The **Laser Ready** light on the front of the instrument comes on when the laser reaches operating temperature.

3 Select **Tools > Full Calibration**.

The following dialog box appears:

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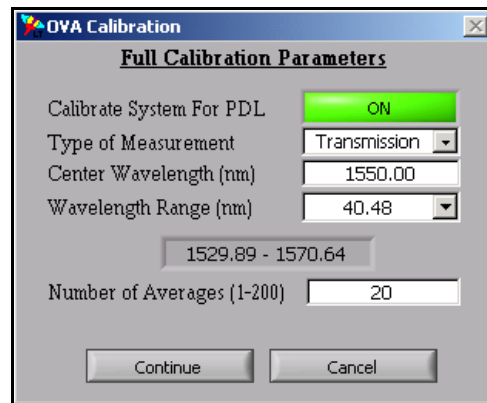
Figure 4-1. Full calibration parameters dialog box.

4 To calibrate for all parameters, including polarization dependent loss (PDL), leave the **Calibrate System for PDL** indicator **ON**. This option requires the use of the supplied polarization controller.

- OR -

If PDL accuracy is not of concern, click the **Calibrate System for PDL** indicator to **OFF**. With this option the user may substitute a fiber patch cord for the polarization controller.

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5 Select **Transmission** or **Reflection** from the **Type of Measurement** pull-down menu. Calibration in reflection requires the supplied gold reflector.

6 Type in the **Center Wavelength** appropriate for the device(s) to be tested following calibration.

7 Select the desired **Wavelength Range** from the pull-down menu.

Note that in order to perform measurements over a broader wavelength range than the one selected during calibration, it is necessary to recalibrate.

8 Enter the **Number of Averages** to perform. A larger number of averages will take more time to calibrate, but will result in more accurate measurement data.

9 Click **Continue**.

The instrument performs several internal scans. Next a prompt appears instructing the user to connect the polarization controller, and, if calibrating in reflection, the gold reflector.

10 Before making connections, be sure to clean all fiber optic connectors. (See "Cleaning Connectors" on page 255.)

11 For a **Transmission** calibration, connect the polarization controller to the **Source** and **Detector** connectors on the front panel of the OVA.

For a **Reflection** calibration, connect one end of the polarization controller to the **Source** connector, and connect the other end to the gold reflector.

12 Align the connector key to fit in the groove in the bulkhead adaptor. Turn the screw ring around the connector clockwise until it is just tightened.

13 Click **OK**.

If the **Calibrate System for PDL** indicator is **OFF**, the system will indicate when the calibration is complete.

- OR -

If the **Calibrate System for PDL** indicator is **ON**, pop-up windows instruct the user to change the position of the paddles twice. Here is an example of a paddle orientation change sequence:

Figure 4-2. Polarization controller, in the beginning paddle position.
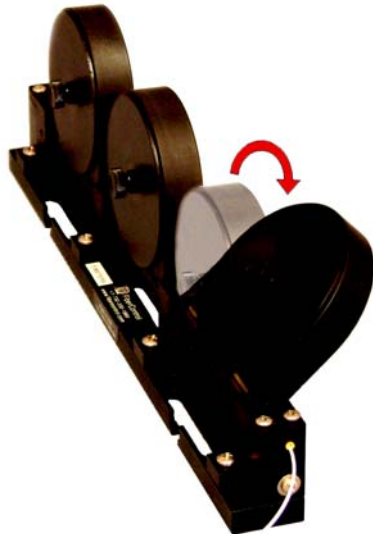
Figure 4-3. First paddle position change.

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Figure 4-4. Second paddle position change.

14 Click **OK** in the dialog box indicating that the instrument has been successfully calibrated.

After calibrating, it is a good idea to check if the calibration was successful. (See "Checking the Calibration" on page 41.)

To perform an internal calibration

1 If a full calibration has not been performed within the past 72 hours, choose a full calibration rather than an internal calibration.

2 Ensure that the OVA unit is powered on and that the laser is on and ready. Select **Tools > Check Warm-Up Timer** to make sure the instrument is ready.

3 If the laser is not already on, select **Tools > Turn Laser ON**.

By default, the laser comes on when the OVA hardware is turned on. If the laser was off, it may take a few minutes to warm up. The **Laser Ready** light on the front of the instrument comes on when the laser reaches operating temperature.

4 Select **Tools > Internal Calibration**.

The following dialog box appears:
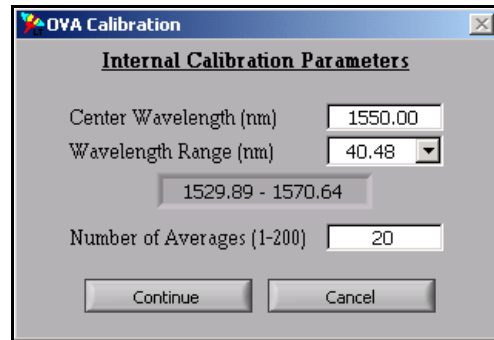
Figure 4-5. Internal calibration parameters dialog box.

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5 Type in the **Center Wavelength** appropriate for the device(s) to be tested following calibration.

6 Select the desired **Wavelength Range** from the pull-down menu.

Note that the available range for the internal calibration must lie within the range of the previous full calibration. The **Center Wavelength** and **Wavelength Range** will be coerced to fall within the available range.

7 Enter the **Number of Averages** to perform. A larger number of averages will take more time to calibrate, but will result in more accurate measurement data.

8 Click **Continue**.

The system will perform the necessary internal calibration scans and indicate when the calibration is complete.

Checking the Calibration

It is a good idea to check the calibration once it is complete to ensure that the system will provide accurate data. The following procedure can be used to check both full and internal calibrations.

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To check the calibration

1 In the case of a full calibration, leave the reference device (patchcord, polarization controller, and/or gold reflector) connected to the OVA.

- OR -

In the case of an internal calibration, remove any device that may be connected to the OVA. Connect the **Source** and **Detector** ports via standard single mode fiber (if calibrating in transmission) or connect the supplied gold reflector to the **Source** port (if calibrating in reflection). Note that the use of connectors can influence the measurement, so it is recommended that the fiber or reflector be spliced into the current front panel connection.

2 Perform a measurement, following the instructions under "To perform a single-scan measurement" on page 49.

3 Display the insertion loss graph, following instructions under "Manipulating Plots" on page 62. Check that the insertion loss measures a nominal value of zero to within the measurement accuracy of the instrument.

If PDL has been calibrated, also check the PDL graph to ensure that it also displays a nominal value of zero to within the measurement accuracy of the instrument.

Automatic Calibration

The OVA is capable of automatically calibrating itself to compensate for any system drift due to changes in the surrounding environment. The automatic calibration consists of an internal calibration that occurs at a user-specified time interval. The automatic calibration uses the internal calibration settings that are set in the internal calibration parameters dialog box (see Figure 4-5 on page 41). Note that in order to change the settings, an internal calibration must be performed for new settings to take effect.

To configure automatic calibration

1 Follow the instructions "To perform an internal calibration" on page 40, setting the internal calibration parameters to the desired values for the automatic calibration.

2 Select **Options > Auto Calibration Settings**.

The following dialog box appears:

Figure 4-6. The Automatic Calibration Settings dialog box.

3 To turn automatic calibration on, click to ensure the A**uto Calibration (On/Off)** indicator is lit: .

-OR-

To turn automatic calibration off, click to ensure the **Auto Calibration (On/Off)** indicator is off: .

4 Select the desired frequency for the automatic calibration from the **Calibration Interval (hrs)** drop-down menu. The menu choices are 0.25, 0.5, 1, 2, 4, or 8 hours.

5 Click **OK** to complete the automatic calibration configuration.

When the specified interval has elapsed, the prompt shown below will appear.
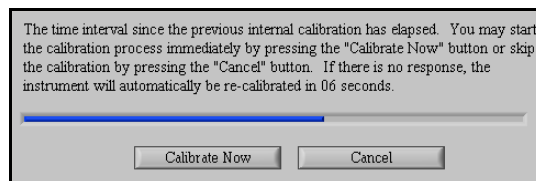
Figure 4-7. The automatic calibration prompt.

Clicking the **Calibrate Now** button will start an internal calibration immediately. If there is no user response, the calibration will begin after 10 seconds.

Note that if the OVA instrument is scanning, the automatic calibration prompt will not appear until the scans are completed.

Information on the Last Calibration

The user may verify the time and conditions of the last calibration by selecting **Tools > Last Calibration Information**. The dialog box shown below appears, showing the type, wavelength range, number of averages, DUT length, and time of the most recent full calibration. The user can click on the **Internal Calibration** tab to check those conditions. Note that the user must click on the third tab to close this window.

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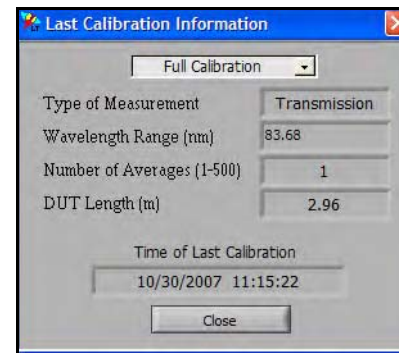
Figure 4-8. The **Last Calibration Information** window.

Finding the DUT Length

Because the OVA is an interferometric measurement system, the length of the device under test (DUT) must be known prior to the measurement. If the length is known to within 0.1 m, the user may input the value manually. Otherwise, the instrument can measure the length of the device.

Please note that for transmission measurements, the length is defined as the length of fiber between the **Source** and **Detector** connectors on the front panel of the OVA.

For reflection measurements, the device length is defined as the length of fiber between the **Source** connector and the point of reflection within the device.

Important ☑	For the OVA instrument to operate properly, the total device length (including leads) must not be greater than the specification of your instrument for a transmission measurement, or half that length for a reflection measurement.

Length Measurement Methods

In order to measure the length of the device correctly, the user must select one of two measurement methods: **Broadband** and **Narrowband**. In general, broadband is used for devices that may stop a small portion of the light, but pass light over most wavelengths. (A bare fiber is the limiting case of a broadband device.) Narrowband is used for devices that pass a small portion of light, but stop light at most wavelengths. The descriptors "broad" and "narrow" are relative to the current scan range setting of the instrument. See Figure 4-9 for representations of typical broadband and narrowband loss curves.

Selecting the proper DUT length finding method does require some knowledge about the spectral properties of the DUT prior to measurement. In most cases, simply knowing the type of device is enough information to select the proper DUT length finding method. Table 4-1 shows the correct DUT length finding method for various common devices.

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Table 4-1: DUT length finding methods for common devices

Broadband	Single mode fiber Coupler input to output Bragg grating in transmission Thin film filter in reflection Interleaver Polarization controller
Narrowband	Bragg grating in reflection Thin film filter in transmission

If nothing is known about the device, try either method, and repeat the measurement. If the method selection is incorrect, the measured length will generally not be repeatable. A repeatable measurement is most likely a correct measurement.

For more detailed information about how the OVA measures the length of the device, see "The OVA Device Length Finding Methods" on page 236.

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For these two cases, either method is likely to work because about 1/2 of the light is passed and 1/2 is stopped.

Broadband   **Narrowband**
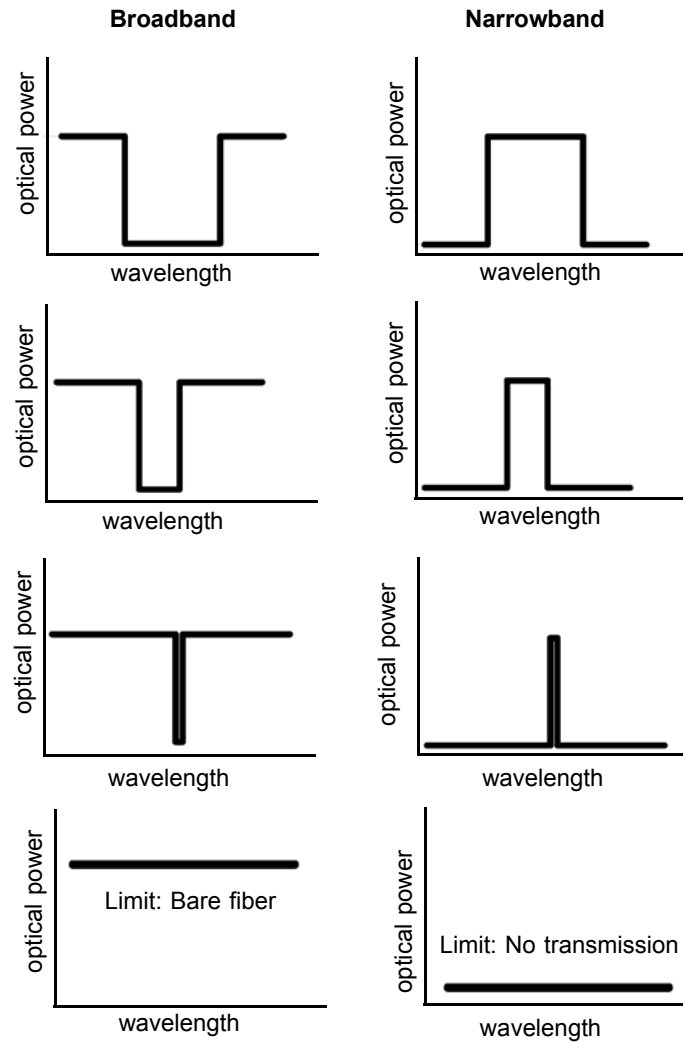
Figure 4-9. *Typical broadband and narrowband loss curves*

The Device Length Measurement Procedure

To find the length of the DUT

1 Be sure that the instrument has been aligned (See "Aligning the OVA Optics" on page 33) and calibrated (See "The Calibration Procedure" on page 37) within the recommended time period.)

2 Before connecting the device to the OVA, be sure to clean all fiber optic connectors. (See "Cleaning Connectors" on page 255.)

3 Connect the device to the OVA. A transmission device must be connected to both the **Source** and **Detector** connectors. A reflection device need only be connected to the **Source** detector.

4 Select **Transmission** or **Reflection** from the **Type of Measurement** pull-down menu in the **System Control** area.

4
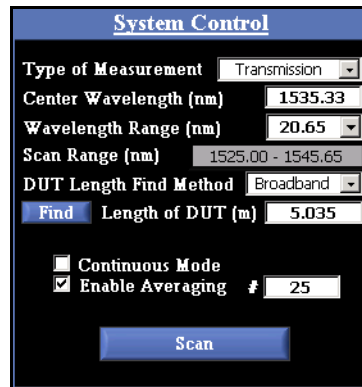
Figure 4-10. The settings for finding the length of the DUT are set in the System Control area of the main screen

5 Enter an appropriate **Center Wavelength** and select a **Wavelength Range** from the pull-down menu.

If the desired scan range falls outside the range of the most recent calibration, either select a different scan range or recalibrate the OVA.

Important ✓	For narrowband devices, the DUT length find algorithm may fail if the correct wavelength range is not specified. If this range does not include the passband of the device, no light will be passed and the instrument will not be able to find the length.

6 Select **Broadband** or **Narrowband** from the **DUT Length Find Method** pull-down menu.

7 Click the blue button marked **Find**, next to **Length of DUT**.

The system then updates the **Length of DUT** field.

High Dynamic Range Averaging

The OVA may be purchased with an option for enhanced dynamic range averaging, which extends the loss measurement range. Please read "High Dynamic Range Averaging" on page 248 to ascertain whether high dynamic range averaging is advantageous for a given measurement.

To use high dynamic range averaging

1 Make sure **Options > Enable High Dynamic Range Averaging** is on, or checked. If this option is grayed out, it was not purchased with the software.

2 Follow the instructions below for "Averaging Mode" on page 50.

Acquiring Data

The OVA has four different options for data acquisition: single scan, averaged scans, continuous mode, and real-time mode. Each mode performs a complete measurement of the Jones matrix of the device under test, and all parameters are available from measurements done in any mode.

Important ✓	Before testing, clean the fiber optic connectors with the appropriate cleaner to guard against errors. For instructions, see "Cleaning Connectors" on page 255.

Single-Scan Mode

The single-scan measurement represents the basic functionality of the OVA. In this mode the instrument performs a single sweep of the laser over the selected wavelength range, and acquires the Jones matrix of the device under test over that range.

To perform a single-scan measurement

1   Ensure that the OVA unit is powered on and that the laser is on and ready. Select **Tools > Check Warm-Up Timer** to make sure the instrument is ready.

2   If the laser is not already on, select **Tools > Turn Laser ON**.

By default, the laser comes on when the hardware is turned on. If the laser was off, it may take a few minutes to warm up. The **Laser Ready** light comes on when the laser reaches operating temperature.

3   Be sure that the instrument has been aligned (See "Aligning the OVA Optics" on page 33) and calibrated (See "The Calibration Procedure" on page 37) within the recommended time period.

4   Before connecting the device to the OVA, be sure to clean all fiber optic connectors. (See "Cleaning Connectors" on page 255.)

5   Connect the device to the OVA. A transmission device must be connected to both the **Source** and **Detector** connectors. A reflection device need only be connected to the **Source** detector.

6   Select **Transmission** or **Reflection** from the **Type of Measurement** pull-down menu in the **System Control** area.

7   Enter an appropriate **Center Wavelength** and select a **Wavelength Range** from the pull-down menu.

If the desired scan range falls outside the range of the most recent calibration, either select a different scan range or recalibrate the OVA.

8   Enter the length of the device (including leads) in the **Length of DUT** field.

- OR -

To have the OVA find the length of the DUT, follow steps seven (7) and eight (8) under "The Device Length Measurement Procedure" on page 47.

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- OR -

To have the OVA find the length of the DUT automatically before each scan, select **Broadband** or **Narrowband** from the **DUT Length Find Method** pull-down menu. Then select **Options > Automatically Find DUT Length**. A check mark by this menu item indicates that the OVA will measure the DUT length before each scan.

9 Check the **Options** menu for functions to be applied to the scan, such as automatic filters or autoscaling. These may also be applied after scanning.

10 Click **Scan**.

The instrument performs the measurement and the software displays the test data.

Averaging Mode

Averaging multiple scans is an effective way to reduce measurement noise and increase measurement accuracy.

Important ✓	The device under test must not move or change during scanning. Therefore care must be taken not to bump the device or expose it to excessive vibrations, especially when scanning long wavelength ranges and/or averaging large numbers of scans.

To average multiple scans

1 In the **System Control** area of the main window, click to select **Enable Averaging**, then type the number of scans to average in the # field.

2 Follow the same measurement procedure as was outlined above under "To perform a single-scan measurement" on page 49.

3 A dialog box appears showing the status of the scans. The scans may be stopped by clicking **Cancel** in this dialog box.

When scanning is completed, the software displays the average of the specified number of scans.

Continuous Scan Mode

Continuous scan mode takes advantage of the fast measurement speed of the OVA to monitor devices whose properties may change slowly with time. It is particularly useful for short (<5 nm) scan ranges, where the update rate is fast enough to allow for near real-time device monitoring.

Important	For accurate measurements, the device must change slowly enough that its properties remain constant while data is acquired. The blue "Scanning" LED on the OVA turns on during data acquisition, indicating this time scale.

When continuous scan mode is operating, the user cannot move data from **Matrix A** to **Matrix B** or **C**. To move data, stop scanning by clicking the grayed **Scan** button in the **System Control** area. Then click the **A->B** or **A->C** button in the **Matrix Memory Functions** area. To resume continuous scanning, click the **Scan** button again.

4

To scan continuously

1   In the **System Control** area of the main window, select **Continuous Scan Mode**.

2   *Optional*: To gain more speed, set the **Graph On/Off Control** in the upper right corner of one of the graphs to the off position: .

3   Follow the same measurement procedure as was outlined above under "To perform a single-scan measurement".

Important	Even if **Options > Automatically Find DUT Length** is selected, the OVA software will not find the length of the DUT automatically in continuous or real-time mode. It must be entered or measured before scanning.

The **Scan** button will turn gray during continuous scanning.

The active graph window(s) will update after each scan.

4   To stop scanning, press the grayed **Scan** button again.

The data stored in local memory will be from the last measurement.

Real-Time Mode

Real-time mode disables several software features in order to acquire data as quickly as possible. Like continuous mode, it is most useful for short (<5 nm) scan ranges. The menu and graph controls that are enabled will not take effect until after real-time scanning is stopped.

The filters selected under the menu settings **Options > Apply Time Domain Window** and **Options > Always Apply Filter** will be applied during real-time mode. Deselecting these filter options will allow real-time mode to operate more quickly.

4

Important ✓	When turning on **Options > Apply Time Domain Window**, be sure to adjust this filter for **Matrix A** in the **Time Domain Window** and select the **Retain Settings** checkbox. Otherwise the default time domain filter will apply.

Users should note that the OVA software will not check if the system goes out of calibration or alignment during real-time mode. Nor will the system perform automatic calibrations. Ensure that the system has been aligned and calibrated before entering real-time mode. The user may perform a single scan after exiting real-time mode to verify that the system is still aligned and calibrated.

To perform real-time scans

1 Select **Options > Enable Real-Time Mode**.

2 To gain more speed, set the **Graph On/Off Control** in the upper right corner of one of the graphs to the off position: .

3 Select the parameter(s) to be displayed in the active plot window(s). Note that the parameter selection cannot be changed while scanning in real-time mode.

4 Make any desired menu changes before scanning, as changes cannot be made during real-time mode scanning. For example, turn filters on (checked) or off (not checked) under the menu settings **Options > Apply Time Domain Window** and **Options > Always Apply Filter**. As always, **Options > Time Segment Length** must be set before scanning. Note that autoscaling does not function during real-time mode.

5 Follow the same measurement procedure as was outlined above under "To perform a single-scan measurement".

Important ☑	Even if **Options > Automatically Find DUT Length** is selected, the OVA software will not find the length of the DUT automatically in continuous or real-time mode. It must be entered or measured before scanning.

The **Scan** button will turn gray while scanning in real-time mode.

The active graph window(s) will update after each scan.

6 During scanning, the user may press "Ctrl-F5" to display the **Update Rate** indicator (shown below) in the **System Status Bar**.

4

Update Rate (Hz) 0.00
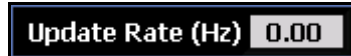
7 To stop scanning, press the **Scan** button again.

The data stored in local memory will be from the last measurement.

Pulse Compression

The OVA may be purchased with the option to compress the impulse response when performing scans. If purchased, this may be set by selecting **Options > Pulse Compression Settings**. The following dialog box appears.
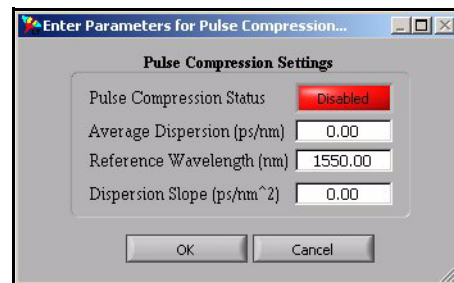
Figure 4-11. Pulse compression settings dialog box.

The user must enable compression in the dialog box above, and enter the **Average Dispersion** (ps/mm), **Reference Wavelength** (nm), and **Dispersion Slope** (ps/nm2)

prior to scanning. These values are generally known, but may also be calculated following the procedure below. (For theoretical background, see "Pulse Compression" on page 250.)

Calculating Average Dispersion and Dispersion Slope

To calculate or confirm the average dispersion and dispersion slope of the DUT, the user may follow the steps below, using Luna Technologies' OFDR software:

1 Measure the DUT using OFDR software.

2 Save the group delay data in a text file.

3 Using appropriate curve analysis software, fit the group delay data to a line. The slope of this line is the **Average Dispersion**, d_a, in ps/nm.

4 Subtract d_a from the group delay curve.

5 Perform a second order fit on the remaining curve versus $\lambda - \lambda_{ref}$, where λ_{ref} is the **Reference Wavelength**, or the center of the wavelength window.

6 Multiply the second order coefficient by two (2) to obtain the **Dispersion Slope**, d_s, in ps/nm^2.

4

Chapter 5

Data Processing and Display

Once a measurement has been performed, the OVA control software provides many tools for manipulating and displaying measured data. Up to three data sets may be stored in the local memory of the software, or data may be saved to a file in either a binary or spreadsheet format. Data stored in the local memory of the software can be used to display any of the parameters described under "Parameter Calculations" on page 217. The software also provides two independent filters for smoothing the data and reducing measurement noise. Also included are powerful zoom and cursor features to enhance the usefulness of the display.

Examples in this chapter use data provided with the software and compiled from actual measurements using the OVA. These sample data files are located in the directory "*C:\Program Files\Luna Technologies\OVA Software\Sample Data*."

5

Matrix Memory Functions

The OVA control software allows the user to store up to three data sets in active memory. These three memory locations are denoted Matrices A, B and C. The most recent measurement is always stored in Matrix A.

Important ☑	New scans are automatically loaded into Matrix A, overwriting any data there. To avoid losing data, see "Moving Data in Local Memory" below, or "Saving and Loading Data Files" on page 57.

Moving Data in Local Memory

Data from **Matrix A** may be moved to **Matrix B** or **C** by clicking the oval labeled **A->B** or **A->C**, respectively, under the **Operations** column of the **Matrix Memory Functions** area shown in Figure 5-1. The original data in **Matrix A** remains in **A** until new data is acquired. Note that scans already in **Matrices B** and **C** cannot be swapped.
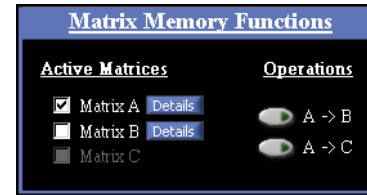
Figure 5-1. The Matrix Memory Functions area in the main OVA software window.

Displaying Stored Data

The control software can display any combination of **Matrices A**, **B**, and **C** simultaneously in the graph windows. By default the data in **Matrix A** is plotted as a blue curve, **Matrix B** is red, and **Matrix C** is yellow. In the example in Figure 5-1 above:

1 **Matrix A** contains data, as indicated by the white name and checkbox and the blue **Details** buttons. **Matrix A** is being graphed, as indicated by the filled-in checkbox. To clear this graph, click to clear the checkbox by **Matrix A**.

2 **Matrix B** also contains data but is not being graphed. Clicking in the second checkbox adds **Matrix B** to the graph window.

3 **Matrix C** has no data in it, as indicated by the grayed name and lack of a **Details** button. To overlay a third plot, the user would have to load data into **Matrix C**.

When data is loaded into local memory (by selecting **File > Load Data File**), it is automatically displayed in the graph window. However, when data is moved *within* local memory (by clicking **A->B** or **B->C**), the user must then click in the corresponding **Active Matrices** checkbox to display the moved data.

Matrix Details

Clicking the **Details** buttons in the **Matrix Memory Functions** area calls up the window shown in Figure 5-2. This window lists the **System Control** values that were set by the user prior to scanning the data in that matrix.
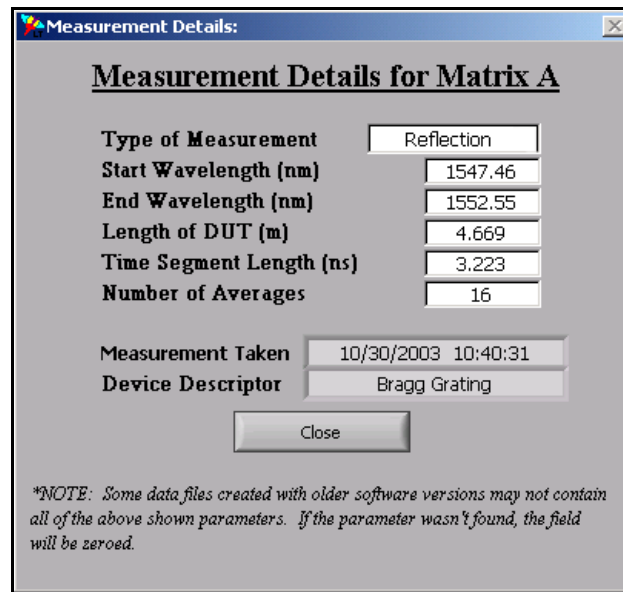
Figure 5-2. Matrix Details window.

Saving and Loading Data Files

The OVA control software provides two different options for saving data files. One is a binary data format that completely captures the measured Jones matrix data and stores it in a format that can be loaded back into the control software at a later time for further manipulation. This format does not store filter settings, as the filters may be set to any value once the data has been loaded back into the control software.

The second format is a text file in a tab-delimited spreadsheet format. The content of this file is selected by the user from the list of all calculated parameters and reflects user-selected filter settings. (See step 5 under "To specify options for saving data" on page 58 for instructions on applying filters to spreadsheets.) Data saved in the spreadsheet format cannot be loaded back into the control software.

It is highly recommended that the binary data format be chosen over the spreadsheet format for data archives. The binary format stores all measurement information, whereas the spreadsheet format stores only a subset of the measured information because it can incorporate filter settings. Furthermore, a spreadsheet file can always be generated from a binary file at a later date, but a binary file cannot be generated from a spreadsheet file. Finally, other data analysis software packages available from

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Luna Technologies accept only the binary data format produced by the OVA control software.

Saving Data

Prior to saving data, the user may customize the format, content, and file extensions of saved data files. The following procedure sets options that will affect how the command **File > Save Data** saves measurement data.

To specify options for saving data

1 Select **File > Select Data Save Options**

The **Select Data Save Options** dialog box shown below opens.
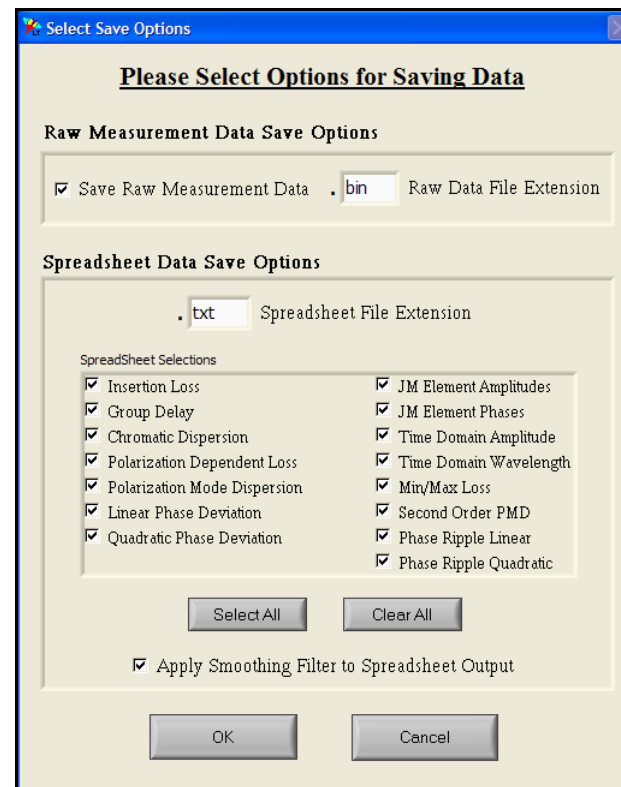
Figure 5-3. Select Data Save Options dialog box.

2   To save a binary Jones matrix data file, ensure that the **Save Raw Measurement Data** checkbox is checked. In order to save *only* a binary data file, click the **Clear All** button under the **Spreadsheet Selections**.

> **Important**
>
> ☑
>
> A saved binary data file includes only the original data from a scan, not data that has been filtered.

- OR -

To save a spreadsheet file only, click to clear the **Raw Measurement Data** checkbox and check the desired **Spreadsheet Selections**.

3   To change the extension of the binary data file, type the extension in the **Raw Data File Extension** text box.

To change the extension of the spreadsheet file, type the extension in the **Spreadsheet File Extension** text box.

4   Select the types of data to be included in spreadsheet files by clicking to select or clear the spreadsheet data option checkboxes. If all options are cleared then no spreadsheet file will be saved.

5   Select whether or not to **Apply Smoothing Filter to Spreadsheet Output**. When this box is checked, the smoothing filter will be applied according to the **Filter Resolution BW** set in the **Data Processing** area. If **Options > Apply Time Domain Filter** is checked, the **Time Domain Window** will be applied to the data as well.

6   Click **OK.**

The control software saves the selected options.

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To save data

1   Select **File > Save Data Files**.

A dialog box appears.

2   Select the file destination and enter a file name. The file extension(s) will be added automatically according to the configuration set using **File > Select Data Save Options**.

If the **Save Raw Measurement Data** checkbox (in the **File > Select Data Save Options** window) is checked, the software will append ".bin" (or another user-specified extension) to the file name and save the raw Jones matrix data. If at least one of the **Spreadsheet Data Save Options** is checked, the software will append ".txt" (or another user-specified extension) to the file name and save spreadsheet data. If both of these options are checked, the software will save two files with the same file name but different extensions.

3   Click **Save**.

Loading Saved Data

Only data saved in the binary Jones matrix format can be loaded into the control software. Sample data files are located in the directory "*C:\Program Files\Luna Technologies\OVA Software\Sample Data*."

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To load a saved data file

1   Select **File > Load Data File** from the pull-down menu.

2   In the dialog box that appears, choose the desired file and click **Open**. (To follow the examples in this chapter, open the file "*C:\Program Files\Luna Technologies\OVA Software\Sample Data\Bragg Reflection.dat*.")

The **Matrix Selection** dialog box opens:
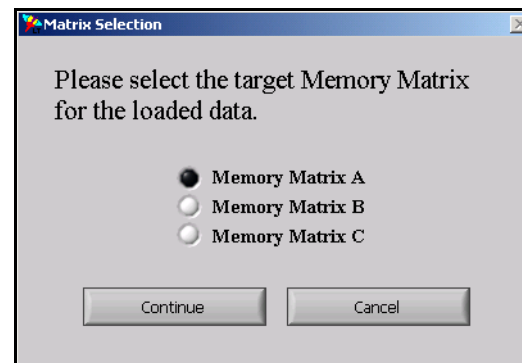
Figure 5-4. The Matrix Selection dialog box appears after selecting File > Load Data File.

3   Select a target matrix memory location for the data file, and then click **Continue**. (In the examples in this chapter, **Matrix A** was selected.)

If the user selects a matrix that already contains data, the software will ask for confirmation to overwrite that data. Clicking **Yes** overwrites the data. Clicking **No** gives the user a chance to select a different matrix destination or to cancel.

The selected matrix memory location becomes active and the data appears in the graphs in the main window.

Spreadsheet File Data Values by Column

Table 5-1 shows the order in which the measured parameters appear in the columns of a spreadsheet file. If any of the parameters are not selected to save under **File > Select Data Save Options**, parameters in later columns shift over to the left.

Table 5-1: Spreadsheet Output

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Column	Value	Column	Value
1 or a	Wavelength (nm)	14 or n	JM Element a Phase
2 or b	Frequency (GHz)	15 or o	JM Element b Phase
3 or c	Insertion loss (dB)	16 or p	JM Element c Phase
4 or d	Group delay (ps)	17 or q	JM Element d Phase
5 or e	Chromatic Dispersion (ps/nm)	18 or r	X-axis - Time (ns)
6 or f	Polarization Dependent Loss (dB)	19 or s	Time Domain (Amplitude) (GW/J)
7 or g	Polarization Mode Dispersion (ps)	20 or t	Time Domain (Wavelength) (nm)
8 or h	Linear Phase Deviation (rad)	21 or u	Max Loss (dB)
9 or i	Quadratic Phase Deviation (rad)	22 or v	Min Loss (dB)
10 or j	JM Element a Amplitude	23 or w	Second Order PMD (ps^2)
11 or k	JM Element b Amplitude	24 or x	Phase Ripple Linear (rad)
12 or l	JM Element c Amplitude	25 or y	Phase Ripple Quadratic (rad)
13 or m	JM Element d Amplitude		

Manipulating Plots

The OVA control software gives the user great control over the content and appearance of the data plots. This section covers plot selection, zooming and scaling tools, and cursors.

Plot Selection

The user can control the content of the two graphs in the main window from a list of parameters in the **Title Bars**. By default, the top graph displays insertion loss, and the bottom graph displays group delay.

To change the content of a graph window

1 Click on the **Title Bar** of the graph. A drop-down list of the available plot parameters appears.
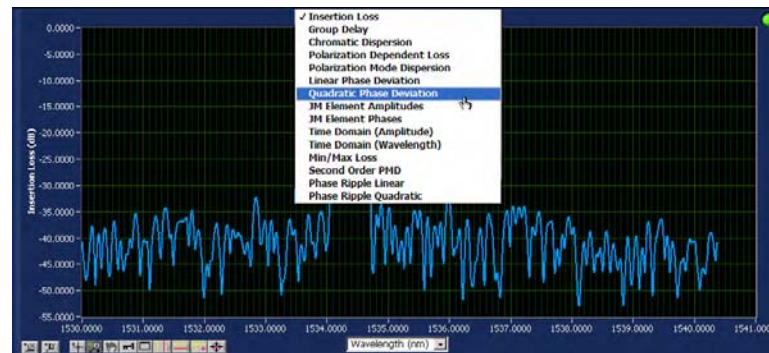
Figure 5-5. Graph window showing the Title Bar pulled down for parameter selection.

2 Drag the cursor to the desired parameter from the list.

5

3 The content of the graph changes, as do the title and the axis labels (if necessary).

Important	The cursors are used to calculate the linear and quadratic phase deviation plots. Because cursors are attached to the first matrix plotted, only the plot of the first matrix displayed is valid. So to calculate the phase deviation of **Matrix C**, for example, deselect **Matrices A** and **B** in the checkboxes in the **Matrix Memory Functions** area. Then set the vertical cursors to the appropriate positions and press the recalculate button, .

Scaling Plot Axes

The OVA control software provides several ways for adjusting the scaling of the graph windows.

Autoscaling

Autoscaling refers to the automatic adjustment of plot axes so that all of the data fits in the graph window.

By default, the graph windows will autoscale when new data is acquired, either by performing a measurement or loading a data file. To toggle this feature on and off select **Options > Autoscale Plot Axes**. A check mark next to this selection indicates that autoscaling is turned on.

At other times, the user may rescale each plot axis independently by using the X- and Y-axis autoscale buttons, and , located in the lower left corner of each graph window.

Manual scaling

The plot axes may be scaled manually by double-clicking on either the lowest or highest value labeled on the axis and typing in a new value. To accept the new value, press enter or click anywhere in the screen.

Note that by using this method it is possible to flip the graph so that increasing values on the X-axis run from right to left, and increasing values on the Y-axis run from top to bottom. Typically this is to be avoided, so be sure to enter appropriate values.

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Synchronizing X-axes

Clicking the **Sync X-Axes** button in the **Display Options** area synchronizes the X-axes of both graphs to the graph area selected in the **To** field. This feature adjusts only the X-axis scale. The Y-axis scale is not affected. Note that the two graphs must be displayed in the same units in order to synchronize them.

Figure 5-6. Display Options area in the main OVA software window.

If both graphs have X or cross-hair cursors on when **Sync X-Axes** is clicked, the cursor style and location will synchronize to the graph selected in the **To** field.

Using zoom tools

There are six available zoom tools, which are accessible by clicking the **zoom menu button**, , located in the lower left corner of each graph window.

When this button is clicked, a pop-up window containing the six zoom tools opens:
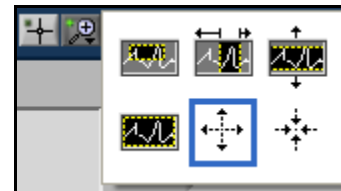
Figure 5-7. Zoom tools pop-up menu. A blue border surrounds the selected tool.

The zoom window tool:

This tool allows the user to zoom in on a rectangular region of the graph window.

To use this tool, first select it from the zoom menu button. Then click in the graph window and hold the mouse button to define one corner of the rectangular region. Then drag the mouse cursor and note that a dotted box appears with corners defined

by the original click position and the current mouse cursor position. Drag the box around the desired region of the graph window and release the mouse button. Both the X- and Y-axis scales adjust so that the selected region fills the entire graph window.

The X-axis zoom tool:

This tool allows the user to zoom in on a region of the X-axis only, without adjusting the Y-axis scale. This is the default tool active in each graph when the software is opened.

To use this tool, first select it from the zoom menu button. Then click in the graph window and hold the mouse button to define one edge of the desired X-axis region. Drag the mouse cursor to the other edge of the desired region and note that a fixed vertical dotted line appears where the original click occurred, and another follows the mouse cursor. When the cursor is positioned at the other edge of the desired region, release the mouse button. The X-axis scale adjusts to show only the selected region.

The Y-axis zoom tool:

This tool allows the user to zoom in on a region of the Y-axis only, without adjusting the X-axis scale.

To use this tool, first select it from the zoom menu button. Then click in the graph window and hold the mouse button to define one edge of the desired Y-axis region. Drag the mouse cursor to the other edge of the desired region, and note that a fixed horizontal dotted line appears where the original click occurred, and another follows the mouse cursor. When the cursor is positioned at the other edge of the desired region, release the mouse button. The Y-axis scale adjusts to show only the selected region.

The return to full zoom tool:

Selecting this button from the zoom menu returns the graph to the full scale of all data.

The zoom in tool:

This tool allows the user to zoom in (magnify) the graph from the point where the cursor is clicked.

5

To use this tool, first select it from the zoom menu button. Then click once to magnify once; or click, hold and release to magnify several times at the cursor location.

The zoom out tool:

This tool allows the user to zoom out from the point where the cursor is clicked.

To use this tool, first select it from the zoom menu button. Then click once to zoom out once; or click, hold and release to zoom out several times at the cursor location.

The pan tool:

This tool lets the user pan around the data in a graph window. To use this tool, first select it from the button menu, then click on the graph and drag the cursor.

Using Cursors and Legends

Cursors

The OVA software offers three types of cursors. By default, vertical cursors and twin locked cursors appear at 10% and 90% of the X-axis range. Horizontal cursors appear at 10% and 90% of the Y-axis range. To move the cursors, select the cross-hair, , then click, drag, and release the cursor.

When any of the cursors are on, a legend appears in the upper right corner giving the exact location of the cursors in the units currently selected. The legend also indicates the distance between the two cursors (dX for vertical cursors, dY for horizontal cursors, and dX and dY for twin locked cursors).
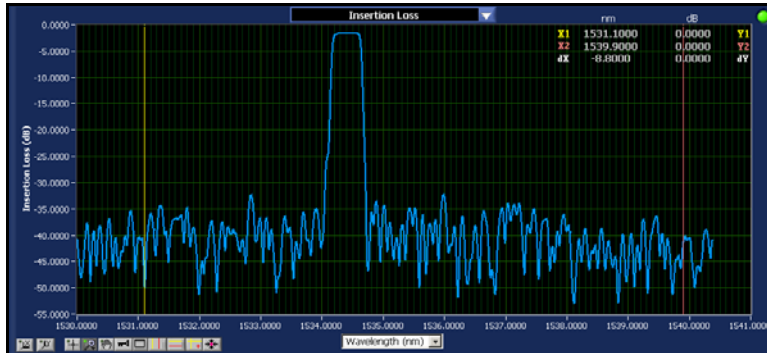
*Figure 5-8. Graph window with vertical cursors appearing at the default location.
The legend at the upper right gives the precise location
of the cursors and the distance between them (dX in this case).*

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Vertical cursors:

Clicking this button toggles two vertical cursors on or off.

Horizontal cursors:

Clicking this button toggles two horizontal cursors on or off.

Twin locked cursors:

Clicking this button toggles twin locked cursors on and off. Regardless of where these cursors are dragged, they will intersect the graph at a data point on the first matrix displayed. So to use twin locked cursors on **Matrix C**, for example, deselect **Matrices A** and **B** in the checkboxes in the **Matrix Memory Functions** area.

Bring cursors to center:

Clicking this button brings the active cursors into the viewed portion of the graph.

Move cursors to peak:

Clicking this button moves the two vertical cursors to the peaks of the regions highlighted by each cursor. Simply click on this button when the vertical cursors are on.

(Note that this button is available in the OFDR software, but not the OVA software.)

Legend

A plot legend can be displayed by clicking the [icon] button in the graph window. The legend lists the matrix, parameter, and color of all plots currently displayed.

Changing graph style and color

The user may change the color or line style of an individual graph by first turning on the legend. Next, click inside the legend on the name of the curve to be adjusted. This calls up a menu which allows the user to select line color, style (dashed or solid), and width.

Recalculating Phase Deviation

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The linear and quadratic phase deviation calculations require a curve fit over some portion of the measurement spectrum. (See "Linear phase deviation" and "Quadratic phase deviation" beginning on page 223.) When either of these quantities are selected in the Title Bar of either graph, the vertical cursor positions are used to define this curve fit region. To recalculate the phase deviation using a curve fit over just the device passband, position the vertical cursors at each end of the passband and click the recalculate button, [icon]. Because cursors are attached to the first matrix plotted, only the plot of the first matrix displayed is valid. To calculate the phase deviation of **Matrix C**, for example, deselect **Matrices A** and **B** in the checkboxes in the **Matrix Memory Functions** area.

Full Screen View

To view an enlarged graph of a given parameter, first select that parameter as described under "Plot Selection" on page 62. Then click on the full screen view button, [icon], of the desired graph. A full screen view of the graph appears, as shown below.

(Note that this button is available in the OVA software, but not the OFDR software.)
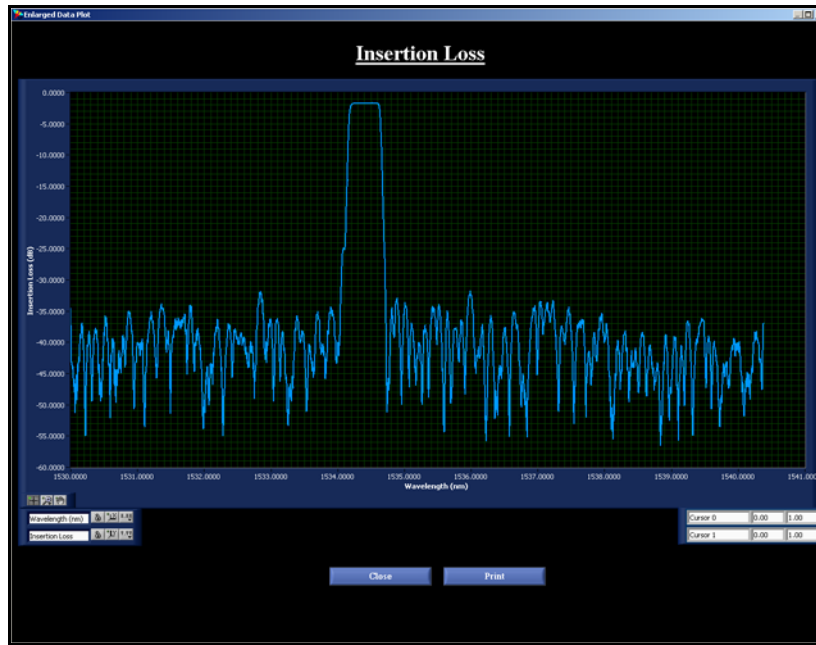
Figure 5-9. Full screen view of insertion loss of a Bragg grating.

The same zoom tools and axis autoscale buttons described above are available in full screen view. However, the legend and cursor buttons are not available. The user may enter X and Y values in the lower right corner in order to view up to two horizontal and vertical cursors. To remove these cursors, enter a value outside the viewing range.

X- and Y-axis formatting buttons:

Full screen view also offers two buttons for controlling how the X-axis and Y-axis units appear. These buttons call up the pop-up menu shown below to adjust the appearance of the X-axis scale and grid. [Note that these buttons are also available in the **Time Domain Window** (see Figure 5-11 on page 72).]
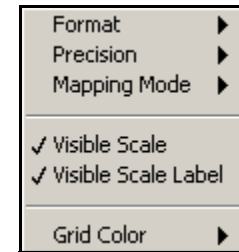
Figure 5-10. X- or Y-axis format menu.

Using this menu, the user may select the **Format** (decimal, scientific, binary, etc.), **Precision** (number of significant digits), and **Mapping Mode** (linear or logarithmic) of the axes. Clicking the **Visible Scale** and **Visible Scale Label** menu selections toggles the axis scale and label on and off. The final menu item allows the user to adjust the **Grid Color**.

The user may print this single graph by clicking the **Print** button in the lower center. To exit full screen view, click on the blue **Close** button.

Filtering Data

The OVA control software provides two methods for filtering data. The first is a time domain filter that is applied to the raw Jones matrix data. It is used to select a portion of the time domain information to be included in the frequency domain representation of the Jones matrix. The second filter is a smoothing filter that is applied to the parametric data calculated from the Jones matrix. It applies an acausal Gaussian filter to each parameter after it has been extracted from the Jones matrix.

Both of these filters can be characterized in terms of a *resolution bandwidth*. The resolution bandwidth refers to the smallest frequency (or wavelength) interval over which spectral features are discernible in the filtered data. Note that this is not the same as the spacing between data points. The resolution bandwidth changes depending on filter settings, whereas the spacing between data points remains constant.

The Time Domain Filter

The time domain filter allows the user to select a portion of the time domain for inclusion in the measurement. This is an effective way to reduce the amount of noise

in the displayed data without losing any information about the device under test. The impulse response of the device under test is typically recognizable as a peak in the time domain; as long as the complete peak remains in the selection, all of the information about the device is preserved. This section will describe how the time domain filter is used in a practical sense. For detailed information on the filter function itself, see "The time domain filter function" on page 244.

Important

☑

This filter operates directly on the Jones matrix data prior to any parameter calculations.

The time domain plot window

To adjust and apply the time domain filter, click the [Time Domain] button in the **Data Processing** area. The window shown in Figure 5-11 appears.

5

The white curve in the impulse response plot window is the sum of the discrete Fourier transforms of the four raw, measured Jones matrix elements. The purple curve is the filter function, which has a flat-top Gaussian shape. The yellow cursors act as handles to define the filter passband. By default, the X-axis range is fixed at approximately 6 ns and is labeled in nanoseconds. The Y-axis is scaled in arbitrary units. The X-axis may also be scaled in meters by clicking on the axis label and selecting **Length** from the drop-down menu.
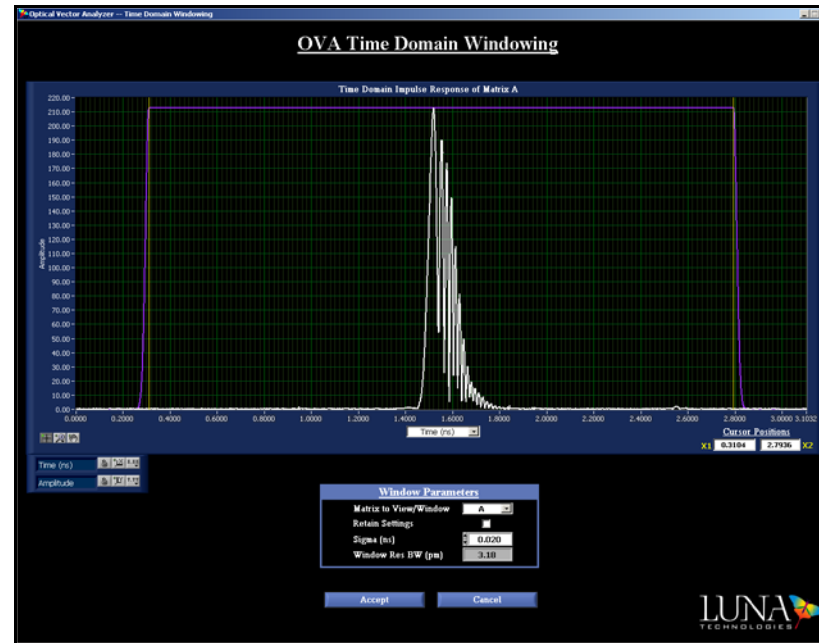
*Figure 5-11. The **Time Domain Window**, showing the impulse response (in white)
of a fiber Bragg grating in reflection (sample data file "Bragg Reflection.dat").
The time domain filter function is shown in purple, and the cursors are yellow.*

To adjust data that extends out of the Time Domain Window

The OVA is capable of making accurate measurements only if the complete impulse response of the device fits within the range of the impulse response plot window. If the impulse response extends outside of the plot range, there are two possible remedies:

1 If the impulse response extends out of the **Time Domain Window** in only one direction, it may be because the **Length of DUT** setting in the **System Control** area of the main window is off slightly. This setting is used to locate the impulse response in the time domain and determines the positioning of the selected time segment relative to the time domain.

Therefore, changing the DUT length setting slightly has the effect of shifting the data in the **Time Domain Window**. Note that light travels approximately 1.2 m through standard single mode fiber in 6 ns.

Changing the DUT length to a smaller value will shift the impulse response peak to the right in the **Time Domain Window**. A larger value will shift the peak to the left.

Important ✔	When the DUT length is changed, the measurement must be performed again by pressing the **Scan** button in order for the change to register in the **Time Domain Window**.

2 If the impulse response extends out of the **Time Domain Window** on both ends, the device may require pulse compression. For details on see "Pulse Compression" on page 53. If the impulse response extends outside the Time Domain Window after pulse compression please contact Luna Technologies customer service at 1-866-LUNAOVA (1-866-586-2682) or by e-mail at support@lunatechnologies.com for other measurement options.

5

The time domain resolution bandwidth

The resolution bandwidth, as determined by the time domain filter setting, is displayed in the field labeled **Window Res BW (pm)** or **Window Res BW (GHz)** in the **Window Parameters** area of the **Time Domain Window**. This value is updated whenever the user changes the filter setting by dragging the cursors or changes the value of **Sigma**.

Note ✔	By default, the **Filter Resolution BW**, the **TD Window Res BW**, and the **Convolved Res BW** (in the main screen) and the **Window Res BW** (in the **Time Domain Window**) are all displayed in units of picometers. To change the units to gigahertz, select **Options** > **Resolution BW Units** > **Gigahertz (GHz)**.

This resolution bandwidth value is also displayed in the field labeled **TD Window Res BW (pm** or **GHz)** in the **Data Processing** area of the main window. When the **Matrix for Res BWs Below** field reads **A**, the next two fields display the time domain and convolved resolution bandwidths for **Matrix A**.

The time domain Hanning window

To apply the Hanning window to impulse response data, make sure that **Options > Apply Time Domain Hanning Window** is checked. To turn it off, select that menu option again to "uncheck" or turn off the Hanning window. (See "Time Domain Hanning Window" on page 246 for more information.)

Applying the time domain filter

To apply the time domain filter

1 Click the [Time Domain] button in the **Data Processing** area of the main window.

The **Time Domain Window** appears. (See Figure 5-12 below.) By default it will display the impulse response of the first matrix containing data.

2 Select which of the three matrices to display using the **Matrix to View/ Window** pull-down menu. Any matrix loaded with data may be selected.

3 Click and drag the yellow vertical lines to position the filter passband around the desired portion of the time domain data.

If the mouse cursor will not "pick up" the yellow lines, click on the [+] button in the graph window.

4 If desired, change the shape of the Gaussian edges of the filter function by entering a new value in the **Sigma (ns)** data field. The purple Gaussian filter curve in the display will update to reflect any change to this value.

If the user enters a sigma value lower than the minimal setting of 0.001 ns, the software automatically resets sigma to 0.001 ns.

5 If desired, change the X-axis option from the default setting of **Time (ns)** to **Length (m)**. The units will be retained on subsequent visits to this window.

6   In order to apply this adjusted **Time Domain Window** to new data acquired or moved to this matrix, make sure the **Retain Settings** box is checked.

Important ☑	To apply a **Time Domain Window** to newly acquired data, perform steps (1) through (6) above on **Matrix A**. Click to **Accept** the changes. Then make sure that **Options > Apply Time Domain Window** is checked before scanning.

7   To adjust the time domain filter of another matrix, select another matrix from the **Matrix to View/Window** menu.

A prompt asks the user whether to save the changes to the previous matrix. If "Yes" is selected, those time domain filter changes will be used when that matrix is displayed, upon exiting the **Time Domain** window by clicking **Accept**.

8   To apply the most recent filter settings to other matrices loaded with data, click the **Sync Matrix Windows** check box. This checkbox only appears if more than one matrix contains data. (See Figure 5-15 on page 79 for an illustration.)

9   At any time, changes to the most recent matrix selected in the **Matrix to View/Window** menu may be undone by clicking **Cancel**.

10 When finished, click **Accept**.

The software returns to the main window and the data in the graph windows now reflects the new filter settings.

Example: Setting the time domain filter window

Below the filter window has been set to include only the impulse response of the fiber Bragg grating, and to exclude other portions of the time domain. All of the information about the device is contained in the peak. The other sections of the time domain only contribute noise to the measurement, so accuracy improves when the impulse response cursors are narrowed close to the peak, as shown below.

5

5
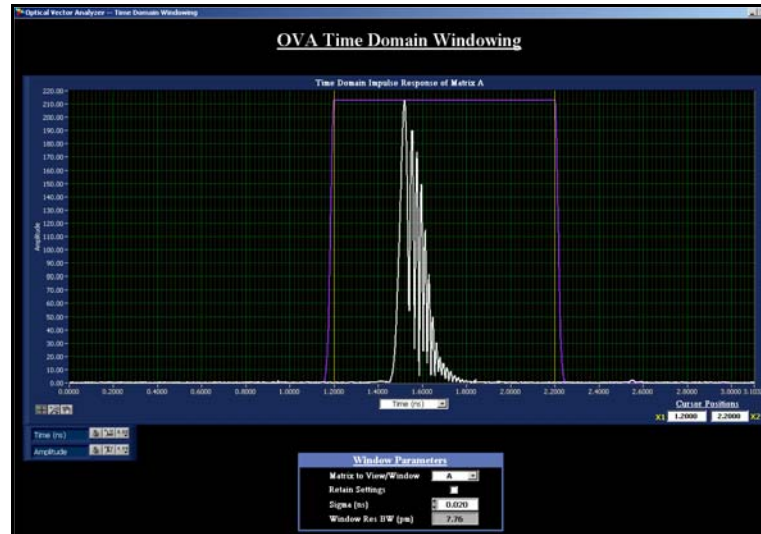
*Figure 5-12. The **Time Domain Window** of the same Bragg grating reflection shown in Figure 5-11, with the impulse response cursors (yellow) set appropriately.*

Examples: Setting the value of Sigma

To broaden the edges of the flat-top Gaussian function, set **Sigma** to a value larger than the default value of 0.02 ns. Below **Sigma** has been set to 0.20 ns.
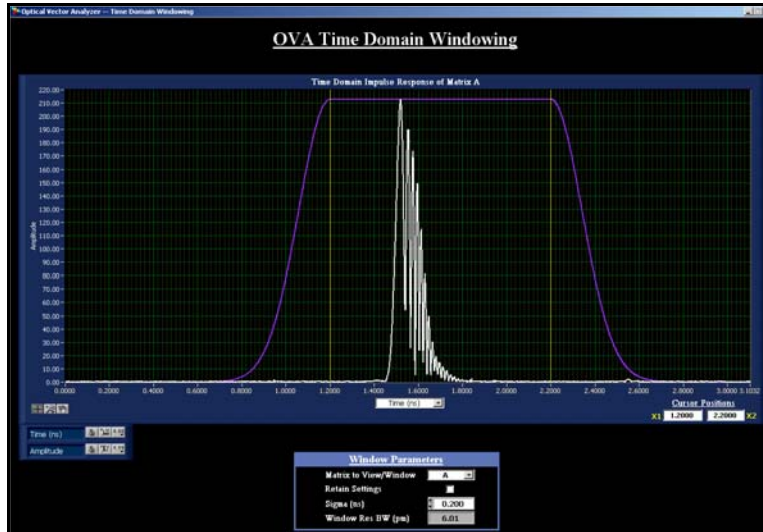
*Figure 5-13. The **Time Domain Window** of the same Bragg grating shown in
Figures 5-11 and 5-12 (sample data file "Bragg Reflection.dat"),
with sigma set to 0.20 ns.*

To tighten the filter function, set **Sigma** to a smaller value. Below Sigma has be set
to 0.01 ns.

5

5
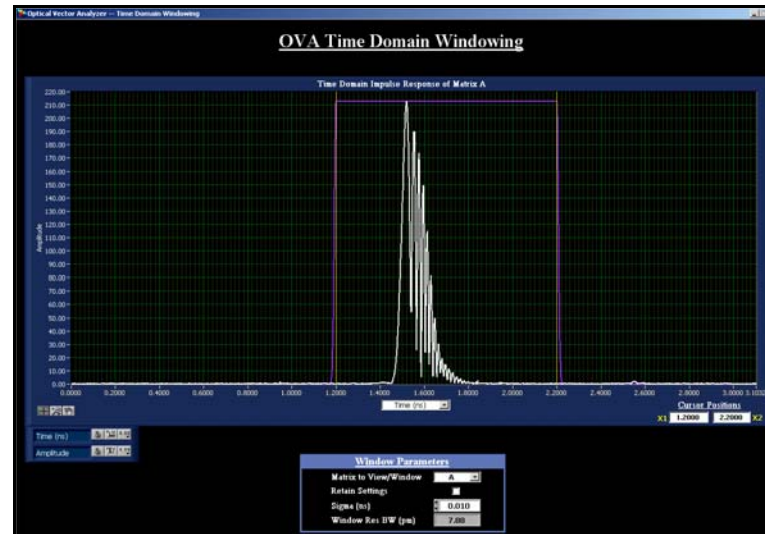
*Figure 5-14. The **Time Domain Window** of the same Bragg grating shown
in the three figures above, with sigma set to 0.01 ns.*

A larger value of **Sigma** will help reduce the "edge-effects" that appear as ripple near the edges of the scan range. A small value of sigma is useful for separating multiple device features for individual inspection.

Retaining time domain filter settings

By default, the control software will reset the time domain filter to 10% and 90% of the time domain range each time new data occupies a matrix memory location, either by performing a new measurement or loading data from a file. When conducting repeated measurements of the same device, however, it is often convenient to retain the filter setting from scan to scan. Retained TD settings also apply to data loaded into that matrix from memory.

To retain time domain filter settings

In the **Time Domain Window**, select the **Retain Settings** checkbox. This only retains the time domain filter settings for the matrix indicated just above this checkbox. To apply these settings to other matrices, see "Synchronizing time domain filter settings" below. To turn off retention of the filter settings, click the checkbox again to clear the check mark.

Synchronizing time domain filter settings

In addition to retaining the time domain filter settings, the user may apply TD filter settings to all the matrices with data loaded in them. This option is only available when more than one matrix contains data.

To synchronize time domain filter settings

1 Scan or load data into the matrices to be filtered.

2 Adjust the time domain filter settings as described under "Applying the time domain filter" on page 74.

3 In the **Time Domain Window**, click on the **Sync Matrix Windows** check box, as shown below.
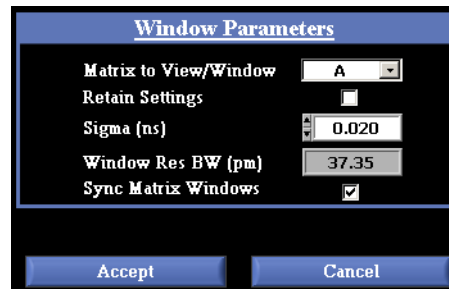
5

*Figure 5-15. The **Window Parameters** area of the **Time Domain Window**, as it appears when more than one matrix contains data.*

4 Click **Accept**.

The software returns to the main window. The data in all matrices containing data now reflect the new TD filter settings.

The Smoothing Filter

The smoothing filter imposes simple curve smoothing of the parametric data using an acausal Gaussian filter. This is equivalent to the use of a sliding Gaussian averaging window. This smoothing method was chosen because it introduces no minima, maxima, or wavelength shift to the data. It operates on insertion loss, group delay, chromatic dispersion, polarization dependent loss, and polarization mode dispersion (PMD) and second order PMD data. It is not applied to the linear phase

deviation, quadratic phase deviation, Jones matrix element amplitudes or phases, either of the time domain plots, or to phase ripple data. For more detailed information about the smoothing filter, see "Smoothing filter operation" on page 247.

The smoothing filter is applied by selecting a resolution bandwidth. This resolution bandwidth becomes the effective wavelength resolution of the frequency domain data. The smoothing filter does not reduce the number of data points, but noise and other features that occur on a wavelength scale smaller than the resolution bandwidth setting will be removed from the displayed data.

Applying the smoothing filter

The smoothing filter can be applied automatically whenever the **Filter Resolution BW (pm** or **Ghz)** setting is changed, or it can be applied manually. To toggle between these two modes, select **Options > Always Apply Filter**. A check mark next to this menu selection indicates that the filter will be applied automatically. By default this option is selected, and the **Filter Resolution BW (pm)** is set to 10 pm. To display data without a smoothing filter, set the **Filter Resolution BW** to 0 pm.

To apply the smoothing filter

1 Enter a value in the **Filter Resolution BW (pm** or **Ghz)** field of the **Data Processing** area of the main screen.

If the **Filter Resolution BW** is set too small, the software automatically resets it to zero and displays unfiltered data.

2 If the **Always Apply Filter** option is selected, press Enter or click anywhere on the screen to accept the value and apply the filter.

-OR-

If the **Always Apply Filter** option is not selected, click the **Apply Filter** button in the **Data Processing** area of the main screen.

Example

Figures 5-16 and 5-17 illustrate the application of the smoothing filter to group delay data from the sample data file "Bragg Reflection.dat". Note the reduction in noise between the two plots.
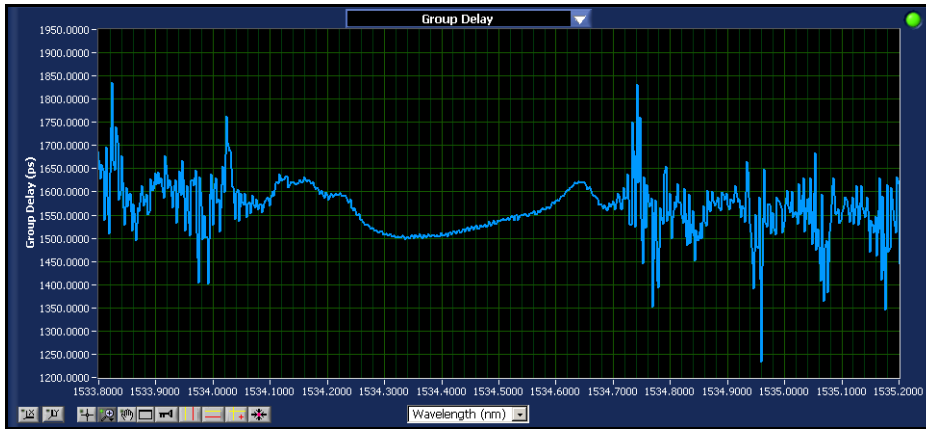
Figure 5-16. Group delay data for a Bragg grating reflection
(sample data file "Bragg Reflection.dat") before filtering.

5
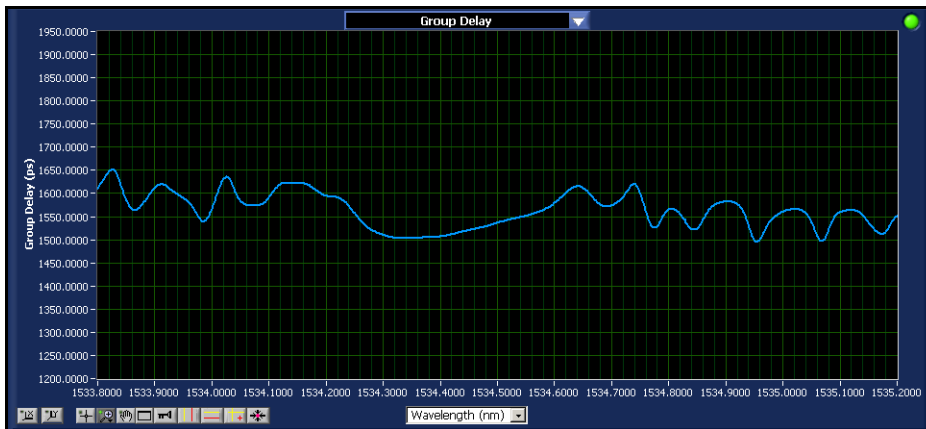
Figure 5-17. Group delay data for the same grating after applying
the smoothing filter with a 50 pm resolution bandwidth.

The Convolved Resolution Bandwidth

Because two independent filters can be applied to the data, the overall frequency (or wavelength) resolution depends on both of the filter settings. This value is displayed in the **Convolved Res BW (pm** or **GHz)** field in the **Data Processing** area of the main window. The setting of **Matrix for Res BWs Below** determines which of the active memory matrix locations is used for this display.

The convolved resolution bandwidth is equal to the square root of the sum of the squares of time domain resolution bandwidth and the smoothing filter resolution bandwidth.

Printing

Printing Two Graphs

The user may print both graphs currently displayed by selecting **File > Print Data Sheet**. The control software prints to any printer defined as the default Microsoft® Windows® printer. The graphs will print with the current filter and axis settings. The legends and cursors will not appear in the printout. Information entered under **File > Specify Device Descriptor** will print in the upper right section of the printout, as shown in Figure 5-18.
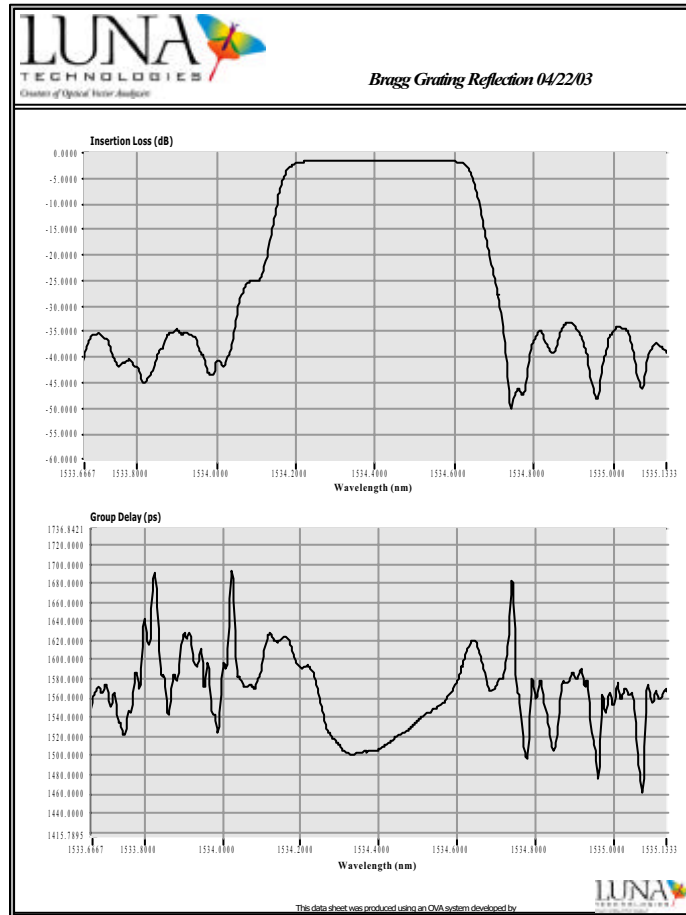
5

Figure 5-18. The data sheet of a Bragg grating in reflection,
*as printed by selecting **File > Print Data Sheet**.*

Printing One Graph

The user may also print one graph at a time. First enter the full screen view, as described under "Full Screen View" on page 68. Click the **Print** button in the lower center. As with printing two graphs, the legends and cursors will not appear. When printing from full screen view, no device descriptor will appear in the printout. The printed graph will fill the page, as shown below, according to the margins set under the Microsoft® Windows® printer controls.

5
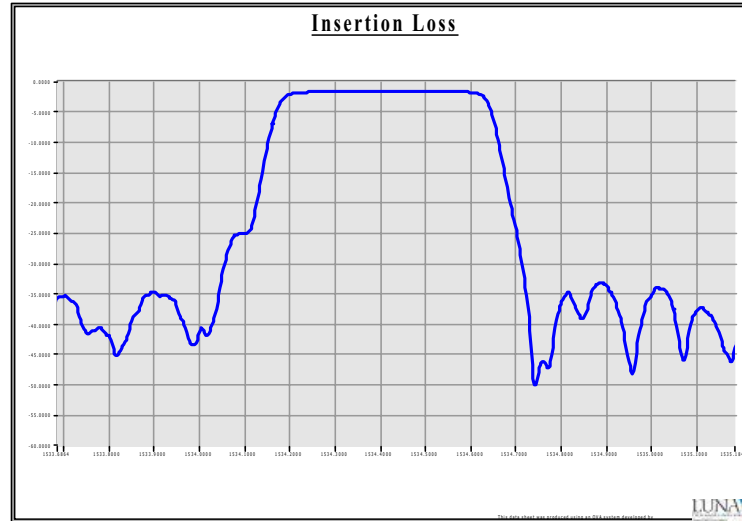
Figure 5-19. The printout of the insertion loss of Bragg grating reflection
data, as printed from the full screen view.

Chapter 6

Polarization Analysis Software

Overview

Luna Technology's Polarization Analysis Software (PAS) displays the response of an optical component to a simulated input polarization. Purchased as an option with Luna's Optical Vector Analyzer, this software eliminates the tedious and difficult task of polarization alignment often required to test modern fiber-optic and guided-wave components.

In the lower graph, the software plots the insertion loss (IL), group delay (GD) and impulse response of an optical component at a user-defined input polarization state. Easy-to-use sliders allow the user to adjust the simulated input polarization to any desired state. Also plotted are the minimum and maximum insertion loss, group delay, chromatic dispersion, and the angle of the principle states of polarization (PSP).

In the upper graph, the software displays all the parameters available in the OVA software: the polarization averaged quantities (IL, GD, chromatic dispersion, etc.) as well as polarization mode dispersion (PMD), polarization dependent loss (PDL), Jones matrix elements, time domain information, second order PMD, and phase ripple. All of the generated data can be saved for export to other plotting and analysis software.

6

Measurement Theory

Luna Technologies' OVA instrument measures the Jones matrix $\mathbf{J}$ of an optical component which may be expressed as

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

The quantities a, b, c, and d are the four scalar transform functions, and ω represents optical frequency.

The electric field input to the component can be described by the complex Jones vector,

$$\grave{E}_{in}(\omega) = \begin{bmatrix} E_x e^{i\phi_x} \\ E_y e^{\phi_y} \end{bmatrix}(\omega) = \begin{bmatrix} \cos\theta e^{i\phi} \\ \sin\theta e^{-i\phi} \end{bmatrix}(\omega).$$

The optical frequency, ω, factor reminds us that all of these quantities are frequency dependant. E_x and E_y are the amplitudes of the field, and $i\phi_x$ and $i\phi_y$ are the phase components of the field.

PAS allows the user to change the rotation angles, phi (ϕ) and theta (θ). This effectively gives the user control over the input polarization state and allows for graphical visualization of how the changes effect the output field. This simulated output field $\grave{E}_{out}$ is calculated by multiplying the Jones matrix of the component by the simulated input electric field:

$$\grave{E}_{out}(\omega) = \mathbf{J}(\omega)\grave{E}_{in}(\omega).$$

Thus the position of the blue line of the lower graph in the PAS software is determined by user-selected values of ϕ and θ.

Descriptions of each parameter available follow under "Parameter Selection" on page 90.

Startup

From the Windows® Start menu, select **Programs > Luna Technologies > Polarization Analysis**, or double-click the **Polarization Analysis** desktop icon. The main window appears, as shown below, although no data will be loaded.
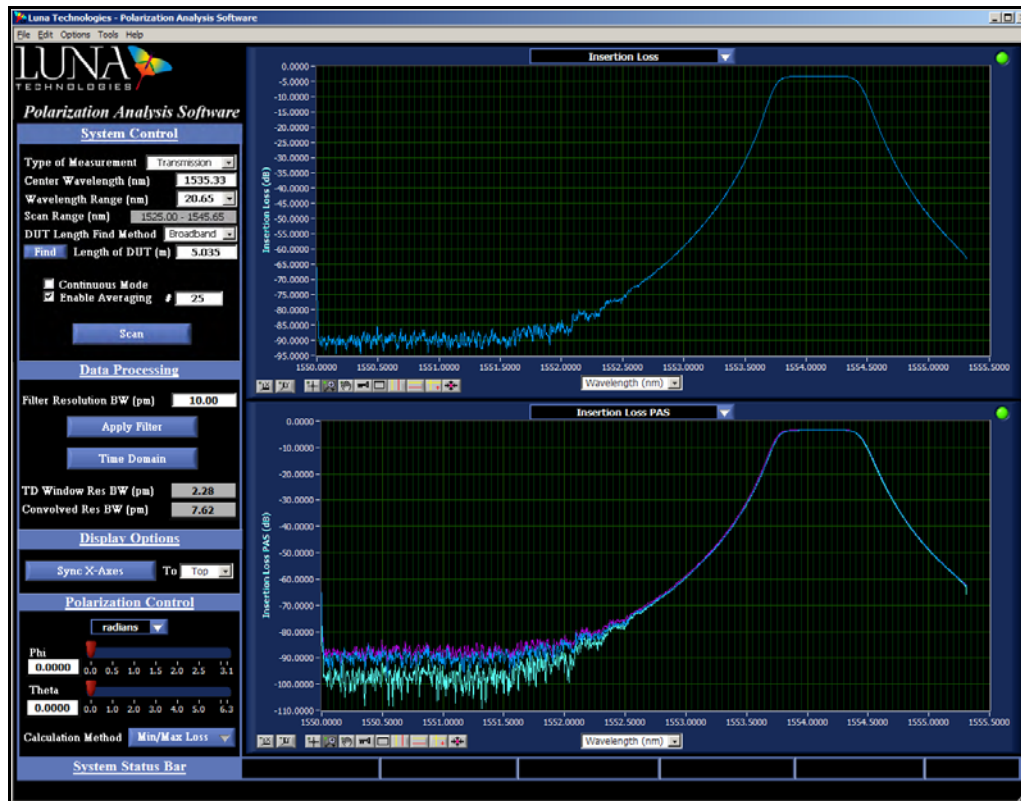
Figure 6-1. Polarization Analysis software main window, with data loaded.

6

The Menu Bar

The PAS menus are exactly the same as the OVA menus, with one addition to the **File** menu for saving PAS data (described below). All other menu items have already been discussed under "The Menu Bar" on page 29.

Saving PAS Data

To save PAS data, the user must select **File > Save Polarization Analysis Files**. This calls up the dialog box shown below, where the user selects which parameters to save.
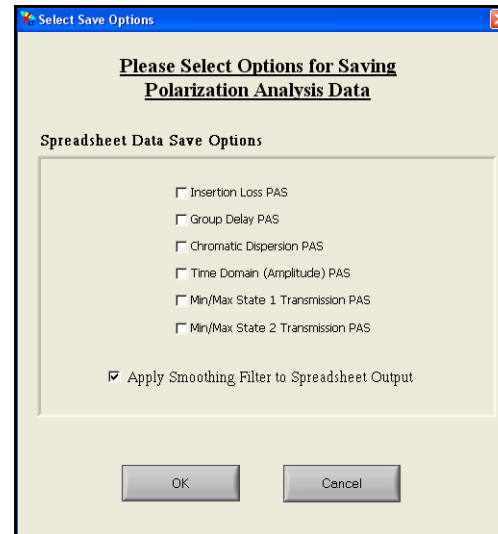
Figure 6-2. ***File > Save Polarization Analysis Files*** *calls up this dialog box.*
Clicking ***OK*** *saves the selected parameters in a text file.*

Clicking **OK** prompts the user to name and select a location for the text file.

The text file header contains information on the measurement and settings; a sample is given below.

Acquired on 10/6/2008 at 16:28:52

Device Descriptor: NONE

Number of Scan Averages: 1

Time Domain Window Resolution Bandwidth (pm): 1.543541

Filter Resolution Bandwidth (pm): 9.859719

Convolved Resolution Bandwidth (pm): 9.979809

Calculation Method: PSP

Phi (radians): 0.000000

Theta (radians): 0.000000

The remaining data in a PAS text file contains three columns for each parameter selected, in the order shown in Table 6-1. If some parameters are not selected, all data columns will shift left accordingly. The first column given for each parameter

gives the "user-set values," meaning the Y-axis values of the blue curve, as determined by the user-set values of ϕ and θ.

Table 6-1: PAS Text File Output

	Value (units)	Column	Value (units)
1 or A	X-axis Wavelength (nm)	10 or J	CD State 1 (Min or Max) (ps/nm)
2 or B	X-axis Frequency (GHz)	11 or K	CD State 2 (Min or Max) (ps/nm)
3 or C	Insertion loss (dB)	12 or L	Time Domain (Amplitude) (electric field, a.u.)
4 or D	IL State 1 (Min or Max) (dB)	13 or M	TD State 1 (Min or Max) (electric field, a.u.)
5 or E	IL State 2 (Min or Max) (dB)	14 or N	TD State 2 (Min or Max) (electric field, a.u.)
6 or F	Group delay (ps)	15 or O	State 1 Phi (Min or Max) (rad)
7 or G	GD State 1 (Min or Max) (ps)	16 or P	State 1 Theta (Min or Max) (rad)
8 or H	GD State 2 (Min or Max) (ps)	17 or Q	State 2 Phi (Min or Max) (rad)
9 or I	Chromatic Dispersion (ps/nm)	18 or R	State 2 Theta (Min or Max) (rad)

6

Manipulating Plots

Most of the buttons and commands used to control the OVA are also available in PAS. Consult earlier chapters for these controls. The upper graph of the PAS software displays all of the parameters available with the OVA. The lower graph displays PAS parameters. Only those controls and parameters unique to PAS are described below.

Parameter Selection

The lower graph displays polarization analysis parameters. Click and drag on the title bar to display the parameters listed below.
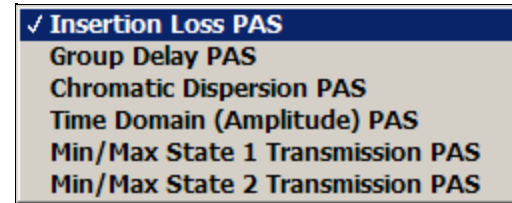
Figure 6-3. The PAS lower parameter menu.

Lower graph parameters

Insertion Loss PAS

The insertion loss PAS graph displays the polarization dependent State 1 (purple) and State 2 (aqua) and user-defined (blue) transmission as a function of wavelength. States 1 and 2 represent either the minimum or the maximum— depending on the component tested. The difference between the minimum and maximum transmission states constitutes the polarization dependent loss (PDL) of the device under test (DUT).

The minimum and maximum states are derived from the eigenvalues of the matrix $\mathbf{J}_i^{\dagger}\mathbf{J}_i$, where $\dagger$ denotes the conjugate transpose. At a given wavelength, the greater eigenvalue represents the maximum transmission and the smaller eigenvalue represents the minimum transmission.[1]

Group Delay PAS

The minimum and maximum group delay are calculated by finding the eigenvalues of the product $\mathbf{J}_{i+1}\mathbf{J}_i^{-1}$, where the indices denote frequency. The phases of the two eigenvalues represent the minimum and maximum transmission time through the DUT.[2]

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[1] For more information on this calculation, see B.L. Heffner, "Deterministic, Analytically Complete Measurement of Polarization-Dependent Transmission Through Optical Devices," IEEE Photonics Tech. Lett., vol. 4, pp. 451-454, 1992.

Chromatic Dispersion PAS

The values displayed for minimum and maximum chromatic dispersion are calculated using the numerical derivative of the group delay values.

Time Domain (Amplitude) PAS

The time domain values are calculated by finding the amplitude of the Fourier transform of the product $\mathbf{J}_i{}^\dagger \mathbf{J}_i$.

Min/Max State 1 Transmission PAS

State 1 of theta and phi will represent either the minimum or the maximum— depending on the component tested.

Min/Max State 2 Transmission PAS

State 2 of theta and phi will represent either the minimum or the maximum— the opposite of State 1.

Upper graph parameters

6

The parameters displayed in the upper graph area of the PAS are those measured by the OVA. Below is a list of the parameters, with references to descriptions of those parameters.

- Insertion Loss (For a complete definition, see "Insertion loss" on page 217).
- Group Delay (See page 218).
- Chromatic Dispersion (See page 219).
- Polarization Dependent Loss (See page 220).
- Polarization Mode Dispersion (See page 220).
- Linear Phase Deviation (See page 223).
- Quadratic Phase Deviation (See page 224).
- Jones Matrix Element Amplitudes (See page 225).
- Jones Matrix Element Phases (See page 225).

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[2] For more information on this calculation see B. L. Heffner, "Automated Measurement of Polarization Mode Dispersion Using Jones Matrix Eigenanalysis," IEEE Photonics Tech. Lett., vol. 4, pp 1066-1069, 1992.

- Time Domain (Amplitude), (See page 225).
- Time Domain (Wavelength), (See page 226).
- Min/Max Loss (See page 227).
- Second Order PMD, (See page 221).
- Phase Ripple Linear (See page 228).
- Phase Ripple Quadratic (See page 229).

Adjusting Phi and Theta

To simulate a change in the input polarization state, the user may adjust phi and theta. Click and drag one of the red bars in the **Polarization Control** area, shown below in Figure 6-4. The lower blue graph adjusts automatically to changes in phi and theta. The exact values of phi and theta are displayed in the white box to the left of the phi and theta control bars. The user may also click in these white boxes and use the keyboard to enter the values of phi and theta.

6
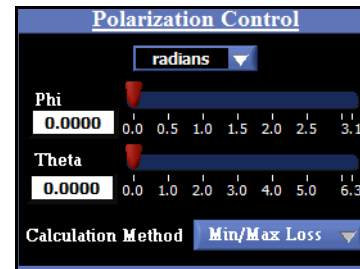
Figure 6-4. The Polarization Control area of the main screen.

Above these bars is a pull-down menu for selecting the units of phi and theta: either **radians** or **degrees**. The lower control allows the user to select the method of calculating minimums and maximums (See "Calculation Method" below).

Calculation Method

The software offers two methods of calculating minimums and maximums: **Min/Max Loss** or **PSPs**. The user may select either method from the pull-down menu in the **Calculation Method** area of the main window.

Min/Max Loss

The minimum and maximum states are derived from the eigenvalues of the matrix $\mathbf{J}_i{}^\dagger\mathbf{J}_i$ where $\dagger$ denotes the conjugate transpose. At a given wavelength, the greater eigenvalue represents the maximum transmission and the smaller eigenvalue represents the minimum transmission.[3]

PSPs

The minimums and maximums may also be calculated using the principal states of polarization (PSPs). The PSPs are defined as the eigenvectors of the product

$\mathbf{J}_{i+1}\mathbf{J}_i{}^{-1}$. The two resulting eigenvectors, or PSPs, are then propagated through the Jones matrix. The two PSPs represent the fast and slow propagation axes through a birefringent device or system.[4]

6

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[3] For more information on this calculation, see B.L. Heffner, "Deterministic, Analytically Complete Measurement of Polarization-Dependent Transmission Through Optical Devices," IEEE Photonics Tech. Lett., vol. 4, pp. 451-454, 1992.

[4] For more information on this calculation see B. L. Heffner, "Automated Measurement of Polarization Mode Dispersion Using Jones Matrix Eigenanalysis," IEEE Photonics Tech. Lett., vol. 4, pp 1066-1069, 1992.

6

Chapter 7

Optical Frequency Domain Reflectometer

As mentioned in the Overview chapter, Luna Technologies' OVA may also be operated as an Optical Frequency Domain Reflectometer (OFDR), if the user purchases this option. By reconfiguring the hardware and data processing algorithms, the OVA can be utilized to measure the full scalar response of an optical system, including both phase and amplitude information in terms of the system transfer function. This allows the data to be presented in two ways:

- The time domain: The amplitude of the time domain data is equivalent to a traditional optical time domain reflectometry (OTDR) measurement.

- The frequency domain: The amplitude of the frequency domain data provides a measure of the insertion loss or return loss of the device. The phase information in the frequency domain can be used to calculate group delay and chromatic dispersion.

7

OFDR Software Overview

To run the OVA as an OFDR, the user launches separately-purchased OFDR software. This section will focus on where the OFDR differs from the OVA software.

The main screen displays time domain data in the upper graph, and frequency domain data in the lower graph. Both amplitude and phase information can be displayed in either domain.
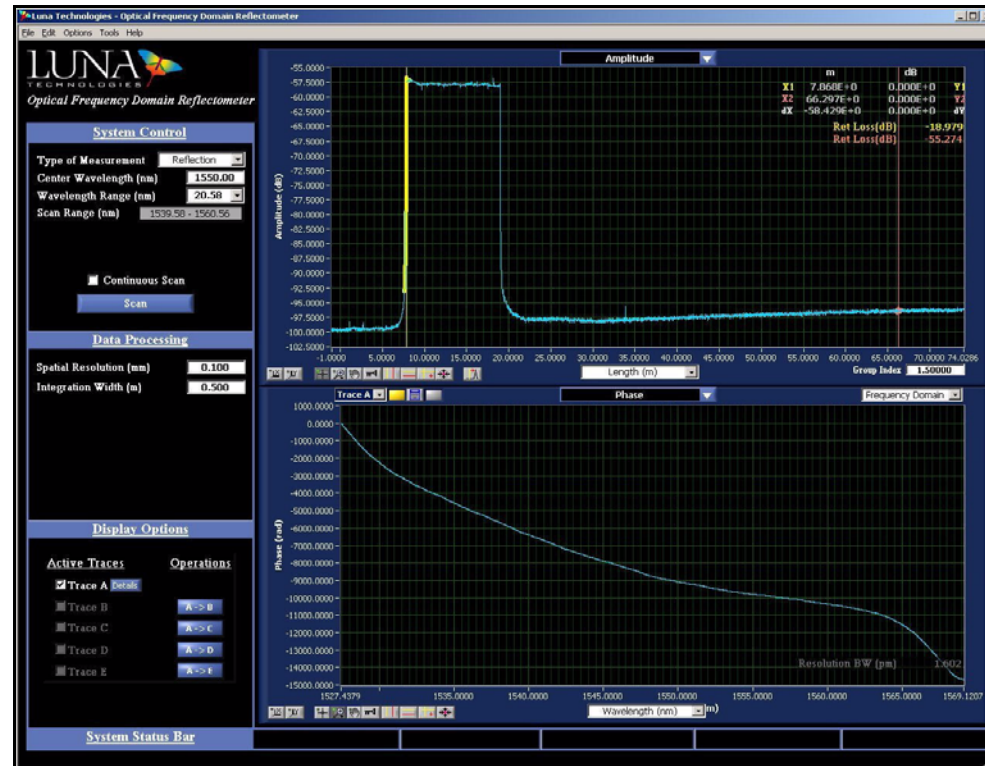
Figure 7-1. OFDR control software main window.

The following parameters are calculated and displayed by the OFDR control software:

Time Domain Data

- (For a complete definition, see "Time Domain Amplitude" on page 131).
- Phase Derivative (See page 132).
- Linear Amplitude (See page 132).

Frequency Domain Data

- Insertion Loss (See page 129).
- Group Delay (See page 129).

    •   Phase (See page 130).

Time Domain

By default, the upper graph displays the amplitude of the time domain data, which is equivalent to a traditional optical time domain reflectometry (OTDR) measurement. In the time domain, each optical path (each optical interface in reflection mode) within the device under test produces a peak. The time domain data can also be displayed in terms of length. This allows the user to quickly and reliably identify and locate reflections along the length of an optical system. (For a graphical display of this concept, see "Measurement Example" on page 133.) The phase derivative of the time domain data can also be displayed in the upper plot window. The phase derivative corresponds to the instantaneous wavelength response of a device. This is particularly useful for devices designed to operate over narrow wavelength bands like DWDM (dense wavelength division multiplexed) filters.

Frequency Domain

The lower plot can display the amplitude and phase derivative of the frequency domain data. The amplitude of the frequency domain data corresponds to the insertion loss or return loss of the device under test. The phase derivative plot in the frequency domain can be used to calculate group delay and chromatic dispersion.

7

The frequency domain plot is calculated based on only the time domain data contained in the plot window above. Therefore it is possible to analyze individual sections of a device or system and determine the insertion loss, group delay, and phase response of each interface separately, by zooming in on their corresponding peaks in the time domain plot. This provides a powerful means for quickly and easily identifying faults and pinpointing their cause within a component, module, or subsystem.

The Average Loss field in the main window shows the single average loss value for quick pass/fail evaluation for each optical path or interface.

Frequency Domain Resolution

The duration of the impulse in the time domain determines the necessary step size for the group delay measurement. If the step is too large, information about the device is lost. If the step is too small, extraneous noise enters the measurement. The Luna OFDR software allows the user to select precisely the correct step size by setting the time domain window so that it includes only the device response. It is also possible to obtain group delay data for a variety of step sizes by changing the setting

of the time domain window and recalculating the frequency domain data. There is no need to perform a new measurement. This contrasts traditional methods of group delay measurement, such as the modulation phase shift technique, where the user must guess at the appropriate step size and perform a new measurement to change that step size.

OFDR Main Window

The main control window of the OFDR is very similar to the OVA software. (Compare the OFDR, Figure 7-1 on page 96, with the OVA, Figure 1-1 on page 3.)

1   The **Display Options** area allows the user to control which traces are being displayed, to move data within local memory, and to view the **Details** of each measurement loaded into memory.

2   The **System Status Bar** at the bottom of the screen displays system messages such as error, laser status, and calibration status information.

3   The two **Graph** areas contain plots of test data. The upper graph displays time domain data, and the lower displays either time domain or frequency domain data. The pull-down menu at the top of each graph allows the user to select which parameter is displayed. Buttons to the lower left on each graph adjust plot axes, cursors, legend, and zoom. The lower center pull-down menu controls X-axis units. By selecting **Options > Lower Graph > Two Plots**, the lower graph can display two parameters simultaneously.

4   The **Menu Bar** contains additional commands for loading and saving data files, printing, controlling calibration and alignment, and for setting various measurement and display options.

System Control

The **System Control** area of the OFDR main window contains fields and menus that control the instrument and set test parameters.

7
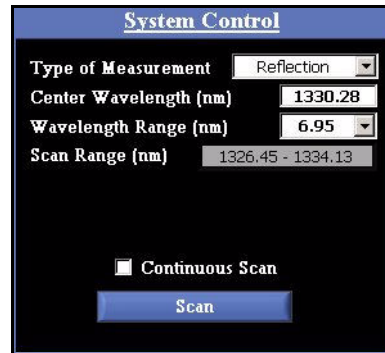
Figure 7-2. The System Control area in the main OFDR software window.

- The **Type of Measurement** pull down menu allows the user to choose the type of measurement: reflection or transmission.

- The **Center Wavelength (nm)** field allows the user to set the center wavelength of a scan. To set this parameter, type in a number within the wavelength range of the instrument.

- The **Wavelength Range (nm)** field allows the user to set the range of the scan. The wavelength range determines the number of nanometers that will be analyzed during the next measurement. A drop-down list contains the range options available for the OFDR model in use.

- The **Scan Range (nm)** field shows the starting and ending wavelengths that will be scanned, as determined by the center wavelength and range wavelength entered by the user in the two fields above.

- **Continuous Scan**, when checked, causes the OFDR to take repeated measurements. The graph displays are continuously updated after each measurement. This mode is started and stopped by clicking the **Scan** button.

- Clicking the **Scan** button starts the measurement of the device under test. This same button is used to stop scanning when operating in **Continuous Mode**.

- Note that the OFDR does not require a **DUT Length** to be entered (as in the **System Control** area of the OVA software.)

7

Data Processing

The **Data Processing** area allows the user to enter **Spatial Resolution** and **Integration Width** settings. For more information, see "Spatial Resolution Calculations" on page 128 and "Integration Width" on page 128.
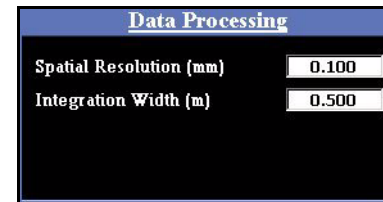
Figure 7-3. The Data Processing area in the main OFDR software window.

Display Options

The **Display Options** area allows the user to store data from the most recent scan to one of five **Traces**. (Note that data locations are called **Matrices** in the OVA, referring to the Jones matrix analysis performed on OVA data.)

The data loaded in a given trace may be graphed by clicking in the adjacent checkbox. It may be moved from **Trace A** to another trace by clicking a button in the **Operations** column.

7
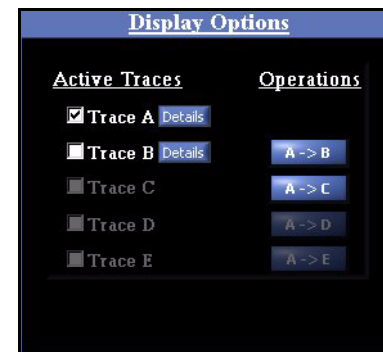
Figure 7-4. The Display Options area in the main OFDR software window.

Graphs

Each **Graph** area contains controls for selecting the content of the graph and for manipulating how the graph is displayed. The upper graph area displays time domain data, and the lower graph displays either time domain or frequency domain data. After **Options > Lower Graph > Two Plots** is selected, the lower graph can display two parameters simultaneously. The left axis displays units for the parameter selected in the left-hand pull-down menu, and the right axis the right parameter.
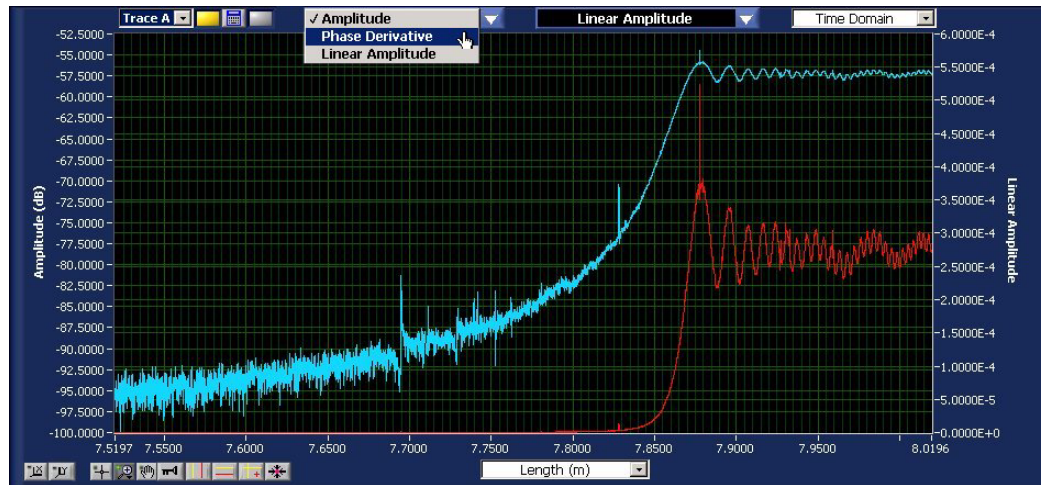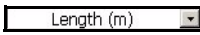
*Figure 7-5. The lower graph area in the main OFDR software window, when **Options > Lower Graph > Two Plots** is checked. Note the pull-down menu on the far upper right, allowing the user to select **Time Domain** or **Frequency Domain** data.*

- The **Title Bar** at the top of each graph contains a pull-down menu allowing the user to select which parameter is graphed. These parameters are defined under "Parameter Calculations" on page 111.

*Figure 7-6. The Title Bars, or parameter selection pull-down menus, before and during selection. The left, **Time Domain** menu is available in the upper and lower graphs. The right, **Frequency Domain** menu is only available in the lower graph.*

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- The pull-down menu [Length (m) ▾] at the bottom of a time domain graph allows the user to select the value and units of the X-axis: **Time (ns)**, **Length (m)** or **Length (ft)**. In the lower frequency domain graphs, the available X-axis units are **Wavelength (nm)**, **Frequency (GHz)**, and **Frequency (THz)**. Note that the Y-axis units are determined by the parameter displayed.

- **Buttons** to the lower left of each graph let the user adjust plot axes, cursors, and zoom, and show or hide a legend. Table 3-1 beginning on page 25 describes the function of each button and gives a page number for further explanation.

The Menu Bar

The menu bar contains additional commands for controlling calibration, alignment, and for setting various measurement and display options. Menu bar commands are organized into five menus.

The File menu

- **Load Data File** loads a binary data file (of the type ".ofdr") previously saved by the OFDR. A dialog box appears allowing the user to select the file.

- **Save Data Files** saves measurement data according to the selections in the **File > Select Save Options** dialog box. (See "To save data" on page 59 for more information.)

- **Select File Options** calls up a dialog box allowing the user to select the file type(s) for data saved. The user may select the file extensions for spreadsheets (.txt) and binary files (.ofdr). Only binary files may be reloaded into the OFDR software. (See "File Names and Types" on page 117 for more information.)

- **Save Software Options** saves user-selected settings from the **Options** menu; these settings are retained the next time the software is run.

- **Print Datasheet** prints the two graphs as they are displayed to the default printer. (For more information, see "Printing" on page 82.)

- **Exit** exits the OFDR control software.

The Edit menu

The edit menus in the OFDR and OVA software are identical. See "The Edit menu" on page 29.

The Options menu

- **Resolution BW Units** allows the user to select either picometers (pm) or gigahertz (GHz) as the resolution bandwidth units. The default setting is picometers. The resolution bandwidth is displayed in the *lower right* of the *lower graph area*, but only when the *upper* vertical cursors are on and when the *lower graph* displays frequency domain data. Data resolution is further discussed under "Calculating the time domain resolution bandwidth" on page 245.

- **Data Decimation (Upper Graph)** allows the user to turn data decimation on (checked) or off (unchecked). It also allows the user to select the level of decimation, as explained under "Data Decimation" on page 124.

- **Display Options** controls several display features:

  > **Auto-Update Lower Graph**, when checked, automatically recalculates the lower graph whenever new data is loaded or scanned, provided the upper vertical cursors are on.

  > **Apply Spatial Resolution Filter** turns on (checked) and off (unchecked) the time domain filter. (See "Spatial Resolution Calculations" on page 128.)

  > **Autoscale Y Axes (Both Graphs)** allows the user to turn on (default setting) and off autoscaling for the Y-axes in both graphs. When this option is selected, the plot axes automatically scale to include the entire data set on the Y-axes when a new measurement is performed.

  > **Autoscale X Axis (Upper Graph)** or **(Lower Graph)** allows the user to turn on and off autoscaling for the X-axis in the upper or lower graph.

- **Cursors** > **Show Integration Area**, when checked (default setting), highlights the data points used to calculate the data for the lower graph. When the integration area is shown, return loss (see p. 110) is displayed in the upper right corner of the upper graph.

- **Lower Graph** allows the user to see one or two plots in the lower graph area. (See Figure 7-5 on page 101.)

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- **Color Palette** calls up a dialog box allowing the user to specify the colors for each graph. These changes may be saved for future times the software is used (by clicking **Save**), or only be applied to the current use of the software (by clicking **Apply**). Clicking **Reload Defaults** allows the user to go back to the original software settings.
- **Remote Interface Setup** calls up a dialog box to set up remote configuration. For more information, see Chapter 6, "Controlling the OFDR Remotely," on page 53.

The Tools menu

- **Turn Laser OFF** or **ON** allows the user to turn the laser on or off from the OFDR control software.
- **Calibrate** calls up a dialog box which allows the user to specify the calibration settings and begin a calibration. (See "Calibrating the System" on page 106 for complete calibration instructions.)
- **Align Optics** performs an alignment of the internal optics of the OFDR, just as described for the OVA under "Aligning the OVA Optics" on page 33.
- **Calibration Information** calls up a screen with information on the laser calibration currently in use.
- **Specify Calibration Filenames** allows the user to use the default calibration filenames (OFDRCal_refl, OFDRCal_trans), or to uncheck this box and type in or select a new calibration filename. For further details, see "Calibration Files" on page 106.
- **Reload Calibration Data** reloads the most recent valid calibration data. This may be used when a calibration fails or is cancelled by the user.

The Help menu

- **About OFDR** displays information about the current software version and contact information for Luna Technologies.

Startup

1 Begin with the full assembled OVA instrument (see "Assembling the OVA" on page 11), stabilized at room temperature, between 10–35 ºC.

2 If your system did not come with the OFDR software preinstalled, contact Luna Innovations Incorporated for installation files and instructions. Make sure there is no other software running, including the OVA software.

3 Start the software from the desktop icon [icon] or select **OFDR Software** from the **Luna Technologies** program group in the Windows® Start menu. An initial window will appear for a few moments while the user interface is initialized.

Important	If the control software is started when the instrument is not powered on, a communication failure error message opens. However, the software can be used in desktop analysis mode when the instrument is not powered by clicking **OK** in the message box.
[checkmark]	To operate in normal mode, turn on the instrument. The software automatically detects the instrument and displays a message. The system can then be used normally.

- Ensure that the instrument is aligned and calibrated. (See "Aligning the OFDR Optics" below, and "Calibrating the System" on page 106.)

Aligning the OFDR Optics

In order to perform accurate measurements, the internal optics of the OFDR must be properly aligned. The three conditions that require an alignment to be performed are listed below.

Alignment must be performed. . .

1 When the instrument is initially set up for the first time.

2 Whenever the OFDR is physically moved from one location to another.

3 Whenever the **Out of Alignment** indicator in the **System Status Bar** is visible.

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To align the OFDR optics

1 Ensure that the OFDR unit is powered on and that the laser is on and ready.

2 Select **Tools > Align Optics**.

Alignment begins. A status bar shows the progress of the alignment. When the alignment is complete, the software returns to the main window.

3 The user must next perform a calibration, as described below.

Calibrating the System

The OFDR system must be calibrated prior to performing measurements. The OFDR calibration removes the effects of the measurement network to ensure that the measured data represent only the device under test.

Calibration Files

Transmission and reflection measurements each require an independent calibration. The most recent calibrations for each measurement type are stored in files, which are loaded by the control software upon start-up. If the software is unable to locate at least one calibration file, a dialog box will appear to alert the user that a calibration must be performed before a measurement can take place. In this event, the **Scan** button will be unavailable until a calibration has been performed.

Calibration files are saved to the same directory as the OFDR.exe file. The default directory for OFDR.exe is "*C:\Program Files\Luna Technologies\OFDR*"

Conditions that Require Calibration

In a typical laboratory or manufacturing environment, calibration should be performed at least once every 24 hours. The need to recalibrate is largely determined by the surrounding environmental conditions. If the temperature is fluctuating rapidly, it may be necessary to calibrate more than every 24 hours. If the surrounding temperature is very stable, a longer interval may suffice.

Calibration must be performed whenever the surrounding temperature has changed by more than ± 5 degrees C. A calibration may also be desirable when the front panel connectors have been reconnected since the last calibration, in order to calibrate out connector effects when splicing devices into the measurement path.

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In certain cases the control software will detect that the internal optics of the instrument have drifted, and it will alert the user via the **System Status Bar** indicator
Out of Calibration . When this occurs performing a calibration will typically suffice.

Consideration Prior to Calibrating

The maximum spatial resolution that can be achieved with the OFDR is related to the wavelength range of the measurement according to

$$\Delta z = \frac{\lambda_1 \lambda_2}{n_{eff} \Delta \lambda},$$

where Δz is the spatial resolution, n_{eff} is the effective index of refraction of the device under test, λ_1 and λ_2 are the start and end wavelengths of the scan, and $\Delta \lambda = |\lambda_{1()} - \lambda_2|$. Thus, calibration over larger wavelength ranges will allow for the highest spatial resolution measurements.

The Calibration Procedure

To calibrate the system

1 Ensure that the OFDR unit is powered on and that the laser is on and ready. The **Laser Ready** light on the front of the instrument comes on when the laser reaches operating temperature.

2 Select **Tools > Calibrate**.

The following dialog box appears:

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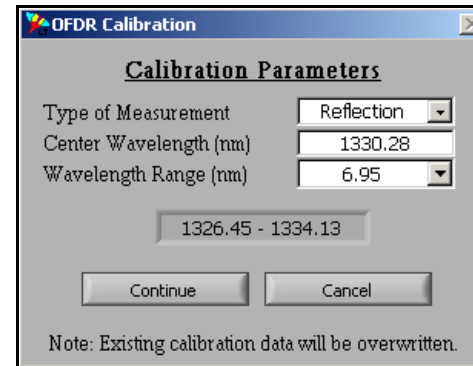
Figure 7-7. Calibration parameters dialog box.

3 Select **Transmission** or **Reflection** from the **Type of Measurement** pull-down menu.

4 Type in the **Center Wavelength** appropriate for the device(s) to be tested following calibration.

5 Select the desired **Wavelength Range** from the pull-down menu.

Note that in order to perform measurements over a broader wavelength range than the one selected during calibration, it is necessary to recalibrate.

6 Click **Continue**.

The instrument performs several internal scans. Next a prompt appears instructing the user to connect the supplied reference fiber to the instrument. *First follow step seven.*

7 Before making connections, be sure to clean all fiber optic connectors. (See "Cleaning Connectors" on page 255.)

8 For a **Transmission** calibration, connect the supplied patch cord to the **Source** and **Detector** connectors on the front panel of the OFDR.

For a **Reflection** calibration, connect the supplied gold reflector to the **Source** connector on the front panel of the OFDR.

9 Align the connector key to fit in the groove in the bulkhead adaptor. Turn the screw ring around the connector clockwise until it is just tightened.

10 Click **OK**.

A dialog box appears as calibration proceeds.

11 Click **OK** in the dialog box indicating that the instrument has been successfully calibrated.

After calibrating, it is advisable to check if the calibration was successful, to ensure that the system will provide accurate data.

Checking the Calibration

1 Follow all the instructions above, under "To calibrate the system" on page 107.

2 Leave the gold reflector (if checking a reflection calibration) or patch cord (if checking a transmission calibration) attached.

3 Perform a scan, following the instructions under "To perform a single-scan measurement" on page 111.

4 Display the insertion loss graph. Check that the insertion loss measures a nominal value of zero to within the measurement accuracy of the instrument.

Storing Multiple Calibrations

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Users may store more than one calibration file, covering different wavelength ranges. Note that users should only use calibration files created in the last 24 hours or so, as explained under "Conditions that Require Calibration" on page 106.

To store or use multiple calibrations

1 Select **Tools > Specify Calibration Filenames**. The dialog box below appears.
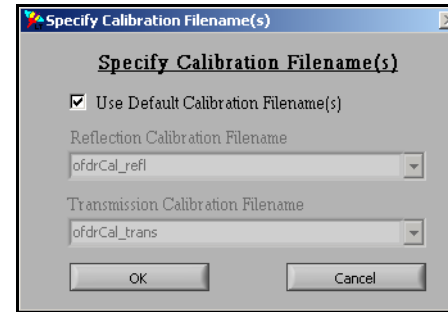
Figure 7-8. Select calibration file dialog box.

2 Click on the **Use Default Calibration Filename(s)** checkbox, leaving it unchecked. The **Calibration Filename** fields become accessible.

3 Type in a new filename. Alternately, if other calibration files have been saved, the user may select a previously-saved calibration file from the pull-down list. The default calibration filenames are ofdrCal_refl and ofdrCal_trans.

4 Click **OK**.

5 If you typed in a new calibration filename, next select **Tools > Calibrate**. Follow the instructions under "The Calibration Procedure" on page 107. The new calibration will then take effect. It will be stored under the filename entered in the **Select Calibration File** window shown above.

—OR—

If you selected an existing calibration file, you must select **Tools > Reload Calibration Data**. Or, if you wish to overwrite this existing filename with a new calibration, simply perform a new calibration.

In either case, the OFDR will not warn you if you are overwriting an existing calibration file.

6 In order for the current calibration file to take effect when the OFDR software is restarted, select **File > Save Software Options**. Otherwise,

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the default calibration files (ofdrCal_refl and ofdrCal_trans) will be loaded upon the next startup.

Important	Again: Renaming the calibration filename under **Tools > Select Calibration File** *does not* change the calibration file used by the OFDR software. To do so, the user must next perform a new calibration, or select **Tools > Reload Calibration Data**.

Acquiring Data

The OFDR has two different options for data acquisition: single scan and continuous mode. Each mode performs a complete scalar measurement of the device under test, and all parameters are available from measurements done in any mode.

Important	Before testing, clean the fiber optic connectors with the appropriate cleaner to guard against errors. For instructions, see "Cleaning Connectors" on page 117.

Single-Scan Mode

The single-scan measurement represents the basic functionality of the OFDR. In this mode the instrument performs a single sweep of the laser over the selected wavelength range, and acquires data for the device under test over that range.

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To perform a single-scan measurement

1 Ensure that the OFDR unit is powered on and that the laser is on and ready. The **Laser Ready** light comes on when the laser reaches operating temperature.

2 Be sure that the instrument has been aligned (See "To align the OFDR optics" on page 106) and calibrated (See "To calibrate the system" on page 107) within the recommended time period.

3 Before connecting the device to the OFDR, be sure to clean all fiber optic connectors. (See "Cleaning Connectors" on page 255.)

4 Connect the device to the OFDR. A transmission device must be connected to both the **Source** and **Detector** connectors. A reflection device need only be connected to the **Source** detector.

5 Select **Transmission** or **Reflection** from the **Type of Measurement** pull-down menu in the **System Control** area.

6 Enter an appropriate **Center Wavelength** and select a **Wavelength Range** from the pull-down menu.

If the desired scan range falls outside the range of the most recent calibration, either select a smaller scan range or recalibrate the OFDR.

If the center wavelength entered falls outside the range of the instrument, the software replaces it with a value within the instrument's range. (See the Specifications Sheet shipped with your instrument for standard instrument wavelength ranges.)

7 Check the **Options** menu for functions to be applied to the scan, such as **Data Decimation** and **Auto-Update Lower Graph**.

8 Click **Scan**.

The instrument performs the measurement and the software displays the test data.

Note that even if **Options > Display Options > Auto-Update Lower Graph** is off (unchecked), data may appear in the lower graph window from a previous scan. To update the lower graph based on the current time domain data, see "Updating Lower Graph" on page 120.

Continuous Scan Mode

Continuous scan mode takes advantage of the fast measurement speed of the OFDR to monitor devices whose properties may change slowly with time. It is particularly useful for short (<5 nm) scan ranges, where the update rate is fast enough to allow for near real-time device monitoring.

Important ☑	For accurate measurements, the device must change slowly enough that its properties remain constant while data is acquired. The blue "Scanning" LED on the OFDR turns on during data acquisition, indicating this time scale.

Note that continuous scan mode will operate more quickly if the lower graph area is "turned off" by unchecking **Options** > **Display Options** > **Auto-Update Lower Graph**. To view this data after scanning, see "Updating Lower Graph" on page 120.

To scan continuously

1 In the **System Control** area of the main window, select **Continuous Scan**.

2 *Optional*: To gain more speed, uncheck **Options** > **Display Options** > **Auto-Update Lower Graph**.

3 Follow the same measurement procedure as was outlined above under "To perform a single-scan measurement" on page 111.

4 The **Scan** button will turn gray during continuous scanning.

   The active graph window(s) will update after each scan.

5 To stop scanning, press the grayed **Scan** button again, or uncheck the **Continuous Scan** box.

   The data displayed in the upper graph will be from the last measurement. If **Options** > **Display Options** > **Auto-Update Lower Graph** was checked, data displayed in the lower graph will also be from the last measurement. However, if **Options** > **Display Options** > **Auto-Update Lower Graph** was off (unchecked), any data appearing in the lower graph window is from a previous scan. To update the lower graph, follow the instructions under "Updating Lower Graph" on page 120.

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Data Processing and Display

Displaying Multiple Traces

The OFDR control software allows the user to store up to five data sets in active memory. These three memory locations are denoted **Traces A** through **E**. The most recent measurement is always stored in **Trace A**.

Important ☑ New scans are automatically loaded into **Trace A**, overwriting any data there. To avoid losing data, see "Moving Data in Local Memory" below, or "Saving and Loading Data Files" on page 116.

Moving Data in Local Memory

Data **Trace A** may be moved to **Trace B** by clicking the button labeled **A->B** under the **Operations** column of the **Display Options** area shown in Figure 7-9. Similarly,

data may be moved to **Traces C**, **D** or **E**. However, only three of the five traces are available when operating in view-only mode (*i.e.* when the laser is off).The original data in **Trace A** remains in **A** until new data is scanned by the instrument or loaded from the hard drive.
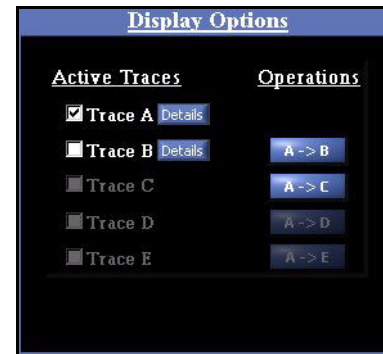
Figure 7-9. The Display Options area in the main OFDR software window. In this example, the laser is off, so only three traces are available. Data has been loaded into Traces A and B, but only Trace A is being displayed, as indicated by the check boxes.

7 Displaying Stored Data

The control software can display any combination of **Traces A** through **E** simultaneously in the graph windows. By default the data in **Trace A** is plotted as a blue curve, **Trace B** is red, **Trace C** green, **Trace D** yellow, and **Trace E** pink. In the example in Figure 7-9 above:

1 **Trace A** contains data, as indicated by the white name and checkbox and the blue **Details** buttons. **Trace A** is being graphed, as indicated by the filled-in checkbox. To clear this graph, click to clear the checkbox by **Trace A**.

2 **Trace B** also contains data but is not being graphed. Clicking in the second checkbox adds **Trace B** to the graph window.

3 **Traces C** has no data in it, as indicated by the grayed name and lack of a **Details** button. To overlay another plot, the user could move data into this trace using the **A->C Operations** button or by loading data from the hard drive. (See "Saving and Loading Data Files" on page 116.)

4 **Traces D** and **E** are unavailable, as indicated by the gray **Operations** buttons. This indicates that the software is operating in "Desktop Analysis" mode. To make these traces available, the user would have to select **Tools > Turn Laser ON**.

When data is loaded into local memory (by selecting **File > Load Data File** or by scanning) or moved within local memory (by clicking an **Operations** button), it is automatically displayed in the upper graph window.

Trace Details

Clicking a **Details** button in the **Display Options** area calls up the **Measurement Details** window shown in Figure 7-10 below. This window lists the type of measurement, the scan range & date, the calibration date, and the gain setting. If the file has been loaded from the hard drive rather than scanned into **Trace A**, the file path will be listed. The user may type in a one-line **Device Descriptor.** The user may also use this dialog box to change the group index of one trace at a time. The **Save and Close** button is only available when new data has been entered into the **Device Descriptor** field or the **Group Index** field.
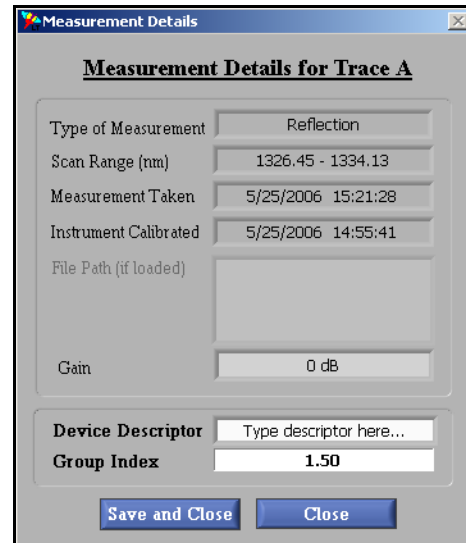
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Figure 7-10. Measurement Details window.

The user can also use the **Group Index** `1.50000` box in the lower right of the upper graph to change the group index, but this effects *all* of the data loaded into **Traces A** through **E**. (See "Adjusting Group Index" on page 124.)

Saving and Loading Data Files

The OFDR control software provides two different options for saving data files. The first file type (.ofdr) is a binary data format that completely captures the measured data and stores it in a format that can be loaded back into the control software at a later time for further manipulation.

The second file type (.txt) is a text file in a tab-delimited spreadsheet format. Text files contain the data displayed in the upper and lower graphs at the time of saving. Data saved in the spreadsheet format cannot be loaded back into the control software.

It is highly recommended that the binary data format be chosen over the spreadsheet format for data archives. The binary format stores all measurement information, whereas the spreadsheet format stores only a subset of the measured information. Furthermore, a spreadsheet file can always be generated from a binary file at a later date, but a binary file cannot be generated from a spreadsheet file. Finally, other data analysis software packages available from Luna Technologies accept only the binary data format produced by the OFDR control software.

7

File Names and Types

Depending on which options are set in the **File > Select File Options** dialog box (Figure 7-11), up to four files may also be saved each time **File > Save Data Files** is selected. As an example, if the user saves the data as *Your_Filename*, the four files would be:

1 *Your_Filename.ofdr* is the complete binary file, which can be reloaded into the OFDR software.

2 *Your_Filename_Segment.ofdr* is a subset of the data displayed in the upper graph. This subset is the region integrated by the vertical cursor in the upper graph and displayed in the lower graph. These files may also be reloaded into the OFDR software.

3 *Your_Filename_Upper.txt* is a spreadsheet file of all of the upper graph parameters selected in the **File > Select File Options** dialog box.

4 *Your_Filename_Lower.txt* is a spreadsheet file of all of the lower graph parameters selected in the **File > Select File Options** dialog box.

Important	When **File > Save Data Files** is selected, the OFDR software will overwrite any files with the filename specified, *without warning the user*.

The first column of each spreadsheet is determined by whatever units are selected and displayed on the respective X-axes when the user selects **File > Save Data Files**. Make sure first to follow instructions under "Updating Lower Graph" on page 120, as the segment displayed will be the one saved.

Spreadsheet files cannot be reloaded into the OFDR software. Therefore, a warning message will be displayed the first time the user saves data with both **Binary File Options** unchecked. This warning will not be displayed again until the user restarts the software.

Saving Data

Prior to saving data, the user may customize the format, content, and file extensions of saved data files. The following procedure sets options that will affect how the command **File > Save Data Files** saves measurement data.

1 Select **File > Select File Options**

The **Select Data File Options** dialog box opens:

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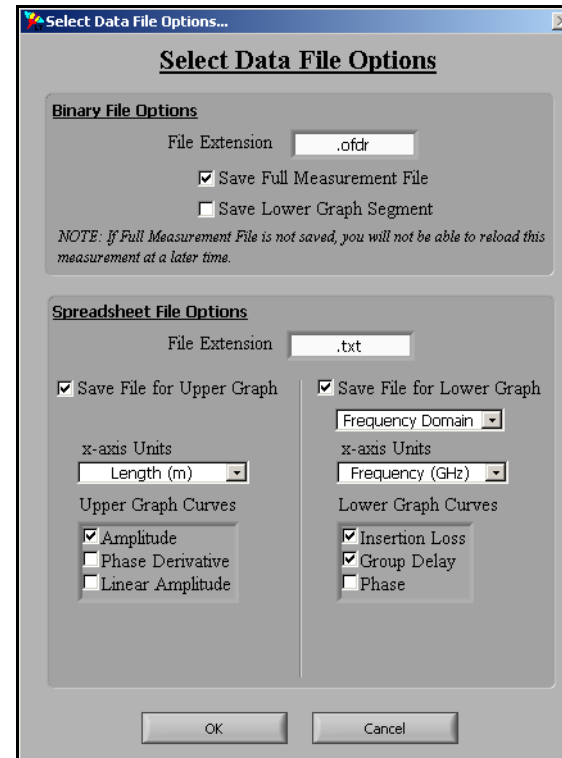
Figure 7-11. Select File Options dialog box. With this setting,
the complete (upper) binary file and two text files will be saved.

2 A binary file of the complete data will only be saved if the **Save Full Measurement File** box is checked. If **Save Lower Graph Segment** is checked, the software will also save a binary file of the data displayed in the lower graph. All of the data in that segment will be saved, not just the parameter displayed. This allows the user to save and manipulate smaller binary files. These lower segment binary files may also be reloaded into the software.

3 To set the software to save spreadsheet text files whenever **File > Save Data Files** is selected, check the appropriate box(es) under **Spreadsheet**

File Options. Use the pull-down menus to determine the x-axis units and domain of the text files saved.

Important

✓

Only binary data files, of type ".ofdr," may be reloaded into the OFDR software.

4 Click **OK.**

The control software saves the selected options.

To save data

1 Select **File > Save Data Files**.

A dialog box appears.

2 Select the file destination and enter a file name. The file extension(s) will be added automatically according to the configuration set using **File > Select File Options**, as described above.

3 Click **Save**.

Loading Saved Data

7

Only data saved in the binary format (.ofdr) can be loaded into the control software.

To load a saved data file

1 Select **File > Load Data File** from the pull-down menu.

2 In the dialog box that appears, choose the desired file and click **Open**.

The loaded data will appear in the upper graph area.

If **Options > Always Update Frequency Domain** is checked, new data will also appear in the lower graph area. If **Options > Always Update Frequency Domain** is unchecked, any data showing in the lower graph is from a previous calculation. To reset the lower graph area, click the recalculate button 🖩 .

Spreadsheet File Data

The header of a spreadsheet file gives the following information:

- Date and time data was acquired

- • Calibration date and time
- • Device descriptor (The user may enter a descriptor after clicking the **Details** button in the Display Options area.)
- • Scan range
- • Measurement type
- • Group index
- • Domain (time or frequency domain)
- • Resolution bandwidth
- • Number of data points
- • Decimation

Only the parameters selected (checked) in the **File > Select File Options** dialog box will be contained in a spreadsheet file. The X-axis units of the data are also determined in that same dialog box. The parameter name and the units are given at the top of each spreadsheet column.

Manipulating Plots

Most of the tools for changing plots are the same in the OFDR and OVA. Features unique to the OFDR software are described below. See "Graphing Tools Common to the OVA and OFDR" on page 125 for references to earlier sections describing common features.

7

Updating Lower Graph

In both the OVA and OFDR software, the data in the upper graph automatically updates when data is scanned (into **Trace A**), moved, or loaded from memory. However, in the OFDR software, the lower graph will not update automatically unless **Options** > **Display Options** > **Auto-Update Lower Graph** is checked. As mentioned earlier, this is often left off (unchecked) to speed up scanning time.

To update the lower graph in OFDR software

1 Turn on the vertical cursors in the upper graph by clicking [icon].

2 By default, the vertical cursors are attached to **Trace A**. To attach the *upper graph* cursors to another trace, select a different trace from the pull-down menu in the *lower graph* **Title Bar** [Trace A ▾].

3 Adjust the cursor locations in the *upper graph* as desired by selecting the cross-hair [icon] tool, then clicking and dragging a cursor.

4 If **Options > Cursors > Show Integration Area** is on (checked), the regions of the graph around the vertical cursors are highlighted. This highlighted segment is the only data that will appear in the lower graph. Lower graphs of all traces will be based on this same segment of the X-axis.

The user may change the width of the highlighted area (and lower graph X-axis) by entering a new **Integration Width** in the **Data Processing** area.

5 Click the blue recalculate button [icon] in the upper left of the *lower graph*.

By default, the lower graph will be based on the data integrated by the left (yellow) cursor from the upper graph, as indicated by the yellow button to the left of the recalculate button.

6 To see the data from the right (orange) cursor, click to the right of the recalculate button; the button will turn from gray to orange: [icon] . Then hit the recalculate button again.

> **Note**
>
> The recalculate button [icon] only appears in the top left of the *lower* graph when the vertical cursors are on in the *upper* graph.

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7 To change the parameter displayed in the lower graph, follow the next set of instructions.

Parameter Selection

As with the OVA, the user can control the content of the two graphs in the main window from a list of parameters in the **Title Bars**. By default, the upper, time domain graph displays amplitude, but it can also display phase derivative or linear amplitude. The lower graph can display the same time domain parameters, or the user can select frequency domain from the pull-down menu [Frequency Domain ▾] to display insertion loss (default), group delay, or phase.

Graphing Two Parameters Simultaneously

The OFDR (but not the OVA) offers the option of displaying two parameters in one graph area. If **Options > Lower Graph > Two Plots** is on (checked), two parameter menus will appear in the lower graph, as shown below.
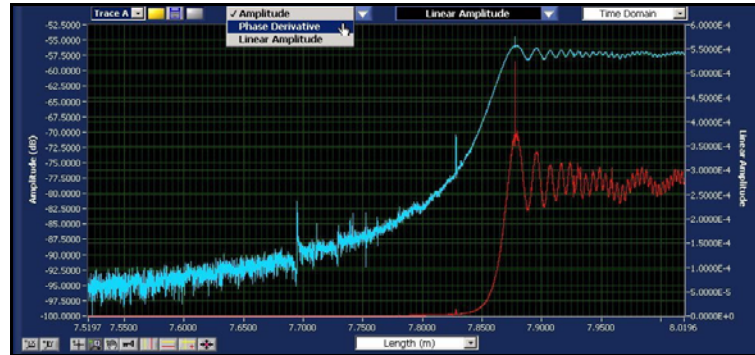
Figure 7-12. Lower graph window showing one Title Bar pulled down for parameter selection.

Click on the desired parameter from the list in a graph's **Title Bar**. The content of the graph changes, as do the title and the axis labels (if necessary).

7
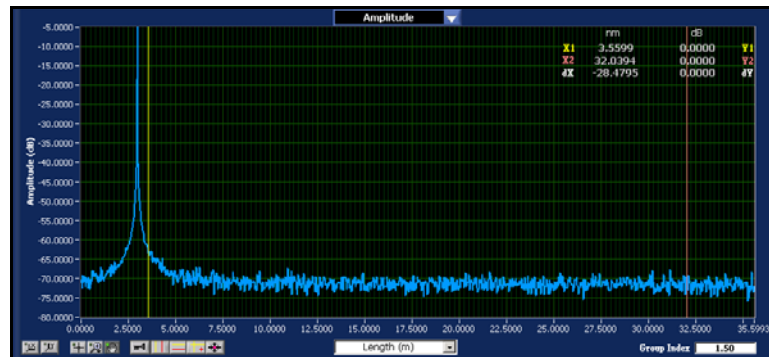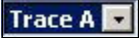
*Figure 7-13. Graph window with vertical cursors appearing at the default location. The legend at the upper right gives the precise location of the cursors and the distance between them (dX in this case). Just beneath that, **Return Loss** is not displayed because the integrated area is not highlighted (**Options > Cursors > Show Integration Area** is unchecked.) For an illustration of the **Return Loss** display, see Figure 1-1 on page 2.*

Vertical cursors: ▮▮▮

This button provides additional functionality in the OFDR. Clicking this button toggles two vertical cursors on or off. Note that when these cursors are on, the data points integrated to calculate return loss (see page 128) are highlighted in contrasting colors, and return loss is displayed in the upper right legend. This highlighted region may be turned off by unchecking **Options > Cursors > Show Integration Area**. This highlighted or integrated region determines the X-axis of the lower graph.

The number of points integrated may be increased (or decreased) by entering a larger (or smaller) number in the **Integration Width** box in the **Data Processing** area to the left of the graphs. For an explanation of how return loss is calculated, see page 128.

By default, all cursors are attached to Trace A. To attach cursors to another trace, use the pull-down menu Trace A ▾ at the upper right of the *lower* graph area.

Select the cross-hair ⊹ tool to move any cursors.

Move cursors to peak: ▮

Clicking this button moves the two vertical cursors to the peaks of the regions highlighted by each cursor. Simply click on this button when the vertical cursors are on. Note that this button is only available in the OFDR software.

Adjusting Group Index

In the OFDR only, when the upper graph X-axis displays meters or feet, the **Group Index** field shown below appears in the lower right corner. The user may enter the index appropriate for the device under test.

Group Index | 1.50000

Figure 7-14. The group Index field, which appears when the upper X-axis is set to length.

Important ☑

Changing the group index in the box shown above changes the group index for *all* the data loaded into memory, **Traces A** through **E**. In order to change the group index of only one trace, click the **Details** button of that trace and change the group index in the details dialog box. (See "Trace Details" on page 115.)

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This setting scales the X-axis length values according to

$$z = \frac{c}{n_g} t,$$

where z is the spatial dimension (X-axis) of the device under test, c is the speed of light in a vacuum, and n_g is the group index of refraction of the device under test.

Data Decimation

Data decimation is only available in the OFDR software. By default, **Options > Data Decimation (Upper Graph) > Decimate Data** is turned on (checked). This means that only the average of roughly every 64 data points is displayed in the upper graph. The user may change the number of data points displayed from a pull-down menu displayed after selecting **Options > Data Decimation (Upper Graph) > Specify Level...**

7
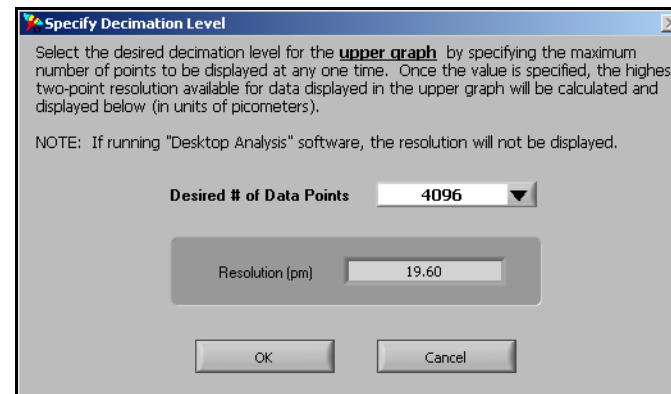
Figure 7-15. The Specify Decimation Level dialog box allows the user to set the number of data points displayed.

Decimation makes the graphs much less "noisy" and quicker to display. Unchecking this option displays the full data set. Note that files saved in the binary (.ofdr) format contain the raw data, undecimated. Text files (.txt) may be reduced in size by making sure data decimation is on before saving. The upper section of a text file notes whether or not data decimation has been applied to the saved data.

Graphing Tools Common to the OVA and OFDR

Measurement Theory

This section describe areas where OFDR and OVA theory or parameters differ. For Measurement Theory on areas where the OFDR and OVA are essentially the same, see these relevant sections:

Optical Network of the OVA in OFDR Mode

A detailed schematic of Luna's OFDR optical network is shown in Figure 7-16. The optical system is comprised of a tunable laser source (TLS), two interferometers (DUT and trigger), a polarization beam splitter (PBS), three data acquisition channels, and a high speed analog to digital converter (ADC). Note that the system can interrogate a DUT in both reflection and transmission via the use of the 1x2 optical switch in one arm of the DUT interferometer. The interference fringes $U_s(t)$, $U_p(t)$, and $U_t(t)$ are labeled at their corresponding detector, where "s" and "p" correspond to the two polarization states of the PBS and "t" denotes the trigger.

7
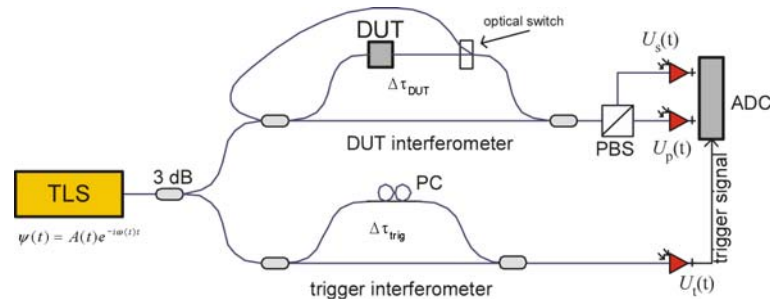
Figure 7-16. OFDR optical network, in reflection mode.

This basic idea from the previous section can be applied to device characterization by including a device under test (DUT) in one arm of a Mach-Zender interferometer, as shown in Figure 7-16. We can describe the DUT by its frequency domain linear transfer function, $H(\omega)$; the linear transfer function contains information about the amplitude, $\rho(\omega)$, and phase, $\phi(\omega)$, response of the DUT and is given by $H(\omega) = \rho(\omega)e^{i\phi(\omega)}$. Given the amplitude and phase response, the detected power is proportional to the intensity, I, given by

$$I = \left|E_0(t)\right|^2 + \left|E_0(t-\tau)\right|^2\rho(\omega)^2$$
$$+ 2\rho(\omega)E_0(t)E_0(t-\tau)\cos[\omega(t)\tau - \phi(\omega)]\,.$$

Next a Fourier transform is performed allowing the three terms in the above expression to be separated spectrally. Note that the first two terms will have only low frequency characteristics, and thus will appear at or near $t = 0$ in the time-domain. The device information resides in the third term of this expression, called the *interference term*. The interference term oscillates at the frequency $\omega(t)\tau$, while the other terms do not oscillate. Its location in the time-domain will be determined by the delay difference τ between the two arms of the interferometer. Provided that τ is large enough, the device response will be separable from the low frequency terms, and thus measurable. The Luna OFDR is designed such that the internal delay path through the device under test is long enough such that the low frequency terms will not influence the measurement, even for very short devices. Thus the OFDR operates with no dead zone.

The Fourier transform of reflected optical intensity (I) for a short length of single-mode fiber as the DUT is plotted in Figure 7-17 (a). Figure 7-17 (b) shows the

selected segment that contains the device information. Because the initial data was acquired as a function of optical frequency, ω, the transformed data is a function of time. For this reason, the transformed data is referred to as *time domain* data.
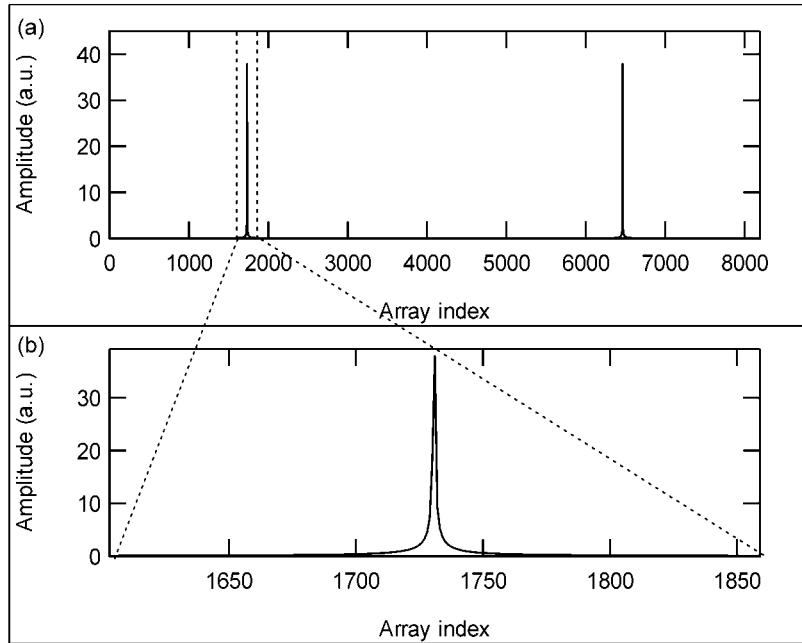
Figure 7-17. (a) The Fourier transform of interference fringes.
(b) The segment of the time domain data that contains device information.

7

Spatial Resolution Calculations

The **Spatial Resolution** field in the **Data Processing** area sets the length of the box-car filter applied to the amplitude data in the time domain. This filter assigns each location in the measurement with the simple sum of all the adjacent points within the range of the filter resolution setting. Because this is not a weighted average, localized reflections—like those at the end of a fiber—will have a rectangular shape equal to the width of the control setting.

Integration Width

The **Integration Width** field in the **Data Processing** area controls the length of the segments centered on the vertical cursors in the top graph, which are used to calculate

the average loss within a two highlighted segment. The width of this segment determines the width of the lower graph X-axis.

Return Loss

When the vertical cursors are on in the upper graph, the average return loss is calculated over the two integration widths and displayed in the upper right as **Ret Loss (dB)**. For example, if the entire time domain axis is given by $t \in [0, T]$ and the data is highlighted at a cursor such that $t \in [t_1, t_2]$, then the average return loss at that cursor is given by

$$RetLoss = 10\log \frac{\sum\limits_{t_1}^{t_2} |\tilde{h}_j|}{\sum\limits_{0}^{T} |\tilde{h}_j|},$$

where $\tilde{h}_j$ is the impulse response, further defined below under "Time Domain Amplitude" on page 131.

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Parameter Calculations

As mentioned above, the OFDR uses coherent interferometry to measure the linear transfer function, $H(\omega) = \rho(\omega)e^{i\phi(\omega)}$, of the DUT. From this, the loss, dispersion and time domain parameters are extracted.

Insertion Loss

Insertion loss (IL) is the ratio of optical power output by the device to the optical power input to the device, and is expressed in dB. In terms of the transfer function, it is defined as

$$IL_i = 20\log(\rho_i).$$

where the subscript "i" corresponds to the "i^{th}" data point and ρ_i is the amplitude response normalized to the response of the reference patch cord for transmission measurements and the reference gold reflector for reflection measurements.
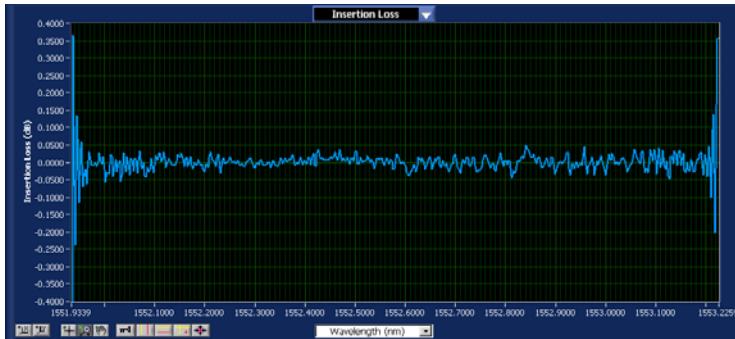
Figure 7-18. Insertion loss data for a patch cord.

Group Delay

Group delay (GD) is defined to be the rate of change of phase as a function of frequency. Physically, this property corresponds to the delay experienced by the sinusoidal envelope of a modulated optical signal as it propagates through the device. In terms of the transfer function, the group delay is given by

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$$GD_i = \frac{\arg(H_{i+1}H_i^*)}{\Delta\omega} \quad ,$$

where $\arg(z)$ denotes the argument (phase) of the complex number z, and $\Delta\omega$ is the change in optical frequency from index i to index $i+1$.
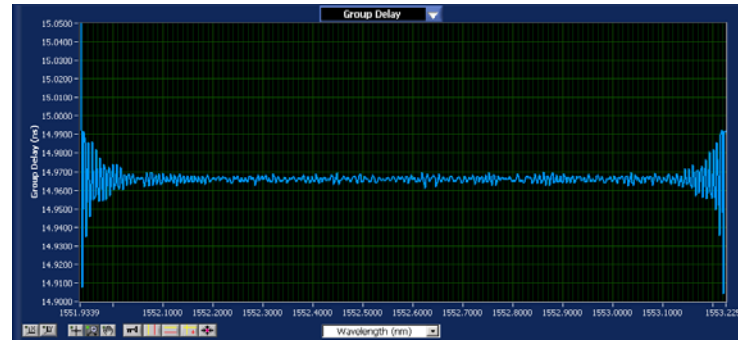
Figure 7-19. Group delay data for a patch cord.

Phase

The frequency domain (lower) graph can also display phase. This represents the optical phase response as a function of wavelength of the portion of the DUT response that is visible in the upper graph. As stated above, group delay is calculated as the numerical derivative of the spectral phase.

Note that the phase is a function of the placement of the data in the upper graph. For example, an impulse occurring in the left of the upper graph will display a phase with negative slope. Conversely, the same impulse repositioned to the right in the upper graph will display a phase with a strong negative slope. An impulse that is centered in the upper graph will have nominally flat phase in the lower graph. This ambiguity in the slope of the phase is due to the fact that the linear term in the phase response for a given component determines, to the first order, the length of the component. One is often more interested in higher order phase terms and thus the strong linear term is undesired in the phase plot. By centering the data in the upper graph, the user has a control over the amount of slope that is "allowed" into the phase plots.
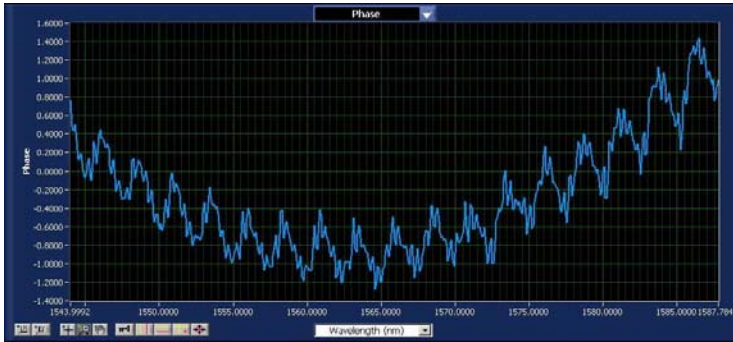
Figure 7-20. Lower graph area showing phase data.

Time Domain Amplitude

The time domain amplitude plot selection displays the amplitude of the impulse response of the device in the time domain. The impulse response is given by the Fourier transform of the transfer function,

$$\tilde{h}_j \ = \ FFT\{H(\omega)\}_j \ ,$$

where $FFT\{H(\omega)\}$ denotes the Fast Fourier Transform of $H(\omega)$. The index j indicates the location in the data array, and corresponds to time.

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The impulse response amplitude is plotted on log scale and is given by

$$\log[|\tilde{h}_j|] \ .$$

This definition yields an average impulse response over all input polarization states. The result is scaled such that

$$\sum_j |\tilde{h}_j| \ = \ 1$$

for a lossless device.
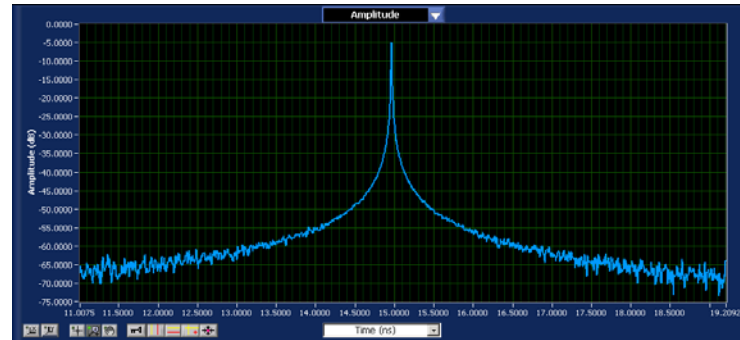
Figure 7-21. Time domain amplitude data for a patch cord.

Time Domain Linear Amplitude

The linear amplitude is the $\left|\tilde{h}_j\right|$ plotted on a linear scale.
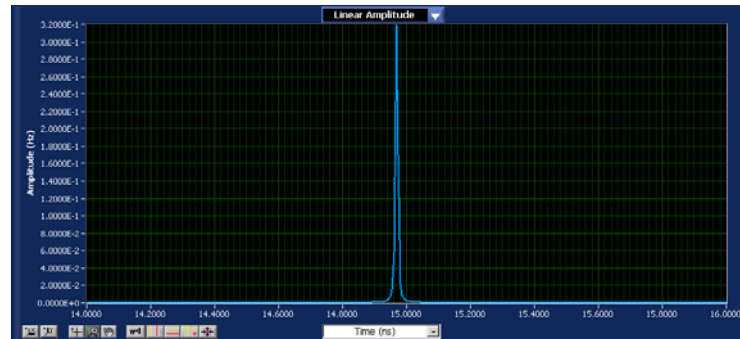
Figure 7-22. Time domain linear amplitude data for a patch cord.

Time Domain Phase Derivative

The time domain phase derivative plot is the derivative of the phase of the impulse response with respect to time. Note that the time derivative of phase is the definition of optical frequency, so this derivative can be scaled as a wavelength. For a device with a distributed impulse response, the time domain phase derivative shows the wavelength distribution as a function of time for an infinitely short pulse as it is dispersed by the device. Another way to think of the time domain phase derivative

is it represents the "wavelength" of the device under test. It is therefore especially meaningful for wavelength conditioning devices and filters.

In terms of the impulse response $\tilde{h}_j$ defined above, the time domain phase derivative, PD_j, is defined as

$$PD_j = \frac{2\pi c \Delta t}{\arg(\tilde{h}_{j+1}\tilde{h}_j{}^*)} \quad ,$$

where c is the speed of light in a vacuum and Δt is the difference in time between index j and index $j + 1$.
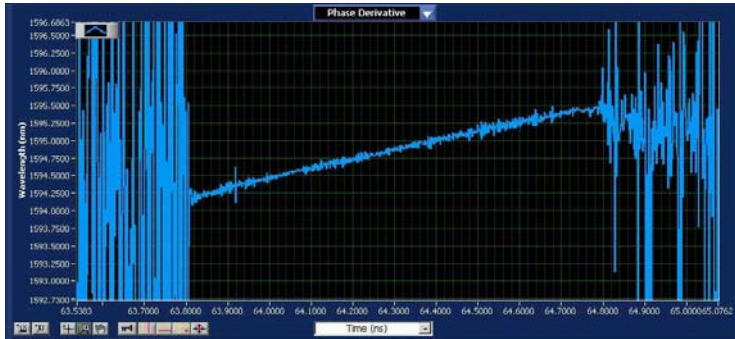
Figure 7-23. Phase derivative of the time domain response of a fiber Bragg grating.

7

Measurement Example

If the OFDR is operating in reflection mode and there are multiple reflecting interfaces within the device under test, each interface will contribute a term to the interference pattern and a peak in the time domain located at the corresponding delay. See Figure 7-24 for an example measurement of a photodetector packaged with a ball lens. Similarly, a transmission measurement of a device with multiple optical paths will also produce multiple peaks in the time domain plot.
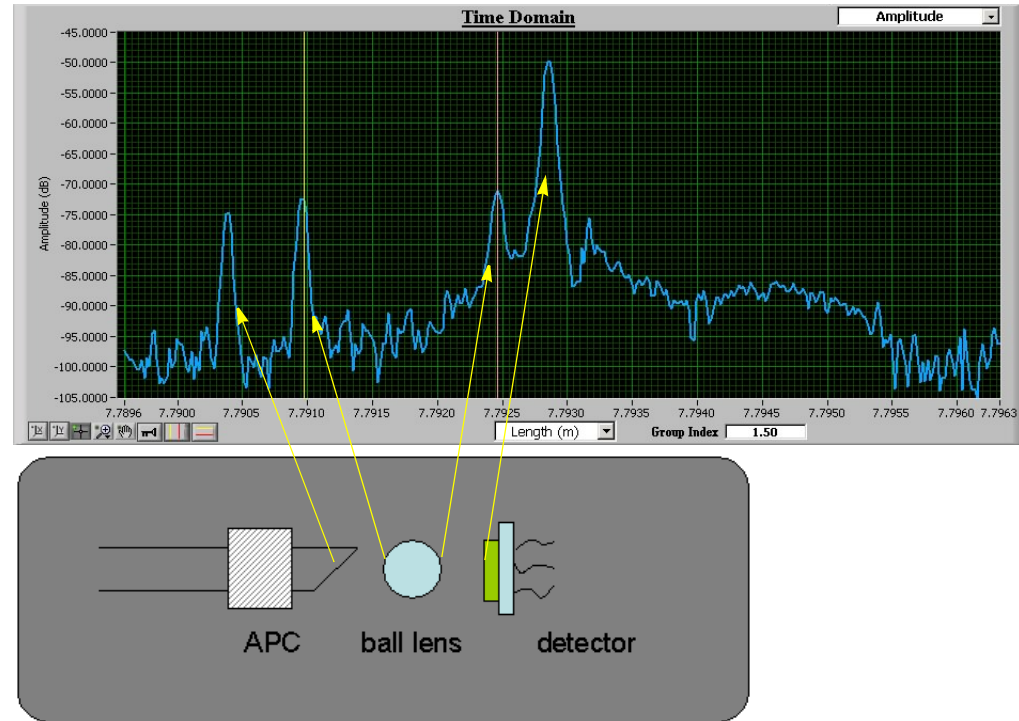
*Figure 7-24. An OFDR measurement of a packaged optical detector.
Reflections from the connector endface, both sides of a ball lens,
and the photodiode are apparent.*

7

Chapter 8

Controlling the OVA Remotely

This chapter provides information about controlling the Optical Vector Analyzer remotely using GPIB or TCP/IP commands. This section assumes that the user already has some familiarity with either GPIB or TCP/IP. For detailed information about GPIB, see IEEE 488.2 standards documents; for information about TCP/IP, see the IEEE 802 standards documents.

Nearly all functions that can be performed using the graphical interface of the control software can also be performed remotely. This includes setting scan parameters, performing measurements, filtering data, loading and saving data files, as well as receiving data over the remote interface. However, continuous and real-time modes are not available with remote operation.

Remote operation offers the additional feature of using the OVA as a tunable light source. For details, see "Using the OVA as a Light Source" on page 195.

Access to the Matrix B and C memory locations is not available through remote operation of the OVA. Remote control commands can store and retrieve data using only the Matrix A memory location.

Full calibration including calibration for PDL is not available through remote operation, because it requires user interaction. To operate remotely using a complete calibration, the user must first calibrate locally (as described under "The Calibration Procedure" on page 37), and then switch to remote operation. The remote command SYST:QCAL (See page 156) allows calibration for insertion loss and dispersion parameters only.

For higher speed remote operation, TCP/IP is recommended over GPIB.

8

Prerequisites for Remote Control Setup

1 Be familiar with the use of GPIB or TCP/IP commands and the OVA control software before attempting to control the OVA remotely.

2 Network cabling must comply with IEEE 488.2 requirements for GPIB operation, or with IEEE 802 requirements for TCP/IP operation.

3 Some OVA functions require several minutes to complete. Adjust GPIB or TCP/IP time-outs for your application accordingly.

4 Each device in the GPIB network must have a unique GPIB address, typically from 1 to 30. The network controller is typically assigned an address of 0.

5 Be aware of the IP address of the OVA PC in order to use TCP/IP remote control.

Remote Control Setup Configuration

The remote interface type, board address and port number can be configured using the OVA menu selection **Options > Remote Interface Setup**. The following dialog box appears, whether using the OVA or the OFDR software:
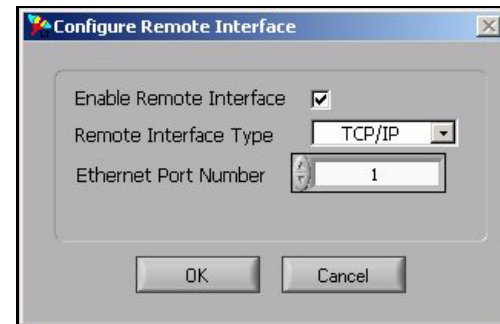
Figure 8-1. The remote interface setup dialog box.

The pull-down menu allows the user to select either GPIB or TCP/IP remote interface. TCP/IP is the default interface. The second field is used to set either the GPIB address or the ethernet port number. By default, both the GPIB address and the ethernet port number are set to "1".

The GPIB board name is set to "GPIB0" by default.

For suggestions on remote setup using TCP/IP, see "Setting Up a TCP/IP Console" on page 195.

Commands for OVA *and* OFDR Software

This section gives a description of every remote control command available with both the OVA and OFDR control software. The next section will give OVA-only commands; a third section will give OFDR-only commands.

The commands are organized by function. For an alphabetical listing of each command, see Table 8-1, "Alphabetical Summary of GPIB and TCP/IP Commands," on page 199.

Each of the commands listed below may be used for either GPIB or TCP/IP interface. The OVA control software accepts all mandatory IEEE 488.2 commands for GPIB, but only responds to the commands described in this section. The OVA does not accept TCP/IP commands that are not listed in this document.

Important	The OVA control software does not support multiple commands on a line, separated by semicolons. Enter each command on a separate line.

IEEE 488.2 defines commands as being either *sequential* or *overlapped*. Sequential commands cause the instrument to ignore other remote control commands until each command has completed. Overlapped commands let the device respond to incoming commands before pending commands completely execute. The OVA processes only sequential commands.

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All commands are case-sensitive, and must be entered exactly as they appear in this chapter.

Examples of how to use these commands with Visual Basic® code are given under "Example Visual Basic Code" on page 188.

Remote control commands are classified by types:

- Standard Commands
- System Control Commands
- Configuration Commands
- Data Capture and Retrieval Commands

Standard Commands

These are mandatory commands required by IEEE 488.2. For consistency, they are also accepted by the OVA when operating with TCP/IP. These commands are generally not necessary for performing measurements with the OVA. For more information about these commands, see the IEEE 488.2 standards documents.

*CLS

Usage:	*CLS
Description:	Clears the status register.
Response:	None.

*ESE

Usage:	*ESE {*mask value*}
Description:	Sets the value of the Status Enable register.
Response:	None.

*ESE?

Usage:	*ESE?
Description:	Queries the current value of the Status Enable register.
Response:	Returns a number ranging from 0 to 255.

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*ESR?

Usage:	*ESR?
Description:	Queries the value of the Event Status register.
Response:	Returns a number ranging from 0 to 255.

*IDN?

Usage:	*IDN?
Description:	Queries the OVA or OFDR for its identification string.
Response:	Returns device information in a string identifying the model, manufacturer, and firmware level for the device in the form:

Optical Vector Analyzer, Luna Technologies Firmware: 3.8.1
Released On: 4/15/2008.

*OPC

Usage: *OPC {0|1}

Description: Sets the event bit in the Standard Event Status register,
              enabling (1) or disabling (0) "operation complete" event
              notification.

Response: None.

*OPC?

Usage: *OPC?

Description: Queries the OVA or OFDR to determine if the operation is
              complete.

Response: When the previous operation is complete, the response is
              "1." If the operation is incomplete, the response is "0." This
              response is sent immediately.

*RST

Usage: *RST

Description: Instructs the OVA or OFDR to reset all parameters to the
              power-on defaults.

Response: None.

*SRE

Usage: *SRE {n}

Description: Sets the Service Request Enable register to n, where n can
              be any number from 0 to 255.

Response: None.

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*SRE?

Usage:	*SRE?
Description:	Queries the current value of the Service Request Enable register.
Response:	Returns the value (0–255) of the Service Request Enable register.

*STB?

Usage:	*STB?
Description:	Queries the value of the Status Byte register.
Response:	Returns the value (0–255) of the Status Byte register.

*WAI

Usage:	*WAI
Description:	Prevents the OVA or OFDR from executing any further commands or queries until all pending operations have been completed.
Response:	None.

*TST?

Usage:	*TST?
Description:	Performs a self-test query.
Response:	None.

*QUIT

Usage:	*QUIT
Description:	Ends a remote session, allowing the OVA or OFDR to go back to local control mode.
Response:	None.

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System Level Commands

SYSTem:WARM?

Usage:	SYST:WARM?
Description:	Queries if the laser is at operating temperature.
Response:	Returns the digit "1" if the laser is at operating temperature, or "0" if it is not at operating temperature.

SYSTem:WarmupTIMeremaining?

Usage:	SYST:WTIM?
Description:	Retrieves the time remaining on the system one hour warm-up timer.
Response:	Returns the current warm-up time left in minutes.
	If the OVA instrument and PC have warmed-up for the specified hour, this command will return zero, "0", meaning no warm-up time is left.
Note:	It is always recommended to query the warm-up timer before calibrating and taking measurements. The OVA must be at a stable temperature in order to consistently perform accurate measurements according to published specifications.

SCAN

Usage:	SCAN
Description:	Tells the OVA to execute an optical scan based on the configured system parameters. Depending on the wavelength range setting and the number of averages, this command may take up to several minutes to complete.
Response:	None.
Note:	It is advisable to use the SYST:ERR? query after each SCAN command and before attempting to retrieve the data with FETC queries. This will reveal any errors that occurred during the scan.

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SYSTem:ALIGn

Usage:	SYST:ALIG
Description:	Aligns the optics.
Response:	None.
Notes:	This process may take several minutes. Adjust the time-outs for your application accordingly.
	After a successful alignment, the system will automatically perform an internal calibration.
	Poll for *OPC? to see whether the operation is completed or not.

SYSTem:ALIGn?

Usage:	SYST:ALIG?
Description:	Queries the OVA if the optics are aligned.
Response:	Returns "1" if the optics are aligned, or "0" if they are not aligned.
Note:	The validity of alignment is checked with every scan. If it is determined that the alignment is no longer valid, then this status switches to "0." Thus it is prudent to issue this query periodically after intervals of scanning to verify that the alignment was valid during the last scan.

SYSTem:CALibration?

Usage:	SYST:CAL?
Description:	Queries the system calibration status.
Response:	Returns "1" if the system is in calibration or "0" if it is not.
Note:	The validity of calibration is checked with every scan. If it is determined that the calibration is no longer valid, then this status switches to "0." In this case, the user may either recalibrate (by using the SYST:FCAL, SYST:ICAL, or SYST:QCAL commands described above), or reload a previous calibration file (by using the SYST:RLDC command described below).

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SYSTem:ReLoaDCalibration

Usage:	SYST:RLDC
Description:	Reloads a calibration file into memory. The OVA software looks for an appropriate calibration file based on the **Type of Measurement** set using the CONF:TEST command. (See "CONFigure:TEST" on page 149.)
Response:	None.
Note:	The user may send this command if SYST:CAL? returns a "0," indicating that the calibration failed. Alternately, the user may recalibrate using the SYST:FCAL, SYST:ICAL, or SYST:QCAL commands described above.

SYSTem:ERRor?

Usage:	SYST:ERR?
Description:	Queries the OVA for the error status of the most recent command or query.
Response:	Returns an error code followed by a text description of the error. Zero (0) indicates no error; i.e. the last command or query completed successfully. Any non-zero number indicates that an error has occurred. A description of the error may be retrieved with the query SYST:ERRD?
	The numeric field ranges from -32767 to +32767, with "0" indicating that the last command or query completed successfully. The total length of the error message will be less than 512 bytes. Two examples of error messages are:
	10: The optics must first be aligned before a scan can be executed
	0: No error
Response:	Returns a numeric error code. A code of 0 indicates no error; *i.e.* the last command or query completed successfully. Any non-zero number indicates that an error has occurred. A description of the error may be retrieved with the query SYST:ERRD?

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SYSTem:ERRorDescription?

Usage:	SYST:ERRD?
Description:	Retrieves the detailed error description for the most recent remote operation.
Response:	Retrieves a string explaining the results of the most recent operation. The total length of the error message will be less than 512 bytes. Two examples of error messages are:
Examples:	Not a valid trace: W
	Missing parameter: <center wavelength>

SYSTem:LASEr

Usage:	SYST:LASE {0|1}
Description:	Turns on the laser if the parameter is "1", or turns it off if the parameter is "0".
Response:	None.

SYSTem:LASEr?

Usage:	SYST:LASE?
Description:	Queries if the laser is on.
Response:	Returns "1" if the laser is on, or "0" if the laser is not on.

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SYSTem:ReaDY?

Usage:	SYST:RDY?
Description:	Queries if the OVA is ready to scan.
Response:	Returns "1" if the OVA is ready to scan, or "0" if it is not ready to scan.

SYSTem:LOAD

Usage:	SYST:LOAD "*{filename.bin}*"
Description:	Loads the external file specified in quotes as a source of data reference for the measurement.
	If the file format is not correct, an error flag will be set. The cause of the error can be determined by using the SYST:ERR? query.
Response:	None.
Note:	The entire file path must be in quotes. Only load "*.bin*" type files. This command always loads the data into Matrix A.
Example:	SYST:LOAD "*C:\SavedFiles\test.bin*" loads the data contained in the file "test.bin" into Matrix A.

SYSTem:LAST?

Usage:	SYST:LAST?
Description:	Queries the last remote command or query processed by the device. This query can be used to determine whether a command was received and processed.
Response:	Returns the name of the last remote command or query processed by the device.
Example:	CONF:INTW 1.5
	SYST:LAST?
	This query returns "CONF:INTW". Note that SYST:LAST? only returns the name of the last command and does not report any parameters included with the command.

SYSTem:VERsion?

Usage:	SYST:VER?
Description:	Queries the software version.
Response:	Returns a string containing the OVA software version.
Example:	3.8.1

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Configuration Commands

CONFigure:CenterWaveLength

Usage OVA:	CONF:CWL {*wavelength*, *operationType*}
Usage OFDR:	CONF:CWL {*centerWavelength*}

Description: Sets the **Center Wavelength** (nm) and for the specified *operationType*. The wavelength parameter must be within the operating range of the instrument.

For the OVA only, the *operationType* is 0 for *measurement*, 1 for *full calibration*, or 2 for *internal calibration*. If no *operationType* is specified, the **Center Wavelength** will be set for *measurement* (0).

Response: None.

Notes: Every time the center wavelength is changed for full calibration or internal calibration, the system will go out of calibration, so the user must then recalibrate the system (using SYST:FCAL or SYST:ICAL, respectively). Failure to do so can result in system malfunction.

If the center wavelength and wavelength range settings for an internal calibration fall outside the most recent full calibration, the internal calibration wavelength settings will be coerced to fit within the most recent full calibration. Likewise, if the range of wavelengths chosen for a measurement fall outside of the internal calibration range, they will be coerced to fit within the internal calibration range.

Examples: "CONF:CWL 1550.0" or "CONF:CWL 1550.0,0"

Either command sets the **Center Wavelength** to 1550.0 nm for the next *measurement*.

"CONF:CWL 1550.0,2" sets the **Center Wavelength** for *internal calibration* to 1550.0 nm.

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CONFigure:CenterWaveLength?

Usage OVA: CONF:CWL? {*operationType*}

Usage OFDR: CONF:CWL?

Description: Queries the current **Center Wavelength**. In the OVA, *operationType* must be specified. The *operationType* is 0 for *measurement*, 1 for *full calibration*, or 2 for *internal calibration*. If no *operationType* is specified, the query will return the **Center Wavelength** for *measurement* (0).

Response: Returns the current **Center Wavelength** in nanometers.

Examples: "CONF:CWL?" or "CONF:CWL? 0" returns the **Center Wavelength** for *measurement* in the form "1550.00" nm.

"CONF:CWL? 1" returns the **Center Wavelength** for *full calibration* in the form "1550.00" nm.

CONFigure:STARtwavelength   *(This command is being phased out.)*

Usage: CONF:STAR {*wavelength*}

Description: Sets the start wavelength for the scan in nanometers. The wavelength parameter must be within the operating range of the instrument.

If the start wavelength falls outside the limits of the instrument and the most recent internal calibration, the command is accepted, but the start wavelength will be coerced to the nearest wavelength within the OVA's limits using the current setting of **Wavelength Range**.

Response: None.

Note: This command is included for backward compatibility only, and may not be supported by future versions of the OVA control software. This command has been replaced by CONF:CWL.

Example: CONF:STAR 1525.0

This command sets the starting wavelength to 1525.0 nm.

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CONFigure:STARtwavelength? *(This command is being phased out.)*

Usage:	CONF:STAR?
Description:	Queries the OVA for the current start wavelength.
Response:	Returns the current start wavelength in nanometers.
Note:	This command is included for backward compatibility only, and may not be supported by future versions of the OVA control software. This command has been replaced by CONF:CWL?.
Example:	CONF:STAR?
	This query returns a message in the form "1525.00."

CONFigure:ENDwavelength?

Usage:	CONF:END?
Description:	Queries the OVA for the current ending wavelength.
Response:	Returns the current ending wavelength in nanometers.
Example:	CONF:END?
	This query returns a message in the form "1590.00" nm.

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CONFigure:RANGe

Usage:	CONF:RANG {*scanRange*, *operationType*}
Description:	Sets the **Scan Range** in nanometers for the specified *operationType*. The OVA only allows scan ranges that have a number of data points equal to a power of two, so the actual value of the **Scan Range** will be set to the valid value closest to *x*.
	The *operationType* is 0 for *measurement*, 1 for *full calibration*, or 2 for *internal calibration.* If no *operationType* is specified, the **Scan Range** will be set for *measurement* (0).
Response:	None.
Notes:	Every time the wavelength range is changed for full calibration or internal calibration, the system will go out of

calibration, so the user must then recalibrate the system (using SYST:FCAL or SYST:ICAL, respectively). Failure to do so can result in system malfunction.

If the center wavelength and wavelength range settings for an internal calibration fall outside the most recent full calibration, the internal calibration wavelength settings will be coerced to fit within the most recent full calibration. Likewise, if the range of wavelengths chosen for a measurement fall outside of the internal calibration range,

Examples: CONF:RANG 5.0 or CONF:RANG 5.0,0 sets the **Scan Range** for the next *measurement* to the valid range closest to 5.0 nm.

CONF:RANG 5.0,2 sets the **Scan Range** for *internal calibration* to the valid range closest to 5.0 nm.

CONFigure:RANGe?

Usage: CONF:RANG? {*operationType*}

Description: Queries the OVA for the current **Scan Range** for the specified *operationType*: 0 for *measurement* or 1 for *internal calibration*. If no *operationType* is specified, the query will return the **Scan Range** for *measurement* (0).

Response: Returns the current **Scan Range** in nanometers.

Examples: "CONF:RANG?" or "CONF:RANG? 0" returns the **Scan Range** for *measurement* in nanometers.

"CONF:RANG? 1" returns the **Scan Range** for *internal calibration* in nanometers.

Returns a message in the form "20.0" nm.

CONFigure:TEST

Usage: CONF:TEST {*measurementType*, *operationType*}

Description: Sets the **Type of Measurement** to reflection (0) or transmission (1) for the specified *operationType*. The *operationType* is 0 for *device measurement*, 1 for *full calibration*, or 2 for *internal calibration*. If no

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operationType is specified, the instrument will be set for scanning, or *measurement* (0).

Response: None.

Examples: "CONF:TEST 0" or "CONF:TEST 0,0" sets the **Type of Measurement** for *device measurement* (scanning) to reflection.

"CONF:TEST 1,1" sets the **Type of Measurement** for *full calibration* to transmission.

CONFigure:TEST?

Usage: CONF:TEST? {*operationType}*

Description: Queries the OVA for the current **Type of Measurement** for the specified *operationType*: 0 for *device measurement*, 1 for full *calibration*, or 2 for *internal calibration*. If no *operationType* is specified, the query will return the **Type of Measurement** for *device measurement*.

Response: Returns "0" if the **Type of Measurement** is set for reflection, or "1" for transmission.

Examples: "CONF:TEST?" or "CONF:TEST? 0" returns the **Type of Measurement** for *device measurement* in the form "0" for reflection or "1" for transmission.

"CONF:TEST? 1" returns the **Type of Measurement** for *full calibration* in the form "0" for reflection or "1" for transmission.

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Data Capture and Retrieval Commands

FETCh:FREQuency?

Usage: FETC:FREQ?

Description: Queries the OVA for the starting frequency and the increment size, both in units of GHz.

Response: Returns two numeric values delimited by a comma. The first value is the starting frequency (GHz), and the second value is the frequency increment size/sample spacing (GHz).

If a successful scan has not been made before this query, the OVA will respond with a 0, indicating that there is no data available. The cause of error can be retrieved by using the SYST:ERR? query.

Example: FETC:FREQ?

This query returns a message in the form "195000,0.321073," meaning the starting frequency is 195000 GHz and the frequency increment size/Sample Spacing is 0.321073 GHz.

FETCh:TimedomainINCrement?

Usage: FETC:TINC?

Description: Queries the OVA for the time increment of the **Time Domain Window** X-axis in nanoseconds (ns).

Response: Returns the time increment of the **Time Domain Window** X-axis in nanoseconds (ns).

If a successful scan has not been made before this query, the OVA will respond with a 0, indicating that there is no data available.

Example: FETC:TINC?

This query returns a message in the form "0.000567" ns.

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FETCh:FSIZe?

Usage: FETC:FSIZ?

Description: Queries the OVA for the size of the data arrays.

                This query should be called before retrieving the X-axis or the optical test results (insertion loss, group delay, etc.) if the controller program needs to pre-allocate space for the data.

Response: The response is an integer indicating the number of data samples to expect from the FETC:XAXI? and FETC:MEAS? queries.

                If a successful scan has not been made before this query, the OVA responds with 65536, the largest data array size available. The cause of error can be retrieved by using the SYST:ERR? query.

Example: FETC:FSIZ?

                This query returns a message in the form "4096" data points.

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FETCh:MEASurement?

Usage: FETC:MEAS? {*x*}

Description: Queries the OVA for the measured data array for the Jones matrix parameter specified by *x*.

The parameter *x* can take values from 0 to 14:

	Jones Matrix Parameter	units
0	Insertion Loss	dB
1	Group Delay	ps
2	Chromatic Dispersion	ps/nm
3	Polarization Dependent Loss	dB
4	Polarization Mode Dispersion	ps
5	Linear Phase Deviation	rad
6	Quadratic Phase Deviation	rad
7	Jones Matrix Element Amplitudes	
8	Jones Matrix Element Phases	rad
9	Time Domain (Amplitude)	GW/J
10	Time Domain (Wavelength)	nm
11	Min/Max Loss	dB
12	Second Order PMD	ps^2
13	Phase Ripple Linear	rad
14	Phase Ripple Quadratic	rad

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This query is usually preceded by the FETC:FSIZ? query to determine the number of data points that will be returned.

Response: Returns an array with each element in floating point format with ten significant digits and possible exponent field of the

form [?]d.ddddddddd[e[?]ddd].

If space needs to be allocated for the receiving buffer, the amount required for each element is 18, including a carriage return as the delimiter.

If a successful scan has not been made before this query, the OVA will respond, "An attempt was made to retrieve data, when no data was acquired or loaded." The cause of error can be retrieved by using the SYST:ERR? query.

Example: FETC:MEAS? 8

This query returns the Jones Matrix element phases (rad) in the form:

-0.169698
-0.182416
-0.151350

and so on.

FETCh:MeasurementDETails?

Usage: FETC:MDET?

Description: Queries the OVA for current measurement details for Matrix A.

Response: Returns a string of information (shown below) about the current Matrix A data.

If a successful scan has not been made before this query, the OVA will respond, "An attempt was made to retrieve data, when no data was acquired or loaded." The cause of error can be retrieved by using the SYST:ERR? query.

Example: FETC:MDET?

This query returns a message in the form:

DUT Length (m): 3.000000
End Wavelength (nm): 1605.000000
Segment Size: 32768
Measurement Type: 1
Sample Spacing (GHz): 0.335265

Start Frequency (ns): 185634.000000

Time Increment (ns): 0.000153

TD Windowed RSBW (GHz): 3.521000

Number of Averages: 5

Measurement Time Stamp: 3/1/2008 09:20:45

Commands for OVA *only*

OVA-only System Command

SYSTem:FullCALibration

Usage:	SYST:FCAL
Description:	Performs a full calibration of the OVA with the PDL calibration option on.
	The OVA control software will prompt the user to connect and move the supplied polarization controller paddles.
Response:	None.
Notes:	Do not use this command in automated test scripts because this command requires user interaction with the OVA software and hardware.
	This process may take several minutes to complete, so adjust application time-outs accordingly.
	A full calibration should be performed every 72 hours.
	Poll for *OPC? to see whether the operation is completed or not.

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SYSTem:InternalCALibration

Usage:	SYST:ICAL
Description:	Performs an internal calibration.
Response:	None.
Notes:	This command does not perform a full calibration of the system. A full calibration should be performed every 72 hours using the SYST:FCAL command, or as described

under "Calibrating the System" on page 34. Internal calibrations should be performed more frequently, as described under "Conditions that Require Calibration" on page 35.

This process may take several minutes to complete, so adjust application time-outs accordingly.

Poll for *OPC? to see whether the operation is completed or not.

SYSTem:QCALibration

Usage:	SYST:QCAL
Description:	Performs a full calibration of the OVA with the PDL calibration option off.
	A reference patchcord or gold reflector [depending on the **Type of Measurement** set using the CONF:TEST command. (See "CONFigure:TEST" on page 149.)] must be connected to the OVA before issuing this command.
Response:	None.
Notes:	This process may take several minutes to complete, so adjust application time-outs accordingly.
	Poll for *OPC? to see whether the operation is completed or not.

SYSTem:FILTer

Usage:	SYST:FILT
Description:	Applies the smoothing filter to all data currently in the memory of the OVA PC.
Response:	None.
Note:	This command applies the filter to data stored in Matrices A, B, and C, but only data in Matrix A is available for retrieval through a remote interface.

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SYSTem:SWEEp

Usage:	SYST:SWEE
Description:	Opens the laser **Source** switch and sweeps the laser through the user-specified wavelengths without performing a scan. This command allows the OVA to function as a tunable light source. Depending on the wavelength range setting, this command can take up to 15 seconds to complete.
Response:	None.
Notes:	Use the CONF:WAVE command (page 172) to set the wavelength for this command.
	It is necessary to close the **Source** switch (using the CONF:SOUR 1" command, page 172) after a sweep before performing a measurement scan.
	It is *not* necessary to open the **Source** switch (using "CONF:SOUR 0" command) before performing a sweep, as the SYST:SWEE command begins by opening the **Source** switch.

SYSTem:SAVeJonesmatrix

Usage:	SYST:SAVJ "{*filename.bin*}"
Description:	Saves the current Jones matrix data in Matrix A as binary data in the *filename.bin* specified.
	An error flag will be set if no data is available to save. The cause of error can be determined by using the SYST:ERR? query.
Response:	None.
Note:	The entire file path must be in quotes, and the file type ".*bin*" must be specified. This command always saves the data from Matrix A.
Example:	SYST:SAVJ "*C:\SavedFiles\JM.bin*" saves the data from Matrix A into the file "JM.bin."

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SYSTem:SAVeStextfile

Usage:	SYST:SAVS "{*filename.txt*}"
Description:	Saves the current data in Matrix A as text data in the *filename.txt* specified. The spreadsheet will contain all parameters.
	An error flag will be set if no data is available to save. The cause of error can be determined by using the SYST:ERR? query.
Response:	None.
Note:	The entire file path must be in quotes, and the file type ".txt" must be specified. This command always saves the data from Matrix A.
Example:	SYST:SAVS "*C:\SavedFiles\measData.txt*" saves the data from Matrix A into the file "*measData.txt.*"

SYSTem:SAVText

Usage:	SYST:SAVT "{*filename.txt*}"
Note:	This same command works with different variables in the OFDR software (see page 176).
Description:	Writes the OVA spreadsheet file to the given name. The file name must be in quotes, and the file type ".txt" must be specified.
	SYST:SAVT writes only the curves selected in the "Select Save Options" dialog in the OVA software. This command is similar to SYST:SAVS, except that SYST:SAVS saves all available curve types, not just the selected curves.
Response:	None
Example:	SYST:SAVT "*C:\data.txt*"
	Saves the selected curves to the file "*C:\data.txt*"

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OVA-only Configuration Commands

CONFigure:AlwaysApplyFilter

Usage:	CONF:AAF {0|1}
Description:	Enables (1) or disables (0) the **Always Apply Filter** boolean. Once this flag is enabled, the resolution bandwidth smoothing filter will be applied automatically. If this flag is disabled, the resolution bandwidth smoothing filter can be applied using "SYST:FILT." The **Always Apply Filter** boolean is disabled (0) if no value is specified.
Response:	None.
Example:	"CONF:AAF 0" disables the **Always Apply Filter** boolean.

CONFigure:AlwaysApplyFilter?

Usage:	CONF:AAF?
Description:	Retrieves the status of the **Always Apply Filter** boolean.
Response:	Returns "0" if the **Always Apply Filter** is disabled, or "1" if enabled.

CONFigure:AVeraGE

Usage:	CONF:AVGE {0|1}
Description:	Enables (1) or disables (0) matrix averaging. The averaging boolean is disabled (0) if no value is specified.
Response:	None.
Example:	"CONF:AVGE 1" enables matrix averaging.

CONFigure:AVeraGE?

Usage:	CONF:AVGE?
Description:	Retrieves the status of matrix averaging.
Response:	Returns "0" if the matrix averaging is disabled, or "1" if enabled.

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CONFigure:AVeraGeSet

Usage: CONF:AVGS {*number, operationType*}

Description: Sets the number of averages to the input *number* for the specified *operationType*. If the value is larger than the maximum number of averages allowed for the **Scan Range** specified by CONF:RANG, the number of averages will be set to the maximum value. If no value is specified, the number of averages is set to 1.

The *operationType* is 0 for *measurement*, 1 for *full calibration,* or 2 for *internal calibration.* If no *operationType* is specified, the OVA will be set for *measurement* (0).

Response: None.

Examples: "CONF:AVGS 10,0" sets the number of averages to 10 for measurement.

"CONF:AVGS 15,1" sets the number of averages to 15 for full calibration.

"CONF:AVGS 20" sets the number of averages to 20 for measurement, which is the default *operationType*.

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CONFigure:AVeraGeS?

Usage: CONF:AVGS? {*operationType*}

Description: Retrieves the number of averages taken per measurement for the specified *operationType*: 0 for *measurement* or 1 for *internal calibration*. If no *operationType* is specified, the query will return the number of averages for measurement.

Response: Returns the number of averages for the specified *operationType*: 0 for *measurement*, 1 for *full calibration*, or

2 for *internal calibration*. If no *operationType* is specified, the number of averages for *measurement* will be queried.

Examples: "CONF:AVGS?" or "CONF:AVGS? 0" returns the number of averages for *measurement*.

"CONF:AVGS? 2" returns the number of averages for *internal calibration*.

CONFigure:TimeDomainWindow

Usage: CONF:TDW {0|1}

Description: Enables (1) or disables (0) the menu setting **Options > Apply Time Domain Window**. The Option will be disabled (0) if no value is specified.

Response: None.

Example: "CONF:TDW 1" enables the menu setting **Options > Apply Time Domain Window**.

CONFigure:TimeDomainWindow?

Usage: CONF:TDW?

Description: Retrieves the status of the menu setting **Options > Apply Time Domain Window**.

Response: Returns "0" if **Options > Apply Time Domain Window** is disabled, or "1" if enabled.

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CONFigure:FindDUTlengthautomatically

Usage: CONF:FDUT {0|1}

Description: Enables (1) or disables (0) the menu setting **Options > Automatically Find DUT Length**. The option will be disabled (0) if no value is specified.

Response: None.

Example: "CONF:FDUT 1" enables the menu setting **Options > Automatically Find DUT Length**.

CONFigure:FindDUTlengthautomatically?

Usage: CONF:FDUT?

Description: Retrieves the status of **Options > Automatically Find DUT Length** menu option.

Response: Returns "0" if the status of **Options > Automatically Find DUT Length** is disabled, or "1" if enabled.

CONFigure:DUTLengthset

Usage: CONF:DUTL {*length*}

Description: Sets the DUT length to the value specified in meters. When this command is sent without a numeric parameter, the OVA determines the length of the DUT automatically using the method selected using "CONF:DUTM."

Response: None.

Examples: "CONF:DUTL 4.3125" sets the length of the DUT to 4.3125 m.

"CONF:DUTL" causes the OVA to scan the DUT and determine its length.

CONFigure:DUTLength?

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Usage: CONF:DUTL?

Description: Queries the OVA for the current DUT length.

Response: Returns the current DUT length in meters.

If the DUT length has not been set by a previous CONF:DUTL command or by using the graphical interface of the OVA software, the default value (3.000) is returned.

CONFigure:DUTlengthfindMethod

Usage: CONF:DUTM {0|1}

Description: Sets the **DUT Length Find Method**.

                     When the parameter is "0," the method is set to **Narrowband**, and when it is set to "1," the method is set to **Broadband**.

Response: None.

Examples: "CONF:DUTM 0" sets the **DUT Length Find Method** to **Narrowband**.

                     "CONF:DUTM 1" sets the **DUT Length Find Method** to **Broadband**.

CONFigure:DUTlengthfindMethod?

Usage: CONF:DUTM?

Description: Queries the OVA for the current method of determining DUT length.

Response: Returns "0" if the **DUT Length Find Method** is set to **Narrowband**, or "1" for **Broadband**.

CONFigure:DUTName

Usage: CONF:DUTN "{*name*}"

Description: Sets the **Device Descriptor** to *name*. The descriptor must be within quotes. If no name is specified, the **Device Descriptor** remains empty.

Response: None.

Example: CONF:DUTN "OVA-TEST"

                     This command sets the **Device Descriptor** to OVA-TEST.

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CONFigure:DUTName?

Usage:	CONF:DUTN?
Description:	Retrieves the **Device Descriptor**.
Response:	Returns the **Device Descriptor**. If no name was assigned for DUT, the default empty string is returned.

CONFigure:PhaseDEviationCursor

Usage:	CONF:PDEC {$x1$, $x2$}
Description:	Defines the effective pass band for linear and quadratic phase deviation measurements, bounded by the cursors $x1$ and $x2$. A subsequent FETC:MEAS 5? (linear phase deviation) or FETC:MEAS 6? (quadratic phase deviation) query will recalculate the phase deviation prior to returning the data.
Response:	None.

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CONFigure:PULSecompression

Usage: CONF:PULS {*enabled*, *averageDispersion, referenceWL, dispersionSlope*}

Description: Sets the OVA's **Pulse Compression** settings, which correspond to settings made in the **Options > Pulse Compression Settings** window.

Enabled, the first parameter, enables (1) or disables (0) pulse compression.

The second parameter sets the *averageDispersion* in ps/mm.

The third sets the *referenceWavelength* in nm.

The last parameter sets the *dispersionSlope* in ps/nm^2.

Response: None.

Examples: CONF:PULS 1, 2.5, 1555, 0

Enables pulse compression, with an average dispersion of 2.5 ps/nm, a reference wavelength of 1555 nm, and a dispersion slope of 0 ps/nm^2.

CONF:PULS 0

Disables pulse compression.

Note: Pulse compression is a purchased option for the OVA. If this feature has not been purchased, the CONF:PULS command will be ignored.

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CONFigure:PULSecompression?

Usage: CONF:PULS?

Description: Queries the OVA for the pulse compression settings.

Response: Returns the following pulse compression parameters,
                separated by commas:

                1 if pulse compression is enabled, 0 if disabled.

                Average Dispersion in ps/mm.

                Reference Wavelength in nm.

                Dispersion Slope in ps/nm^2.

Example: CONF:PULS?

                This query returns a message in the form
                "1,0.00,1550.00,0.00". This response would indicate that
                compression is enabled with an average dispersion of 0 ps/
                nm, a reference wavelength of 1550 nm, and a dispersion
                slope of 0 ps/nm^2.

Note: Pulse compression is a purchased option for the OVA. If this
                feature has not been purchased, the CONF:PULS?
                command will be ignored.

CONFigure:DISPersion

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Usage: CONF:DISP {x}

Description: Sets the average dispersion (ps/nm) used for pulse
                compression. This corresponds to setting average dispersion
                in the **Options > Pulse Compression Settings** window.

Response: None.

Example: "CONF:DISP 4.25" sets the average dispersion to 4.25 ps/
                nm.

Note: To set all of the pulse compression settings, use the
                CONF:PULS command above.

CONFigure:DISPersion?

Usage:	CONF:DISP?
Description:	Retrieves the average dispersion (ps/nm) used for pulse compression.
Response:	Returns the average dispersion in the form "4.25".

CONFigure:ReSolutionBandwidthUnits

Usage:	CONF:RSBU {0|1}
Description:	Configures the **Resolution Bandwidth Units** for both filters to either picometers (1) or gigahertz (0). If no parameter is selected, the OVA sets the resolution bandwidth units to GHz.
Response:	None.
Examples:	"CONF:RSBU 1" sets the **Resolution Bandwidth Units** to picometers.
	"CONF:RSBU 0" sets the **Resolution Bandwidth Units** to gigahertz.

CONFigure:ReSolutionBandwidthUnits?

Usage:	CONF: RSBU?
Description:	Retrieves the **Resolution Bandwidth Units**.
Response:	Returns "1" if the **Resolution Bandwidth Units** are picometers, and "0" if they are gigahertz.

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CONFigure:FilterResolutionBandWidth

Usage:	CONF:FRBW {*value*}
Description:	Sets the smoothing **Filter Resolution Bandwidth** to the requested value in the units specified using CONF:RSBU.
Response:	None.
Note:	If the specified value is not a valid setting, the smoothing filter resolution bandwidth is set to the value of the time domain filter resolution bandwidth. Query the system using

the SYST:ERR? command to ensure that the requested value was valid.

Example: "CONF:RSBW 0.125" sets the **Filter Resolution Bandwidth** to 0.125 in the units specified using CONF:RSBU.

CONFigure:FilterResolutionBandWidth?

Usage: CONF:FRBW?

Description: Queries the OVA for the current smoothing **Filter Resolution Bandwidth**.

Response: Returns the current smoothing **Filter Resolution Bandwidth** in the units specified using CONF:RSBU.

Example: CONF:FRBW?

This query returns the current smoothing **Filter Resolution Bandwidth** in the form "1.50" in the units specified using CONF:RSBU.

CONFigure:TimedomainWindowResolutionBandwidth?

Usage: CONF:TWRB?

Description: Queries the OVA for the current **Time Domain Window Resolution Bandwidth**.

Response: Returns the current **TD Window Res BW** in the units specified using CONF:RSBU. The default value is 0.00.

Example: CONF:TWRB?

This query returns a message in the form "10.00" in the units specified using CONF:RSBU.

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CONFigure:ConvolvedResolutionBandWidth?

Usage:	CONF:CRBW?
Description:	Queries the OVA for the **Convolved Resolution Bandwidth**.
Response:	Returns the **Convolved Res BW** in the units specified using CONF:RSBU. The default value is 0.00.
Example:	CONF:CRBW?
	This query returns a message in the form "26.458" in the units specified using CONF:RSBU

CONFigure:SampleRESolution?

Usage:	CONF:SRES?
Description:	Queries the OVA for the current **Sample Resolution**.
Response:	Returns the current **Sample Resolution**.
Example:	CONF:SRES?
	This query returns a message in the form "6.13" ns.

CONFigure:TimedomainSIGma

Usage:	CONF:TSIG {*value*}
Description:	Sets the **Sigma** *value* in nanoseconds to create the **Time Domain Window**. Once this *value* is set, the **Time Domain Window** will be calculated and applied to the data currently in Matrix A. The change in the data can be identified by fetching any measurement data.
	The default value of sigma is 0.02 ns.
Response:	None.
Example:	"CONF:TSIG 0.50" sets the **Sigma** value to 0.50 ns.

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CONFigure:TimedomainSIGma?

Usage:	CONF:TSIG?
Description:	Queries the OVA for the current value of **Sigma (ns)** from the **Time Domain Window**.
Response:	Returns the value of **Sigma (ns)**. The default value is 0.02 ns.
Example:	CONF:TSIG?
	This query returns a message in the form "0.02" ns.

CONFigure:TimeLIMits

Usage:	CONF:TLIM {*lowerLimit*, *upperLimit*}
Description:	Sets the limits in nanoseconds that determine the roll-off points for the flat-top Gaussian filter function in the time domain. Once these values are set, the time domain filter will be calculated and applied to the data currently in Matrix A. The change of data can be identified by fetching any measurement data.
Response:	None.
Note:	The default upper and lower limits are set at 10% and 90% of **Time Domain Window** X-axis width.
Example:	"CONF:TLIM 1.50,1.80" sets the **Time Domain Window** X-axis limits to 1.50 ns and 1.80 ns.

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CONFigure:TimeLIMits?

Usage:	CONF:TLIM?
Description:	Queries the OVA for the current **Time Domain Window** limits.
Response:	Returns the current **Impulse Response** X-axis limits used to create the **Time Domain Window**. The response is in the units of nanoseconds.
Example:	CONF:TLIM?
	This query returns a message in the form "1.05,1.80" in ns.

CONFigure:TimedomainsettingsRETain

Usage:	CONF:TRET {0|1}
Description:	Enables (1) or disables (0) the **Retain Settings** function in the **Time Domain Window**. Enabling will retain the current **Time Domain Window** parameters and apply them to future measurements.
Response:	None.
Examples:	"CONF:TRET 0" disables the **Retain Settings** function.
	"CONF:TRET 1" retains **Time Domain Window** settings.

CONFigure:TimedomainsettingsRETain?

Usage:	CONF:TRET?
Description:	Queries the OVA for the **Retain Settings** status in the **Time Domain Window**.
Response:	Returns "1" if **Retain Settings** is enabled in the **Time Domain Window**, or "0" if it is disabled.
Example:	CONF:TRET?
	This query returns a message in the form "1."

CONFigure:TimedomainHANning

Usage:	CONF:THAN {0|1}
Description:	Enables (1) or disables (0) the **Time Domain Hanning Window**.
Response:	None.
Example:	"CONF:THAN 0" disables the **Time Domain Hanning Window**.
Note:	By default, the Hanning window is applied to time domain data.

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CONFigure:TimedomainHANning?

Usage:	CONF:THAN?
Description:	Queries the OVA to determine if the Hanning window is currently being applied to the time domain data.
Response:	Returns "1" if the **Time Domain Hanning Window** is enabled, or "0" if it is disabled.

CONFigure:SOURce

Usage:	CONF:SOUR {0|1}
Description:	Sets the **Source** switch position to either Open (0) or Closed (1).
Response:	None.
Example:	"CONF:SOUR 1" sets the **Source** switch to the Closed position.
Note:	Use this command to return to normal OVA operation after using the SYST:SWEE command (see page 157).

CONFigure:SOURce?

Usage:	CONF:SOUR?
Description:	Queries the **Source** Switch position.
Response:	Returns "0" if the **Source** switch is Open, "1" if Closed.

CONFigure:WAVElength

Usage:	CONF:WAVE
Description:	Sets the wavelength to be used by the command SYST:SWEE (page 157).
Response:	None.
Example:	"CONF:WAVE 1550.00" sets the light source mode wavelength to 1550.00 nm.

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CONFigure:WAVElength?

Usage: CONF:WAVE?

Description: Queries the wavelength to be used by the command
              SYST:SWEE (page 157).

Response: Returns the light source mode wavelength in the form
              "1550.00" nm.

OVA-only Data Capture and Retrieval Commands

FETCh:PolarizationDependentFrequency?

Usage: FETC:PDF? {*centerFrequency, threshold*}

Description: Queries the OVA for the polarization dependent frequency
              for the specified center frequency (GHz) and threshold (dB).

Response: Returns the polarization dependent frequency in units of
              GHz.

Example: FETC:PDF? 193000, 0.5

              Returns the polarization dependent frequency for 193000
              GHz and 0.5 dB, in the form "0.318247" GHz.

FETCh:JONesElements?

Usage: FETC:JONE?

Description: Queries the OVA for the raw Jones matrix elements, with
              real and imaginary parts.

Response: Returns the Jones matrix data in the form:

              A_{real} A_{imag} B_{real} B_{imag} C_{real} C_{imag} D_{real} D_{imag}

              ...

Note: Each Jones Matrix element (A_{real}, A_{imag}, etc.) is separated
              by a tab character, with each data point separated by a line
              break.

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FETCh:XAXIs?

Usage:	FETC:XAXI? {*x*}
Note:	This same command works with different variables in the OFDR software (see page 187).
Description:	Queries the OVA for the X-axis (frequency domain or time domain) data. The number of data points expected should be determined by first using the FETC:FSIZ? query.

The parameter *x* can take values from 0 to 4:

0 - Frequency Domain (nm)

1 - Frequency Domain (GHz)

2 - Frequency Domain (THz)

3 - Time Domain (ns)

4 - Frequency Domain (m)

The default query "FETC:XAXI?" will return values for the frequency domain in nanometers.

Response:	Returns an array with each element in floating point format with ten significant digits and possible exponent field of the form [?]d.ddddddddd[e[?]ddd].

If space needs to be allocated for the receiving buffer the amount required for each element is 18, including a carriage return as the delimiter.

If a successful scan has not been made before this query, the OVA will respond, "An attempt was made to retrieve data, when no data was acquired or loaded." The cause of error can be retrieved by using the SYST:ERR? query.

Examples:	"FETC:XAXI? 0" or "FETC:XAXI?"

Either of these queries returns the Frequency Domain X-axis data in nanometers, in the form:

1509.97
1509.99
1510.01

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1510.02 and so on.

"FETC:XAXI? 3"

This query returns the **Time Domain Window** X-axis data in nanoseconds, in the form:

0.3250

0.3255

0.3260

0.3265 and so on.

Commands for OFDR *only*

OFDR-only System Level Commands

SYSTem:ACQuired?

Usage:	SYST:ACQ?
Description:	Queries whether data has been acquired.
Response:	Returns "1" if data has been acquired by the OFDR, "0" if not.

SYSTem:CALibration

Usage:	SYST:CAL
Description:	**Calibrates** the system for either reflection or transmission, as set by the CONF:TEST command.
	A gold reflector must be connected to the OFDR before issuing this command.
Response:	None.
Notes:	This process may take several minutes to complete, so adjust application time-outs accordingly.
	Poll for *OPC? to see whether the operation is completed.

SYSTem:CALibrationFile

Usage:	SYST:CALF {*measurementType*, filename}
Description:	Sets the name of the calibration file for the **Type of Measurement** specified: reflection (0) or transmission (1). If the filename is not specified, this command sets

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calibration file to the default filename for reflection (ofdrCal_refl) or transmission (ofdrCal_trans).

Response:	None.
Example:	SYST:CALF 1, c_band
	This instructs the OFDR to use the "c_band" calibration file for transmission measurements.
	SYST:CALF 0
	This instructs the OFDR to use the default calibration file for reflection, ofdrCal_refl.

SYSTem:CALibrationFile?

Usage:	SYST:CALF? {*measurementType*}
Description:	Retrieves the name of the calibration file for the **Type of Measurement** specified: reflection (0) or transmission (1).
Response:	Returns the name of the calibration file currently in use.

SYSTem:COPY

Usage:	SYST:COPY {*source, destination*}
Description:	Copies data from the *source* trace to the *destination* trace.
Response:	None.
Example:	SYST:COPY A, C
	Copies the data from Trace A to Trace C.

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SYSTem:SAVText

Usage:	SYST:SAVT {*"filename.txt", trace, domain, graphType, units, spatialResolution*}
Note:	This same command works with different variables in the OFDR software (see page 158).
Description:	Saves the specified *trace* (A, B, C, D or E) data as a spreadsheet or text file using the specified filename. The file name must be in quotes, with the file type ".txt" inside the

quotes as well. If no *trace* is specified, *Trace A* will be saved.

Domain can be set to 0 for time domain, or 1 for frequency domain.

GraphType can take values from 0 to 2, as shown below. The assignment of *graphType* depends on which *domain* is specified.

	Graph/Parameter Name
Time Domain (*domain* = 0) Values	
0	Amplitude
1	Phase Derivative
2	Linear Amplitude
Frequency Domain (*domain* = 1) Values	
0	Insertion Loss
1	Group Delay
2	Phase

Units for the time domain can be set to 0 for time (ns), 1 for length (m), or 2 for length (ft).

Units for the frequency domain can be set to 0 for wavelength (nm), 1 for frequency (GHz), or 2 for frequency (THz).

SpatialResolution sets the spatial **Resolution Bandwidth** (mm).

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Response: None.

Example: SYST:SAVT "C:\SavedFiles\measData.txt", E

Saves the data from Matrix E into the file "measData.txt."

OFDR-only Configuration Commands

CONFigure:FrequencydomainWINdow

Usage: CONF:FWIN {0|1}

Description: Sets the frequency domain window flag, indicating whether or not a frequency domain window is applied to new measurements. A value of 0 (do not apply window) or 1 (apply window) must be specified as a parameter.

Response: None

Example: CONF:FWIN 1

                This command causes the frequency domain filter to be applied to all new measurement scans.

CONFigure:FrequencydomainWINdow?

Usage: CONF:FWIN?

Description: Queries the frequency domain window flag, indicating whether or not a frequency domain window is applied to new measurement scans.

Response: Returns a value of 0 (window is not applied) or 1 (window is applied).

Example: CONF:FWIN?

                This query returns 0 or 1.

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CONFigure:GRouP

Usage: CONF:GRP {*groupIndex*}

Description: Sets the OFDR **Group Index**.

Response: None.

CONFigure:GRouP?

Usage: CONF:GRP?

Description: Retrieves the OFDR **Group Index**.

Response: Returns the OFDR **Group Index**.

CONFigure:INTegrationWidth

Usage:	CONF:INTW {*integrationWidth*}
Description:	Sets the OFDR integration width (m).
Response:	None.
Note:	The integration width, along with the integration start (CONF:INTS) or center set (CONF:INTC) commands, defines the area that will be used for data capture and retrieval commands such as FETC:MEAS. All frequency domain values are based on this integration width and start or center. Setting the integration width to 0 indicates that the entire measurement area should be used for such commands.
	Setting the integration width will cause the integration center to be adjusted to match the new integration width and the integration start set using the CONF:INTS command.

CONFigure:INTegrationWidth?

Usage:	CONF:INTW?
Description:	Retrieves the OFDR integration width in meters.
Response:	Returns the OFDR integration width in meters.

CONFigure:INTegrationStart

Usage:	CONF:INTS {*integrationStart*}
Description:	Sets the OFDR integration area start (m).
Response:	None.
Note:	Setting the integration start will cause the integration center to be adjusted to match the new integration start and the integration width set using the CONF:INTW command.

CONFigure:INTegrationStart?

Usage:	CONF:INTS?
Description:	Retrieves the OFDR integration area start in meters.
Response:	Returns the OFDR integration area start in meters.

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CONFigure:INTegrationCenter

Usage:	CONF:INTC {*integrationCenter*}
Description:	Sets the OFDR integration center start (m).
Response:	None.
Note:	Setting the integration center will cause the integration start to be adjusted to match the new integration center and the integration width set using the CONF:INTW command.

CONFigure:INTegrationCenter?

Usage:	CONF:INTC?
Description:	Retrieves the OFDR integration area center in meters.
Response:	Returns the OFDR integration area center in meters.

CONFigure:RESolutionGhz?

Usage:	CONF:RESG?
Description:	Retrieves the **Resolution Bandwidth** in GHz.
Response:	Returns the **Resolution Bandwidth** in GHz.

CONFigure:RESolutionPicometers?

Usage:	CONF:RESP?
Description:	Retrieves the **Resolution Bandwidth** in picometers.
Response:	Returns the **Resolution Bandwidth** in picometers.

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CONFigure:SpatialresolutionFILter

Usage:	CONF:SFIL {0|1}
Description:	Sets the **Spatial Resolution Filter**, or smoothing filter, flag on (1), or off (0).
Response:	None.
Note:	Data can be filtered after a scan.

CONFigure:SpatialresolutionFILter

Usage:	CONF:SFIL?
Description:	Retrieves the **Spatial Resolution Filter** flag.
Response:	Returns "1" if the **Spatial Resolution Filter** flag is on, "0" if it is off.

CONFigure:SpatialResolutionBandWidth

Usage:	CONF:SRBW {*spatialResolution*}
Description:	Sets the spatial **Resolution Bandwidth** (mm).
Response:	None.

CONFigure:SpatialResolutionBandWidth?

Usage:	CONF:SRBW?
Description:	Retrieves the spatial **Resolution Bandwidth** in millimeters.
Response:	Returns the spatial **Resolution Bandwidth** in millimeters.

CONFigure:SpatialResolutionFilterWidth

Usage:	CONF:SRFW {*filterWidth*}
Description:	Sets the **Spatial Resolution Filter** width (ns).
Response:	None.

CONFigure:SpatialResolutionFilterWidth?

Usage:	CONF:SRFW?
Description:	Retrieves the **Spatial Resolution Filter** width in nanoseconds.
Response:	Returns the **Spatial Resolution Filter** width in nanoseconds.

CONFigure:XaxisUNIts

Usage:	CONF:XUNI {units}
Description:	Sets the X-axis units being used to specify the integration area. These are the units that will be used by the CONF:INTW, CONF:INTS, and CONF:INTC commands and queries to report or set the integration width, start, and center. The units parameter must have one of the following values:
	0 : nanoseconds
	1 : meters
	2 : feet
Response:	None
Example:	CONF:XUNI 0
	CONF:INTW?

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Response: 15.010384

The CONF:XUNI command sets the x-axis units to nanoseconds. This means that the CONF:INTW? response should be interpreted as 15.01 nanoseconds, and that any CONF:INTW, CONF:INTS, or CONF:INTC commands should specify their units in nanoseconds.

CONFigure:XaxisUNIts?

Usage:	CONF:XUNI?
Description:	Queries the X-axis units being used to specify the integration area. These are the units that will be used by the CONF:INTW, CONF:INTS, and CONF:INTC commands and queries to report or set the integration width, start, and center.
Response:	Returns a number indicating the x-axis units used to define the integration area. The possible responses are:

0 : nanoseconds

1 : meters

2 : feet

Example:	CONF:XUNI?

Response: 1

CONF:INTW?

Response: 1.5

The CONF:XUNI? response of 1 means that x-axis units are meters. This means that the CONF:INTW? response should be interpreted as 1.5 meters, and that any CONF:INTW, CONF:INTS, or CONF:INTC commands should specify their units in meters.

OFDR-only Data Capture and Retrieval Commands

FETCh:RAW?

Usage:	FETC:RAW? {*trace*}
	Trace is specified as a single letter: A, B, C, D or E.
Description:	Retrieves the raw S and P data for the specified *trace*.
	The portion of the data that is returned is determined from the integration area previously specified with the

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	CONF:INTW, CONF:INTS, and CONF:INTC commands. If the integration width is set to 0, then the data is returned for the entire measurement area.
Response:	Returns a series of four tab-separated numbers, each set of numbers representing the S and P values for a single point. The number of points is the same as the value obtained by sending the FETC:RSIZ? request with the same trace parameter.
	The values for each point are formatted as:
	{S real \<tab\> S imaginary \<tab\> P real \<tab\> P imaginary}
	The string "///" is returned after the last data point to indicate that the response is complete.
	If no *trace* is specified, the data for *Trace A* will be returned. If a successful scan has not been made before this query, the OFDR responds with "Trace A (B, etc.) contains no data."
Example:	FETC:RAW? C
	Returns the S and P data for *Trace C* in the form:

```
-6.27743856e+066   -6.27743856e+066  -6.27743856e+066   -6.27743856e+066
-6.27743856e+066   -6.27743856e+066  -6.27743856e+066   -6.27743856e+066
...
-6.27743856e+066   -6.27743856e+066  -6.27743856e+066   -6.27743856e+066
-6.27743856e+066   -6.27743856e+066  -6.27743856e+066   -6.27743856e+066
///
```

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FETCh:RawdataSIZe?

Usage:	FETC:RSIZ? {*trace*}
Description:	Retrieves the size of the raw S and P data for the specified *trace*. This is the number of data points that will be returned by the FETC:RAW? query using the current integration area as specified by the CONF:INTW, CONF:INTS, and CONF:INTC commands.
Response:	Returns the size of the raw S and P data for the specified *trace*.
	If no *trace* is specified, the data size for *Trace A* will be returned. If a successful scan has not been made before this query, the OFDR responds with "Trace A (B, etc.) contains no data."

FETCh:WaveLength?

Usage:	FETC:WL? {*trace*}
	Trace is specified as a single letter: A, B, C, D or E.
Description:	Retrieves the starting wavelength (nm) for the specified *trace*.
Response:	Returns the starting wavelength, in nanometers, for the specified *trace*. If no *trace* is specified, the starting wavelength for *Trace A* is returned. If a successful scan has not been made before this query, the OFDR responds with "Trace A (B, etc.) contains no data."

FETCh:WaveLengthCenter?

Usage:	FETC:WLC? {*trace*}
	Trace is specified as a single letter: A, B, C, D or E.
Description:	Retrieves the center wavelength (nm) for the specified *trace*.
Response:	Returns the center wavelength, in nanometers, for the specified trace. If no *trace* is specified, the center wavelength for *Trace A* is returned. If a successful scan has not been made before this query, the OFDR responds with "Trace A (B, etc.) contains no data."

FETCh:WaveLengthEnd?

Usage:	FETC:WLE? {*trace*}
	Trace is specified as a single letter: A, B, C, D or E.
Description:	Retrieves the ending wavelength (nm) for the specified *trace*.
Response:	Returns the ending wavelength, in nanometers, for the specified trace. If no *trace* is specified, the ending wavelength for *Trace A* is returned. If a successful scan has not been made before this query, the OFDR responds with "Trace A (B, etc.) contains no data."

FETCh:FrequencydomainDeTail?

Usage:　　　　FETC:FDTL? {*trace, graphType, decimate*}

　　　　　　　Trace is specified as a single letter: A, B, C, D or E.

　　　　　　　GraphType should be set to 1 for **Group Delay**, the only parameter which generates average.

　　　　　　　Decimate can be set to 1 to use decimation, or 0 to use all points when calculating the average delay.

Description:　 Retrieves the average delay (ns) for the specified *trace*.

Response:　　 Returns the average delay, in nanoseconds, for the specified trace. If no *trace* is specified, the average delay for *Trace A* is returned.

　　　　　　　If a successful scan has not been made before this query, the OFDR responds with "Trace A (B, etc.) contains no data."

FETCh:INTegrationLoss?

Usage:　　　　FETC:INTL? {*trace*}

　　　　　　　Trace is specified as a single letter: A, B, C, D or E.

Description:　 Retrieves the loss of the current integration area for the specified *trace*. The integration area is the area previously specified by the CONF:INTW, CONF:INTS, and CONF:INTC commands.

Response:　　 Returns the loss in dB for the current integration area of the specified *trace*. If no *trace* is specified, the loss for *Trace A* is returned. If a successful scan has not been made before this query, the OFDR responds with "Trace A (B, etc.) contains no data."

FETCh:TIMeStart?

Usage:　　　　FETC:TIMS? {*trace*}

　　　　　　　Trace is specified as a single letter: A, B, C, D or E.

Description:　 Retrieves the start time for the specified *trace*.

Response:　　 Returns the start time in nanoseconds for the specified trace. If no *trace* is specified, the start time for *Trace A* is returned. If a successful scan has not been made before this query, the OFDR responds with "Trace A (B, etc.) contains no data."

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FETCh:TIMEnd?

Usage:	FETC:TIME? {*trace*}
	Trace is specified as a single letter: A, B, C, D or E.
Description:	Retrieves the end time for the specified *trace*.
Response:	Returns the end time in nanoseconds for the specified *trace*. If no *trace* is specified, the end time for *Trace A* is returned. If a successful scan has not been made before this query, the OFDR responds with "Trace A (B, etc.) contains no data."

FETCh:LENgthStart?

Usage:	FETC:LENS? {*trace*}
	Trace is specified as a single letter: A, B, C, D or E.
Description:	Retrieves the start length for the specified *trace*.
Response:	Returns the start length in meters for the specified *trace*. If no *trace* is specified, the start length for *Trace A* is returned. If a successful scan has not been made before this query, the OFDR responds with "Trace A (B, etc.) contains no data."

FETCh:LENgthEnd?

Usage:	FETC:LENE? {*trace*}
	Trace is specified as a single letter: A, B, C, D or E.
Description:	Retrieves the end length for the specified *trace*.
Response:	Returns the end length in meters for the specified *trace*. If no *trace* is specified, the end length for *Trace A* is returned. If a successful scan has not been made before this query, the OFDR responds with "Trace A (B, etc.) contains no data."

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FETCh:XAXIs?

Usage: FETC:XAXI? {*trace, domain, units, decimate*}

Trace is specified as a single letter: A, B, C, D or E.

Domain can be set to 0 for time domain, or 1 for frequency domain.

Units for the time domain can be set to 0 for time (ns), 1 for length (m), or 2 for length (ft).

Units for the frequency domain can be set to 0 for wavelength (nm), 1 for frequency (GHz), or 2 for frequency (THz).

Decimate can be set to 1 to use decimation, or 0 to return all points.

Note: This same command works with different variables in the OFDR software (see page 174).

Description: Retrieves the X-axis data for the specified parameters.

All parameters must be specified.

Response: Returns a series of numbers representing the X-axis data points for the requested area. The number of points is the same as the value obtained by sending the FETC:FSIZ? query with the same parameters. The string "///" is returned after the last data point to indicate that the response is complete.

The data are returned as an array with each element in floating point format with ten significant digits and possible exponent field of the form [?]d.ddddddddd[e[?]ddd].

If space needs to be allocated for the receiving buffer the amount required for each element is 18, including a carriage return as the delimiter.

If a successful scan has not been made before this query, the OFDR responds with "Trace A (B, etc.) contains no

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data." The cause of error can be retrieved by using the SYST:ERRD? query.

Example: FETC:XAXI? C, 1, 0, 1

This query returns the frequency domain X-axis data from Trace C, in nanometers, decimated, in the form:

> 1509.97
> 1509.99
> ...
> 1525.01
> 1525.02
> ///

Example Visual Basic Code

This section provides sample code in Visual Basic to explain how the OVA behaves when accessed remotely. Users can write their own applications in Visual Basic using the sample code given below for multiple types of parameters. Note: Visual Basic is used only as an example, and users may use other programming languages of their choosing.

Notes:

- The device GPIB handle is "OVAGpibHandle"

- To open an OVAGpibHandle use: OVAGpibHandle% = ildev (BOARD_INDEX, PRIMARY_ADDR, SECONDARY_ADDR, TIM-EOUT, EOTMODE, EOSMODE)

- To clear an OVA GpibHandle use: ilclr OVAGpibHandle%.

- To close an OVA GpibHandle use: ilonl OVAGpibHandle%, 0.

- To write to the instrument board use: ilwrt OVAGpibHandle%, OVA-Command, Len(OVACommand).

- To read the response from the instrument use: ilrd OVAGpibHandle%, Response, Len(Response).

- To check response size use: ibcntl.

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Sending Commands without Parameters

```
Public Sub DoScan()

    Const OVACommand = "SCAN"
    ilwrt OVAGpibHandle%, OVACommand, Len(OVACommand)

End Sub
```

Sending Commands with Single Numeric Parameters

```
Public Sub SetConfigureDutl(ByVal Dutl As Double)
' check input parameter

   If (Dutl < 0) Then
      Exit Sub
   End If

   Dim OVACommand As String

   OVACommand = "CONF:DUTL" & CStr(Dutl)
   ilwrt OVAGpibHandle%, OVACommand, Len(OVACommand)

End Sub
```

Sending Commands with Single String Parameters

```
Public Function CommandSystemLoadFile(ByVal FilePath As String)

   Dim OVACommand As String
   OVACommand = "SYST:LOAD "& FilePath
   ilwrt OVAGpibHandle%, OVACommand, Len(OVACommand)

End Function
```

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Sending Commands with Two Numeric Parameters

```
Public Sub ConfigureAxisIndeces(ByVal ParamString As String)

   Dim OVACommand As String

   OVACommand = "CONF:PDEC"& CStr(ParamString)
   ilwrt OVAGpibHandle%, OVACommand, Len(OVACommand)

End Sub
```

Sending Queries which return Numeric Results

```
Public Function QueryOperateComplete() As Integer

    Const OVACommand = "*OPC?"
    ilwrt OVAGpibHandle%, OVACommand, Len(OVACommand)
    Response = ""
    ilrd OVAGpibHandle%, Response, Len(Response)

    If ibcntl < Len(Response) And ibcntl > 0 Then
        Response = Left(Response, ibcntl)
    End If

    If IsNumeric(Response) Then
        QueryOperateComplete = CInt(Response)
    Else
        QueryOperateComplete = 0
    End If

End function
```

Sending Queries which return Double Results

```
Public Function QueryConfigureDutl() As Double

    Const OVACommand = "CONF:DUTL?"
    ilwrt OVAGpibHandle%, OVACommand, Len(OVACommand)
    Response = ""
    ilrd OVAGpibHandle%, Response, Len(Response)

    If ibcntl < Len(Response) And ibcntl > 0 Then
        Response = Left(Response, ibcntl)
    End If

    If IsNumeric(Response) Then
        QueryConfigureDutl = CDbl(Response)
    Else
        QueryConfigureDutl = 0
    End If

End function
```

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Sending Queries which return Two Double Results

```
Public Sub QueryFrequency(ByRef Frequency As Double, ByRef
Increment As Double)

    Dim TabPos As Integer
    Dim TempStr As String
    Const OVACommand = "FETC:FREQ?"
    ilwrt OVAGpibHandle%, OVACommand, Len(OVACommand)
    Response = ""
    ilrd OVAGpibHandle%, Response, Len(Response)

    If ibcntl < Len(Response) And ibcntl > 0 Then
        Response = Left(Response, ibcntl)
    End If

    TabPos = InStr(1, Response, vbTab)
    If (TabPos = 0) Then
        Exit Sub
    End If

    TempStr = Left(Response, TabPos - 1)
    If IsNumeric(TempStr) Then
        Frequency = CDbl(TempStr)
    Else
        Frequency = 0
    End If

    TempStr = Right(Response, Len(Response) - TabPos)

    If IsNumeric(TempStr) Then
        Increment = CDbl(TempStr)
    Else
        Increment = 0
    End If

End Sub
```

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Sending Queries which return String Results

```
Public Function QueryID() As String

    Const OVACommand = "*IDN?"
    ilwrt OVAGpibHandle%, OVACommand, Len(OVACommand)
    Response = ""
    ilrd OVAGpibHandle%, Response, Len(Response)
```

```
        If ibcntl <= Len(Response) And ibcntl > 0 Then
            QueryID = Left(Response, ibcntl)
        Else
            QueryID = ""
        End If


    End function
```

Sending Queries which return Arrays of Double Results

Sample Basic for the "FETC:XAXI? x", "FETC:MEAS? x" commands depends on the FetchData subroutine:

```
Public OVAGpibHandle As Integer

Const ElementLength = 18

Global Const JonesArraySize = 8

Const ArraySize = 1024              ' Size of read buffer

Dim Response As String * ArraySize ' fixed-length string

Private Sub FetchData(ByVal OVAQuery As String, ByRef _ DataArray()
As Double, ByVal DataSize As Long)
' DataArray is 1D array, that is, (0 To DataSize - 1)

    On Error Resume Next

    Dim PrevCRPos As Long, CurCRPos As Long
    Dim DynamicResponse As String, TempStr As String
    Dim ArrayIndex As Long
    Dim ExitLoop As Boolean

    If DataSize <= 0 Then
        Exit Sub
    End If

    ' Send Query
    ilwrt OVAGpibHandle%, OVAQuery, Len(OVAQuery)

    ' Allocate Buffer Dynamically
    DynamicResponse = Space(DataSize * ElementLength)

    ' Receive Data
```

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```
ilrd OVAGpibHandle%, DynamicResponse, Len(DynamicResponse)

If ibcntl <= Len(DynamicResponse) And ibcntl > 0 Then
    DynamicResponse = Left(DynamicResponse, ibcntl)
Else
    Exit Sub
End If


PrevCRPos = 1
ArrayIndex = 0
ExitLoop = False

Do
    CurCRPos = InStr(PrevCRPos, DynamicResponse, vbCr)

    If (CurCRPos = 0) Then
        CurCRPos = Len(DynamicResponse) + 1
        ExitLoop = True
    End If

    TempStr = Mid(DynamicResponse, PrevCRPos, CurCRPos -
PrevCRPos)

    If IsNumeric(TempStr) Then
        DataArray(ArrayIndex) = CDbl(TempStr)
    Else
        DataArray(ArrayIndex) = 0
    End If

    PrevCRPos = CurCRPos + 1
    ArrayIndex = ArrayIndex + 1
    If ArrayIndex = DataSize Then
        ExitLoop = True
    End If
Loop Until ExitLoop = True

End Sub
```

Command Errors

When a command is ill-formed, such as when a required parameter is omitted, the OVA ignores the command.

Use the SYST:ERR? query to retrieve the most recent error.

Execution Errors

Execution errors indicate problems during the execution of a valid command, and may happen when:

- The instrument fails to communicate to the control computer because of a problem with the instrument or cable connections.
- A command is given in an improper sequence; for example, a command to scan is given before the DUT length has been set.

Like command errors, execution errors can only be retrieved if the controlling computer queries the OVA using the SYST:ERRD? query.

OVA-Specific Application Notes

Working With Time Domain Impulse Response

The duration of the device impulse response is a useful piece of information that can be used to select the appropriate resolution bandwidth for the current measurement. The OVA provides a direct means to utilize this information using the Impulse Response Plot Window and the time domain filter. (See "The Time Domain Filter" on page 70.)

The same functionality can be achieved through remote operation. It is necessary that the remote interface provides a means to view measured data graphically. Use the following sequence of commands to set the time domain filter after data has been acquired using the SCAN command:

1 Fetch the time domain X-axis data in units of nanoseconds using FETC:XAXI? 3. (See "FETCh:XAXIs?" on page 174.)

2 Fetch the time domain (amplitude) data using FETC:MEAS? 9. (See "FETCh:MEASurement?" on page 153)

3 Plot the time domain (amplitude) vs. time, and determine the desired location of the time domain filter.

4 Set the limits of the time domain filter using CONF:TLIM {*lowerLimit*, *upperLimit*}. (See "CONFigure:TimeLIMits" on page 170.)

5 Set the value of **Sigma** (see "Examples: Setting the value of Sigma" on page 76) using CONF:TSIG {*value*}. (See "CONFigure:TimedomainSIGma" on page 169.)

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6 *Optional*: Retain the time domain filter settings for subsequent measurements using CONF:TRET 1. (See "CONFigure:TimedomainsettingsRETain" on page 171).

7 Fetch the desired frequency domain data using FETC:XAXI? and FETC:MEAS?. (See "FETCh:XAXIs?" on page 174 and "FETCh:MEASurement?" on page 153.) The result will have the time domain filter applied.

Using the OVA as a Light Source

The OVA may be used as a tunable light source using the SYST:SWEE command (see page 157). Following the command SYST:SWEE, the OVA opens the **Source** switch and performs a sweep of the user-specified wavelengths. Scanning and sweeping wavelengths may be set in the main window in the **System Control** area. They may also be set remotely using the CONF:CWL and CONF:RANG commands (see page 148).

Important	The user must close the **Source** switch after a sweep before scanning by issuing the command "CONF:SOUR 1" (see page 172).

The user does not need to use the "CONF:SOUR 0" command to open the **Source** switch prior to sweeping; this is done automatically by the command SYST:SWEE. (Using the separate "CONF:SOUR 0" command will not cause errors; it will only slow OVA processing).

The **Source** switch is set to its default closed state after calibration and after finding the DUT Length. The user may query the **Source** switch position using the CONF:SOUR? command (page 172).

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Setting Up a TCP/IP Console

Use the following steps to install a TCP/IP remote controller for the OVA instrument:

1 Copy the executable file named "SendCmd.exe" from the supplied CD to the local hard drive (usually the C:\ drive) of the host computer.

2 Run SendCmd.exe from the DOS command prompt.

3 Enter commands in the following format:

```
C:\SendCmd [CmdStr] [IPaddr] [PortNum] [Comment]
```

where

- [CmdStr] is the remote control command to be sent to the OVA.
- [IPaddr] is the IP address of the OVA PC.
- [PortNum] is the port number where OVA instrument is listening (port number is '1' by default, but this can be configured using pull down menu **Options > Remote Interface Setup**).
- [Comment] is an optional comment to be passed with the command.

Notes:

- Accessing the local machine does not require [IPaddr]. This option allows the console application to run on the OVA PC.

- The argument [IPaddr] can be a system name or an IP address of a machine where the OVA software is running.

- To ascertain the IP address of the OVA PC, select **Run** from the Windows® **Start** menu. Type in "ipconfig" in the text box and click **OK**. The IP address should be listed in the screen that opens. Or, the user may call "ipconfig" from the DOS command line to get the IP address.

Example:

```
SendCmd CONF:TEST? Ravi
     //Where "Ravi" is a machine name and "CONF:TEST?" is an
OVA query.

     -OR-

SendCmd CONF:TEST? 10.1.1.69 1
     //Where 10.1.1.69 is the IP address of the OVA computer
and port  number is 1.

     -OR-

SendCmd CONF:TEST?
     //In this case the TCP/IP console application is running
on the OVA computer rather than on a remote computer. Thus no
IP address is needed.
```

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- When accessing OVA remotely using TCP/IP, make sure to provide the port number. The OVA will be listening and responding at port 1 by default. The remote controller should use the same port number as the OVA.

- Commands, queries, and arguments must be in quotes if they contain spaces.

  Example:

  ```
  SendCmd "CONF:AVGS 5" 10.1.1.69 2
  ```

- To avoid problems in the parsing of commands, each optional argument must be replaced with "" in the command line if you do not want to give some optional arguments.

  Examples:

  ```
  SendCmd CONF:TEST? Ravi 2 "#Measurement Query"
  SendCmd CONF:TEST? "" "" "#Measurement Query"
  ```

- The results of a command or query can be redirected to a file using "> Filename" or ">> Filename" at the end of the command.

  Examples:

  ```
  SendCmd "FETC:MEAS? 1" > GDdata.txt
  SendCmd "FETC:MEAS? 3" >> PMDdata.txt
  ```

- The argument [Comment] may be up to 512 bytes in size and must be entered in quotes. If no comment is entered, a the default comment will appear, giving a general description of the command or query. Comments are generally used to record the type of data when results of a command are saved to a file. (For example, one might comment "PMD data acquired with 10 measurement averages.")

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- Multiple commands may be grouped together in scripts.

  Examples:

  ```
  systemSetup.sh is a shell script that runs all commands as a batch.
      {
          SendCmd SYST:ALIG 10.1.1.69 1
          SendCmd "CONF:TEST 1,1" 10.1.1.69 1
          SendCmd "CONF:CWL 1550.0,1" 10.1.1.69
          SendCmd "CONF:RANG 80,1" 10.1.1.69 1
          SendCmd "CONF:AVGS 5,1" 10.1.1.69 1
  ```

```
        SendCmd SYST:CAL 10.1.1.69 1
        SendCmd SYST:ERR? 10.1.1.69 1
    }
acqMeasurement.sh is a shell script that runs all commands as a
batch.
    {
        SendCmd "CONF:STAR 1525.00" 10.1.1.69 1
        SendCmd "CONF:RANG 80" 10.1.1.69 1
        SendCmd "CONF:DUTM 1" 10.1.1.69 1
        SendCmd CONF:DUTL? 10.1.1.69 1
        SendCmd SCAN 10.1.1.69 1
        SendCmd FETC:GD? 10.1.1.69 1 > C:\80nmScan\acquireGD.txt
        SendCmd FETC:CD? 10.1.1.69 1 > C:\80nmScan\acquireCD.txt
        SendCmd FETC:PMD? 10.1.1.69 1 > C:\80nmScan\acquirePMD.txt
    }
```

- All commands are case sensitive in this application, but the user may write applications without case sensitivity.

- Note that some of the OVA commands (SYST:CAL, SCAN, SYST:ALIG, CONF:DUTL) may require a large amount of time to run. When writing a host or controller application, make sure to allow enough delay for these commands. After executing one of these commands, check to see if the operation is complete using the query *OPC?.

8 Alphabetical Command Summaries

The table below provides summaries of GPIB and TCP/IP commands, listed alphabetically by command. For detailed information about each command, see "Commands for OVA and OFDR Software" above, beginning on page 137. All commands are given in their truncated form, and are case-sensitive. They must be entered exactly as they appear in this chapter. However, the user may write applications without case sensitivity.

Important	The OVA control software does not support multiple commands on a line, separated by semicolons. Enter each command on its own separate line.
✓	

Table 8-1: Alphabetical Summary of GPIB and TCP/IP Commands

Command	Description	Page	OBR / OFDR
IEEE 488.2 standard commands			
*CLS	Clears the status register.	138	Both
*ESE {*mask value*}	Sets the value {0-255} of the Status Enable register.	138	Both
*ESE?	Queries the current value of the Status Enable register.	138	Both
*ESR?	Queries the value of the Status Event Status register.	138	Both
*IDN?	Queries the OVA for its identification string.	138	Both
*OPC {0|1}	Sets the event bit in the Standard Event Status register, enabling (1) or disabling (0) "operation complete" event notification.	139	Both
*OPC?	Queries the OVA to determine if the operation is complete.	139	Both
*RST	Instructs the OVA to reset all parameters to the power-on defaults.	139	Both
*SRE {*n*}	Sets the Service Request Enable register to *n*, where *n* = 1-255.	139	Both
*SRE?	Queries the current value of the Service Request Enable register.	140	Both
*STB?	Queries the value of the Status Byte register.	140	Both
*TST?	Performs a self-test query.	140	Both
*WAI	Prevents the OVA from executing any further commands or queries until all pending operations have been completed.	140	Both
Configuration commands		**Page**	
CONF:AAF {0|1}	Enables (1) or disables (0) **Always Apply Filter**.	159	OVA

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Table 8-1: Alphabetical Summary of GPIB and TCP/IP Commands

CONF:AAF?	Retrieves the current status of **Always Apply Filter**.	159	OVA
CONF:AVGE {0|1}	Enables (1) or disables (0) matrix averaging.	159	OVA
CONF:AVGE?	Retrieves the current status of matrix averaging.	159	OVA
CONF:AVGS {*number*, *operationType*}	Sets the *number* of averages for the specified *operationType*: *measurement* (0), *full calibration* (1), or *internal calibration* (2).	160	OVA
CONF:AVGS? {*operationType*}	Retrieves the number of averages for the specified *operationType*: *measurement* (0), *full calibration* (1), or *internal calibration* (2).	160	OVA
CONF:CRBW?	Queries the OVA for the current **Convolved Resolution Bandwidth**.	169	OVA
CONF:CWL {*wavelength*, *operationType*}	Sets the **Center Wavelength** (nm) for the specified *operationType*: *measurement* (0), *full calibration* (1), or *internal calibration* (2). **Note:** For OFDR, the user does not specify an *operationType*.	146	Both, but with different variables.
CONF:CWL? {*operationType*}	Queries the OVA for the current **Center Wavelength** (nm) for the specified *operationType*: *measurement* (0) *full calibration* (1), or *internal calibration* (2).	147	Both
CONF:DISP {*x*}	Sets the average dispersion for pulse compression.	166	OVA
CONF:DISP?	Queries the average dispersion for pulse compression.	167	OVA
CONF:DUTL {*length*}	Sets the DUT length in meters.	162	OVA
CONF:DUTL?	Queries the OVA for the current DUT length.	162	OVA
CONF:DUTM {0|1}	Sets the method used to calculate the DUT length to **Narrowband** (0) or **Broadband** (1).	163	OVA
CONF:DUTM?	Queries the OVA for the current method of determining DUT length.	163	OVA

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Table 8-1: Alphabetical Summary of GPIB and TCP/IP Commands

CONF:DUTN "{*name*}"	Sets the **Device Descriptor** to the DUT *name* entered within quotes.	163	OVA
CONF:DUTN?	Retrieves the current DUT *name*.	164	OVA
CONF:END?	Queries the OVA for the current ending wavelength.	148	Both
CONF:FDUT {0|1}	Enables (1) or disables (0) the menu setting **Options > Automatically Find DUT Length**.	161	OVA
CONF:FDUT?	Returns "0" if the status of **Automatically Find DUT Length** is disabled, or "1" if enabled.	162	OVA
CONF:FRBW {*value*}	Sets the smoothing **Filter Resolution Bandwidth** in the units specified using CONF:RSBU {0|1}.	167	OVA
CONF:FRBW?	Queries the OVA for the current filter resolution bandwidth.	168	OVA
CONF:FWIN {0|1}	Sets the frequency domain window flag.	178	OFDR
CONF:FWIN?	Retrieves whether or not a frequency domain window is applied to new measurement scans.	178	OFDR
CONF:GRP	Sets the OFDR **Group Index**.	178	OFDR
CONF:GRP?	Retrieves the OFDR **Group Index**.	178	OFDR
CONF:INTC	Sets the OFDR integration center start (m).	180	OFDR
CONF:INTC?	Retrieves the OFDR integration area center in meters.	180	OFDR
CONF:INTS	Sets the OFDR integration area start (m).	179	OFDR
CONF:INTS?	Retrieves the OFDR integration area start in meters.	179	OFDR
CONF:INTW	Sets the OFDR integration width (m).	179	OFDR
CONF:INTW?	Retrieves the OFDR integration width in meters.	179	OFDR

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Table 8-1: Alphabetical Summary of GPIB and TCP/IP Commands

CONF:PDEC {*x1, x2*}	Defines the effective channel for linear and quadratic phase deviation measurements, bounded by *x1* and *x2*. A subsequent FETC:MEAS 5? (linear phase deviation) or FETC:MEAS 6? (quadratic phase deviation) query will recalculate the phase deviation prior to returning the data.	164	OVA
CONF:PULS {*enabled, averageDispersion, referenceWL, dispersionSlope*}	Sets the OVA's **Pulse Compression** settings. *enabled* enables (1) or disables (0) pulse compression. *averageDispersion* in ps/mm. *referenceWavelength* in nm. *dispersionSlope* in ps/nm2. This command will be ignored if the **Pulse Compression** option was not purchased with the OVA.	165	OVA
CONF:PULS?	Queries the OVA for the **Pulse Compression** settings (as listed above) separated by commas. This command will be ignored if the **Pulse Compression** option was not purchased with the OVA.	166	OVA
CONF:RANG {*scanRange, operationType*}	Sets the **Scan Range** in nanometers for the specified *operationType*: *measurement* (0), *full calibration* (1), or *internal calibration* (2).	148	Both
CONF:RANG? {*operationType*}	Queries the OVA for the current **Scan Range** for the specified *operationType*: *measurement* (0), *full calibration* (1), or *internal calibration* (2).	149	Both
CONF:RSBU {0|1}	Configures **Resolution Bandwidth Units** to pm (0) or GHz (1).	167	OVA
CONF:RESG?	Retrieves the **Resolution Bandwidth** in GHz.	180	OFDR
CONF:RESP?	Retrieves the **Resolution Bandwidth** in picometers.	180	OFDR
CONF:RSBU?	Queries for resolution bandwidth units.	167	OVA
CONF:SFIL	Sets the **Spatial Resolution Filter**, or smoothing filter flag on (1), or off (0). Data can be filtered after a scan.	180	OFDR

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Table 8-1: Alphabetical Summary of GPIB and TCP/IP Commands

CONF:SFIL?	Retrieves the **Spatial Resolution Filter** flag.	180	OFDR
CONF:SOUR {0|1}	Sets the **Source** switch position to either Open (1) or Closed (0).	172	OVA
CONF:SOUR?	Queries the **Source** Switch position.	172	OVA
CONF:SRBW	Sets the spatial **Resolution Bandwidth** (mm).	181	OFDR
CONF:SRBW?	Retrieves the spatial **Resolution Bandwidth** in millimeters.	181	OFDR
CONF:SRES?	Queries the OVA for the current **Sample Resolution**.	169	OVA
CONF:SRFW	Sets the **Spatial Resolution Filter** width (ns).	181	OFDR
CONF:SRFW?	Retrieves the **Spatial Resolution Filter** width in nanoseconds.	181	OFDR
CONF:STAR {*wavelength*}	This command has been replaced by CONF:CWL. Sets the start *wavelength* (nm) for the scan.	147	Both
CONF:STAR?	This command has been replaced by CONF:CWL?. Queries the OVA for the current start wavelength.	148	Both
CONF:TDW {0|1}	Enables (1) or disables (0) the menu setting **Options > Apply Time Domain Window**.	161	OVA
CONF:TDW?	Returns "0" if **Apply Time Domain Window** is disabled, or "1" if enabled.	161	OVA
CONF:TEST {*measurementType, operationType*}	Sets the **Type of Measurement** to reflection (0) or transmission (1) for the specified *operationType*: *device measurement* (0), *full calibration* (1), or *internal calibration* (2).	149	Both
CONF:TEST? {*operationType*}	Queries the OVA for the current **Type of Measurement** for the specified *operationType*: *device measurement* (0), *full calibration* (1), or *internal calibration* (2).	150	Both
CONF:THAN {0|1}	Enables (1) or disables (0) the Hanning window applied to time domain data.	171	OVA
CONF:THAN?	Returns "0" if the Hanning window is disabled, or "1" if it is enabled.	172	OVA

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Table 8-1: Alphabetical Summary of GPIB and TCP/IP Commands

CONF:TLIM {*lowerLimit,upperLimit*}	Sets the **Impulse Response** X-axis limits to the input parameters in nanoseconds.	170	OVA
CONF:TLIM?	Queries the OVA for the current **Time Domain Window** limits.	170	OVA
CONF:TRET {0|1}	Enables (1) or disables (0) the **Retain Settings** function in the **Time Domain Window**.	171	OVA
CONF:TRET?	Queries the OVA for the **Retain Settings** status in the **Time Domain Window**.	171	OVA
CONF:TSIG {*value*}	Sets the **Sigma** *value* in nanoseconds to create the **Time Domain Window**.	169	OVA
CONF:TSIG?	Queries the OVA for the current value of **Sigma** (ns) from the **Time Domain Window**.	170	OVA
CONF:TWRB?	Queries the OVA for the current **Time Domain Window Resolution Bandwidth**.	168	OVA
CONF:WAVE	Sets the wavelength to be used by the command SYST:SWEE.	172	OVA
CONF:WAVE?	Queries the OVA for the wavelength to be used by the command SYST:SWEE.	173	OVA
CONF:XUNI	Sets the x-axis units being used to specify the integration area.	181	OFDR
CONF:XUNI?	Queries the x-axis units being used to specify the integration area.	182	OFDR
Data capture and retrieval commands		**Page**	
FETC:FDTL? {*trace, graphType, decimate*}	Retrieves the average delay (ns) for the specified *trace* (A-E) and *graphType*. Currently *graphType* can only be set to one (1) for group delay. *Decimate* determines whether this average is calculated from decimated (1) or undecimated (0) data.	185	OFDR
FETC:FREQ?	Queries the OVA for the starting frequency (GHz) and the increment size (nm).	151	Both
FETC:FSIZ?	Queries the OVA for the size of the data arrays.	152	Both

Table 8-1: Alphabetical Summary of GPIB and TCP/IP Commands

FETC:INTL? {*trace*}	Retrieves the loss of the current integration area for the specified *trace*.	185	OFDR
FETC:JONE?	Queries the OVA for the raw Jones matrix elements, with real and imaginary parts separated by tabs. Each data point is separated by a line break.	173	OVA
FETC:LENE? {*trace*}	Retrieves the end length for the specified *trace*.	186	OFDR
FETC:LENS? {*trace*}	Retrieves the start length for the specified *trace*.	186	OFDR
FETC:MDET?	Queries the OVA for current measurement details for Matrix A.	154	Both
FETC:MEAS? {x}	Queries the OVA for the measured data array for the parameter specified by x. For definitions of x, see page 153.	153	Both
FETC:PDF? {*centerFrequenc y, threshold*}	Queries the OVA for the polarization dependent frequency (GHz) for the specified center frequency (GHz) and threshold (dB).	173	OVA
FETC:RAW? {*trace*}	Retrieves the raw S and P data for the specified *trace*.	182	OFDR
FETC:RSIZ? {*trace*}	Retrieves the size of the raw S and P data for the specified *trace*.	183	OFDR
FETC:TIME? {*trace*}	Retrieves the end time for the specified *trace*.	186	OFDR
FETC:TIMS? {*trace*}	Retrieves the start time in nanoseconds for the specified *trace*.	185	OFDR
FETC:TINC?	Queries the OVA for the time increment of the **Time Domain** X-axis in nanoseconds (ns).	151	Both
FETC:WL? {*trace*}	Retrieves the starting wavelength (nm) for the specified *trace*.	184	OFDR
FETC:WLC? {*trace*}	Retrieves the **Center Wavelength** (nm) for the specified *trace*.	184	OFDR

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Table 8-1: Alphabetical Summary of GPIB and TCP/IP Commands

FETC:WLE? {trace}	Retrieves the ending wavelength (nm) for the specified *trace*.	184	OFDR

FETC:XAXI? {trace, domain, units, decimate}	Retrieves the X-axis data for the specified variables:
	Trace can be A, B, C, D or E.
	Domain = 0 for the time domain, 1 for frequency domain.
	Units for the time *domain* (0):
	    0 = time (ns)
	    1 = length (m)
	    2 = length (ft)
	Units for the frequency *domain* (0):
	    0 = wavelength (nm)
	    1 = frequency (GHz)
	    2 = frequency (THz).
	Decimate: 1 = use decimation, 0 = return all points.
		187	OFDR version of FETC:XAXI?

FETC:XAXI? {x}	Queries the OVA for the X-axis (Frequency Domain or Time Domain) data. The parameter *x* can take values from 0 to 4:
	    0 - Frequency Domain (nm)
	    1 - Frequency Domain (GHz)
	    2 - Frequency Domain (THz)
	    3 - Time Domain (ns)
	    4 - Frequency Domain (m)
	For further details, see page 174.
		174	OVA version of FETC:XAXI?

System level commands		**Page**	
SCAN	Tells the OVA to execute an optical scan based on the configured system parameters.	141	Both
SYST:ACQ?	Queries whether data has been acquired (1) or not (0).	175	OFDR
SYST:ALIG	Aligns the optics	142	Both
SYST:ALIG?	Queries the OVA if the optics are aligned	142	Both

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Table 8-1: Alphabetical Summary of GPIB and TCP/IP Commands

SYST:CAL	**Calibrates** the system. (Use SYST:ICAL, SYST:FCAL or SYST:QCAL for OVA)	175	OFDR
SYST:CAL?	Queries the system calibration status. Returns "1" if the system is calibrated successfully or "0" if it is not.	142	Both
SYST:CALF {*measurementTy pe*, filename}	Sets the name of the calibration file for the **Type of Measurement** specified: reflection (0) or transmission (1). If the filename is not specified, this command sets calibration file to the default filename for reflection (ofdrCal_refl) or transmission (ofdrCal_trans).	175	OFDR
SYST:CALF? {*measurementTy pe*}	Retrieves the name of the calibration file for the **Type of Measurement** specified: reflection (0) or transmission (1).	176	OFDR
SYST:COPY {*source, destination*}	Copies data from the *source* trace (A-E) to the *destination* trace (A-E).	176	OFDR
SYST:ERR?	Returns a numeric error code. Zero (0) indicates no error; *i.e.* the last command or query completed successfully. Any non-zero number indicates that an error has occurred. A description of the error may be retrieved with the query SYST:ERRD?	143	Both
SYST:ERRD?	Retrieves the detailed error description for the most recent remote operation.	144	Both
SYST:FCAL	Performs a full calibration with the Calibrate for PDL option on.	155	OVA
SYST:FILT	Applies the resolution bandwidth smoothing filter to Matrix A data.	156	OVA
SYST:ICAL	Performs an internal calibration.	155	OVA
SYST:LASE {0|1}	Turns on the laser if the parameter is "1", or turns it off if the parameter is "0".	144	Both
SYST:LASE?	Queries if the laser is on (1) or off (0).	144	Both

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Table 8-1: Alphabetical Summary of GPIB and TCP/IP Commands

SYST:LAST?	Returns the name of the last command or query processed, without the parameters specified with that command.	145	Both
SYST:LOAD "{*filename.bin*}"	Loads the external file *filename.bin* as a source of data reference.	145	Both
SYST:QCAL	Performs a full calibration with the Calibrate for PDL option off.	156	OVA
SYST:RDY?	Queries if the OVA is ready to scan (1) or not (0).	144	Both
SYST:RLDC	Reloads a calibration file into memory.	143	Both
SYST:SAVJ "{*filename.bin*}"	Saves the current Jones matrix data in Matrix A as binary data in the *filename.bin* specified in quotes.	157	OVA
SYST:SAVS "{*filename.txt*}"	Saves the current Jones matrix data in Matrix A as text data in the *filename.bin* specified in quotes.	158	OVA

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Table 8-1: Alphabetical Summary of GPIB and TCP/IP Commands

SYST:SAVT {*"filename.txt"*, *trace, domain, graphType, units, spatialResolution* }	Saves the current data from the *trace* specified (A-E) as text or spreadsheet data in the *path* specified in quotes, based on the following variables:
	Trace can be A, B, C, D or E.
	Domain = 0 for the time domain, 1 for frequency domain.
	GraphType values for the time *domain* (0):
	    0 = Amplitude
	    1 = Phase Derivative
	    2 = Linear Amplitude
	GraphType values for the frequency *domain* (1):
	    0 = Insertion Loss
	    1 = Group Delay
	    2 = Phase
	Units for the time *domain* (0):
	    0 = time (ns)
	    1 = length (m)
	    2 = length (ft)
	Units for the frequency *domain* (0):
	    0 = wavelength (nm)
	    1 = frequency (GHz)
	    2 = frequency (THz).
	SpatialResolution sets the spatial **Resolution Bandwidth** (mm).
		176	OFDR version of SYST:SAVT

SYST:SAVT "*{filename.txt}*"	Saves text data of only the curves selected in the "Select Save Options" dialog in the OVA software. This commands is similar to SYST:SAVS, except that SYST:SAVS saves all available curve types, not just the selected curves.	158	OVA version of SYST:SAVT
SYST:SWEE	Opens the laser **Source** switch and sweeps the laser through the through the user-specified wavelengths without performing a scan.	157	OVA
SYST:VER?	Returns the version of the OVA software.	145	Both

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Table 8-1: Alphabetical Summary of GPIB and TCP/IP Commands

SYST:WARM?	Queries if the laser is at operating temperature (1) or not (0).	141	Both
SYST:WTIM?	Displays the time remaining on the system one hour warm-up timer.	141	Both

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Chapter 9

Measurement Theory

The OVA is the only fiber optic test instrument to use a rigorous linear systems approach to characterizing optical fiber components. This approach reduces the industry-standard multi-parameter characterization of fiber optic components to a single Jones matrix characterization.

This chapter will cover the following topics: the Jones matrix and its use for system modeling and parameter calculations, how to use optical phase error data, the OVA device length finding methods, wavelength calibration, and filter theory.

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 two 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 and phase 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 called the *Jones matrix*:

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

The quantities a, b, c and d are the four scalar transfer functions, and ω represents optical frequency. The term Jones matrix, however, is somewhat ambiguous. For a

particular device, there exist several matrices that can be correctly termed the Jones matrix of the device, but convey various amounts of information.

At a minimum, the Jones matrix describes the evolution of the polarization state as light passes through the device. In many cases the absolute amplitude and phase information is not needed, and the input vector is normalized. The matrices are then scaled such that the output vector is also normalized. This definition, which we will call the *normalized* Jones matrix, is often taught in introductory college optics courses. It leads to the familiar normalized Jones matrices for common devices shown in Table 9-1.

Table 9-1: Normalized Jones Matrices of Common Optical Devices

Vertical linear polarizer	$\begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$
Horizontal linear polarizer	$\begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$
Linear polarizer at $45°$	$\frac{1}{2}\begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$
Lossless fiber transmission	$\begin{bmatrix} e^{i\phi}\cos\theta & -e^{-i\psi}\sin\theta \\ e^{i\psi}\sin\theta & e^{-i\phi}\cos\theta \end{bmatrix}$
Right circular polarizer	$\frac{1}{2}\begin{bmatrix} 1 & i \\ -i & 1 \end{bmatrix}$
Left circular polarizer	$\frac{1}{2}\begin{bmatrix} 1 & -i \\ i & 1 \end{bmatrix}$

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Table 9-1: Normalized Jones Matrices of Common Optical Devices

Quarter-wave plate, fast axis vertical	$e^{i\pi/4}\begin{bmatrix} 1 & 0 \\ 0 & -i \end{bmatrix}$
Quarter-wave plate, fast axis horizontal	$e^{i\pi/4}\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$

A more complete form of the Jones treatment of optical systems uses the full electric field vector to represent the input to the system. This is a two-element complex vector that contains both the amplitude and phase of each polarization component. Because phase is always measured relative to some reference point, the absolute phase of an optical wave is arbitrary. Therefore it is often ignored altogether, and the electric field is known only to within a constant phase. In this case, the absolute phase response of the device is often ignored as well. So the Jones matrix is then defined to include the amplitude response of the device and the relative phase between elements, but lacks the absolute phase response.

This version of the Jones matrix is in fact the matrix measured by the original technique described by Jones himself.[1] The more recent Jones matrix measurement technique of Heffner[2] also lacks the absolute phase response.

Without this phase information, the Jones matrix is an incomplete description of the operation of the device on the input signal. It contains insertion loss, polarization dependent loss, and polarization mode dispersion information, but will not yield group delay or chromatic dispersion. More importantly, it does not constitute the complete transfer function of the device.

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Jones and Heffner did not include the absolute phase response of the device in their versions of the Jones matrix because their measurement techniques were not equipped to measure it. The absolute phase of a device response is well-defined, however, and can be measured. The phase of the output can always be defined

[1] The original Jones papers on polarization are reprinted in *Polarized Light*, W. Swindell, ed. 1975.

[2] B.L. Heffner, "Deterministic, analytically complete measurement of polarization-dependent transmission through optical devices," *IEEE Photonics Technology Letters* **4**:5, May 1992.

relative to the phase of the input. When absolute phase response is included, along with the amplitude response, the Jones matrix is equivalent to the transfer function of the device. This is the Jones matrix measured by the OVA. Any linear parameter describing the device can be calculated from this function.

To summarize, there are three different matrix functions that all have been termed "the Jones matrix":

1 "Normalized" Jones matrix: The first understanding of the Jones matrix describes how the polarization state changes as light passes through a device, but says nothing of how the amplitude or phase of a signal is affected. Polarization dependent loss and polarization mode dispersion are the only two parameters that can be calculated from this normalized Jones matrix.

2 "Common" Jones matrix: The most common understanding of the Jones matrix includes the amplitude response of the device in addition to the polarization information, but lacks the absolute phase response. In addition to PDL and PMD, insertion loss information is available. This is the matrix that is measured by most instruments that claim to measure the Jones matrix. However, it does not constitute the rigorous transfer function of the device.

3 "Complete" Jones matrix: The most complete version of the Jones matrix includes all of the information contained in the first two, and contains the absolute phase response of the device as well. This Jones matrix is equivalent to the transfer function of linear systems theory, and contains all linear parameters, including insertion loss, group delay, PDL, and PMD. This is the matrix measured by the OVA.

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From this point onward and elsewhere in this manual, the term Jones matrix will be used to refer to the complete Jones matrix, the third definition above.

System Modeling

The Jones matrix of a device is an ideal tool for modeling how the component will operate in a system. Because it is a fully rigorous description of how light propagates through the device, the Jones matrix can be used to mathematically propagate a bit signal through the device, and an eye diagram can be calculated at the output.

A bit stream input to a device can be represented by its electric field ($\mathbf{E}$) as a function of time, $\mathbf{E}_{in}(t)$. The spectrum of this signal is given by its Fourier transform,

$\tilde{\mathbf{E}}_{in}(\omega)$. The output signal spectrum, $\tilde{\mathbf{E}}_{out}(\omega)$, is easily calculated using the Jones matrix, $\mathbf{J}(\omega)$:

$$\tilde{\mathbf{E}}_{out}(\omega) \; = \; \mathbf{J}(\omega)\tilde{\mathbf{E}}_{in}(\omega).$$

The output bit stream $\mathbf{E}_{out}(t)$ is then found by taking the inverse Fourier transform of the output spectrum.

Figure 9-1 shows the spectra for a 10 and 20 Gb/s signal transmitted with a center wavelength of 1534.5 nm. Overlaid on this plot is the amplitude response of an optical filter. Multiplication of the signal electric field by the measured Jones matrix of the component produces the output electric field. After transforming this output field back to the time domain, an eye diagram can be produced by calculating the detected optical power as a function of time. Figure 9-2 shows the computed eye diagrams for the 10 and 20 Gb/s signals.

The Jones matrix approach also provides a simple, straightforward way to model systems composed of many components. A single system Jones matrix can be formed by multiplying together the component Jones matrices in the proper order. By placing arbitrary lossless transmission matrices between components in the numerical models, all possible states of the connecting fiber can be checked for acceptable operation. 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.

The Jones matrix, as measured by the OVA, provides a rigorous and complete model of device performance that is both direct and simple. It is much more straightforward than modeling system performance based on traditional parametric measurements, which provide only indirect clues as to how a device will perform.

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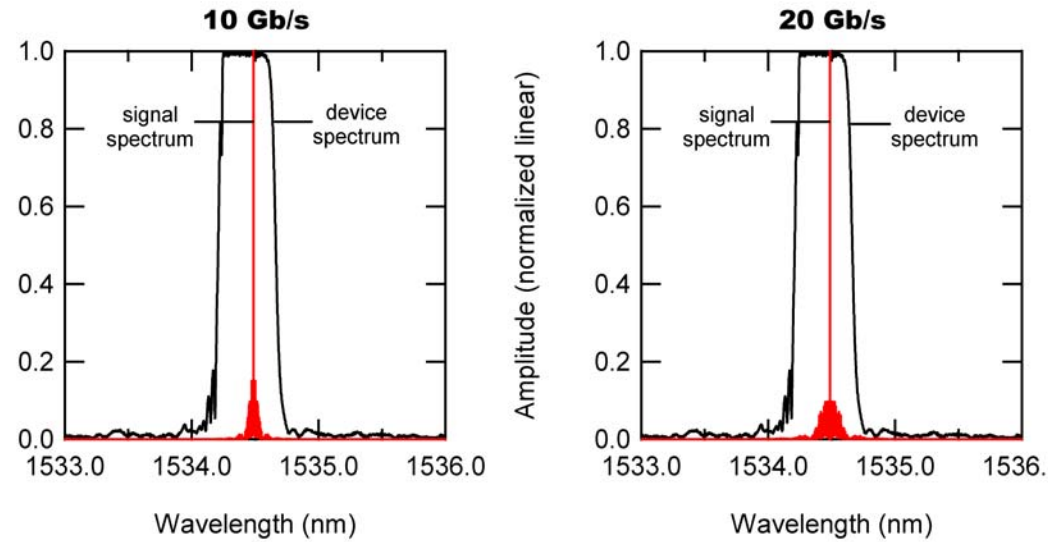
Figure 9-1. Signal and grating spectra.
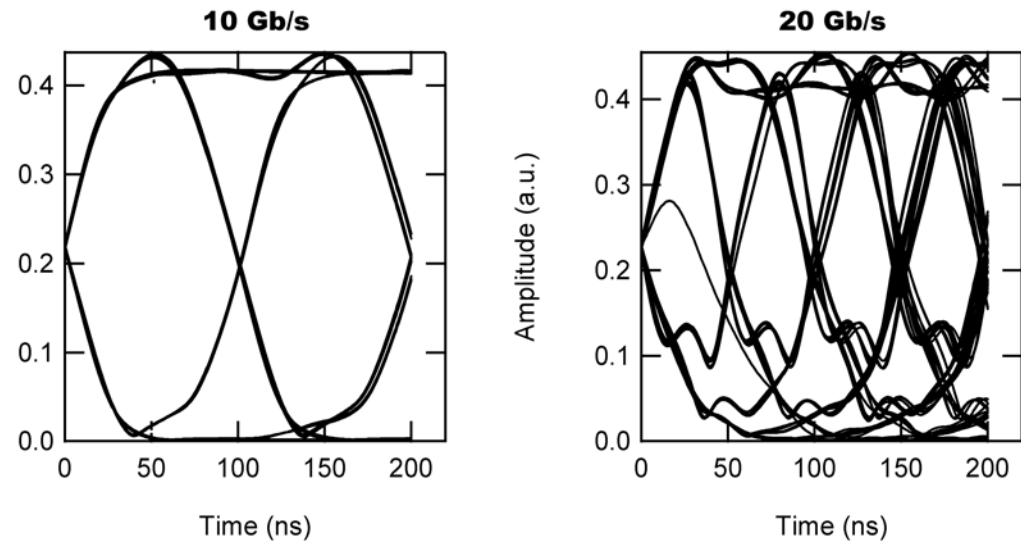
Figure 9-2. Eye diagrams for 10 and 20 Gb/s.

Parameter Calculations

Despite the ability to directly model components and systems using the measured Jones matrix, it is still often useful to know the values of individual parameters for particular devices. Because the Jones matrix embodies the full mathematical description of a device, all linear parameters describing that device are contained in the Jones matrix.

The OVA mathematically defines each parameter precisely by measuring the Jones matrix and then extracting parameters. This is in contrast to traditional means of performing measurements. For example, it may not be clear whether the result of a traditional insertion loss measurement yields the loss for a particular input polarization state, or for some type of average over polarization states. With the complete Jones matrix, it is possible to calculate the loss for any input state, so one may define the loss in the most useful fashion, and use that definition to perform the loss calculation.

The OVA control software performs several built-in parameter calculations using the definitions presented below. These definitions were chosen to produce results that agree with nearly all implementations of traditional measurements for each parameter. If other definitions are necessary for particular applications, the Jones matrix data is available for users to perform their own parameter calculations. Keep in mind that the parameters are mathematical constructs, and that the true description of the device lies in the Jones matrix itself.

The following parameter definitions are written in terms of the Jones matrix $\mathbf{J}_i$ expressed as

$$\mathbf{J}_i = \begin{bmatrix} a_i & b_i \\ c_i & d_i \end{bmatrix},$$

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where i indicates the index location in the data array, and corresponds to optical frequency (wavelength).

Insertion loss

Insertion loss (IL) is the ratio of optical power output by the device to the optical power input to the device, and is expressed in dB. In terms of the Jones matrix elements, it is defined as

$$IL_i = 10 \log \left(\frac{|a_i|^2 + |b_i|^2 + |c_i|^2 + |d_i|^2}{2} \right).$$

This definition yields the average insertion loss over all input polarization states (for example, a polarizer would measure as -3 dB). The measured insertion loss for a thin film filter appears in Figure 9-3.
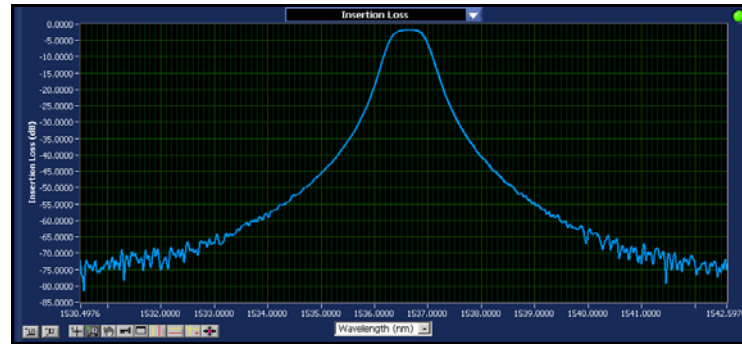
Figure 9-3. Insertion loss measurement of a thin film filter.

Group delay

Group delay (GD) is defined to be the rate of change of phase as a function of frequency. Physically, this property corresponds to the delay experienced by the sinusoidal envelope of a modulated optical signal as it propagates through the device. In terms of the Jones matrix elements, it is defined as

$$GD_i = \frac{\arg(a_{i+1}a_i^* + b_{i+1}b_i^* + c_{i+1}c_i^* + d_{i+1}d_i^*)}{\Delta\omega},$$

where $\arg(z)$ denotes the argument (phase) of the complex number z, and $\Delta\omega$ is the change in optical frequency from index i to index $i+1$. This definition yields a weighted average group delay over polarization states, where the weighting function is the amplitude response for each state.

An example group delay measurement for one channel of a thin film filter appears in Figure 9-4.
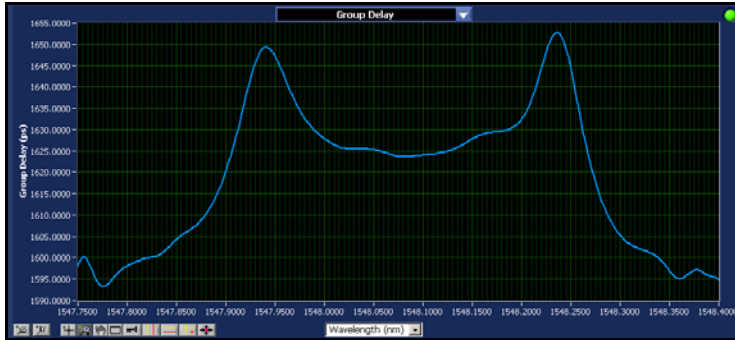
Figure 9-4. Group delay measurement for a single channel of a thin film filter.

Chromatic dispersion

Chromatic dispersion (CD) is the derivative of the group delay with respect to wavelength. The group delay is calculated first from the Jones matrix using the definition above, and then chromatic dispersion is found using

$$CD_i = \frac{GD_{i+1} - GD_i}{\Delta\lambda},$$

where $\Delta\lambda$ is the change in wavelength from index i to index i+1.

Polarization dependent loss

Polarization dependent loss (PDL) is the ratio of the maximum transmitted power to the minimum transmitted power over all polarization states, where each state contains the same launched power. To express the PDL in term of the Jones matrix $\mathbf{J}_i$, first define $\kappa_{i,1}$ and $\kappa_{i,2}$ to be the eigenvalues of the matrix $\mathbf{J}_i^\dagger\mathbf{J}_i$, where $\dagger$ denotes the conjugate transpose. The PDL is then given by[3]

$$PDL_i = \left| 10 \log\left(\frac{\kappa_{i,1}}{\kappa_{i,2}}\right) \right|.$$

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[3] B.L. Heffner, "Deterministic, Analytically Complete Measurement of Polarization-Dependent Transmission Through Optical Devices," *IEEE Photonics Tech. Lett.* **4**, pp. 451-454, 1992.

Examples of PDL measurements appear in Figure 9-5.
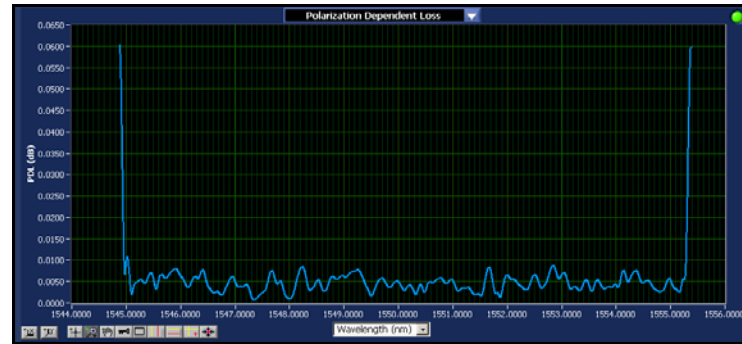
Figure 9-5. Polarization dependent loss of a ~0 dB fiber patch cord.

Polarization mode dispersion

Polarization mode dispersion (PMD), or differential group delay (DGD), is the maximum difference in group delay over all polarization states. Equivalently, PMD is a measure of the maximum rate of change of the polarization state. To express the PMD in terms of the Jones matrix $\mathbf{J}_i$, first define $\rho_{i,1}$ and $\rho_{i,2}$ to be the eigenvalues of the matrix $\mathbf{J}_{i+1}\mathbf{J}_i^{-1}$. The PMD is then given by

$$PMD_i = \left| \frac{\arg\left(\frac{\rho_{i,1}}{\rho_{i,2}}\right)}{\Delta\omega} \right|,$$

where $\Delta\omega$ is the change in optical frequency from index i to index $i+1$.[4]

Examples of PMD measurements appear in Figure 9-6.

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[4] B. L. Heffner, "Automated Measurement of Polarization Mode Dispersion Using Jones Matrix Eigenanalysis," *IEEE Photonics Tech. Lett.* **4**, pp 1066-1069, 1992.
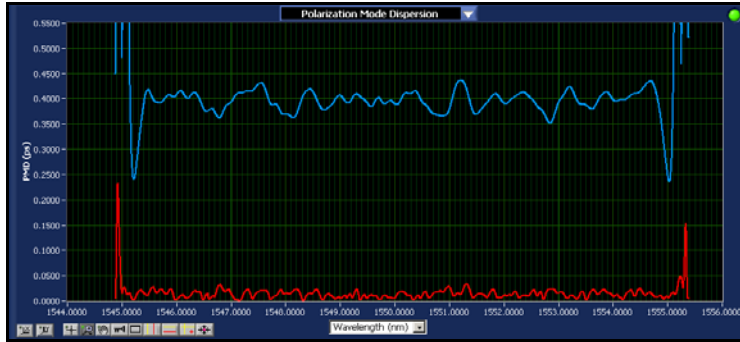
*Figure 9-6. PMD measurements for a 0.42 ps nominal PMD standard
and a ~0 ps SMF patch cord.*

Second Order Polarization Mode Dispersion

Second order PMD (SOPMD) is defined as the frequency derivative of the PMD vector, $\Omega(\omega) = \Delta\tau(\omega)\hat{q}(\omega)$,[5] where $\Delta\tau(\omega)$ is the differential group delay (DGD = first-order PMD) between the two principal states of polarization (PSPs), and $\hat{q}$ is a unit vector that points in the direction of the fast principle axis. Hence, the second-order PMD is given by

$$ SOPMD = \frac{d\Omega(\omega)}{d\omega} = \frac{d\Delta\tau(\omega)}{d\omega}\hat{q}(\omega) + \Delta\tau(\omega)\frac{d\hat{q}(\omega)}{d\omega}. $$

The two terms in the above equation are often treated separately by breaking the second-order PMD into parallel and perpendicular components:

$$ \Omega_{\omega\parallel} = \frac{d\Delta\tau}{d\omega}\hat{q} \qquad \text{and} \qquad \Omega_{\omega\perp} = \Delta\tau\frac{d\hat{q}}{d\omega}, $$

where $\Omega_{\omega\parallel}$ causes polarization dependent chromatic dispersion, and $\Omega_{\omega\perp}$ represents a frequency dependent rotation of the PSP's of the DUT, both of which, in turn, cause signal depolarization. Also, we have used the short-hand $\Omega_\omega = \frac{d\Delta\tau}{d\omega}$.

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[5] J. P. Gordon and H. Kogelnick, "PMD fundamentals: Polarization mode dispersion in optical fibers," P*roc. Nat. Acad. Sci.* **97**, pp. 4541–4550, 2000.

We can use the Jones matrix to calculate a components second-order PMD.[6] If $|s_1\rangle$ and $|s_2\rangle$ are the eigenvectors of the product $\mathbf{J}_{i+1}\mathbf{J}_i^{-1}$, then they are also the PSP's of the DUT.[7] The unit vector $\hat{q}$ is found by identifying the eigenstate associated with the fast principal axis and casting that state in a Stokes space. If

$$|s_1\rangle = \begin{bmatrix} a_x e^{i\phi x} \\ a_y e^{i\phi y} \end{bmatrix},$$

then the Stokes vector corresponding to that PSP is

$$S = \begin{bmatrix} a_x^2 - a_y^2 \\ a_x a_y \sin\phi \\ a_x a_y \cos\phi \end{bmatrix},$$

where $\phi = \phi_x - \phi_y$, ϕ is the relative optical phase of the vector, and a_x and a_y are the amplitudes of the x and y components, respectively.[8]

This yields the value of the unit vector $\hat{q}$:

$$\hat{q} = \frac{S}{|S|}.$$

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The control software plots the square root of the sum of the squares of the two second order PMD components, i.e.:

$$SOPMD = \sqrt{|\Omega_{\omega\parallel}|^2 + |\Omega_{\omega\perp}|^2},$$

[6] H. Kogelnick, L. E. Nelson, J. P. Gordon, and R. M. Jopson, "Jones matrix for second-order polarization mode dispersion," *Opt. Lett.* **25**, pp. 19–21 2000.

[7] B. L. Hener, "Automated measurement of polarization mode dispersion using Jones matrix eigenlysis," *IEEE Photon. Technol. Lett.* **4**, pp. 1066–1069, 1992.

[8] M. Born and E. Wolf, *Principles of Optics* (Cambridge University Press, Cambridge, Massachusetts, 1999), seventh edn.

where

$$|\Omega_{\omega\|}| = \frac{d\Delta\tau}{d\omega} \qquad \text{and} \qquad |\Omega_{\omega\perp}| = \Delta\tau\frac{d\theta}{d\omega},$$

and θ is the PSP orientation angle. The term $d\theta$ is calculated as

$$d\theta_i = \cos^{-1}(\hat{q}_{i-1} \cdot \hat{q}_i).$$

For a more complete explanation of how the OVA calculates SOPMD, please to refer to the paper "Second-Order PMD in Optical Components" by B. J. Soller, posted on the Luna Technologies website:
http://www.lunatechnologies.com/applications/2nd%20Order%20PMD.pdf.
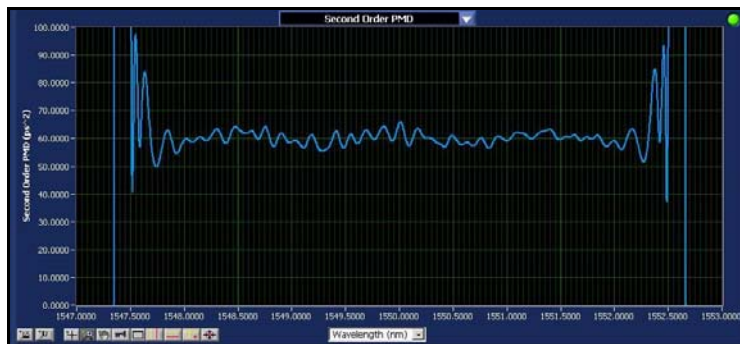
Figure 9-7. Second Order PMD measurement of three segments of PM fiber spliced together.

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The user should note that when PMD nears zero, the frequency derivative of PMD may become discontinuous and the omega parallel term may exhibit abrupt change. Also, when PMD is near zero, the Stokes vector is prone to rotate rapidly, since the orientation of the fast axis is ill-defined. For these reasons, the SOPMD calculation may produce large values that are best to disregard when the PMD approaches zero.

Linear phase deviation

Linear phase deviation (LPD) is the deviation of the optical phase vs. frequency from a linear function. In terms of the Jones matrix elements, the optical phase ϕ through the device is defined as

$$\phi_k = \sum_{i=0}^{k} \arg(a_{i+1}a_i{}^* + b_{i+1}b_i{}^* + c_{i+1}c_i{}^* + d_{i+1}d_i{}^*).$$

A line f_k is then fit to ϕ_k, and the linear phase deviation is given by

$$LPD_k = \phi_k - f_k .$$

The line f_k is typically fit over the passband of the device under test. See "Recalculating Phase Deviation" on page 68 for information on how to select the passband for this curve fit. An example linear phase deviation plot for a chirped Bragg grating appears in Figure 9-8.
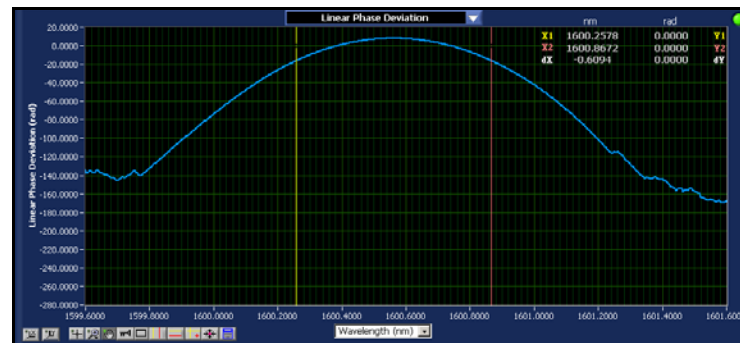
Figure 9-8. The linear phase deviation for a chirped Bragg grating.

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Quadratic phase deviation

Quadratic phase deviation (QPD) uses the same definition of the optical phase ϕ as the linear phase deviation. However, instead of fitting a line, a parabola p_k is fit to the phase, and the QPD is given by

$$QPD_k = \phi_k - p_k .$$

See "Recalculating Phase Deviation" on page 68 for information on how to select the curve fit region for the parabola p_k.

Figure 9-9 displays the quadratic phase deviation for the same chirped Bragg grating that appears in Figure 9-8.
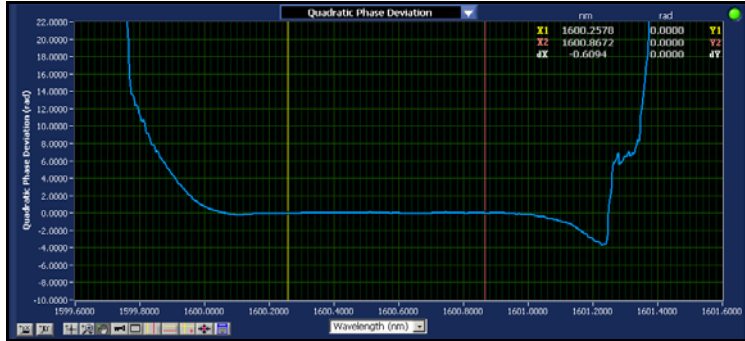
Figure 9-9. The quadratic phase deviation for a chirped Bragg grating.

Jones matrix element amplitudes

Selecting Jones matrix element amplitudes produces four curves per data set, where each curve is the amplitude of one of the Jones matrix elements: $|a|$, $|b|$, $|c|$, and $|d|$.

Jones matrix element phases

Selecting Jones matrix element phases produces four curves per data set, where each curve is the phase of one of the Jones matrix elements: $\arg(a)$, $\arg(b)$, $\arg(c)$, and $\arg(d)$.

Time domain (amplitude)

The time domain (amplitude) plot selection displays the amplitude of the impulse response of the device in the time domain. It is expressed in terms of the impulse response matrix,

$$\mathbf{H}_j = \begin{bmatrix} \tilde{a}_j & \tilde{b}_j \\ \tilde{c}_j & \tilde{d}_j \end{bmatrix},$$

where $\tilde{a}_j$ is the discrete Fourier transform of a_i, and likewise for the other matrix elements. The index j indicates the location in the data array, and corresponds to time.

The plotted impulse response amplitude $|h_j|$ is defined as

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$$|h_j| = |\tilde{a}_j|^2 + |\tilde{b}_j|^2 + |\tilde{c}_j|^2 + |\tilde{d}_j|^2 \,.$$

This definition yields an average impulse response over all input polarization states. The result is scaled such that

$$\sum |h_j| = 1$$

for a lossless device.

An example time domain (amplitude) plot appears in Figure 9-10.
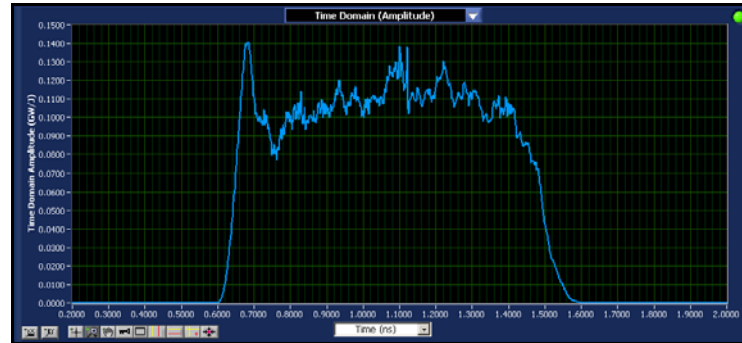
Figure 9-10. The time domain (amplitude) data for a chirped Bragg grating.

Time domain (wavelength)

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The time domain (wavelength) plot is the derivative of the phase of the impulse response with respect to time. Note that the time derivative of phase is the definition of optical frequency, so this derivative can be scaled as a wavelength. For a device with a distributed impulse response, the time domain (wavelength) shows the wavelength distribution as a function of time for an infinitely short pulse as it is dispersed by the device.

In terms of the impulse response matrix $\mathbf{H}_j$ defined above, the time domain (wavelength) response TDW_j is defined as

$$TDW_j = \frac{2\pi c \Delta t}{\arg(\tilde{a}_{j+1}\tilde{a}_j{}^* + \tilde{b}_{j+1}\tilde{b}_j{}^* + \tilde{c}_{j+1}\tilde{c}_j{}^* + \tilde{d}_{j+1}\tilde{d}_j{}^*)} ,$$

where c is the speed of light in a vacuum and Δt is the difference in time between index j and index $j + 1$.

An example time domain (wavelength) plot appears in Figure 9-11.
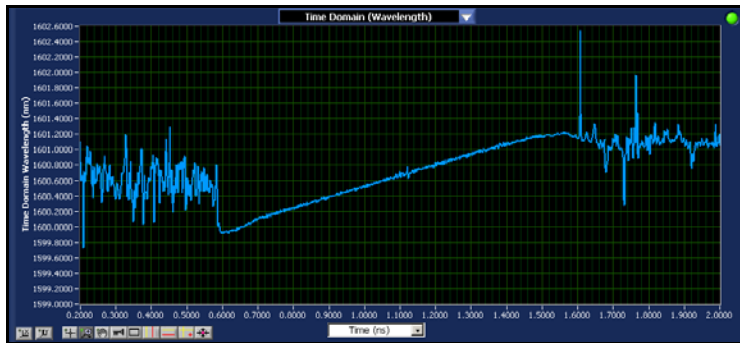
Figure 9-11. The time domain (wavelength) data for a chirped Bragg grating.

Minimum and maximum transmitting states (Min/Max Loss)

The Min/Max Loss graph displays the polarization dependent minimum and maximum transmission as a function of wavelength. The difference between the minimum and maximum transmission states constitutes the PDL of the DUT. The minimum and maximum states are derived from the eigenvalues of the matrix $\mathbf{J}_i^\dagger \mathbf{J}_i$ where † denotes the conjugate transpose. At a given wavelength, the greater eigenvalue represents the maximum transmission and the smaller eigenvalue represents the minimum transmission. An example of the Min/Max Loss curves for a fiber Bragg grating are shown in the figure below.

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Figure 9-12. The Min/Max Loss plot, showing maximum (blue) and minimum (purple) transmission states.

Phase Ripple

Phase Ripple Linear and Phase Ripple Quadratic represent parameter calculations from the Jones Matrix data of the linear and quadratic phase ripple over a user-specified channel width.

Selecting the Channel Width

The channel width is set by entering a value in the **Channel Width** field that appears below the graph when either of the phase ripple parameters are selected. The units of the channel width are determined by the units of the graph display. The units can be changed by selecting a different x-axis unit in the pull-down menu below each graph.

Linear Phase Ripple Calculation

Linear phase ripple is calculated from the average phase of the JM based on a user-specified **Channel Width**. Phase is calculated as the integral of group delay (see "Group delay" on page 218). This results in a weighted average of the DUT phase response over polarization states, again as described for the group delay calculation. For each wavelength (frequency) value in the data, the following process is used to calculate the phase ripple:

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1   The phase is fit to a linear curve over the channel width, centered at the wavelength associated with the data point.

2   The linear fit is subtracted from the phase data.

3   The maximum value of the resulting phase deviation is calculated.

4   This maximum is recorded as the phase ripple for this wavelength.

This calculation results in a curve for linear phase ripple as a function of wavelength that contains the same number of data points as contained in the other parameter curves. The linear phase ripple data, then, represents the maximum deviation from linear phase over the specified channel width at each data point.
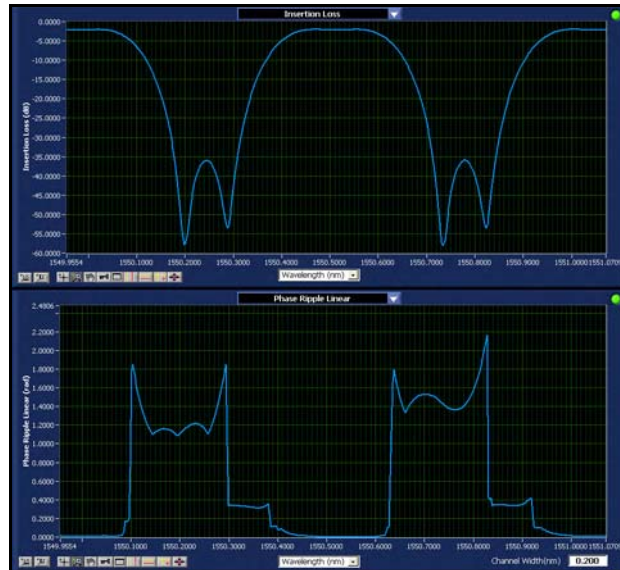
Figure 9-13. Insertion loss (upper graph) and phase ripple linear of an interleaver.

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Quadratic Phase Ripple Calculation

The quadratic phase ripple is calculated in the same way as the linear phase ripple, except the linear fit is replaced with a quadratic fit. This results in a phase ripple that represents the maximum deviation from quadratic phase over the specified channel width at each data point.
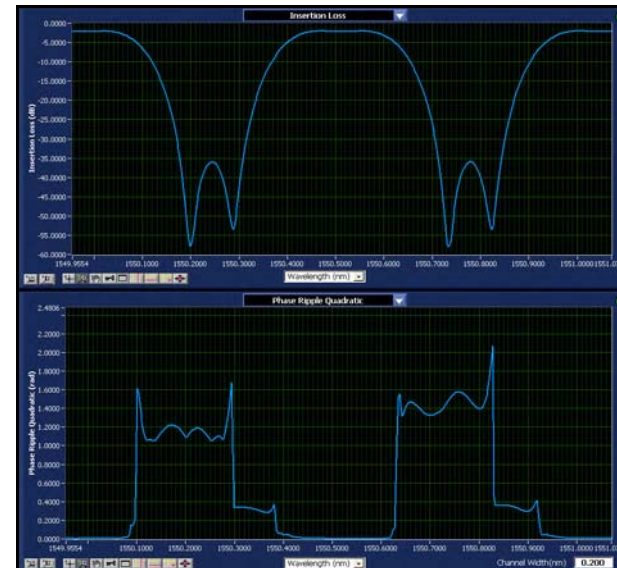
*Figure 9-14. Insertion loss (upper graph) and phase ripple quadratic of the same
interleaver data shown in Figure 9-13.*

Saving Phase Ripple Data

The phase ripple data curves can be saved by checking next to those parameters in
the **File > Select Save Options** configuration window.

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Note

The **Channel Width** specified below the upper graph is
used to calculate these data curves for saving to the text
file. The channel width is reported in the header of the
resulting text file.

Using Optical Phase Error

The OVA is the first instrument capable of providing optical phase measurements
for fiber-optic components. Without optical phase information, group delay and
chromatic dispersion measurements must be carefully interpreted to predict the
effects of an optical filter on a transmission system. Optical phase measurements
make the characterization of the dispersive effects of components significantly less
complicated than it has been in the past.

A system with a strictly linear phase response will delay a signal without distorting it. Any deviation from the 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 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 of optical phase measurements 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 a 10 Gb/s. As component quality is increased, component characterization can remain the same, which tremendously simplifies 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.

Optical Phase Error: References

For more information on optical phase error, please see the following references:

M. Froggatt, E. Moore, and M. Wolfe, "Interferometric measurement of dispersion in optical components," WK1, *Optical Fiber Communication Conference*, March 2002.

H. Yoshimi, Y. Takushima, and K. Kikuchi, "A simple method for estimating the eye-opening penalty caused by group-delay ripple of optical filters," 10.4.4, *28th European Conference on Optical Communication*, Sept. 2002.

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Fiber Optic Interferometry

The OVA uses swept-wavelength coherent interferometry to measure the Jones matrix. Here this technique is presented at an introductory level. For more information see the references at the end of this section.

The two basic types of fiber interferometers are shown in Figure 9-15. A Mach-Zehnder design uses one 3 dB coupler to split the light, and another 3 dB coupler

to recombine the light. In general, the two paths between the couplers are of different lengths. A detector is placed at the output of the second coupler. A Michelson interferometer uses a single 3 dB coupler to both split and recombine the light. Mirrors are placed at each of the outputs on one side of the coupler, and in general the two paths are of different lengths. On the other side of the coupler, one lead is used to inject the light, and the other is directed to a detector.

(a)   (b)

coupler: ⬭   detector: ⊣   mirror: ▦
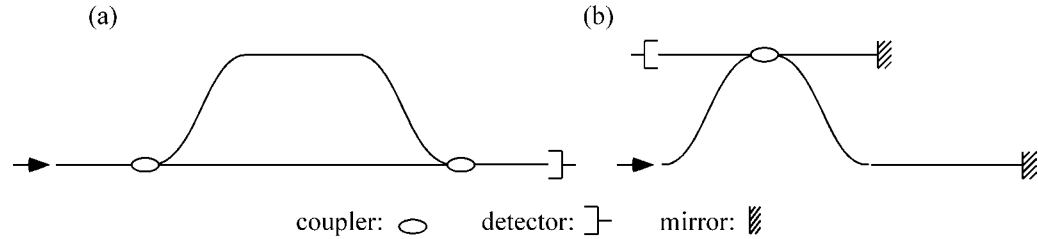
Figure 9-15. Two basic types of fiber interferometers:
(a) Mach-Zehnder and (b) Michelson.

Both of these interferometer designs can be treated in a basic way using the same set of mathematics. Consider an input field of the form

$$E_{in} = E_0(t)e^{-i\omega(t)t},$$

where ω is angular optical frequency, and $\omega(t)$ describes the instantaneous frequency of the tunable laser source.

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The spatial dependence of the signal may be ignored because the light is detected only at a single point. At the first coupler, the input field is split into two fields, E_1 and E_2. After propagating through different lengths of fiber, the two fields are recombined, and the resulting field at the detector is

$$E_{out} = E_0(t+\tau_1)e^{-i\omega(t+\tau_1)t} + E_0(t+\tau_2)e^{-i\omega(t+\tau_2)t},$$

where τ_1 and τ_2 are the delays through the two paths of the interferometer.

The electrical output of the detector is proportional to the optical intensity, I, which is given by the square magnitude of the electric field:

$$I(\omega) = |E_0(t)|^2 + |E_0(t-\tau)|^2 + 2E_0(t)E_0(t-\tau)\cos[\omega(t)\tau] \quad ,$$

where the time delay difference between the interferometer paths $\tau = \tau_1 - \tau_2$.

Optical Network for OVA

This basic idea can then be applied to device characterization by including a device under test (DUT) in one arm of the interferometer,[9] as shown in Figure 9-16.
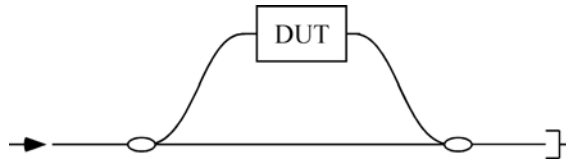
Figure 9-16. A Mach-Zehnder interferometer with a device under test in one arm.

We can describe the DUT by its frequency domain linear transfer function, $H(\omega)$; the linear transfer function contains information about the amplitude, $\rho(\omega)$, and phase, $\phi(\omega)$, response of the DUT and is given by $H(\omega) = \rho(\omega)e^{i\phi(\omega)}$. Given the amplitude and phase response, the detected power is proportional to the intensity, *I*, given by

$$
I = |E_0(t)|^2 + |E_0(t-\tau)|^2\rho(\omega)^2 \\
+ 2\rho(\omega)E_0(t)E_0(t-\tau)\cos[\omega(t)\tau - \phi(\omega)]
$$

.

Next a Fourier transform is performed allowing the three terms in the above expression to be separated spectrally. Note that the first two terms will have only low frequency characteristics, and thus will appear at or near $t = 0$ in the time-domain. The device information resides in the third term of this expression, called the *interference term*. The interference term oscillates at the frequency $\omega(t)\tau$, while the other terms do not oscillate. Its location in the time-domain will be determined by the delay difference τ between the two arms of the interferometer. Provided that τ is large enough, the device response will be separable from the low frequency terms, and thus measurable. The Luna OVA is designed such that the internal delay path through the device under test is long enough such that the low frequency terms will not influence the measurement, even for very short devices. Thus the OVA operates with no dead zone.

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[9] For a more complete description of the OVA network, see D. K. Gifford et al., "Optical vector network analyzer for single-scan measurements of loss, group delay, and polarization mode dispersion," *Applied Optics*, vol. 44, no. 34, 1 Dec. 2005.

The Fourier transform of reflected optical intensity (*I*) for a short length of single-mode fiber as the DUT is plotted in Figure 9-17 (a). Figure 9-17 (b) shows the selected segment that contains the device information. Because the initial data was acquired as a function of optical frequency, ω, the transformed data is a function of time. For this reason, the transformed data is referred to as *time domain* data.
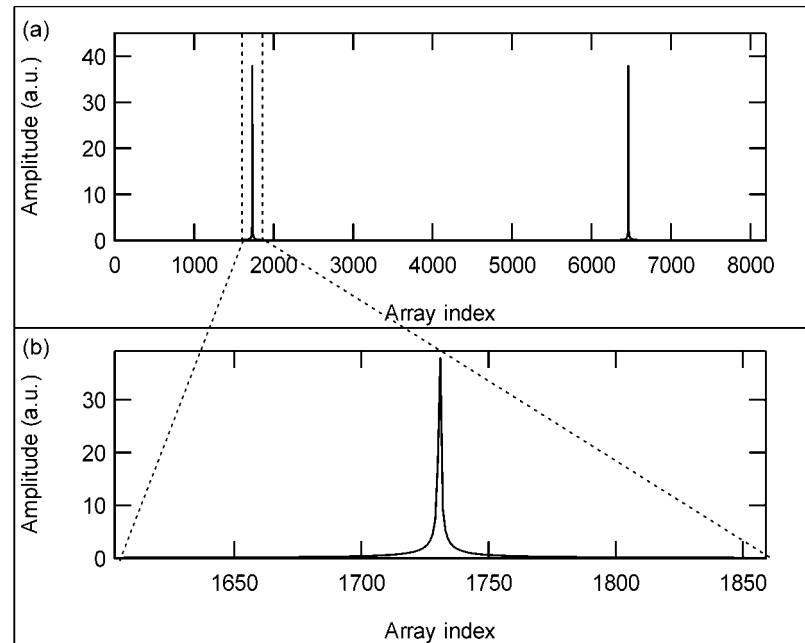
Figure 9-17. (a) The Fourier transform of interference fringes.
(b) The segment of the time domain data that contains device information.

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If there are multiple reflecting interfaces within the device under test, each interface will contribute a term to the interference pattern and a peak in the time-domain located at the corresponding delay.

In order to more easily locate the source of reflections within a device, the time-domain data can be scaled in units of length, using the speed of light and the group index of the DUT.

To arrive at a measure of the frequency response of the device, an inverse Fourier transform is performed on only the section of the time-domain data that contains the device response. The OVA software allows the user to select any portion of the

time-domain data so the response due to different optical paths or interfaces can be separated and measured independently.

Once the data has been transformed back into the frequency-domain, the calibrated amplitude response yields the loss of the test device. The derivative of the phase response yields the group delay.

Triggering and Resolution

In a practical measurement system, the function $I(\omega)$ must be sampled at a set of discrete points, and the Fast Fourier Transform (FFT) algorithm is used to convert to the time domain. In order to perform the FFT, it is necessary that $I(\omega)$ be sampled at equal increments of optical frequency. It is not sufficient to use time synchronous sampling and rely on a constant tuning rate of the laser. Instead, a second interferometer is used for triggering. The trigger interferometer must have a delay difference between its two paths that is at least twice as long as the delay difference in the device interferometer to avoid undersampling. Thus it is the length of the trigger interferometer that determines the device length limit for the OVA.

The length of the segment in Figure 9-17 (b) can be controlled by the user by simply scaling the X-axis (see "Scaling Plot Axes" on page 63). This length determines the sample resolution of the frequency domain data according to the Fourier transform relationship

$$\Delta\omega = \frac{2\pi}{N\Delta t} = \frac{2\pi}{T}.$$

Here $\Delta\omega$ is the sample spacing in the frequency domain, Δt is the sample spacing in the time domain, N is the number of points, and T is the range in the time domain, or equivalently, the time segment length.

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Fiber Interferometry: References

M. Froggatt, T. Erdogan, J. Moore, S. Shenk, "Optical frequency domain characterization (OFDC) of dispersion in optical fiber Bragg gratings," **FF2**, *Special Meeting on Bragg Gratings, Photosensitivity, and Poling in Glass Waveguides*, Sept. 1999.

B. Soller, D. Gifford, M. Wolfe and M. Froggatt, "High resolution optical frequency domain reflectometry for characterization of components and assemblies," *Optics Express*, **13:666-674**, Jan. 2005.

B. J. Soller, M. Wolfe, M. E. Froggatt, "Polarization resolved measurement of Rayleigh backscatter in fiber-optic components," paper NWD3, *OFC Technical Digest*, Los Angeles, March 2005.

M.M. Ohn, S.Y. Huang, S. Sandgren, R. Measures, T. Alavie, "Measurement of fiber grating properties using an interferometric and Fourier-transform-based technique," **WJ2**, *Optical Fiber Communication Conference*, March 1997.

M. Froggatt, J. Moore, and T. Erdogan, "Full complex transmission and reflection characterization of a Bragg grating in a single laser sweep," **WB1**, *Optical Fiber Communication Conference*, March 2000.

M. Froggatt, E. Moore, and M. Wolfe, "Interferometric measurement of dispersion in optical components," **WK1**, *Optical Fiber Communication Conference*, March 2002.

U. Glombitza and E. Brinkmeyer, "Coherent frequency-domain reflectometry for characterization of single-mode integrated-optical waveguides," *J. Lightwave Tech.* **11**, 1377-1384, 1993.

The OVA Device Length Finding Methods

In order to properly perform a full Jones matrix characterization, the data processing algorithm in the OVA control software must be provided with the length of the device under test (DUT). The OVA can measure the length of the DUT, or it may be entered manually. This section will explain why the device length is necessary, and provide detail on how the OVA performs a measurement of the device length.

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Why is the device length necessary?

When the OVA performs a measurement scan, the raw data is acquired in the form of interference fringes on two detector channels. The Fourier transform of these fringes produces a time domain representation of the measurement interferometer where each optical path produces a peak. The location of each peak corresponds to the delay through its corresponding optical path. For a typical Jones matrix measurement, each of the four Jones matrix elements appears as a peak, or impulse response, in the time domain. Two matrix elements are measured on each of the two detector channels. The peaks on each channel are separated by a fixed delay, which is determined by the hardware design of the OVA measurement network.

In order to process the Jones matrix correctly, the two impulse responses on each channel must be separated. Therefore it is necessary to select only a portion of the

time domain data around each of the four impulse responses. This results in four data sets, which become the measured Jones matrix elements after an inverse Fourier transform and application of calibration data. The length of the selected section around each impulse response depends on the sample resolution setting, or time segment length. (For more information, see "High Dynamic Range Averaging" on page 48.) Note that this segment length cannot be greater than the fixed separation delay between the impulse responses.

The length of the DUT must be provided to the software algorithm that performs this segmenting process in order for it to position the selection windows properly in the time domain. If the length of the DUT is entered incorrectly, the selection windows will not contain the four impulse response functions; instead they will contain only noise. See Figures 9-18 and 9-19 for graphic illustrations of the windowing process for both correct and incorrect values of the device length. Figure 9-18 represents a correct and accurate measurement of the DUT. Figure 9-19 depicts incorrect positioning of the selection regions due to an incorrect DUT length setting. This will yield a measurement where all parameters are returned as nothing but noise.
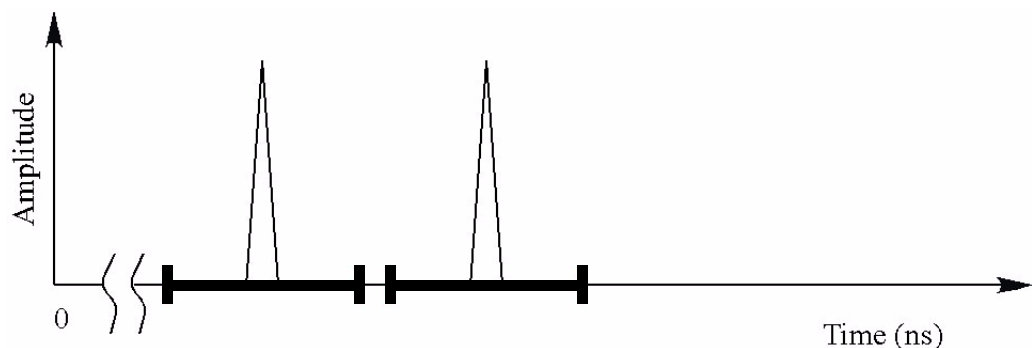
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Figure 9-18. Illustration of the impulse response selection process on one detector channel. The two peaks correspond to two elements of the Jones matrix. The bold regions represent the selected sections of the time domain, and their locations are determined by the DUT length setting.
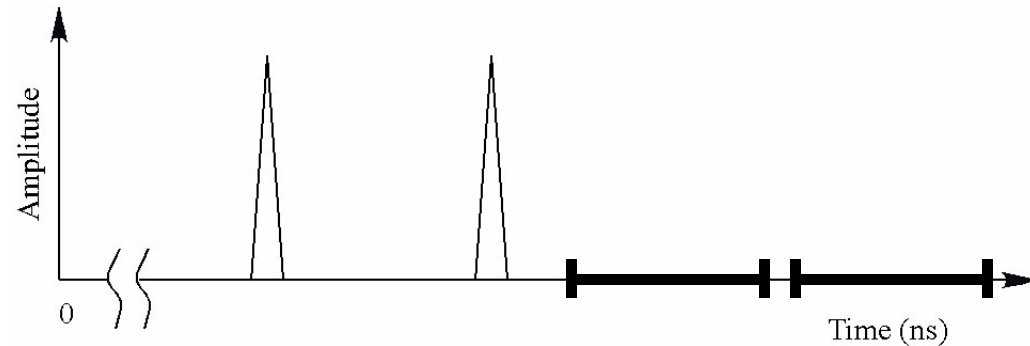
Figure 9-19. Illustration of the impulse response selection regions for an incorrect value of the DUT length.

In addition to the situations illustrated in Figures 9-18 and 9-19, there exists a special case where an incorrect DUT length setting will yield measurement data that contains device information, and therefore does not appear as noise, but is nevertheless incorrect. If the device length setting is off from the correct value by an amount equivalent to the fixed separation delay between impulse responses, then only one of the two impulse responses on each detector channels will be included by the windowing process. This situation is illustrated in Figure 9-20. In this case two of the four Jones matrix elements are measured to be essentially zero, so this situation can be diagnosed by noting that the measured PDL will be greater than 40 dB across the entire measurement spectrum. Note however that an impulse response will appear in the **Time Domain Window** (accessed by the **Time Domain** button), since this plot displays the sum of the four measured device impulse response functions.

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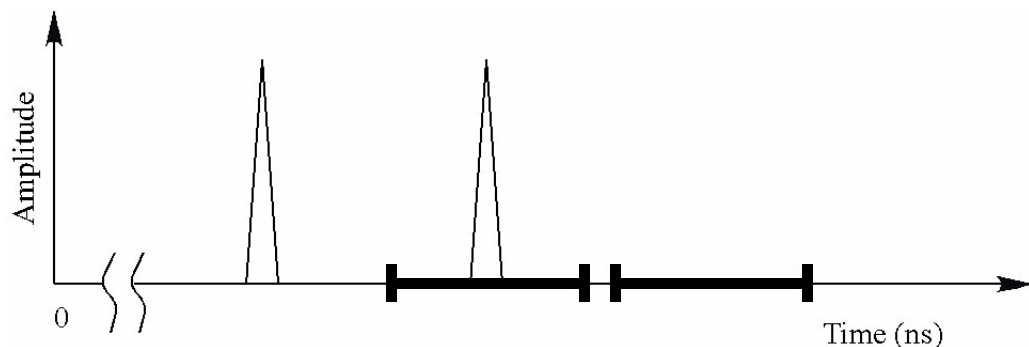
Figure 9-20. Illustration of the special case where the entered device length differs from the actual value by an amount equivalent to the fixed separation delay.

Entering the DUT length manually

For the majority of fiber optic devices, entering the physical length of the device (including leads) with an accuracy of ± 0.1 m will lead to accurate Jones matrix characterization by the OVA. For devices with long impulse responses that approach the length of the **Time Domain Window** (such as some dispersion compensators), the length will need to be known more accurately. This is because a longer impulse response will begin to extend outside of the **Time Domain Window** for a smaller displacement from the center of the window than a short impulse response.

Entering the correct length for a given device will place the impulse response in the center of the **Time Domain Window**. It is a good idea to open the **Time Domain Window** (by clicking the **Time Domain** button) after a measurement to ensure that the full impulse response in contained in the window. If the impulse response extends outside of the window in one or both directions, it may be necessary to change some measurement parameters and perform the measurement again. See "To adjust data that extends out of the Time Domain Window" on page 72 for information on how to address this situation.

It is important to note that while the position of the selection windows is determined using a control scaled in units of length, it is actually the delay through the DUT that determines the location of the impulse response peaks in the time domain. The OVA control software converts between length and delay assuming an index of refraction of 1.5. This is an appropriate assumption for most fiber optic devices. For the case of a device with a refractive index that differs significantly from 1.5, entering

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the precise physical length of the device may cause the time domain selection windows to be positioned incorrectly, and the measurement will fail. In this case it would be advisable to allow the OVA software to measure the length. The length returned by the software will deviate from the actual physical length, but it will be the appropriate value to correctly position the time domain selection windows for an accurate Jones matrix characterization of the DUT.

Choosing the DUT length finding method

To measure the length of the DUT, the OVA configures the internal optical network such that a single scalar device impulse response is measured in the time domain, rather than the four impulse response functions that correspond to the four Jones matrix elements. The position of the impulse response in the time domain is determined by the length of the DUT, so it is possible to invoke a numerical algorithm to locate the impulse response, and thus measure the DUT length.

Unfortunately, a single algorithm will not successfully locate the impulse response for all types of devices. Two different methods are necessary to cover the majority of fiber optic components. The appropriate method for a particular component is determined primarily by the optical bandwidth passed by the component. For this reason, the two methods are termed **Broadband** and **Narrowband** within the OVA control software. A broadband device is one that passes light at a large range of wavelengths, and blocks only small set of wavelengths, if it blocks any at all. (See Figure 4-9 "Typical broadband and narrowband loss curves" on page 46.) The converse is a narrowband device, which passes only a small wavelength range, while blocking all other wavelengths. In the context of OVA measurements, the relative terms *broad* and *narrow* refer to how much of the current measurement spectrum is passed by the device.

Note that many devices can be either broadband or narrowband depending on how they are used in a system. For example, a fiber Bragg grating is a narrowband device when used in reflection, but it is a broadband device when used in transmission. For other examples of broadband and narrowband devices, see Table 4-1 on page 45.

The Broadband method

Because a broadband device passes the majority of the wavelengths incident upon it, the amplitude of its impulse response is large. Its location can be determined by simply finding the location of the maximum amplitude value in the time domain data array.

The Narrowband method

A narrowband device, on the other hand, passes only a small subset of the incident wavelengths, leading to an impulse response with a relatively small amplitude. It is entirely possible that small broadband reflections in the system, such as those that occur at fiber optic connectors, could produce an impulse response peak with a larger amplitude than the DUT. Therefore simply searching for the maximum amplitude could yield erroneous results for the DUT length.

Instead of using the amplitude of the time domain data, the OVA software finds the length of narrowband devices using the phase of the impulse response. The phase is defined only where the impulse response has nonzero amplitude, so the phase of the time domain data will be purely noise except where an amplitude peak is located. If the impulse response is narrow, it can be difficult to locate a small region of well-defined phase. However, the narrow spectral response of a narrowband device necessarily implies that its impulse response has an appreciable width. Therefore, the impulse response can be located by searching for an area of well-defined phase.

The OVA software locates a region of well-defined phase by first calculating a numerical derivative of the time domain phase data. It then uses a small sliding window over which it calculates the standard deviation of the phase derivative. In regions of noise, the standard deviation will be large, but in regions of well-defined phase it will be much lower. The location of the impulse response is then taken to be the point where the standard deviation is minimum. This yields the device length for a narrowband device.

It is important to note that the OVA uses the current center wavelength and wavelength range settings when executing a device length measurement. Therefore it is critical that these values are set such that they include the pass band of a narrowband device. If the wavelength range does not include the pass band, the device will not pass any light and the length measurement will fail.

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Wavelength Calibration

The OVA measurement network includes a hydrogen cyanide (HCN) gas cell to calibrate wavelength during each measurement scan. The HCN gas cell is NIST Standard Reference Material #2519, and is used for wavelength calibration over the C-band. This section will describe how the HCN cell is used for wavelength calibration within the OVA.

Hydrogen cyanide has a very well known absorption spectrum that appears in Figure 9-21. Each absorption line occurs at a precise wavelength that is known to within ±1.5 pm. Table 9-2 lists the wavelength for each absorption line.
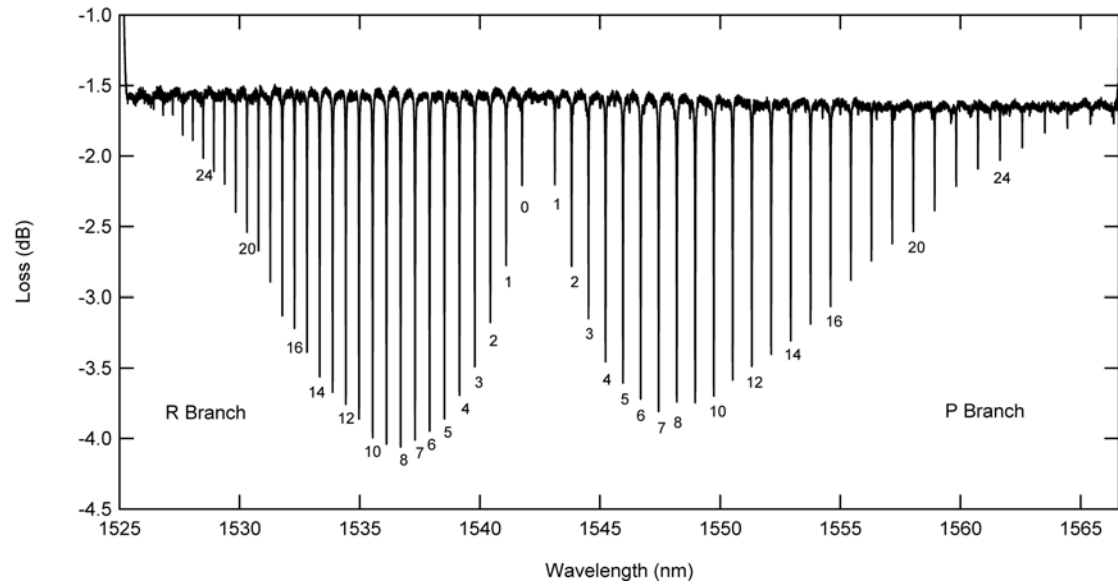
Figure 9-21. The HCN absorption spectrum.

Table 9-2: HCN absorption line wavelengths at 100 Torr

R Branch	Wavelength (nm)	P Branch	Wavelength (nm)
25	1528.0541	1	1543.1148
24	1528.4862	2	1543.8094
23	1528.9271	3	1544.5147
22	1529.3762	4	1545.2314
21	1529.8376	5	1545.9563
20	1530.3061	6	1546.6902
19	1530.7856	7	1547.4354
18	1531.2764	8	1548.1904
17	1531.7738	9	1548.9554
16	1532.2825	10	1549.7302
15	1532.8024	11	1550.5149
14	1533.3291	12	1551.3106
13	1533.8671	13	1552.1157

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Table 9-2: HCN absorption line wavelengths at 100 Torr

R Branch	Wavelength (nm)	P Branch	Wavelength (nm)
12	1534.4159	14	1552.9308
11	1534.9723	15	1553.7560
10	1535.5401	16	1554.5892
9	1536.1170	17	1555.4346
8	1536.7034	18	1556.2919
7	1537.2997	19	1557.1573
6	1537.9069	20	1558.0329
5	1538.5224	21	1558.9185
4	1539.1494	22	1559.8143
3	1539.7855	23	1560.7185
2	1540.4314	24	1561.6344
1	1541.0872	25	1562.5625

The Automatic Laser Calibration Utility (see "Packing and Shipping the OVA" on page 260) uses all of the HCN absorption lines to calibrate the tuning function of the laser. This tuning function provides wavelength accuracy of approximately 50 pm. During each measurement scan, the OVA acquires transmission data through the HCN cell and uses that data to refine the wavelength accuracy.

The wavelength calibration routine that occurs during each measurement scan is illustrated in Figure 9-22. The illustration is for a 2.5 nm scan centered at 1551.25 nm. Because data is sampled at intervals of equal optical frequency (see "Fiber Optic Interferometry" on page 231), it is sufficient to calibrate the absolute wavelength at a single point in the data array. Relative wavelength accuracy within the data array is ensured by interferometric triggering. The laser tuning function need only be accurate enough to determine which HCN absorption line will be used for calibration. The absorption lines are separated by roughly 0.5 nm, so ± 50 pm accuracy is sufficient. Data is acquired over a range somewhat larger than the requested scan range, and the HCN line nearest to the center of the scan is then used to determine the absolute wavelength at one point in the data array. Counting data points in either direction determines the points in the extended data array that correspond to the requested beginning and end wavelengths. The remaining data points outside this range are dropped.

Because the HCN gas cell absorption lines lie only within the C-band, special consideration must be made to calibrate the wavelength of scans that occur within the L-band. In the case of an L-band scan, the laser sweep is begun in the C-band such that at least one absorption line is included in the scan range. This line is used

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to calibrate the wavelength, and then the data set is truncated to include only the requested L-band scan range.
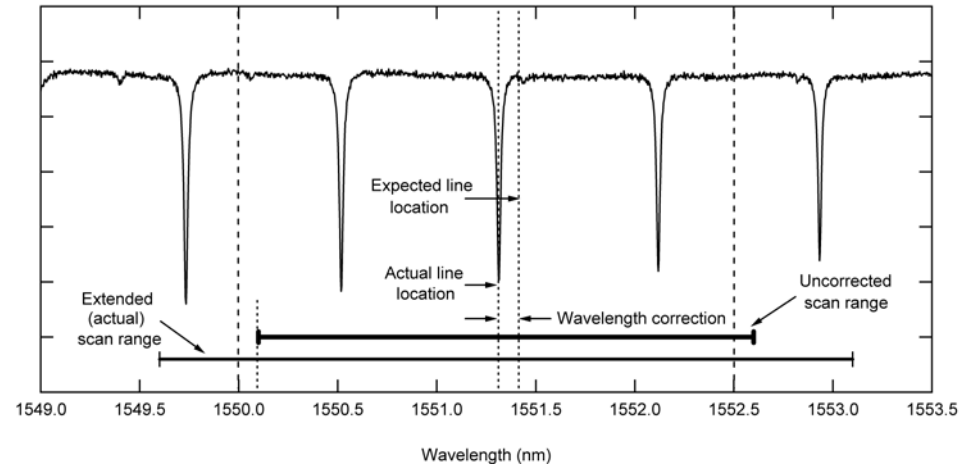
Figure 9-22. An illustration of the wavelength calibration routine
for a measurement scan from 1550 nm to 1552.5 nm.

Filter Theory

The time domain filter function

The illustration of the **Time Domain Window** shown in Figure 5-11 on page 72 is reproduced in Figure 9-23 below. The time domain filter function appears as the purple curve. It is a flat-top Gaussian function, and it is multiplied by the discrete Fourier transform of each Jones matrix element before the matrix is transformed back into the frequency domain for parameter calculations. The flat center region has a value of unity between the two points defined by the two yellow vertical cursors. The user may drag these cursors to change the portion of the time domain data passed by the filter. By default the cursors are located at 10% and 90% of the time domain range.

Outside of the area between the cursors the filter function has a value given by

$$e^{-[(t - t_{1,2})/\sigma]^2},$$

where $t_{1,2}$ are the positions of the two cursors, and σ is defined in the data field labeled **Sigma (ns)** in the **Window Parameters** area of the **Time Domain Window**. The shape of the Gaussian edges can be controlled by changing the value of σ. For display purposes, the filter function is scaled according to the maximum value of the impulse response.
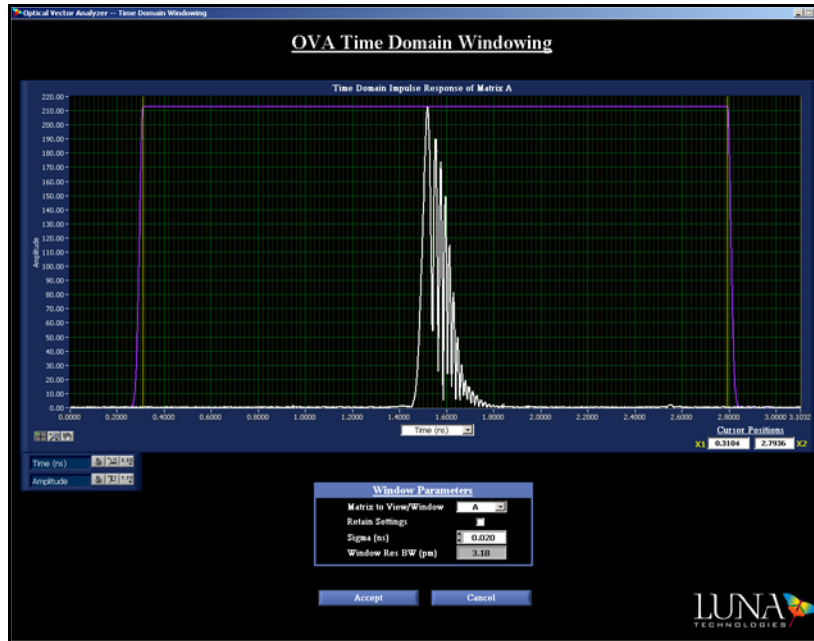
*Figure 9-23. The **Time Domain Window**, showing the impulse response (in white)*
of a fiber Bragg grating in reflection (sample file "Bragg Reflection.dat").
The time domain filter function is shown in purple, and the cursors are yellow.

9

Calculating the time domain resolution bandwidth

Because the Jones matrix and the impulse response are related to one another by a discrete Fourier transform, the width of the filter function in the time domain determines the resolution of the data in the frequency (wavelength) domain. If the full width at half maximum of the filter function is denoted Δt_f and given in units of nanoseconds, then the resolution bandwidth (RBW) is given by

$$RBW\,[\text{GHz}]\ =\ \frac{1}{\Delta t_f}$$

or

$$RBW\,[\text{pm}]\ =\ \frac{\lambda^2}{c\Delta t_f},$$

where λ is the center scan wavelength and c is the speed of light in a vacuum.

Time Domain Hanning Window

The operating software for the OVA allows the user to choose whether or not to apply a Hanning window, or raised cosine window, to the data. It is applied by selecting **Options > Apply Time Domain Hanning Window**. The purpose of the Hanning window is to "sharpen" narrow peaks in the time domain. This window should therefore be used when measuring components that have broadband features (and hence narrow features in the time domain).

If a_i represents one entry of the Jones matrix, where the subscript "i" denotes frequency, the Hanning-windowed data is of the form

$$a_{hi} = 0.5a_i[1-\cos(\frac{2\pi i}{n})],$$

for $i = 0,1,2,\ldots,n\text{-}1$, where n is the number of elements in a_i.

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The window is applied separately to each Jones matrix element and is only applied when viewing time-domain data. An example below shows both windowed and unwindowed data of the impulse response of a short length of fiber. Note the "sharpening" effect of the Hanning window.
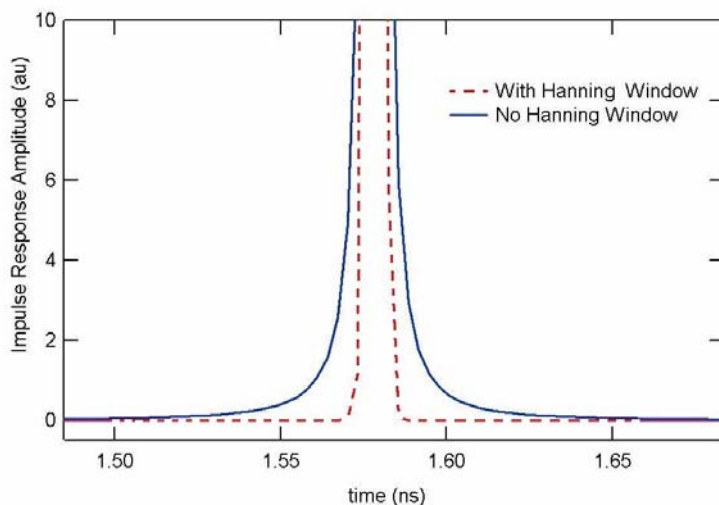
*Figure 9-24. Hanning windowed (red dashes) and unwindowed (blue) impulse
response amplitude of a short length of single-mode fiber.*

Smoothing filter operation

For all data quantities upon which it operates except polarization mode dispersion (*i.e.* IL, GD, CD, PDL, and phase ripple), the smoothing filter operates by taking a discrete Fourier transform of the data, multiplying by an acausal Gaussian filter function, and then inverting the Fourier transform. The filter operation on polarization mode dispersion data will be discussed in the following subsection.

The width of the Gaussian curve applied to the data is determined by the setting of **Filter Resolution BW (pm** or **GHz)** in the **Data Processing** area of the main window. As mentioned earlier, one can change all resolution bandwidth units from the default setting of picometers to gigahertz by selecting **Options > Resolution BW Units > Gigahertz (GHz)**.

The $1/e$ width Δt_s of the Gaussian filter function is given by the reciprocal of the resolution bandwidth setting in GHz. The following plot illustrates a 10 pm resolution bandwidth filter applied to the insertion loss data for a fiber Bragg grating:

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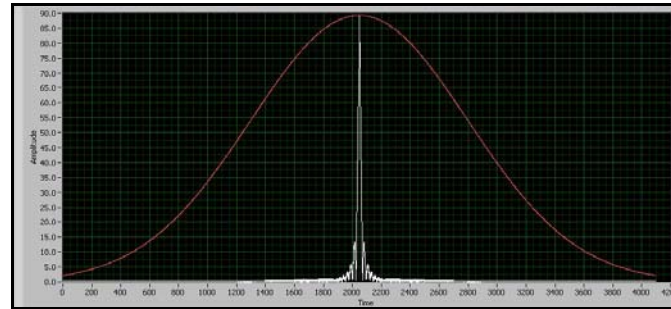
Figure 9-25. A 10 pm resolution BW smoothing filter (shown in red) applied to the insertion loss data (shown in white) for a fiber Bragg grating.

The transform of the insertion loss data appears in white, and the filter function appears in red. Note that this type of plot does not appear anywhere in the OVA control software. It is included here only to illustrate how the smoothing filter operates.

Smoothing filter operation on PMD and SOPMD data

When applied to polarization mode dispersion data, the smoothing filter performs another step in addition to applying the Gaussian filter described above. Calculation of PMD involves a numerical derivative, for which a frequency step size must be specified. (See "Polarization mode dispersion" on page 220.) With no smoothing filter applied, this step size is set to the current sample spacing as determined by the setting of the time segment length. (See "High Dynamic Range Averaging" on page 48.) Application of the smoothing filter causes the PMD calculation to use the setting of **Filter Resolution BW (pm** or **Ghz)** as the step size. Therefore, when the smoothing filter is applied, the control software re-executes the PMD calculation using the new step size.

Following the updated PMD calculation, the acausal Gaussian filter is applied to the PMD data in the transform domain in the same manner as it is applied to the other parametric data sets.

High Dynamic Range Averaging

The OVA may be purchased with an option for enhanced dynamic range averaging, which extends the loss measurement range. (See the specifications given on our website at www.lunatechnologies.com.) This mode of operation is designed to allow the user to measure weak signals in the presence of strong signals. A bandpass filter

is an example of a DUT that displays such behavior. In the "pass" or "in-band" spectral region, most of the input light is transmitted. This represents the strong signal. In the "stop" or "out-of-band" regions, very little or no light will be passed, depending on the design of the filter. One might then be interested in the rejection ratio, or the ratio of the amount of light passed to the amount of light "stopped." High dynamic range mode allows the OVA user to measure this rejection ratio to greater than the normal specification levels. Figure 9-26 displays the difference in measurement results for an optical filter using the standard (blue curve) and high dynamic range (red curve) averaging modes of operation,
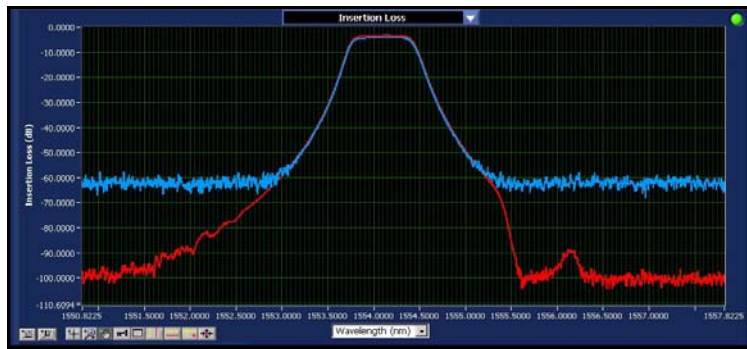
*Figure 9-26. Insertion Loss of an optical fiber measured with standard (blue curve)
and high dynamic range (red curve) averaging modes.*

One might ask, why not always use the extended dynamic range operational mode? A very sophisticated, proprietary phase averaging technique is employed to achieve the enhanced dynamic range. The technique is, as stated above, specifically tailored to measurement applications that require high dynamic range. The algorithm can generate small insertion loss errors for DUTs that do not require high dynamic range (>60dB) capability. This is illustrated in Figure 9-27, where a 0.1 dB "bowing" error is evident when **Options > Enable High Dynamic Range Averaging** is used to measure a nominally lossless fiber patch cord. Thus high dynamic range averaging should only be used when measuring filters with greater than 60 dB rejection ratio.

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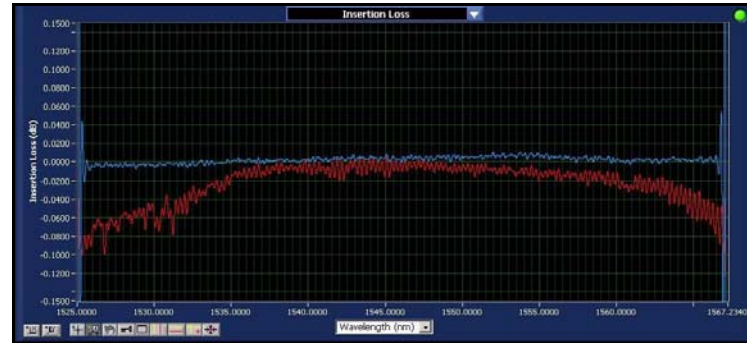
Figure 9-27. "Bowing" errors are evident when using high dynamic range averaging (red curve) on nominally lossless fiber patch cord, where the normal dynamic range would suffice (blue curve).

Pulse Compression

The OVA may be purchased with the option to perform pulse compression on the data, according to the values set before a scan under **Options > Specify Compression Settings**. Compressing the impulse response allows coherent interferometric Jones matrix measurements of highly dispersive devices.[10]

The available range in the time domain is determined by the acquisition step size in the frequency domain. This range is generally much longer than the duration of the scalar impulse response of the device under test, so the unused portion of the range can be utilized to simultaneously measure the four Jones matrix elements.[11] When measuring multiple elements, however, a stricter limit exists on their duration because they must not overlap in the time domain. This limit is usually not a problem except for dispersion compensating devices, which tend to have very long impulse responses. Compressing the impulse response of dispersive devices expands the applicability of coherent interferometric measurement.

In order to measure multiple elements, the measurement system must be constructed such that a temporal separation exists between each response. This is accomplished

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[10]E. Moore et al., "Impulse response compression for vector characterization of highly dispersive devices," OFC, 2004.

[11]D. K. Gifford et al., "Optical vector network analyzer for single-scan measurements of loss, group delay, and polarization mode dispersion," *Applied Optics*, vol. 44, no. 34, 1 Dec. 2005.

by careful selection of the optical path length, which determines the separation between each impulse. The separation time is chosen such that the impulse responses for most devices can be measured without overlapping. Most fiber optic components have impulse response durations on the order of 1 ns or less, so a separation time of several ns will suffice. In the OVA, this separation is set at 7 ns.

While this fixed separation time of 7 ns will work for nearly all fiber optic components, the one notable exception is dispersion compensators. In the case of seamless whole-band dispersion compensation devices, the change in group delay across the band can approach 100 ns, which translates to an impulse response of approximately the same length. This overlap can be eliminated by utilizing prior knowledge about the approximate average dispersion and dispersion slope of the device. This value is typically known by design. (For instructions on using OFDR software to calculate these values for your DUT, see "Calculating Average Dispersion and Dispersion Slope" on page 54.)

The phase response of the device, $\phi(\omega)$ may be expressed as

$$\phi(\omega) \ = \ \phi_0 + \tau_g(\omega - \omega_0) + O^2.$$

Here ω_0 is a chosen point in the device spectrum, ϕ_0 is a constant phase offset, and τ_g is the group delay at ω_0. Note that the first two terms will not affect the duration of the impulse response. The constant phase offset is arbitrary, and a constant group delay only shifts the position of the impulse response without otherwise affecting it. Broadening of the impulse response, and distortion of a bit signal, is caused by terms of order 2 and higher (O^2). For most dispersion compensators the broadening of the impulse response is dominated by the second order term, average dispersion (d_a). In some cases, the third order term, dispersion slope (d_s) also plays a significant role.

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In order to compensate for these broadening factors, we calculate a correction term which subtracts out the user-input values for the second and third order terms, average dispersion and dispersion slope, respectively. Given that wavelength λ is related to the change in frequency $\Delta\omega$ of the device by:

$$\lambda_i \ = \ \frac{c}{\frac{c}{\lambda_0} + \frac{i\Delta\omega}{2\pi}},$$

we integrate the phase with respect to frequency. This yields a correction term $\phi_{c,n}$ specific to the DUT:

$$\phi_{c,n} = \sum_{i=0}^{n} \Delta\omega \cdot [d_a \cdot \lambda_i + d_s \cdot \lambda_i^2].$$

To compress the impulse response, the OVA subtracts this correction term from the phase of the device response, yielding much narrower impulse response peaks.

If desired, the impulse responses can be expanded back to their original states after being separated by multiplying by the complex conjugate of $\phi_c(\omega)$ in the frequency domain. If this is not done, it simply must be noted that a quadratic factor has been removed from the phase when calculating parameters from the measured transfer function. For instance, the resulting measured dispersion will be

$$CD(\lambda) - (d_a + d_s\lambda),$$

rather than the actual device dispersion $CD(\lambda)$. Equivalently, the group delay will have a slope removed that corresponds to d_a. When using the measured transfer function directly for modelling purposes, it is imperative that the phase factor be replaced.

Pulse Compression Example

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Impulse response compression using the design values for both chromatic dispersion and dispersion slope was used to measure a full-C-band dispersion compensating grating (DCG). The nominal dispersion value was -225 ps/nm at a wavelength of 1545 nm, and the nominal dispersion slope was -7.8 ps/nm^2. The interferometric characterization measured the full grating Jones matrix, with a fixed separation delay of approximately 7 ns. The impulse response duration of the grating was approximately 9 ns. Both the compressed and uncompressed versions of the scalar impulse response appear in Figure 9-28. The compressed impulse response is narrower than the original by a factor of 35.
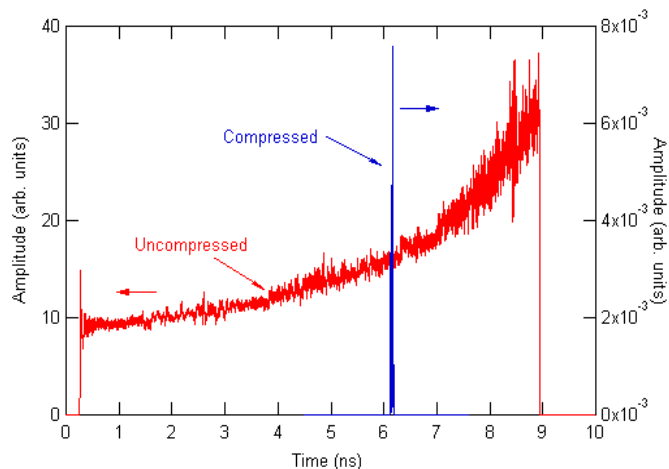
*Figure 9-28. The compressed and uncompressed impulse response for a
full-band dispersion compensating grating.*

The Jones matrix characterization of the grating allows all linear grating parameters
to be calculated. Impulse response compression does not affect the amplitude (loss)
parameters in any way, as it involves only a phase factor. The measured grating
insertion loss and polarization dependent loss appear in Figure 9-29.

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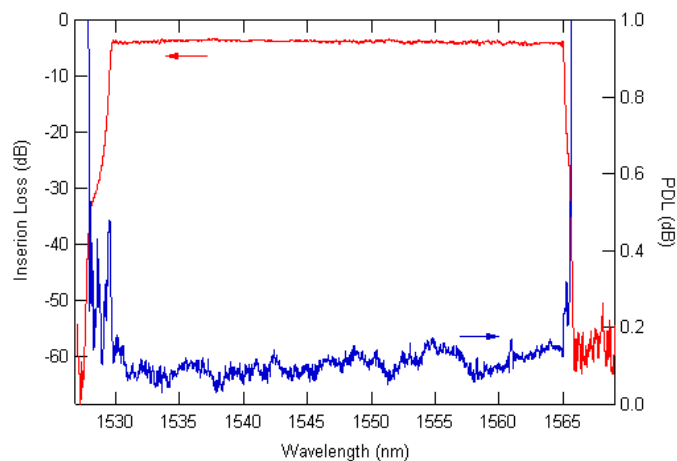
Figure 9-29. Measured insertion loss and PDL of the DCG.

Because the compression used both dispersion and dispersion slope, the measured group delay has a parabola removed and is thus termed the residual group delay. In many cases the residual group delay is desirable, as it is otherwise difficult to discern group delay ripple due to the large group delay changes in dispersion compensators. A 25 pm resolution bandwidth filter was applied to the data set.

The differential group delay (DGD) measurement is also unaffected by compression, and this data appears in Figure 9-30, along with the residual group delay data for the entire bandwidth of the device.
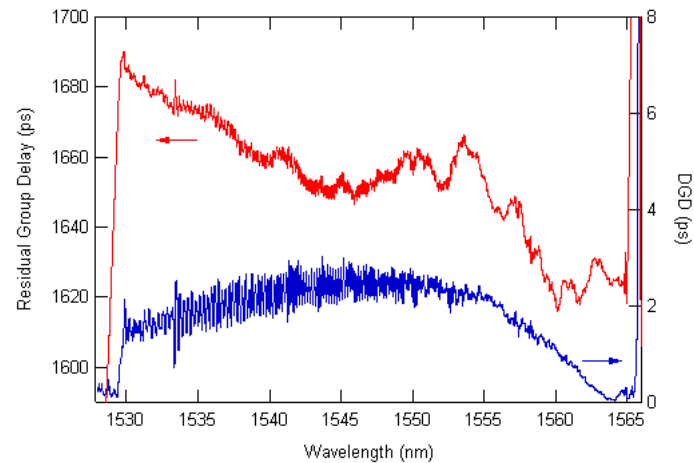
Figure 9-30. Group delay and differential group delay of the DCG.

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Chapter 10

Maintenance

Cleaning Connectors

It is extremely important to clean connectors before attaching optical fibers to the OVA for testing. Failure to do so may result in erroneous or noisy data.

Optical fiber connectors on devices should be cleaned before every connection to the OVA. The bulkhead connectors on the front panel of the OVA should be cleaned frequently, roughly once every 25 connections.

The optical fiber connector cleaner is used for cleaning connectors:

Mini foam swabs are used for cleaning the OVA bulkhead connectors:

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The cleaning supplies used with the OVA are:

- CLETOP connector cleaner - P/N F1-6270
- CLETOP connector cleaner replacement reel - P/N F1-6271
- Mini foam swabs (50/package) - P/N F1-0005

These supplies can be ordered from:

FIS Incorporated
161 Clear Road
Oriskany NY 13424
Web: www.fiberinstrumentsales.com
E-mail: info@fiberinstrumentsales.com.

Important ✓	Use only cleaners approved for use with fiber optic bulkheads and fiber connectors. Do not use any type of cleaning fluid, cotton swabs, or cloths.
	Using unapproved cleaning tools or fluids may result in erroneous or noisy data, or may damage the fibers and OVA components.

Cleaning Optical Fiber Connectors

Important ✓	Optical fiber connectors on devices should be cleaned before every connection to the OVA.

1   Expose the cleaning tape by pushing down the cover release lever.

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Cleaning tape cover closed   Cleaning tape cover open

cover release lever   tape cover   cleaning tape

The cleaner tape has two cleaning strips:
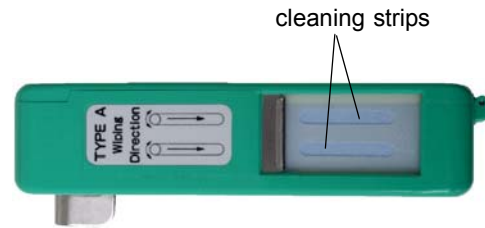
cleaning strips

2 Holding the fiber connector perpendicular to the cleaner tape surface, swipe the tip of the connector down the first cleaning strip, then swipe on the second strip.
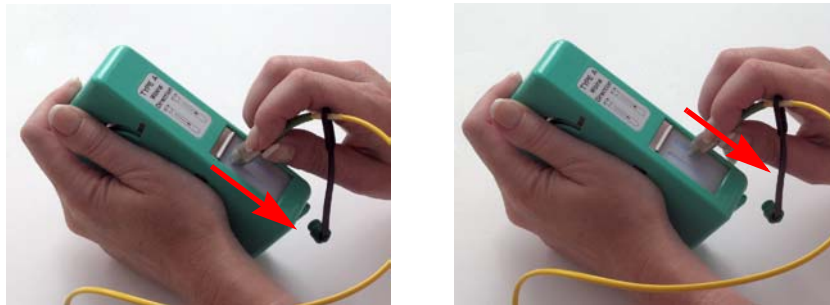
3 Close the cleaning tape cover before swiping another connector. This advances the cleaning tape.

Cleaning Bulkhead Connectors

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Important

☑ All three bulkhead connectors (source, detector, and aux) should be cleaned about once every 25 connections.

1 Either turn off the OVA, or turn off the laser by selecting **Tools > Turn Laser OFF**.

2 Make sure that no devices are connected to the OVA.

3 Turn the white cap counterclockwise to remove it. Gently insert one of the supplied mini foam swabs, as shown below. Twist the swab in one direction, and then remove. *Discard miniswabs after single use.*

Figure 10-1. Remove plastic cap from the bulkhead connectors. Gently insert supplied mini foam swab, rotate in one direction, then remove. Use a new swab for the next connector.

4 Replace the cap to protect the connector.

Cleaning the Case

Keep the unit free of dust and debris. Clean the case by wiping it with a soft cloth dampened with water or a mild, non-abrasive cleaning fluid such as window cleaner.

> **Caution**
>
> ⚠️
>
> Do not spray any fluid directly on case surfaces. It may seep into the interior of the case and damage components.

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Replacing Fuses

The fuse drawer is located on the power module on the instrument case back panel:

fuse drawer

power module
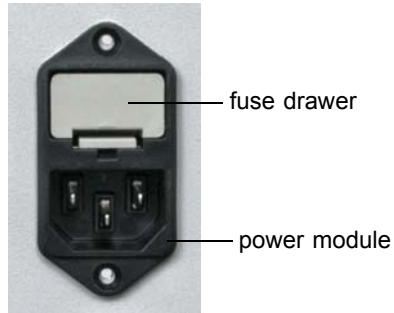
Warning

To avoid the risk of serious injury or death, ensure that the power cord is disconnected from the instrument when checking or replacing fuses.

To replace fuses

1 Disconnect the instrument power cord.

2 Place the blade of a screwdriver or similar tool in the slot at the bottom of the fuse drawer, then gently pry the drawer out of the power module.

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3 Replace fuses with Bussmann AGC-2 type 2A @ 250VAC 1 ¼" x ¼" fast acting (FA) fuses, rated FS01008.
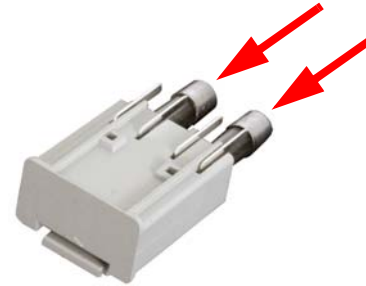
4 Push the drawer back into the power module until it snaps into place.

5 Reconnect the power cord.

Packing and Shipping the OVA

The OVA should only be packed and shipped in its original packing materials. If these have been discarded, contact Luna Technologies for packing material. To minimize physical shock during shipping, the OVA system should always be shipped via air instead of ground, by a reputable shipping service provider.

Required Packing Materials
- OVA Shipping Box (#1)
- Dell CPU Box (#2)
- Dell Monitor Box (#3)
- OVA Shipping Foam
- Dell Monitor Shipping Foam
- Dell CPU Shipping Foam
- OVA Accessory Box
- CPU Accessory Box
- Plastic Caps
- Sturdy packaging tape to seal the boxes

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Packing Procedure

1 Check that all materials to be shipped are ready to be packed using the "Components List" on page 7.

2 Place the supplied caps over all bulkhead ports, turning them clockwise until tightened.

3 Obtain an OVA Shipping Box (#1).

4 Seal the bottom center and edges of the box.

5 Pack the OVA in the OVA Shipping Box using the original styrofoam insert on each side of the OVA.

6 Pack the User Software, the User Guide, the OVA Accessory Pack, the GPIB Cable, and the USB Cable in the OVA Accessory Box.

7 Place the OVA Accessory Box on top of the OVA.

8 Seal the top of the box, taping the center and open edges.

9 Obtain a Luna CPU Shipping Box (#2).

10 Seal the bottom center and edges of the box.

11 Pack the CPU in the CPU Shipping Box using the original styrofoam inserts on each side of the CPU.

12 Pack the DELL Software and Manuals, as well as the mouse, keyboard, and CPU Power Cord in the CPU Accessory Box.

13 Place the CPU Accessory Box on top of the re-packaged CPU.

14 Seal the top of the box, taping the center and open edges.

15 Obtain a Luna Technologies Monitor Shipping Box (#3).

16 Seal the bottom center and edges of the box.

17 Pack the monitor in the Luna Technologies Monitor Box using the original styrofoam inserts on each side of the monitor. The Monitor Box should contain the monitor, the monitor software and manuals, the power supply and the power cord.

18 Seal the top of the box, taping the center and open edges.

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Chapter 11

Troubleshooting

This chapter describes how to troubleshoot OVA hardware and software errors. The first section describes what to do when the various **Status Bar Messages** appear. **General Troubleshooting** contains procedures for problems that occur without accompanying error messages. **Error Message Troubleshooting** explains error messages which appear in dialog boxes. The middle two sections are organized roughly in the order in which a user would operate the equipment and software. The last section describes Luna's **Self-Diagnostic Software**.

If you have problems or error messages not listed here, or if the solutions provided here do not resolve a problem, please run the Self-Diagnostic software and send the resulting text file to Luna (as described beginning on page 272). Then contact Luna Technologies toll free at 1-866-LUNAOVA (1-866-586-2682) or by e-mail at support@lunatechnologies.com.

Status Bar Messages

Please note that status bar messages are not "fatal" error messages. Rather they advise the user of the status of the instrument.

Error Message	Solution(s)
Laser Not Ready	This indicator will be displayed if the laser is not ready to perform a measurement. If this indicator does not go off within several minutes of turning on the instrument, please see "Laser Ready light does not come on within several minutes" on page 265.

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Error Message	Solution(s)
Out of Alignment	Realign, wait an hour, then recalibrate. For instructions, see "Aligning the OVA Optics" on page 33, and "Calibrating the System" on page 34. Measurements may still be performed if this indicator is displayed on the screen, but the data may not meet the documented specifications.
Out of Calibration	Recalibrate. If an internal calibration (see "To perform an internal calibration" on page 40) does not clear the indicator light, perform a full calibration (see "To perform a full calibration" on page 37). Measurements may still be performed if this indicator is displayed on the screen, but the data may not meet the documented specifications.
Wavelength Cal Failed	This message is displayed if a measurement cannot be calibrated to the wavelength. This simply means that the data acquired is accurate in terms of the parameter displayed on the screen, but the data is shifted in either direction in terms of wavelength. This problem may occur once in a while, but the occurrences should be fairly sparse. First try to scan again or try scanning over a different wavelength range to see if the warning indicator is displayed again. If the error light persists, it generally means that the laser (not just the instrument) needs to be recalibrated. Run the Self-Diagnostic software and send the resulting text file to Luna (as described beginning on page 272). Then you may contact Luna Technologies toll free at 866-LUNAOVA (866-586-2682) or by e-mail at support@lunatechnologies.com.

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General Troubleshooting

The OVA will not power on

Cause(s)	Solution(s)
The OVA is not plugged in or turned on.	Plug in the OVA. Turn on the power switch on the front of the instrument.
Blown fuse.	Replace the fuse. For instructions, see "Replacing Fuses" on page 258.

Laser Ready light does not come on within several minutes

Cause(s)	Solution(s)
The OVA has not stabilized to room temperature.	Allow time for the entire system to stabilize at room temperature before trying to operate.
Laser overheated because air flow to the OVA is restricted.	Move the OVA away from objects or surfaces that restrict air flow through the fan duct on the back of the OVA.
Laser overheated because of excessively high ambient temperature.	Move the OVA to a cooler environment or decrease the ambient temperature to within the OVA operating range of 10–35°C. If all of the above conditions are met and the Laser Ready light still does not come on, please run the Self-Diagnostic software and send the resulting text file to Luna (as described beginning on page 272). Then you may contact Luna Technologies toll free at 866-LUNAOVA (866-586-2682) or by e-mail at support@lunatechnologies.com.

Control software will not load

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Cause(s)	Solution(s)
Generally this occurs when other software is installed on the PC.	Remove any software not originally installed on the OVA PC, then restart. If the problem persists, reinstall the OVA control software from the OVA software CD.

All software controls are disabled or unavailable

Cause(s)	Solution(s)
The instrument is not properly connected to the PC.	Ensure that the cable connecting the instrument to the PC is securely attached.
The instrument could not be configured properly due to a communication error.	Reboot the PC. Turn the instrument off and then back on again. Restart the OVA control software. If the problem persists, reinstall the OVA control software from the OVA software CD.

Control software seems to lock up

Cause(s)	Solution(s)
The hardware may have stopped responding to the software.	Exit the software, using the Windows® Task Manger if necessary. [Click Ctrl + Alt + Del, then click the Task Manger button, then select the OVA software, and click End Task.] Turn the instrument off and then back on again. Restart the OVA control software.
Multiple Luna Technologies software applications may be running at the same time.	Ensure that you are only running one control software program at a time. Software applications cannot share the OVA instrument, so running more than one at a time will produce undesirable results.
The PC has entered an unusable state.	Reboot the PC. Turn the instrument off and then back on again. Restart the OVA control software. If the problem persists, reinstall the OVA control software from the OVA software CD.

Cannot align the OVA

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Cause(s)	Solution(s)
Laser not on.	Turn the laser on by selecting **Tools >Turn Laser ON**. Then realign after the Laser Ready light comes on. For instructions on aligning the optics, see "Aligning the OVA Optics" on page 33.

Alignment unsuccessful

Cause(s)	Solution(s)
Normal alignment procedure occasionally fails.	Retry. See "Aligning the OVA Optics" on page 33.

OVA will not scan

Cause(s)	Solution(s)
Laser not on or ready.	If the laser is not on, turn it on by selecting **Tools > Turn Laser ON**. Then re-scan after the Laser Ready light comes on. If the laser is on but the ready light is not lit, the laser is still warming up. Wait until the Laser Ready light comes on, then scan. If the Laser Ready indicator does not light within several minutes of turning on the instrument, see "Laser Ready light does not come on within several minutes" on page 265.
Optics not aligned. (The "Out of Alignment" indicator should be lit in this case.)	Realign, wait an hour, then recalibrate. See "Aligning the OVA Optics" on page 33, and "Calibrating the System" on page 34.
The instrument is not calibrated. (The "Out of Calibration" indicator should be lit in this case.)	Recalibrate. For instructions, see "Calibrating the System" on page 34
The instrument is not properly connected to the PC.	Ensure that the cable connecting the instrument to the PC is securely attached.

Excessive noise in data

Cause(s)	Solution(s)
Wrong DUT length setting.	Reset the DUT length. For detailed information, see "Finding the DUT Length" on page 44.
Wrong type of measurement selected.	Select the correct type of measurement, either Transmission or Reflection.

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Cause(s)	Solution(s)
Incorrect time domain filter setting.	Reset the filter parameters. For detailed information, see "The Time Domain Filter" on page 70.
Mechanical vibration.	Move, remove, or shut down any sources of vibration such as fans or other motor-driven equipment. Isolate the OVA from those sources.
Loose DUT connection.	Tighten the DUT (device under test) connections.
Dirty DUT or bulkhead connections.	Clean all connections. For instructions, see "Cleaning Connectors" on page 255.
OVA not aligned.	Realign, wait an hour, then recalibrate. For instructions, see "Aligning the OVA Optics" on page 33, and "Calibrating the System" on page 34.
OVA not calibrated.	Recalibrate. For instructions, see "Calibrating the System" on page 34.
Wrong fiber connector type.	Ensure that the fiber connectors interfacing with the front panel of the OVA are FC/APC connectors.
Incorrect or out-of-date calibration file loaded on startup.	Recalibrate. For instructions, see "Calibrating the System" on page 34.
DUT too long.	Shorten the leads or replace the DUT to comply with the length limit of the OVA.
Cracks in bulkhead connector alignment sleeve.	Contact Luna Technologies at 1-866-LUNAOVA (866-586-2682) or support@lunatechnologies.com for service.
OVA not warmed up.	In order to achieve accurate results within published specifications, the system should be allowed a full hour to warm up and settle after powering on. Check the menu item **Tools > Check Warm-Up Timer** to verify that the full hour has elapsed.

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No data after scan

Cause(s)	Solution(s)

Incorrect graph range settings.	Rescale the plot axes. For detailed information, see "Scaling Plot Axes" on page 63.

Unexpected or abnormal data

See "Excessive noise in data" on page 267.

Instrument drifts out of calibration

Cause(s)	Solution(s)
Temperature changes will cause the instrument to drift.	Recalibrate. For instructions, see "Calibrating the System" on page 34. Or see "Automatic Calibration" on page 42 to set the OVA for automatic calibration.

Error Message Troubleshooting

Errors can occur while operating the OVA software. These errors will be described on the screen in a standard Microsoft® Windows® dialog box, showing the numerical error code as well.

However, if the instrument is being operated remotely, error messages will not be displayed in a dialog box. The user will need to query the instrument for errors to ensure that the previous action was completed successfully. For more details, see "Controlling the OVA Remotely" on page 135.

11

Errors on Software Startup

Instrument not calibrated

Cause(s)	Solution(s)
On startup, the software attempts to load calibration data from a file. If this message is displayed, the file was not found or was found to be corrupted.	Calibrate the instrument. Once the instrument is calibrated successfully for both transmission and reflection, the user will never see this message again (unless the calibration data files are deleted manually).

Configuration information could not be loaded from the instrument; the software goes into "Desktop Analysis" mode

Cause(s)	Solution(s)
The USB cable connections could be loose.	Check the connections to ensure that the cable is connected properly to both the instrument and the PC.
The instrument is not turned on.	Ensure that the instrument is plugged into the proper type of outlet and turn on the power switch.
The software is in an unknown state.	Exit and restart the software.
The hardware is in an unusable state and is not responding to the software.	Exit the software. Turn the instrument off and then back on again. Restart the PC and the control software.
The USB cable is faulty.	If the above solutions do not work, run the Self-Diagnostic software and send the resulting text file to Luna (as described beginning on page 272). Then you may contact Luna Technologies toll free at 866-LUNAOVA (866-586-2682) or by e-mail at support@lunatechnologies.com to obtain a replacement cable if the problem persists.

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Remote interface (i.e. GPIB or Ethernet) could not be initialized properly

Cause(s)	Solution(s)
Either there is a problem with the GPIB board or it is not installed in the PC.	Ensure that the name of the GPIB board installed in the PC has not been changed from the default of "GPIB0" (using the "Measurement and Automation" shortcut on the desktop). If the card is not found in the system, please contact Luna Technologies toll free at 866-LUNAOVA (866-586-2682) or by e-mail at support@lunatechnologies.com.

Errors During Calibration

Wavelength calibration failed while acquiring data

Cause(s)	Solution(s)
None of the requested scans that were acquired were properly adjusted to wavelength. Although this is not a major error when performing a measurement, it is a problem when calibrating the instrument.	Attempt the operation again. If the problem persists, run the Self-Diagnostic software and send the resulting text file to Luna (as described beginning on page 272). Then you may contact Luna Technologies toll free at 866-LUNAOVA (866-586-2682) or by e-mail at support@lunatechnologies.com.

The optics were detected to not be aligned properly

Cause(s)	Solution(s)
This is just a warning letting the user know that the optics are not aligned properly.	The user will have the option of continuing with the calibration even without the optics aligned. It is preferable to realign, wait one hour, then recalibrate. For instructions, see "Aligning the OVA Optics" on page 33, and "Calibrating the System" on page 34.

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Calibration data contains invalid values

Cause(s)	Solution(s)
The calibration was unsuccessful due to some problem in the hardware or software.	Attempt the calibration again. If the problem persists, please run the Self-Diagnostic software and send the resulting text file to Luna (as described beginning on page 272). Then you may contact Luna Technologies toll free at 866-LUNAOVA (866-586-2682) or by e-mail at support@lunatechnologies.com.

Errors During Scanning or Calibration

Any number of errors can be displayed during a scan. However, many of the errors are not major problems and most will be isolated incidents. In those cases, the error message will be displayed during one scan and the subsequent scans will be performed without any error. If any error occurs consistently, please run the Self-Diagnostic software and send the resulting text file to Luna (as described beginning on page 272). Then you may contact Luna Technologies toll free at 866-LUNAOVA (866-586-2682) or by e-mail at support@lunatechnologies.com.

The specified timeout occurred before all of the requested data could be acquired

Cause(s)	Solution(s)
There may be a problem with the hardware.	If this problem occurs more than once at any time, exit the software. Turn the instrument off and then back on again. Restart the PC and the control software.
	If none of these actions fix the problem, run the Self-Diagnostic software and send the resulting text file to Luna (as described beginning on page 272). Then you may contact Luna Technologies toll free at 866-LUNAOVA (866-586-2682) or by e-mail at support@lunatechnologies.com.

11

Self-Diagnostic Software

Each Luna Technologies PC is loaded with both operating and Self-Diagnostic software. If the above-described error messages and solutions do not solve issues, please run the Self-Diagnostic software before contacting Luna. The Self-Diagnostic

software outputs a text file (*c:\selfdiag:txt*) which will help Luna's support staff correct errors.

Running the Self-Diagnostic Software

1 Exit the OVA software (by selecting **File > Exit**) and any other software.

2 Go to the Windows® Start menu and select **Programs > Luna Technologies > Self-Diagnostic**.

The following window box appears:

3 Click the blue **Start** button.

4 Follow instructions as they appear.

5 When the diagnosis is finished, the window will change appearance, as shown below:
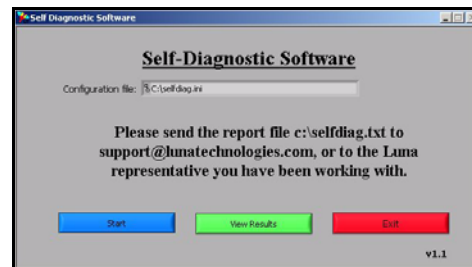
6 You may view the results and then click the red **Exit** button.

7 As instructed in the above window, send the resulting text file (*c:\selfdiag:txt*) as an attachment to support@lunatechnologies.com. Luna's support staff will examine the file and contact you.

11

11

Appendix A

Specifications

	Specification	Units
PC I/O		
Input/Output devices	• IEEE-488/GPIB • Ethernet port • 3.5-inch HDD • CDRW drive • Printer port • Keyboard/Mouse • Display	
Input voltage range	100-240	VAC
Input frequency range	50-60	Hz
Operating power	100	VA
Environmental Requirements		
Operating temperature range	10-35	ºC
Storage temperature range	0-40	ºC
Relative humidity (non-condensing)	< 80	%
Physical Characteristics		
Weight (PC not included)	16.2 35.8	kg lbs
Case size (W X D X H)	510 X 420 X 200 20.1 X 16.5 X 7.9	mm inches

For current performance specifications, check our website at www.lunatechnologies.com.

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Minimum PC Requirements

Pentium 4 or Core 2 Processor

1 GB RAM

USB 2.0 port

Windows 2000/XP (Vista not supported)

Screen Resolution: 1280 x 1024

(Laptop resolution setting must be > 1280 x 1024)

Class 1 Laser Product

The Luna Technologies OVA is a **Class 1 Laser Product**, which meets the requirements of Class 1 in standard **IEC 60825-1: 2007** and complies with **21CFR1040.10**.

Maximum rated output power: 2.4 mW

Internal laser module maximum rated output power: 10.0 mW

Emitted wavelengths: 1265–1335 or 1525–1610 nm

CAN/CSA Testing

This product has been tested to the requirements of **CAN/CSA-C22.2 No. 61010-1**, second edition, including Amendment 1, or a later version of the same standard incorporating the same level of testing requirements.

IP Rating: IP 20

According to EN60 529/IEC 529, the OVA is rated IP 20, meaning the OVA is protected against solid foreign objects with a diameter of 12.5mm and greater; the OVA is not protected against water.

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