ODiSI-A

Optical Distributed Sensor Interrogator

Users Guide

LUNA

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IEC 60825-1, 2007
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*.

Optical Distributed Sensor Interrogator Model ODiSI A
Versions: *User Guide ODiSI-A* Software 1.3

Luna
3157 State Street
Blacksburg, VA 24060
Phone: (540) 961-5190
Fax: (540) 961-5191
E-mail: solutions@lunainc.com
Web: www.lunainc.com

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Chapter 1 System Overview

Luna Technologies' Optical Distributed Sensor Interrogator (ODiSI) uses swept-wavelength coherent interferometry to measure temperature and strain using optical fiber as the sensor. The ODiSI offers the ability to test a structure at numerous specific points of interest over an extended area with user-configurable sensing locations and gauge lengths.

Fiber optics undergo well defined physical changes as a result of changes in temperature and strain. The ODiSI is able to measure the strain or temperature at every location in a fiber at a given time. By comparing measurements made at two different times the ODiSI calculates and displays the change in strain or temperature.

One advantage of using optical fibers as sensors is that they are extremely small and light weight. ODiSI sensors are optical fiber with a width of less than 0.2 mm and can be as long as 50 m or as short as desired. A second advantage is that optical fibers do not require electrical connections at the measurement point. Typical foil strain gauges have a sensing region that is 3 mm long— though the entire gauge is much larger than that—and measure strain at a single point over time. Foil strain gauges also require that each gauge be wired to a measurement channel.

Another advantage of the ODiSI over other measurement systems is that the ODiSI can identify each sensing fiber and detect where the fiber begins relative to a known point such as the end of a patch cable. In order to identify and locate a fiber the fiber data file must be installed into the software. The software can then identify which fiber is physically attached to the ODiSI.

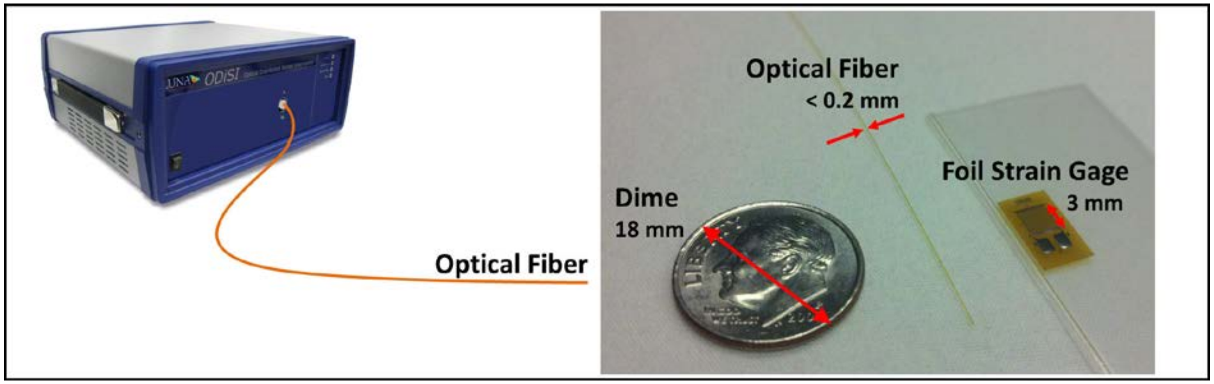


Figure 1-1. Figure 1-1 ODiSI sensor fiber is much thinner and longer than traditional foil strain gauges.

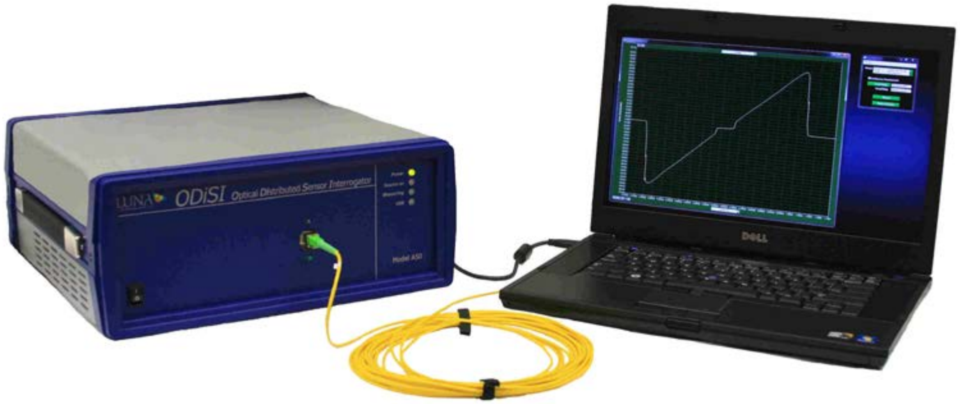


Figure 1-2 ODiSI measurement system. The ODiSI measures strain and temperature at user specified locations along the fiber. Data is presented graphically, providing the user with unprecedented data density and resolution.

The Control Software

The ODiSI control software includes an intuitive graphical interface. All controls, options, and measurement results are easily accessible from several windows.

Caution

Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous laser radiation exposure and one or more safety protections may be impaired or rendered ineffective.

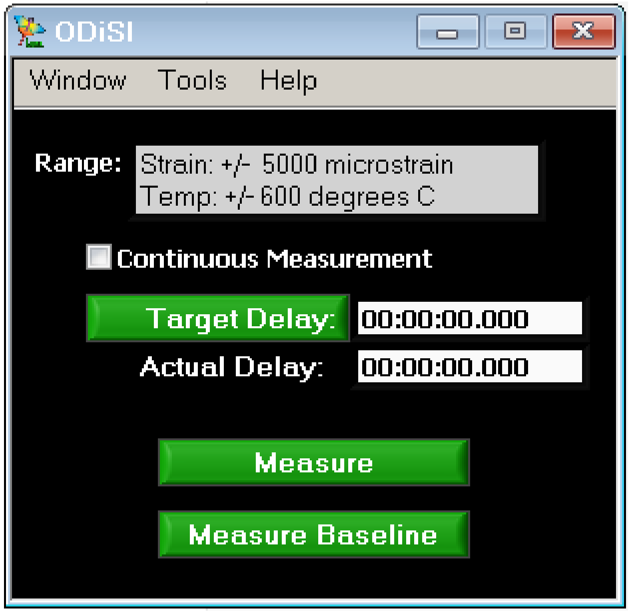


Figure 1-3. Control software initial window. The window will be inactive when the software starts. It will become active when the instrument completes its self test.

Chapter 2 Assembly and Startup

The Optical Distributed Sensor Interrogator (ODiSI) is shipped with everything needed to conduct strain and temperature measurements, 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 ODiSI.

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

The ODiSI is shipped with either a laptop or a PC with monitor, keyboard and mouse. All other components shown below are shipped with each ODiSI instrument.

Optical Distributed Sensor Interrogator instrument.

Getting started kit includes: 1 meter temperature sensing fiber, 1 meter strain&temperature sensing fiber, and 2 meters of fiber to practice attaching fiber to a structure.

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

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

ODiSI laptop PC (or desktop PC, shown below)

Laptop power supply

ODiSI desktop PC (or laptop PC, shown above)

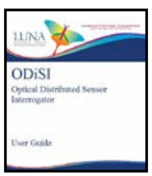
17-inch flat panel monitor (with desktop only)

Monitor-PC interface cable (with desktop only)

Keyboard (with desktop only)

Mouse (with desktop only)

Standoff cable



This *ODiSI User Guide (pdf file located on software CD)*

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.

Setting up the ODiSI

To set up the ODiSI

1 Remove all the ODiSI components from the shipping containers and verify that no components are missing. (See components list.)

Important

Place the ODiSI away from walls or objects that will restrict the air flow through the fan duct on the back and sides of the unit.

2 For best performance, place the ODiSI on a stable surface, capable of supporting the weight of the entire unit. For the weight and dimensions of the unit, see Appendix A, “Specifications”.

Important

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

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. Luna Technologies advises against user-supplied instrument controllers.

Important

Do not turn on the instrument 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 on the PC using the proper cable for the printer, according to the PC manufacturer instructions enclosed.

5 If necessary, install the drivers for local or network printers.

Important

Do not install any software on the ODiSI 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 ODiSI.

6 Optional: To connect the ODiSI to a network, connect a network cable (not provided) to the ethernet port on the PC.

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

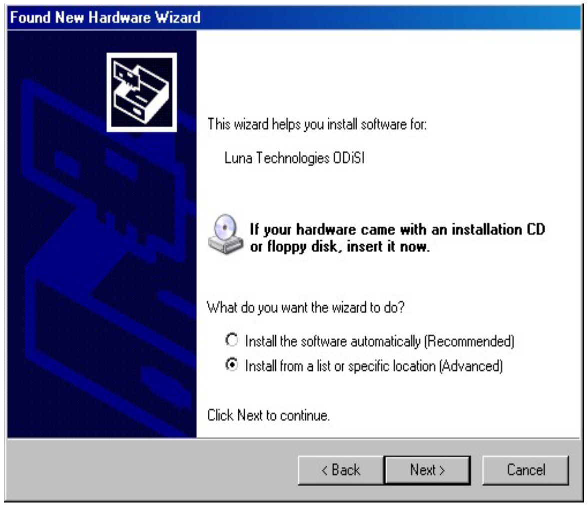
8 On the front of the instrument, there is a metal trap door to protect the source port. Do not prop this door open or look into the port while the ODiSI is turned on.

9 Attach the power cords provided to the instrument and to the PC. To ensure safe operation, position the instrument to allow easy access to the power cord. Note that the ODiSI requires surge-protected, grounded outlets.

Initial Startup

1 After full assembly above, turn on the PC (according to manufacturer's instructions), allowing it to fully load up Microsoft® Windows® 7 or XP. (Note that the screen appearance shown in this *User Guide* may vary according to Windows® version and options.)

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

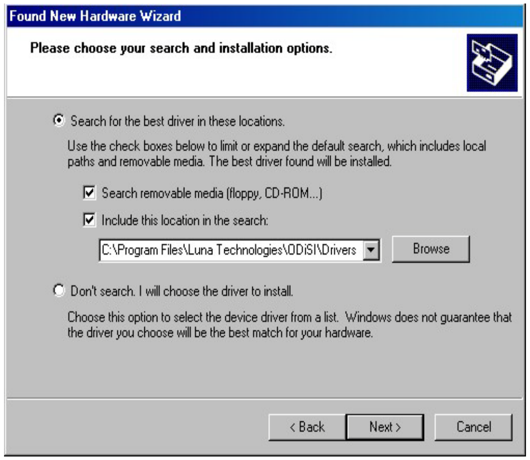


3 Ensure that the ODiSI is powered **OFF**.

4 Connect the ODiSI to the PC using a standard USB cable (provided).

5 Turn on the ODiSI using the power switch on the front panel.

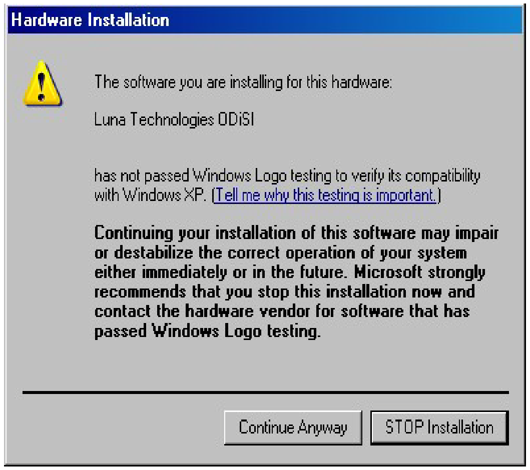
6 All LEDs on the front panel of the instrument will turn on, then all but the **Power** LED will turn off. The **Power** LED will remain lit until the unit is powered off.



7 The PC will automatically detect the device and display the “Found New Hardware Wizard” dialog window.

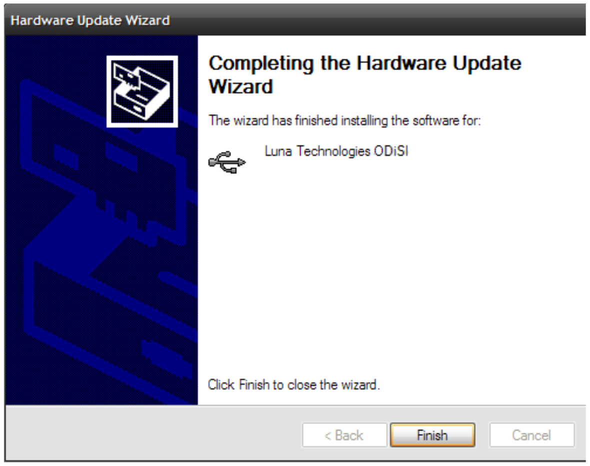
8 Select the “**No, not this time**” option and click the “**Next**” button to continue. A new window similar to the one above will be displayed.

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 to the right, is displayed.

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\ODiSI\Drivers). 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 will be displayed.

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

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 ODiSI instrument. If the instrument is ever connected to a different USB port, it may require that this driver installation procedure be completed again.

Important

If the control software is started when the instrument is not powered on, the software will start in desktop analysis mode. To acquire measurements exit the software, turn on the ODiSI and restart the software.

Start Up

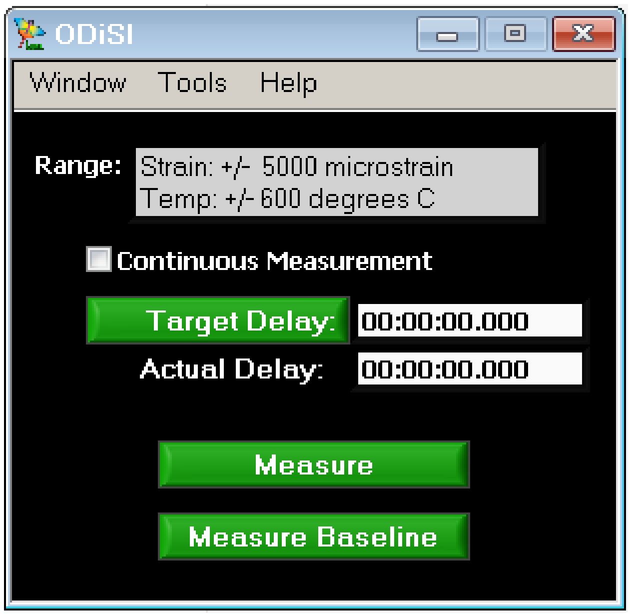
The front panel of the Optical Distributed Sensor Interrogator contains the power switch and the optical connector necessary to perform measurements.

Four LEDs indicate the state of the instrument:

- The **Power** LED lights when the power is on.
- **Source On** lights after the laser has been turned on.
- **Measuring** lights when the instrument is recording data.
- **USB** lights after a scan, while the ODiSI unit is sending data to the PC.

Start the control software by double-clicking the desktop icon, or by selecting **ODiSI Software** from the programs group in the Windows® Start menu. The **ODiSI Control** window will appear. The instrument will take a few moments to calibrate before it is ready to use.

See Chapter 3 and 4 for details about using the software.



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 perform temperature and strain measurements.

This chapter provides an overview of the location and function of all controls and indicators included in the control software. Chapter 4, "Performing Measurements," provides greater detail on how to use the ODiSI to perform specific measurements. Chapter 5, "Software Development Kit" assists the user with developing their own software to perform ODiSI tasks.

Important

If the control software is started when the instrument is not powered on then the software will open in data analysis mode. To take measurements exit the software, turn on the ODiSI instrument, and restart the software.

Starting the software

Double Click on the ODiSI icon on the desktop or select Luna Technologies\ODiSI from the start menu.

The **Control** window will open and the instrument will configure.

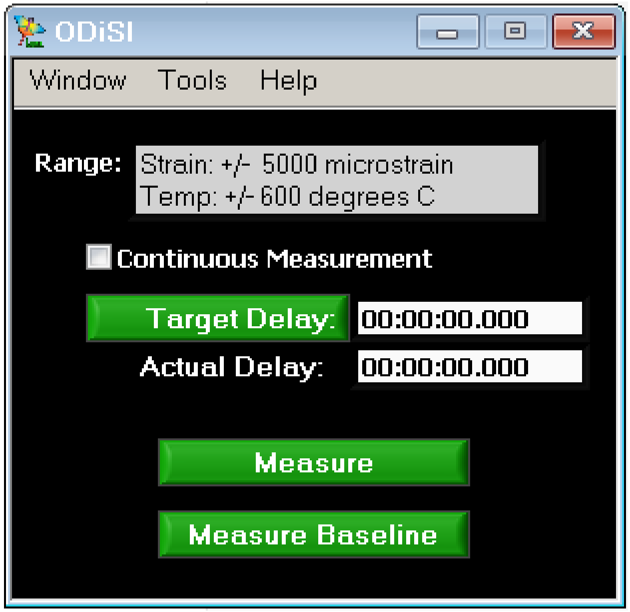


Figure 3- 1 ODiSI Control window is the main user interface

Window Features

Control Window

The **Control** window contains fields that control the ODiSI instrument and set test parameters, as shown below.

- Continuous Scan, when checked, causes the ODiSI to take repeated measurements. The graph display is continuously updated after each measurement. This mode is started and stopped by pressing the Measure button.

- Target Delay: Allows the user to set the time between measurements when operating in Continuous Scan. Time is entered in Hours:Minutes:Seconds:Milliseconds.
- Actual Delay: Displays that actual delay between measurements.
- Clicking the Measure button starts the measurement. This same button is used to stop scanning when operating in Continuous Mode**.**
- Clicking the “Measure Baseline” button will record the current state of sensor temperature and strain. Measurements are always displayed as a difference relative to the baseline.

The Control window menu bar contains three items:

1 Window, for opening other ODiSI windows.

2 Tools, for checking the optical path for strong reflections and aligning the internal optics of the ODiSI.

3 Help, to provide information about the ODiSI

Graph Window

Open this window by selecting **Window > Graph** in the upper left of the **Control** window. The **Graph** window contains controls for selecting the content of the graph and for manipulating how the graph is displayed.

Figure 3- 2 The Graph window. Used to display measured data

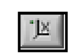
- The **Parameters Menu** at the center top of each graph is a pull-down menu allowing the user to select which parameter is graphed: **Strain**, **Temperature**, **Spectral Shift, or Shift Quality**.

- The pull-down menu at the bottom of the graph allows the user to select the value and units of the X-axis: **Length (m)**, **Length (mm)**, **Length (ft)**, **Length (in) or Time (ns)**.

Graph Buttons

Buttons to the lower left of each graph let the user adjust plot axes, zoom, and pan. The ODiSI control software provides several ways for adjusting the scaling of the graph windows.

Autoscaling

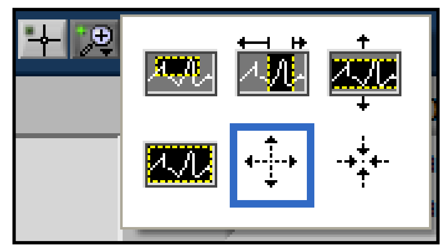
The user may rescale each plot axis independently by using the autoscale buttons for the X-axis  and the Y-axis , located in the lower left corner of each graph window.

Manual scaling

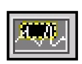
The plot axes may be scaled manually by double-clicking on either the lowest or highest value labeled on the axis and typing in a new value. To accept the new value, press enter or click anywhere in the screen.

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.

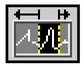
Using zoom tools



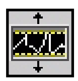
There are six available zoom tools, which are accessible by clicking the **zoom menu button**  located in the lower left corner of each graph window. When this button is clicked, a pop-up window containing the six zoom tools opens. A blue border surrounds the selected tool.

The zoom window tool: 

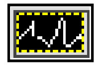
This tool allows the user to zoom in on a rectangular region of the graph window. To use this tool, first select it from the zoom menu button. Then click in the graph window and hold the mouse button to define one corner of the rectangular region. Then drag the mouse cursor and note that a dotted box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

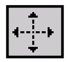
This tool allows the user to zoom in on a region of the X-axis only, without adjusting the Y-axis scale. To use this tool, first select it from the zoom menu button. Then click in the graph window and hold the mouse button to define one edge of the desired X-axis region. Drag the mouse cursor to the 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: 

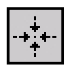
This tool allows the user to zoom in on a region of the Y-axis only, without adjusting the X-axis scale. To use this tool, first select it from the zoom menu button. Then click in the graph window and hold the mouse button to define one edge of the desired Y-axis region. Drag the mouse cursor to the 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: 

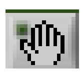
Selecting this button from the zoom menu returns the graph to the full scale of all data.

The zoom in tool: 

This tool allows the user to zoom in (magnify) the graph from the point where the cursor is clicked. 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 allows the user to click in the graph window and drag the data to the left or right. To use this tool, first select it from the zoom menu button. Then click and hold the click in the graph area. Scroll the mouse left or right to move the data.

Fiber Config Window

Open this window by selecting **Window > Fiber Config** in the upper left of the **Control** window.

A tree structure of all installed sensors is shown on the left. On the right is a button to install new fibers into the software. Below the install button is a button that will cause the ODiSI to compare the fiber that is physically attached to the system with all the fiber files that have been installed. The ODiSI software displays the serial number and name of the attached fiber in the text box labeled “Attached Fiber”. The user can review data for the attached fiber by clicking “Select Attached Fiber” or by selecting the fiber serial number (name) of the fiber in the fiber tree.

The directory C:\ProgramData\Luna Technologies\ODiSI contains all of the saved data for the ODiSI software. It is possible for this data, in extreme circumstances, to become corrupted. Therefore, it is recommended that once all of the user’s fiber configurations have been setup this folder be duplicated and saved in a secure location. If ever the configuration in the save directory becomes corrupted the backup folder can be used to replace the corrupted folder.

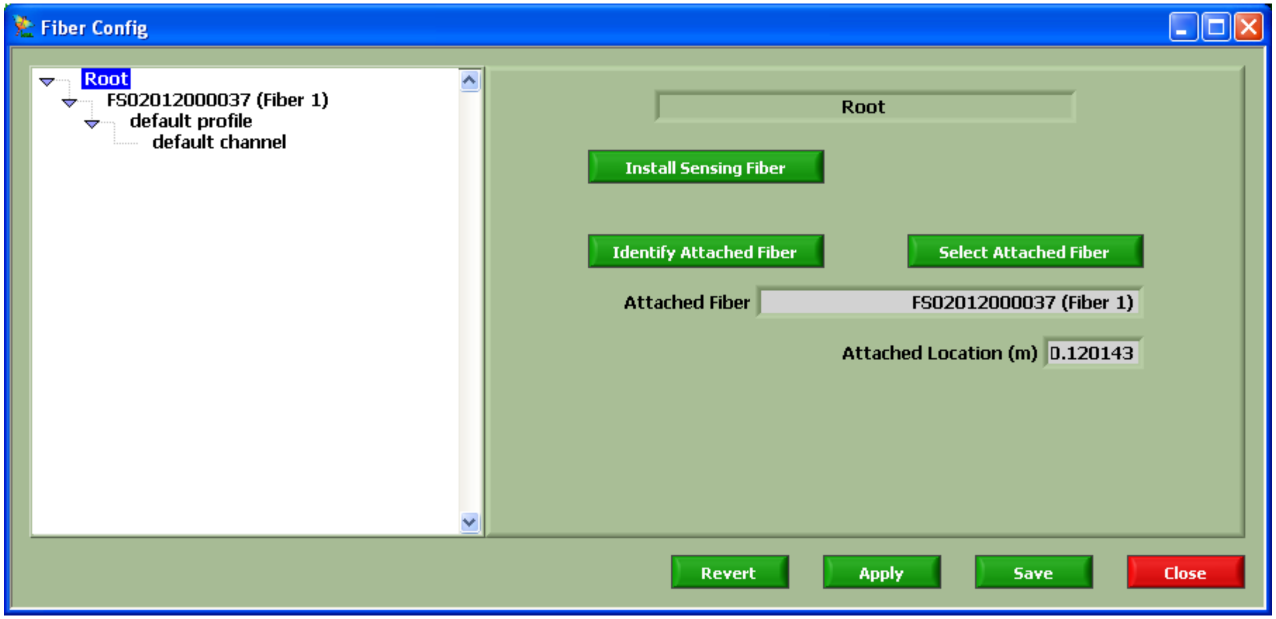


Figure 3- 3 The Fiber Config Window. Used to configure the fiber

Installed Fiber display

The installed fiber display is activated by selecting a particular fiber from the fiber tree on the left of the Fiber Configure window. The primary use for the Installed Fiber display is to enter the number of the Optical Switch Port that is attached to a particular fiber. The value of the Optical Switch Port is not used within the ODiSI GUI. The value can be read using the ODiSI Software Development Kit so user applications can set the correct port value before measuring. Fibers can be uninstalled from the software by clicking the red Uninstall button in the upper right corner. Note: you cannot uninstall a fiber that is set as the Attached fiber in the Fiber Select window. New profiles can be added to a fiber by clicking the New Profile button.

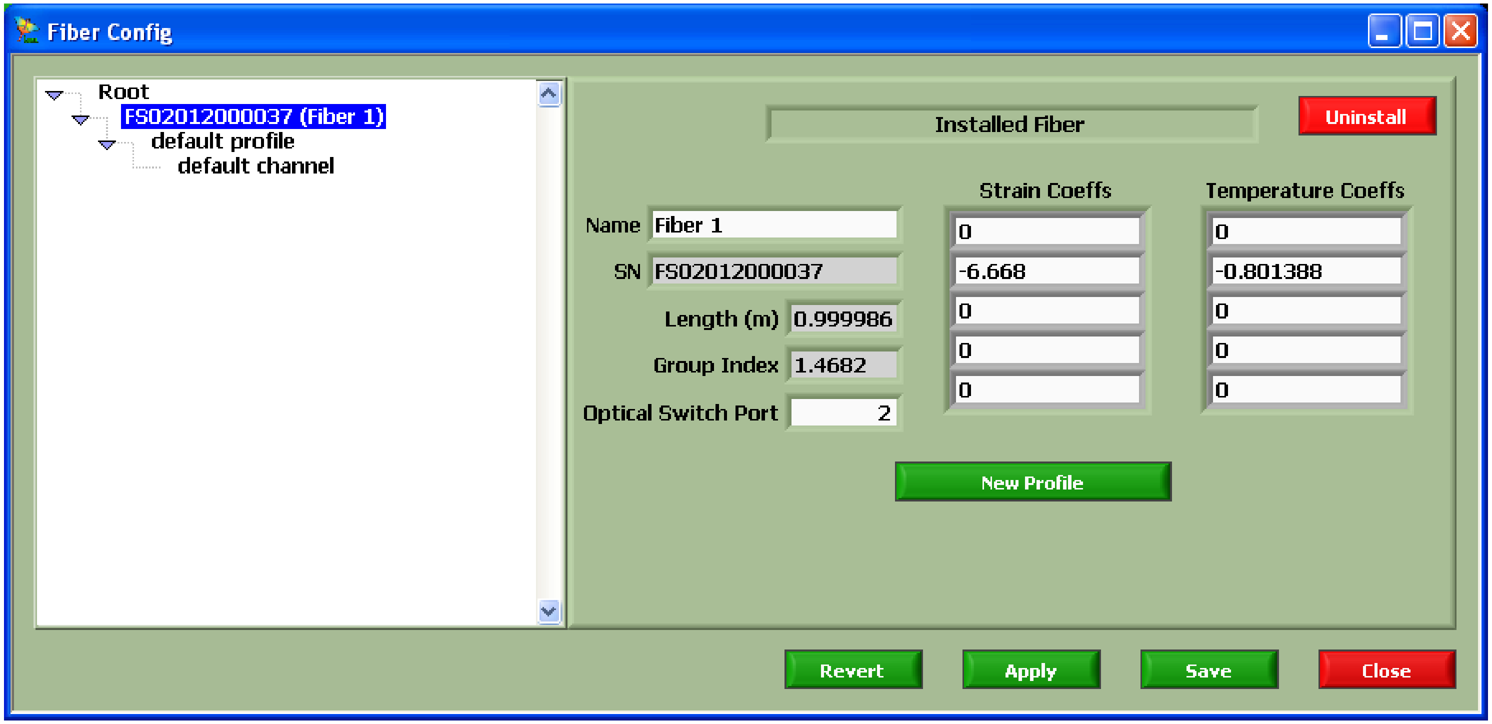
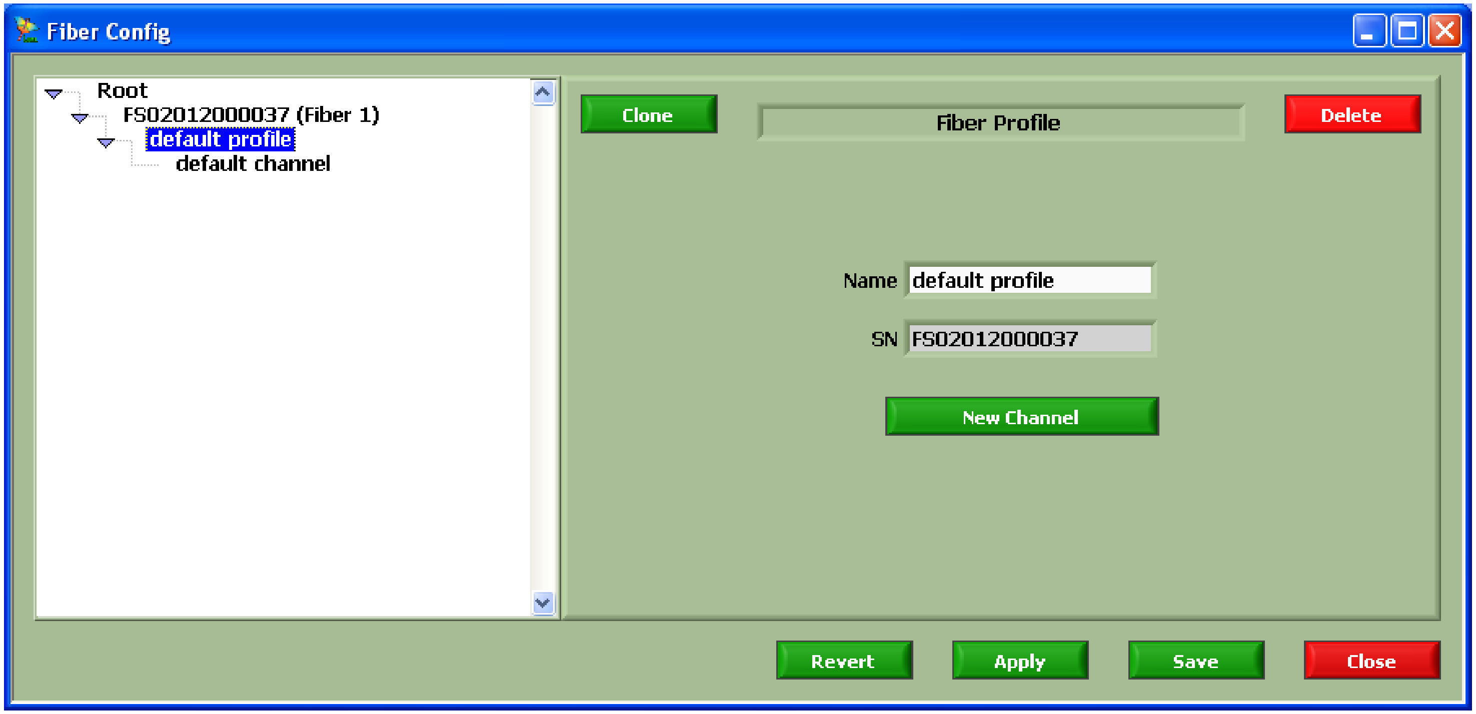


Figure 3-4 The Installed fiber display.

Fiber Profile Display

The Fiber Profile display is activated by selecting a particular profile from the fiber tree on the left of the Fiber Configure window. The Fiber Profile display allows the user to create new channels in the selected profile and to delete the selected profile. Note: you cannot delete the profile that is selected as the Active Profile in the Fiber Select window.



3-5 The Fiber Profile Display

Channel Configuration Display

The Channel Configuration display is activated by selecting a particular channel from the fiber tree on the left of the Fiber Configure window. In the Channel Configuration display the user configures the exact measurements to be displayed. The Measurement can be selected as Strain or Temperature. The Baseline can be set to any previously recorded baseline that was measured for the same fiber. Data can be Remapped to the graph horizontal axis with an arbitrary, user input, offset distance. The remap feature is useful to match the data graph to locations on the structure that is being measured.

Each channel can be configured to be either Distributed or Point Group. Distributed Channel Type will plot uniformly spaced measurements between the start location and the end location with a defined spacing and Gauge Length. Point Group Channel Type allows the user to enter an arbitrary number of measurement locations where each location can have an arbitrary Gauge length and Remap Location.

Each channel can only be one type of measurement (Strain or Temperature) and (Distributed or Point Group) but the user can create an arbitrary number of channels in each profile.

3-6 Channel Configuration Display. The display appearance is changed by selecting Point Group or Distributed Channel Type.

Fiber Select Window

Open this window by selecting **Window > Fiber Select** in the upper left of the **Control** window. Use this window to set the active fiber and profile for measurement. Also use this window to verify the fiber location during setup.

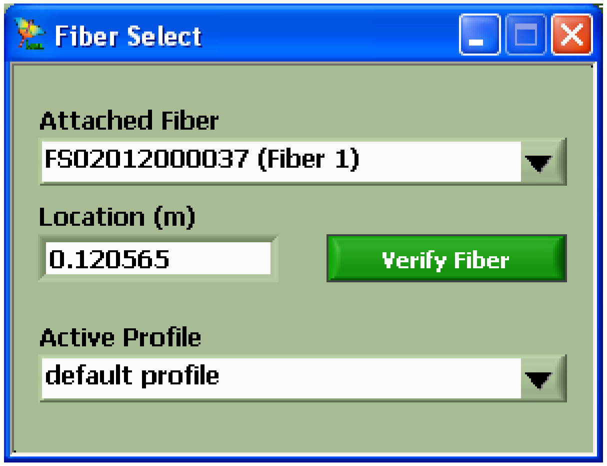


Figure 3- 7 The Fiber Select Window.

Data Logger Window

Open this window by selecting **Window > Logger** in the upper left of the **Control** window. Use this window to store measurements. Push “Start Logging” to save every measurement to disk. Push “Log Current Scan” to save the previous measurement to disk.

Important

In order for logged files to be replayed later using the Log Player Window, the fiber associated with the logged data files will need to be installed. Do not uninstall this fiber.

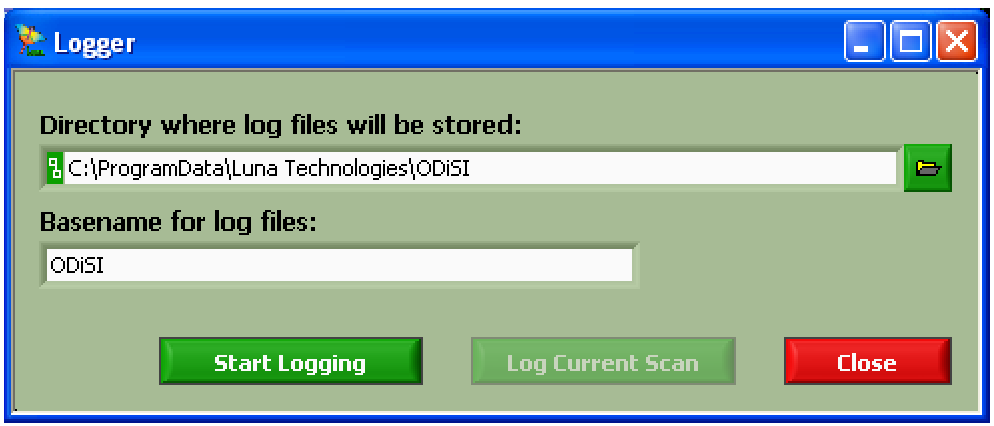


Figure 3- 8 The Data Logger Window. Use to set where and if raw measurement data will be logged, or saved.

Log Player Window

Open this window by selecting **Window > Log Player** in the upper left of the **Control** window. This window allows you to display measurements that were previously stored.

Important

In order for logged files to be replayed, the fiber associated with the logged data files will need to be installed and chosen in the Fiber Select Window.

In the case where the fiber associated with the logging is not currently installed and cannot be installed, the following steps can be followed to replay the logged data:

1. Copy the folder C:\ProgramData\Luna Technologies\ODiSI to a safe location (backup directory).
2. Once a copy has been saved, delete the contents of C:\ProgramData\Luna Technologies\ODiSI.
3. Open the folder containing the logged data (logged directory), located the folder named with the serial number of the fiber associated with the logging, copy and paste the folder into the directory C:\ProgramData\Luna Technologies\ODiSI.
4. Run the ODiSI Control Software.

5. Once the Control Software is finished initializing, open the fiber select window and select the only fiber profile available.
6. The log player will now play back the logged data; however, the other functions of the Control Software will not work.
7. To regain full functionality of the control software; close the Control Software, delete the contents of C:\ProgramData\Luna Technologies\ODiSI, open the backup directory and copy and paste its contents to C:\ProgramData\Luna Technologies\ODiSI.

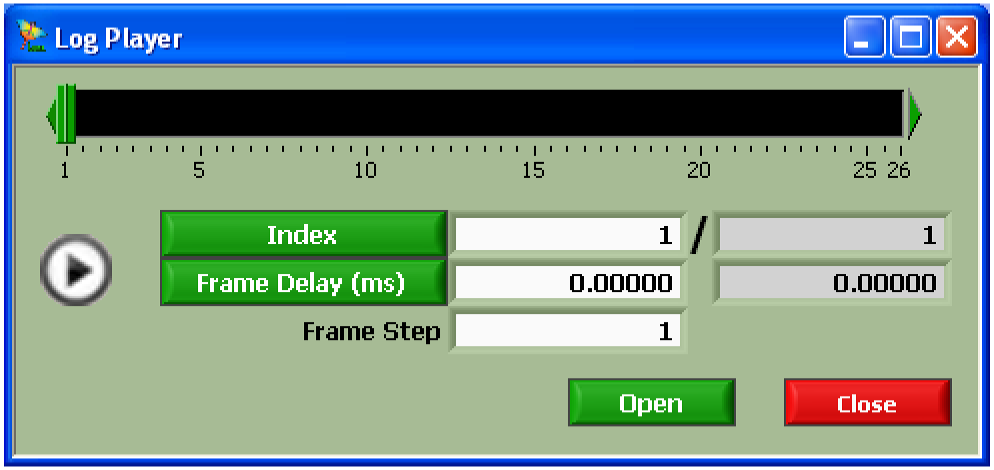
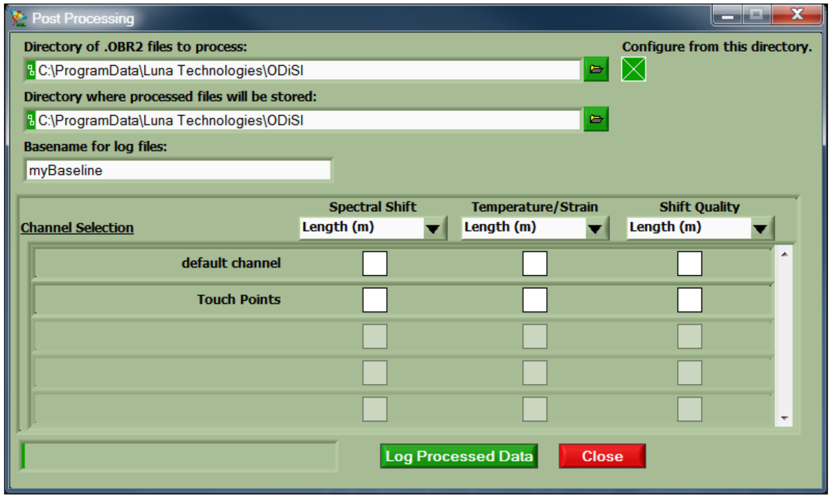


Figure 3- 9 The Log Player Window. Use to replay data that was previously logged.

Post Processing Window

Open this window by selecting **Window > Post Processing** in the upper left of the **Control** window. This window allows you to translate stored measurements into text files. Set the locations where the raw data is stored and the location to store the results before clicking “Log Processed Data”. Clicking Log Processed Data with the “Configure from this directory” box unchecked will process the stored measurements using the currently active profile, including baseline, and save the results as a text file. If this box is checked, the data will be processed using the configuration stored with the data. It is the user’s responsibility to choose the active profile to produce meaningful results. Processing stored data with a baseline measured from a different fiber will produce erroneous results. Most users will want to check the Temperature/Strain box as shown in figure 3-10.



3-10 The Post Processing Window. Use to convert logged data files into text files.

Chapter 4 Performing Measurements

Acquiring Data

Important

Before attaching any fiber, clean the fiber optic connector with the appropriate cleaner to guard against errors or equipment damage. For instructions, see “Cleaning Connectors” in the Maintenance Chapter

The next section explains the basic steps for performing a measurement. More details describing how to get the most from your ODiSI follow this quick start example.

Quick Start to perform your first measurement

Step 1: Setup the hardware

Ensure that the ODiSI unit is powered off.

Be sure to clean all fiber optic connectors before connecting the supplied patch cord to the **Source** port on the front of the ODiSI and to your fiber sensor.

Attach the 10 meter standoff cable to the ODiSI. Attach a sensor from the getting started kit to the standoff cable.

Step 2: Start the software

Turn on the ODiSI using the power switch on the front panel.

Start the control software by double-clicking the ODiSI desktop icon or by selecting **ODiSI Software** from the programs group in the Windows® Start menu. The **ODiSI Control** window will appear after the instrument has performed an internal calibration.

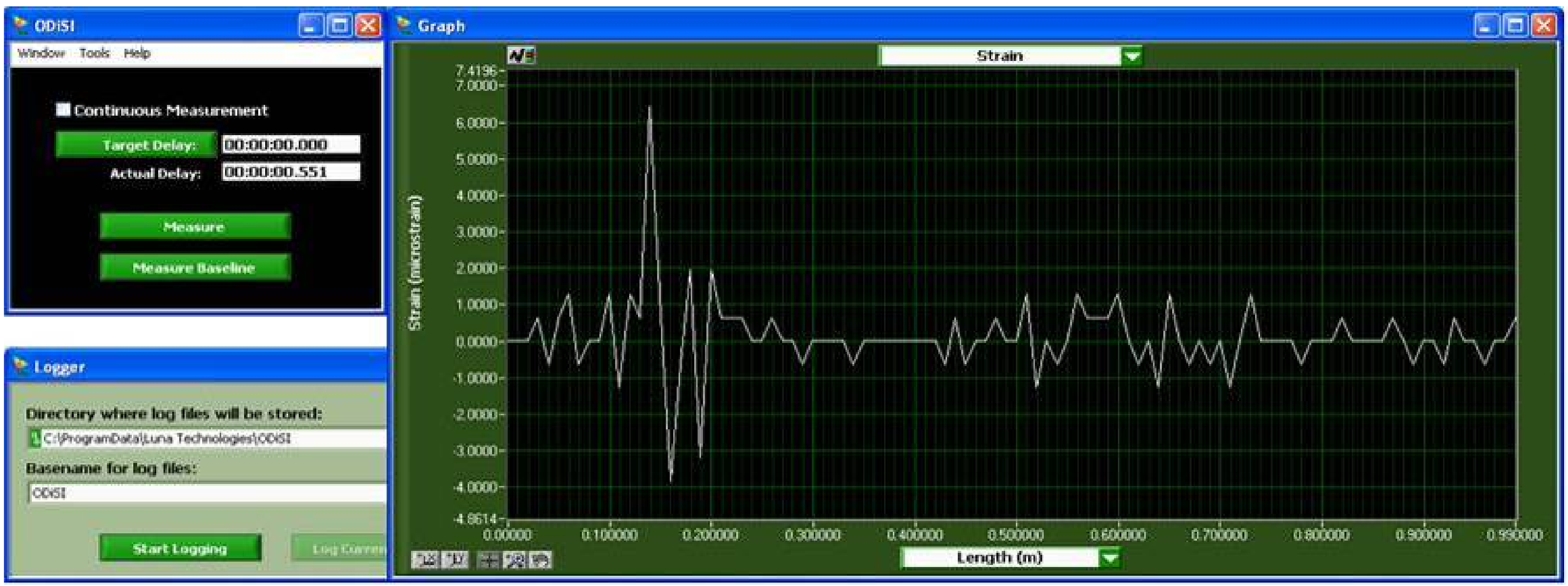
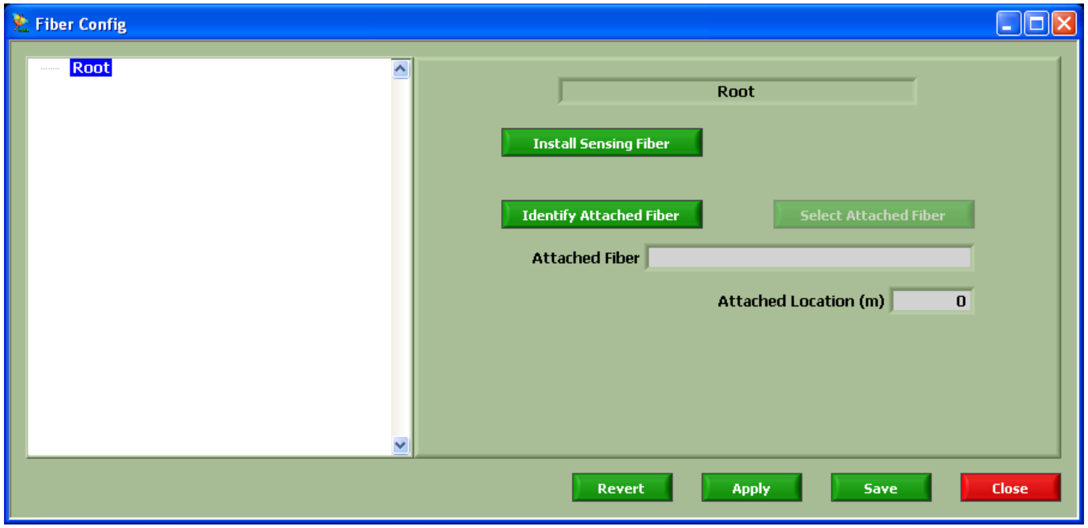


Figure 4- 1 The ODiSI software after startup and internal calibration.

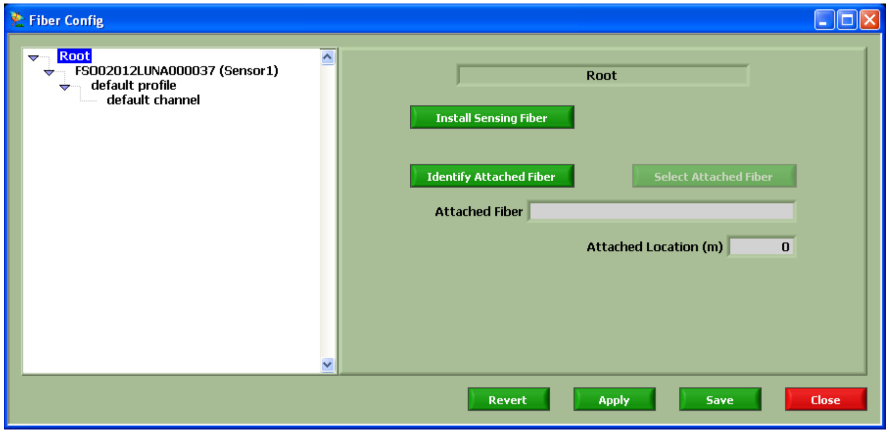
Step 3: Install the fiber file into software

Each sensing fiber is supplied with a fiber file that must be installed into the software before the fiber can be used. (Sensors include in the Getting-Started Kit will be pre-installed by Luna. Skip to Step 4 if you are using fibers that were include in the kit.) Select **Window > Fiber Config** in the **ODiSI Control** window. The window below appears.



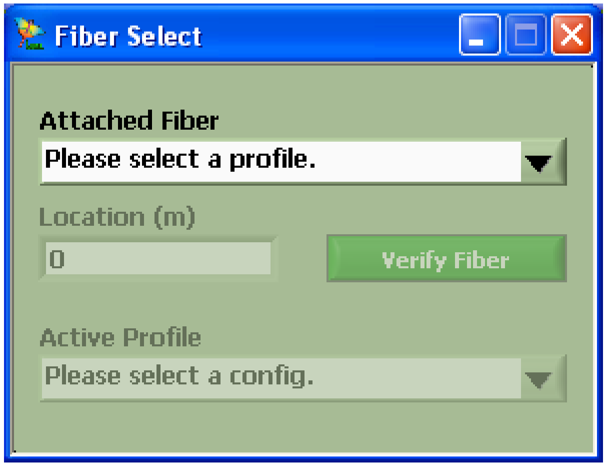
In the **Fiber Config** window, select **Install Sensing Fiber**. Then in the **Path** field of the window that pops up, select the ***.fbr*** file which corresponds to the fiber sensor currently attached to the ODiSI. A ***.fbr*** file is delivered with each fiber. In the **Name** field, give the sensor any name that seems appropriate. We use “Sensor1” in this example.

The fiber serial number should now appear with the name in the Fiber tree, as shown below.

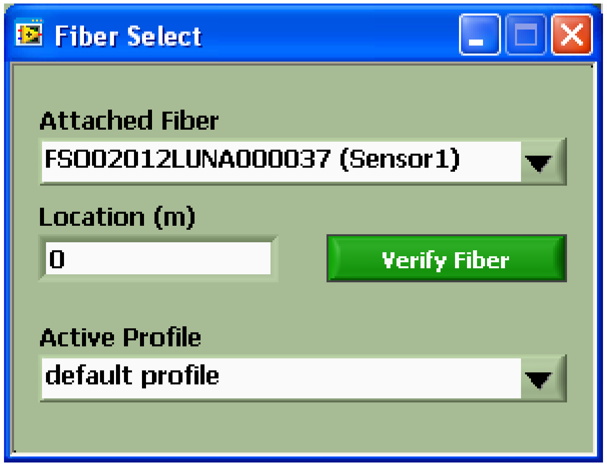


Step 4: Selecting a fiber in software

After a fiber is installed it must be selected in the Fiber Select window. Open the Fiber Select window by choosing **Window > Fiber Select** in the **ODiSI Control** window. The window below appears.



Use the pull down menu under **Attached Fiber** to select the fiber you want to use for measurement. Then use the pull down menu under **Active Profile** to select the profile that will be used with the selected fiber. In this example we use the default profile. Click Verify Fiber to cause the ODiSI to verify the location of the fiber.



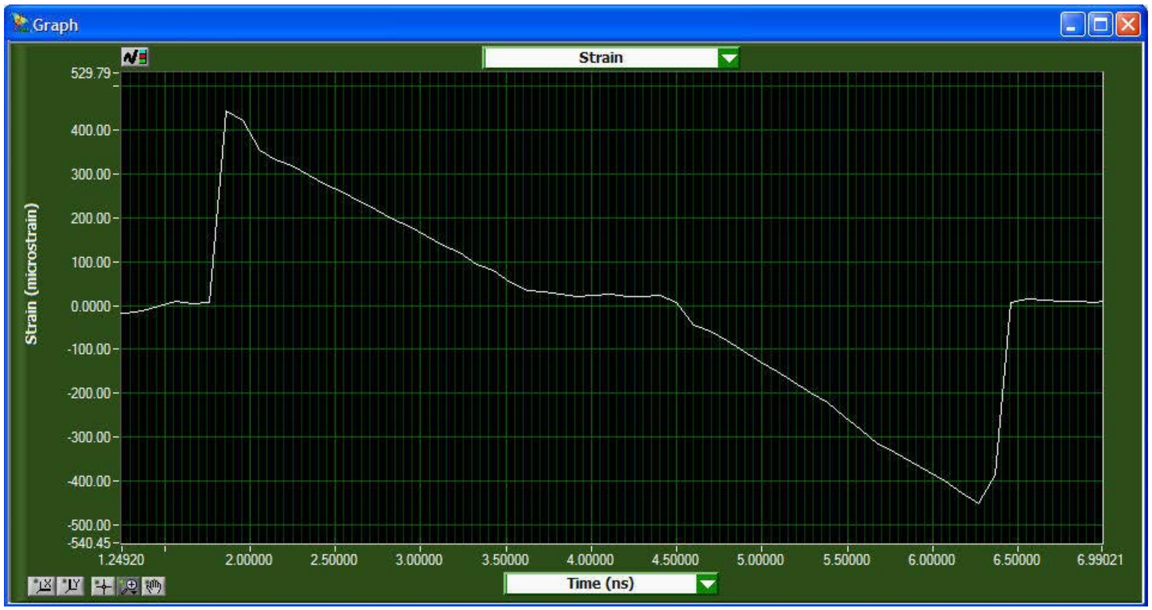
Step 5: Measure a Baseline

In the control window click **Measure Baseline** to record the current state of the fiber. All strain and temperature measurements are displayed as a difference between the Baseline and the measurement.

A popup window will open so you can choose the strain range and name the baseline measurement. In the **Name** field, give the baseline any name that seems appropriate. We use “Baseline1” in this example.

In the control window click **Measure**. The graph will update with the measured data. You might need to autoscale the x and y axis to see the data.

Check the box next to **Continuous Measurement** in the control window. Click **Measure** again and the graph will continue to update until you click **Measure** again. Touch the fiber with your finger while the ODiSI is measuring. Notice that the Strain or Temperature displayed in the graph will increase. It is important to note that fiber optics sensors cannot distinguish between strain and temperature therefore proper choice of sensors is required to distinguish between the two. Sensors designated as temperature sensors are protected by a loose-fitting plastic jacket that prevents external strain from affecting the fiber. Sen-



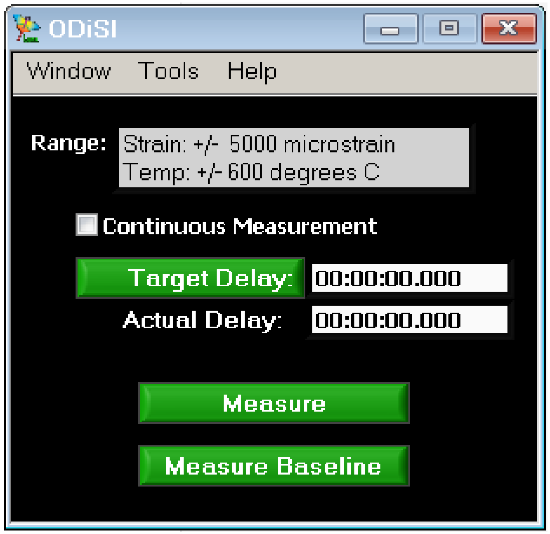
sors without a jacket are sensitive to both strain and temperature changes.

The ODiSI Windows

This section gives details of the **ODiSI Control Window**, and then each explains the additional windows that are available from **ODiSI Control Window** through the pull-down **Window** menu.

ODiSI Control Window

The **ODiSI Control Window** provides central control for the ODiSI and the basic controls to measure a fiber. *Closing this window causes the software to exit.*



- **Window:** This pull-down menu in the upper left gives access to all other ODiSI windows: **Graph**, **Logger**, **Fiber Config**, **Fiber Select, Post Processing,** and **Log Player.** (Each is described in the sections below.)
- **Tools:** Used to align the optics internal to the ODiSI

- **Help:** Provides information about how to get help
- **Continuous Measurement:** Clicking in this box enables the continuous measurement mode. If the Measure button is clicked while **Continuous Measurement** is checked, the ODiSI will interrogate the sensor repeatedly until the **Measure** button is clicked again.
- **Target Delay:** This field allows the user to set a delay (in hours: minutes:seconds:milliseconds) between **Continuous Measurements**. When set to the default of 00:00:00.000, the ODiSI will acquire data at the maximum acquisition rate attainable.
- **Actual Delay:** This field displays the actual delay between ODiSI acquisition measurements when **Continuous Measurement** is enabled.
- **Measure:** When **Continuous Measurement** is *not* enabled, clicking the **Measure** button takes a single measurement scan. With **Continuous Measurement** enabled, the first click of the **Measure** button begins **Continuous Measurement**, and the second click turns measurements off.
- **Measure Baseline** – Acquires a single baseline measurement scan. When this button is pressed the user will be prompted to enter a name for this baseline. The user also sets the measurement range for strain and temperature. Alternate baselines for a given configuration can be selected in the *Fiber Configuration* window. All strain and temperature measurements are displayed as a difference between the Baseline and the measurement.

ODiSI Graph Window

Graph – Calculates and displays any one of the following:

a. Strain – Displays the calculated change in strain between the baseline and the measured data.

b. Temperature - Displays the calculated change in temperature between the baseline and the measured data.

b. Spectral Shift – Displays the frequency shift of the light reflected from the fiber between the baseline and the measured data.

d. Spectral Shift Quality – Displays a calculated merit function to assess the quality of the measurement. All values above 0.15 indicate the strain and temperature measurements are accurate.

The system is able to acquire data faster than it can calculate strain/temperature/spectral shift. The rate the ODiSI scans and acquires raw data is shown in ‘Actual Delay’ of the *ODiSI Control* window. For example, in **Continuous Measure** with *Graph* open and logging enabled, data is being acquired and saved to the hard drive according to the ‘Actual Delay’ displayed in *ODiSI Control*, while the *Graph* may be updating at a slower rate.

If the Graph window is not open, it is still possible to acquire, and log, data with the ODiSI system.

Fiber Config Window

Fiber Config – Managing your fiber sensors. This window contains controls to install fiber data into the software, define various measurement profiles and create measurement channels. This window, and it's various displays, are covered in detail in the following section.

Fiber Select Window

Path Config – Managing your data acquisition system. After one or more fibers in installed into the software use the Fiber Select window to choose which fiber to measure and which profile to use for that fiber.

Logger Window

Logger – Functionality for saving the raw data acquired by the ODiSI. Select a directory where files are to be stored, and a basename. Each measurement will record the full data set and append the current time to the filename. Since the recorded data contains the full measurement it can later be reprocessed to display the strain or temperature at any position with any gauge length.

a. **Start Logging** – For use in **Continuous Measurement** mode. Measurements will be automatically stored to the appropriate directory/basename.

b. **Log Current Scan** – Save the most recent scan acquired. This allows the user to save a scan after it has been measured.

Log Player Window

Log Player – Replay your data stored by the Logger from a desired index, at a desired frame delay. Open a folder where logged data is stored.

b. **Index** – Specify the starting index of the total number of acquisitions to replay, or specify any one index to view just that.

b. **Frame Delay** – Specify a desired frame delay. Any delay *less* than the time it takes to calculate each file, will cause the *Log Player* to run as fast as possible.

c. **Play button** – Start/Stop replay of logged data

d. **Open** – Specify the containing folder of the logged data you would like to display

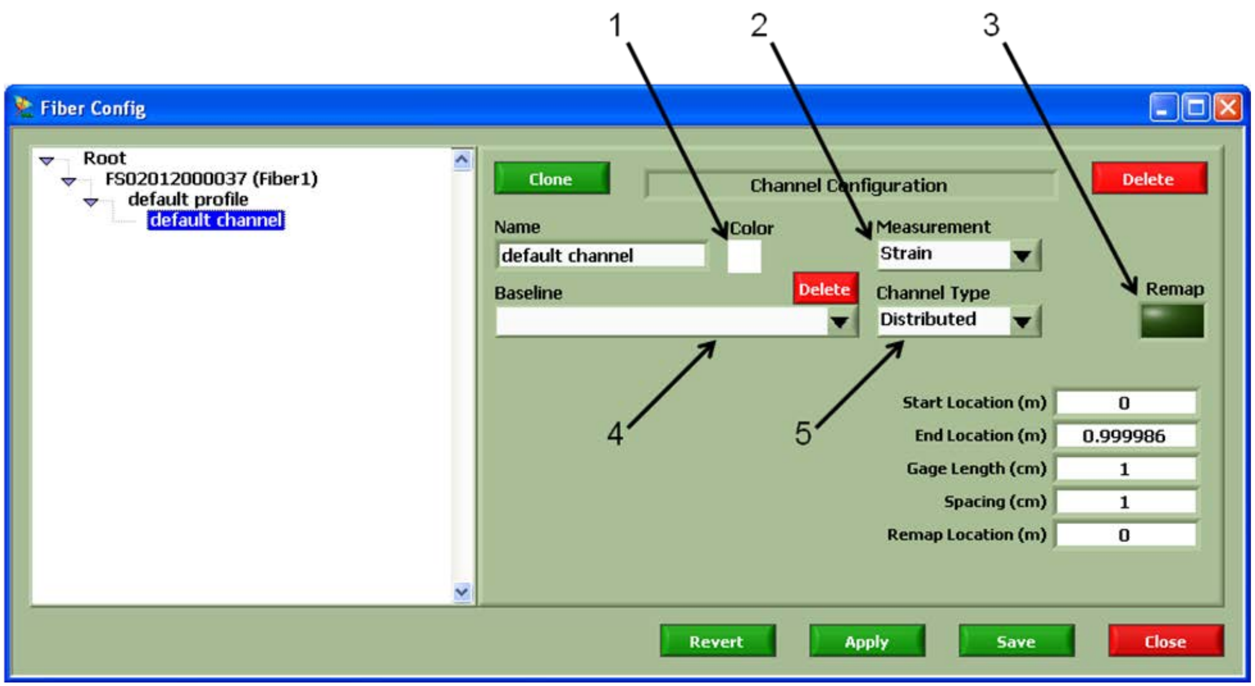
e. **Close** – Closes *Log Player*

Setting up a Measurement

Use the Fiber Select window to “Attach” a fiber in software. Once a fiber is Attached you can select any profile that is defined for that fiber. The measurement profile defines which Channels are used. Channels define virtually configured sets of strain gauges. The first step in setting up a measurement is to configure the fiber.

Fiber Configuration

The Fiber Configuration window is opened from the Window option in the ODiSI Control menu bar. Highlight the Root of the tree in the fiber configuration window. This reveals the “Install Sensing Fiber” button. Click the Install Sensing Fiber button and choose the fiber file that was packaged with the sensor. Select an individual channel in the Fibers tree to configure the channel using the Channel Configuration panel shown below.

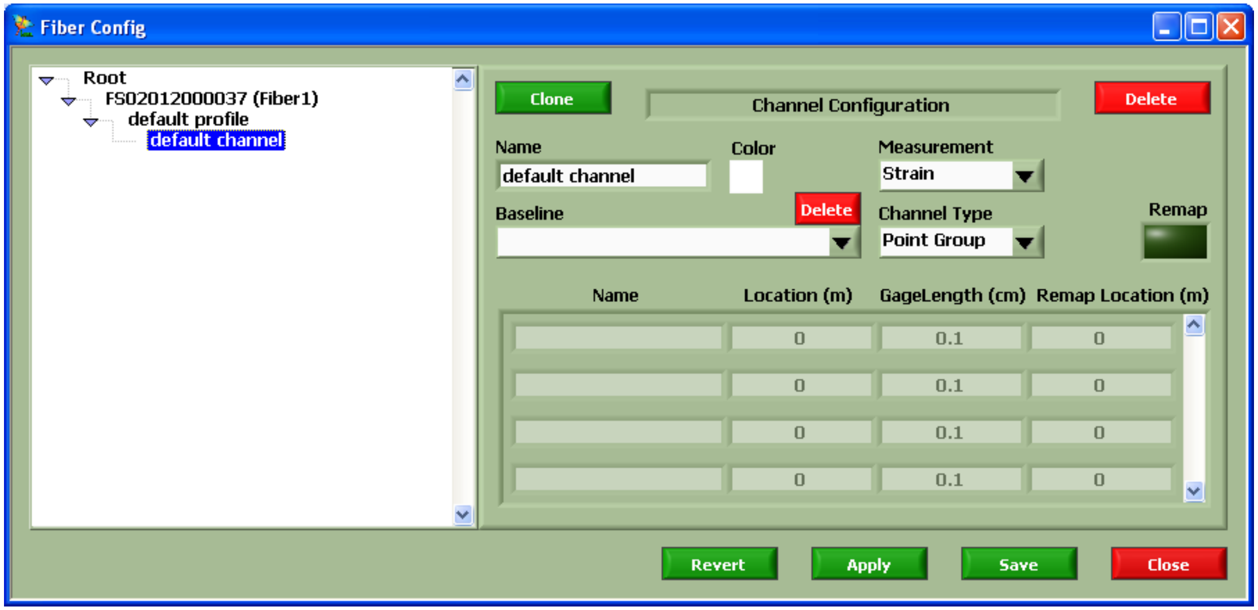


Configuring a Channel

Parameters to set in the Channel Configuration

1) Plot Attributes: Controls how data acquired on this Channel will be displayed in the Graph.
2) Measurement: Choose between Strain or Temperature
3) Remap: A click box that turns remapping on (bright green) and off (dull green)
4) Baseline: Select the Baseline measurement that will be used for measurements acquired on this Channel.
5) Channel Type: Choose between Distributed or Point Group
    a. Distributed allows the user to quickly define a string of sensors. The string of sensors is defined by five parameters
        i. Start Location: The length along the fiber where the string of sensors should start.
        ii. End Location: The length along the fiber where the string of sensors should end.
        iii. Gauge Length: The length of data from the fiber that will be integrated to give a single data point. A longer length improves accuracy.
        iv. Spacing: The length between the center of each gauge.
        v. Remap Location: Distance to offset displayed data from location in fiber. Used to concatenate data from multiple fibers into a 'real-world' geometry.

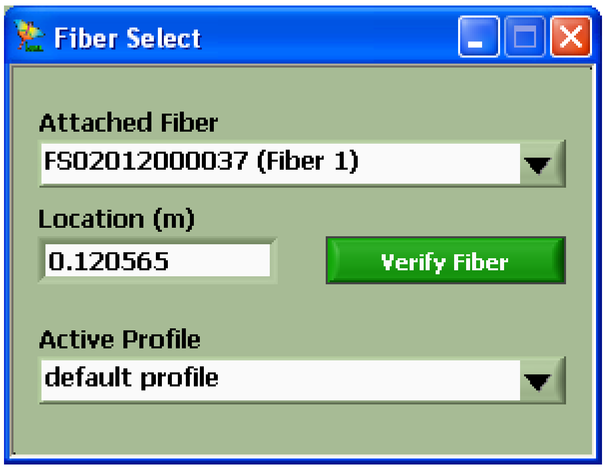
b. Point Group allows the user to define an arbitrary number of sensors at arbitrary locations in the fiber with arbitrary gauge lengths and remap locations.



You may configure as many Channels as desired. Each fiber can have multiple channels. You could, for example, attach a fiber to a mechanical structure with periodic spaced loops of unattached fiber. One channel could be configured to measure temperature of the loops and another channel could be configured to measure strain in the attached fiber. Both channels could be applied to the same fiber. Channels are applied to fibers by adding the channels to a profile as described below.

Selecting a Fiber

The Fiber Select is opened from the Window option in the ODiSI Control menu bar. In the fiber select window you can choose an individual fiber to attach to the ODiSI from the fibers that have been installed. After attaching a fiber the Verify Fiber button verifies that the fiber is Physically attached to the measurement path and returns the distance of the first sensing region from the end of the patch cable. The Active Profile pull down menu allows you to select from among all the profiles that exist under the currently attached fiber.



Making Measurements

After a fiber is attached and the active profile is set you can start a measurement from the ODiSI Control window. With the graph window open click the measure button once. The graph will update and display the measured data. If you want to log measurements open the Raw Measurement logger and set up the logging as previously described. Click start logging to begin saving data to disk. If you want to take a series of measurement at set intervals enter the interval in Target Delay and check the Continuous Measurement box. Click Measure to start the Measurement and click Measure again to stop the measurements.

You can also log data from individual measurements by starting logging and clicking measure each time you want to record a single scan.

Improved Accuracy

Setting Strain and Temperature Coefficients

By selecting a fiber serial number in the “Fibers” tree you open a panel that allows you to enter fourth order strain coefficients and temperature coefficients. These coefficients are set to give optimal accuracy with sensors as delivered over a broad range of test conditions. In certain circumstances a user might wish to calibrate fibers to give more accurate measurements in the intended test range. The Fiber Configuration window allows the user to enter the coefficients for a fourth order polynomial that the user determines through careful calibration over the range of interest. This should only be attempted by users with an in-depth knowledge of fiber optic sensors.

Chapter 5 Software Development Kit

Overview

The ODiSI SDK is a collection of software routines that allows users of Luna Technologies' ODiSI to develop custom software utilities targeted for a specific measurement application. By utilizing the SDK software package, ODiSI users have the ability to write custom graphical user interfaces and data analysis packages using the same source code used to develop the instrument operational software.

The SDK includes sample code in C++ and LabVIEW. The example programs were written and tested using Visual Studio 2005 and LabVIEW 2010.

The example programs call functions contained in DLLs (primarily ODiSI.DLL) to control the ODiSI and to perform calculation. It may be possible to call these same DLL functions from other programming languages; however C++ and LabVIEW are the only languages currently supported by the SDK.

Getting Started

Copying SDK files

The SDK consists of a set of directories and files, which should be copied to a directory on your PC. For the sake of clarity, it is recommended that the software be copied to the folder *C:\ODiSI_SDK_v1.0.* They can be placed in an alternate path if desired, but remainder of these instructions will assume that you have used the default name.

The SDK contains the following folders:

bin – contains the DLLs used by the ODiSI SDK

Setup – contains the Microsoft Runtime installer

C-C++ -- contains the ODiSISDK.h and DataTypes.h files described in the C/C++ Support section

LabVIEW – contains a folder “example” with example LabVIEW programs and a folder “lib” with a Labview LLB of low level Vis.

Runtime installer

The SDK DLLs require that the Microsoft C++ 2005 Runtime Library be installed on your computer. To install this, run the program *vcredist_x86.exe* from the *ODiSI_SDK_v#.#\Setup* folder. If the computer running the SDK already has the ODiSI software installed, this step should be unnecessary.

Using the ODiSI SDK

The easiest way to begin using the SDK is to run the provided example programs. These programs demonstrate the various operations that can be performed with the SDK, and can serve as starting templates for writing your own programs.

LabVIEW Support

Low Level *VIs* and Example Programs

The LabVIEW code provided in the SDK is divided into two folders. The Labview LLB *C:\ODiSI_SDK_v1.0\LabVIEW\lib\ODiSI SDK* contains low level *VIs* that call the DLLs in the *C:\ODiSI_SDK_v1.0\bin* folder. These *VIs* serve as building blocks for writing more complex programs.

The folder *C:\ODiSI_SDK_v1.0\LabVIEW\examples* contains example programs that use the low level VIs to control the ODiSI and compute measurements. These programs demonstrate how to load configurations, connect to the system, retrieve and set information, acquire measurements, log and load measurements, as well as process and plot data.

This guide will now explain each of the example programs.

SDK Meas Log.vi

SDK Meas Log.vi demonstrates how to set the runtime directory of the DLLs, load the configurations and connect to the system, identify the attached fiber and set that fiber to be active, view available profiles and set one to be active, set a scan range and take a new baseline measurement, as well as acquire a measurement and save the measurement data for later use.

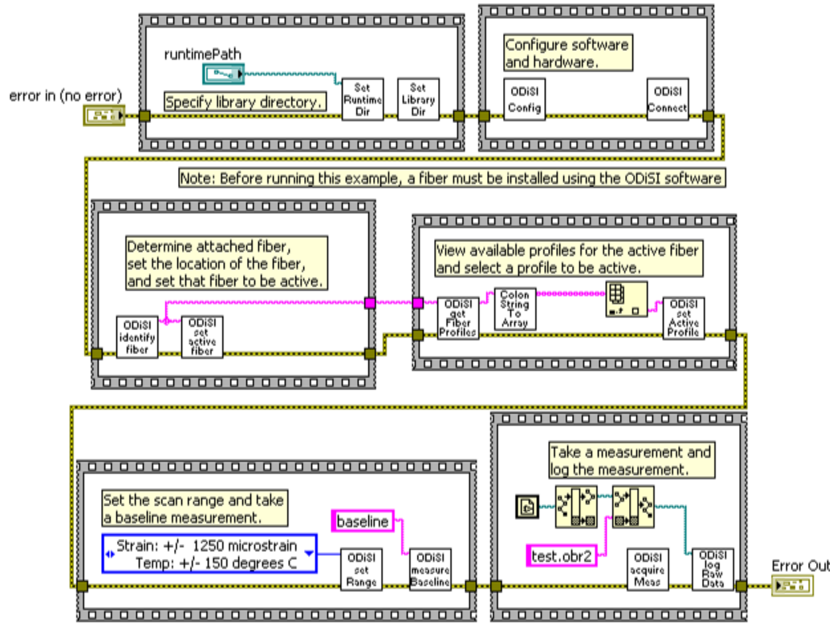


Figure 5-1 SDK Meas Log.vi

There is not a graphical component to SDK Meas Log.vi beyond the “Error” control, the “Error Out” indicator and the “runtimePath” control input.

To prepare the system to take a measurement the call sequence is Set Runtime Dir.vi, Set Library Dir.vi, ODiSI_configure.vi, followed by ODiSI_connect.vi. Set Runtime Dir.vi requires the directory path to the DLLs and Set Library Dir.vi requires no inputs. ODiSI_configure.vi loads the configuration files from the default directory. If the configuration files are not stored in the default directory then a directory where the files are located must be provided to ODiSI_configure.vi during the call. ODiSI_connect.vi connects to and prepares the ODiSI system. ODiSI_connect.vi does not require any inputs; however it will output a Boolean result of its success once complete.

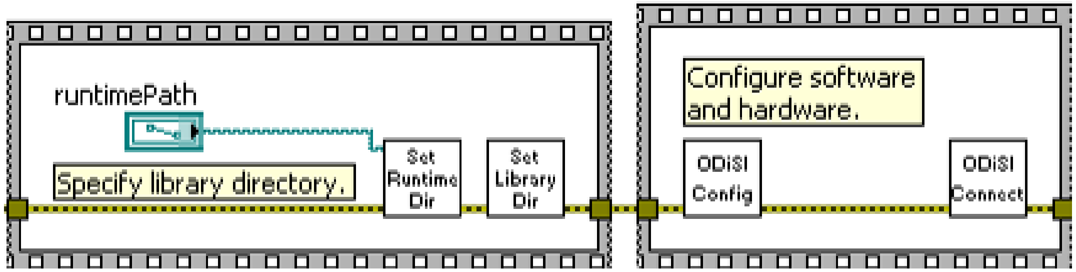


Figure 5-2 Set runtime directory, configure software, and connect to the system.

Calling ODiSI_identifyFiber.vi will output the name and location of the start of the attached fiber. Feeding the name of the fiber into ODiSI_setActiveFiber.vi will make that the active fiber. Once an active fiber is selected, ODiSI_getFiberProfiles.vi can be called to view the active fiber's profiles. The output to ODiSI_getFiberProfiles.vi is a single string of all profiles names decimated by ":"; Colon String to Array.vi converts this output into an array of strings. Feeding one of the profile names into ODiSI_setActiveProfile.vi will make it the active profile.

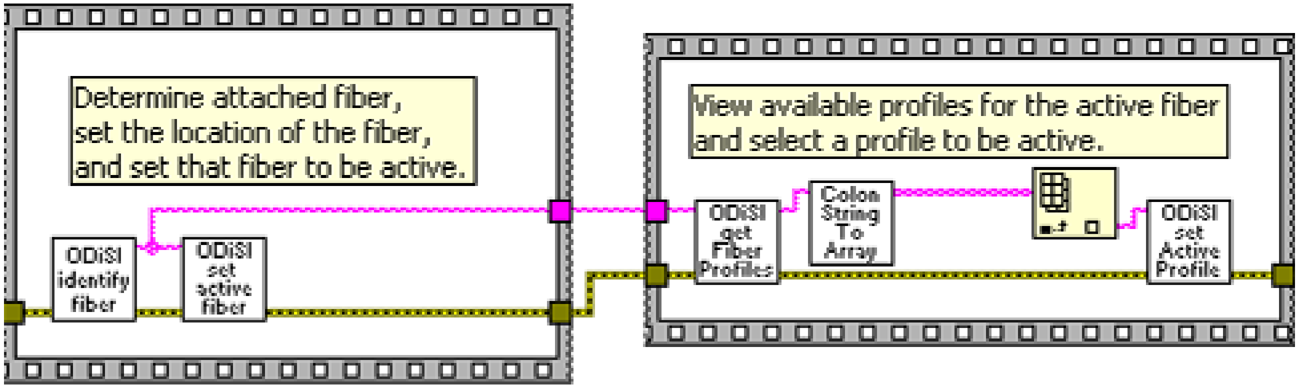


Figure 5-3 Identify the attached fiber, set active fiber, and set active profile.

Calling ODiSI_setRange.vi with an enumerated input for range will set the scan range. Next, calling ODiSI_measureBaseline.vi will measure a baseline for the previously set range and save it under the name input during the call. Omitting ODiSI_setRange.vi and ODiSI_measureBaseline.vi will cause the previously set up baseline to be used. ODiSI_acquireMeas.vi takes a measurement and requires no inputs. ODiSI_logRawData.vi stores the unprocessed data from the measurement in a file defined by the directory input “OBR2 Filename”.

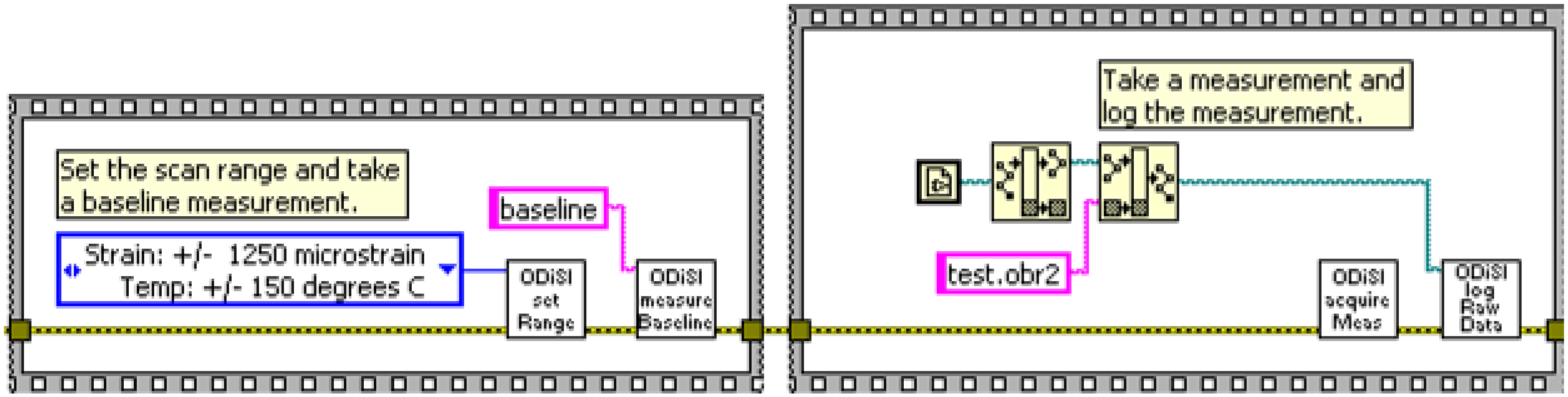


Figure 5-4 Set scan range, take a baseline, acquire a measurement, and log the measurement.

SDK Load Plot.vi

SDK Load Plot.vi demonstrates how to set the runtime directory of the DLLs, load the configurations, view installed fibers and set the fiber corresponding to a saved data file to be active, view available profiles and set the profile corresponding to a saved data file to be active, load a previously acquired measurement, as well as process and plot the results.

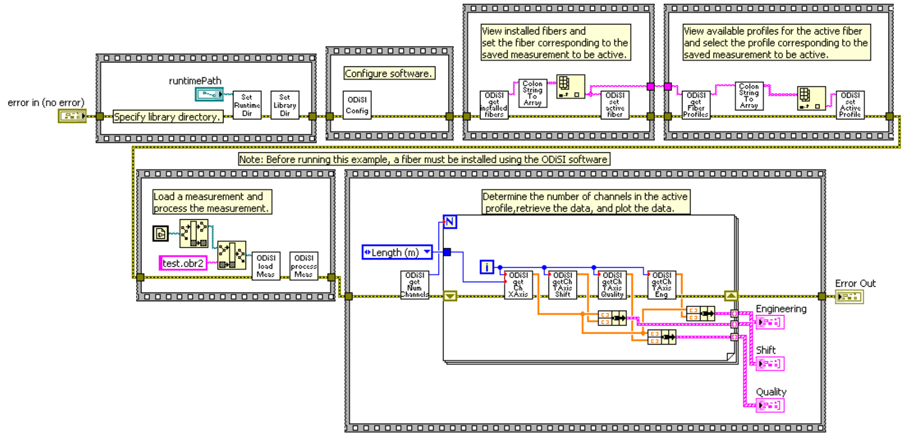


Figure 5-5 SDK Load Plot.vi

To prepare the system to take a measurement the call sequence is similar to the example SDK Meas Load.vi above except there is no need to call ODiSI_connect.vi and connect to the ODiSI system in this example.

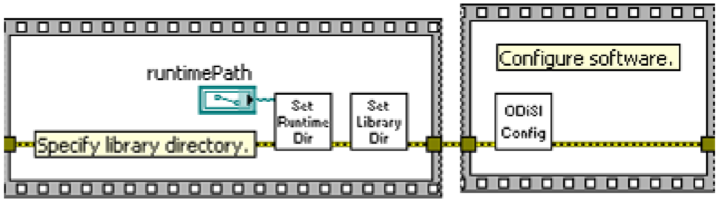


Figure 5-6 Set runtime directory, configure software, and connect to the system.

The fiber and profile corresponding to the data file need to be made active so that the number of channels in the data file can later be ascertained. Calling ODiSI_getInstalledFiber.vi will output the names of installed fibers in a single string decimated by ":" so Colon String to Array.vi will again need to be used as described above. Next, the correct fiber can be indexed and fed into ODiSI_setActiveFiber.vi to make it the active fiber. Just as in SDK Meas Log.vi described above, the active profile can be set by calling ODiSI_getFiberProfiles.vi, Colon String to Array.vi and ODiSI_setActiveProfile.vi.

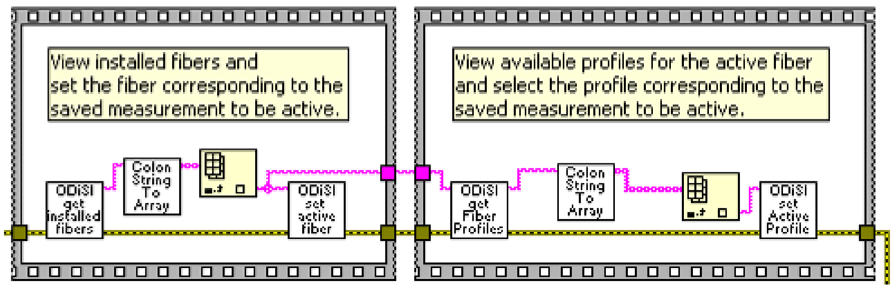


Figure 5-7 Load and process data

In order to load and process a measurement, ODiSI_loadMeas.vi must be called followed by ODiSI_processMeas.vi. When calling ODiSI_loadMeas.vi, the full directory file name of the saved data must be provided. Next, ODiSI_processMeas.vi can be called and requires no inputs.

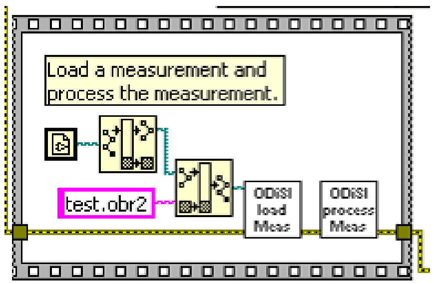


Figure 5-8 Load measurement and process data

In order to plot the processed data the number of channels must be known. ODiSI_getNumChannels.vi outputs the number of channels in the active profile. Three sets of plot data can be obtained “Shift”, “Quality”, and “Engineering”. “Shift” shows the amount of optical frequency shift in GHz of the processed data. “Quality” shows the quality of the correlation between the baseline and the measurement. “Engineering” shows the strain or temperature change in engineering units. In order to display this plot data, the X-axis information must be retrieved. ODiSI_getChXAxis.vi requires the X-axis units and channel index (starting at zero) as inputs. In this example, “Length (m)” is used. In this example, a for loop is used to retrieve data for all available channels. Next, ODiSI_getChYAxisShift.vi, ODiSI_getChYAxisQuality.vi, and ODiSI_getChYAxisEng.vi can be called with the only input required being the channel index used for ODiSI_getChXAxis.vi. ODiSI_getChYAxisShift.vi provides the Y-axis data for “Shift”, ODiSI_getChYAxisQuality.vi provides the Y-axis data for “Quality”, and ODiSI_getChYAxisEng.vi provides the Y-axis data for “Engineering”.

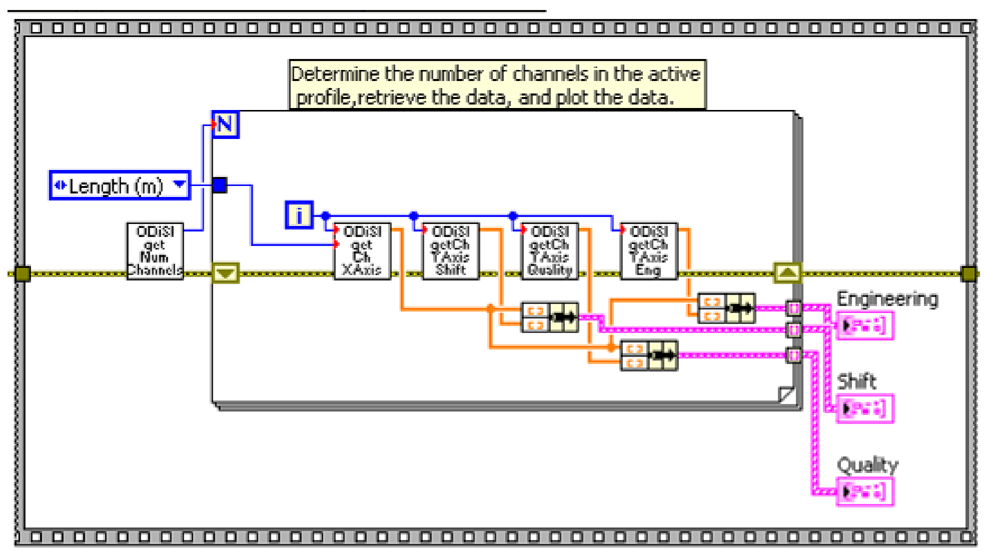


Figure 5-9 Plot measurement results

C/C++ Support

There is a C/C++ header file included with the SDK. This file is all that is required to begin compiling and working with the library. Below is the name of the file along with a brief description.

ODiSISDK.h –contains all of the prototypes of the functions that are specific to the ODiSI product.

DataTypes.h – the header file that contains the data type definitions that are used in the SDK project. The source code included with SDK uses data types based on the standard C/C++ types, but with a naming convention that defines the size of the data type (e.g. FLOAT64 is defined for double – a 64-bit float variable).

LabVIEW is a registered trademark of National Instruments Inc.

Visual C++ is a registered trademark of Microsoft Corporation.

Chapter 6 Measurement Theory

The Luna ODiSI utilizes swept-wavelength interferometry to interrogate fiber optic sensors. Physical changes in the sensors create a measurable change to the light that is scattered in the fiber. By comparing the scattered light of a sensor to a reference measurement that was recorded with the fiber in a known state one can determine the physical state of the fiber at the time of measurement. The state of the fiber is coupled to the local environmental temperature and strain.

Distributed Sensing Parameters

ODiSI uses swept-wavelength interferometry (SWI) to measure the Rayleigh backscatter as a function of position in the optical fiber. Rayleigh backscatter in optical fibers is caused by random fluctuations in the index profile along the fiber length. Scatter amplitude is a random but static property of a given fiber.

The physical length and index of refraction of the fiber are intrinsically sensitive to environmental parameters: temperature and strain, and to a lesser extent, pressure, humidity (if the fiber coating is hydroscopic), electromagnetic fields, etc. In most practical cases the effects of temperature and strain will dominate the spectral response of the Rayleigh backscatter, so we concentrate our examination on these parameters.

Changes in the local period of the Rayleigh scatter cause temporal and spectral shifts in the locally-reflected spectrum. These shifts can be scaled to form a distributed sensor. This SWI-based technique enables robust and practical, distributed temperature and strain measurements, with millimeter-range spatial resolution over tens to hundreds of meters of standard fiber, with strain and temperature resolution as fine as 1 $\mu\varepsilon$ and 0.1 °C.

Measurement Technique

A strain or temperature sensor is formed by first measuring and storing the Rayleigh scatter signature of the fiber under test (FUT) at an ambient state; this data is stored as the **Baseline Measurement**. Then the scatter profile is measured at a later time with strain or heat applied at some point along the length of the fiber. The scatter profiles from the two data sets are cross correlated at the sensor locations to determine the spectral shift of the scattered light.

A change in temperature or strain from the baseline condition results in a shift in the spectrum of light scattered in the fiber. This shift in the spectrum in response to strain ε or temperature *T* is analogous to a shift in the resonance wavelength $\Delta\lambda$ or the spectral shift $\Delta\nu$ of a Bragg grating:

$$\frac{\Delta\lambda}{\lambda} = -\frac{\Delta\nu}{\nu} = K_T \Delta T + K_\varepsilon \varepsilon ,$$

where λ and ν are the mean optical wavelength and frequency, and K_T and K_ε are the temperature and strain calibration constants, respectively. The default values for these constants are set at values common for most germanosilicate core fibers: K_T = 6.45 x 10^{-6} ºC^{-1} and K_ε = 0.780. The ODiSI software allows the user to set their own values for these constants, according to their specific application.

The values for K_T and K_ε are somewhat dependent on the dopant species and concentration in the core of the fiber, but also to a lesser extent on the composition of the cladding and coating. Variations of 10% in K_T and K_ε between standard telecom fibers are common.

It is important to note that the **Gauge Length**, Δz, affects the spectral resolution and the signal-to-noise ratio of the measurement. There is, therefore, a relationship between the spatial resolution of the measurement and its accuracy in measuring the change in strain or temperature. The longer the gauge length used, the better the measurement accuracy. However, if the strain or temperature varies rapidly with position, a smaller segment size is often necessary to prevent the distortion in the position scale from blurring the cross correlation spectra.

Spectral Shift

In SWI the backscatter optical power $U(\nu)$ is collected in the spectral frequency domain: detectors collect light backscattered from the FUT (fiber under test) as the laser spectral frequency is tuned through a range of frequencies. The data is processed with a Fourier Transform to generate the backscatter optical power $U'(\tau)$ as a function of time delay τ, which can be scaled to show the backscattered optical power as a function of FUT length.

The fiber configuration defines the location and length of data that will be used to compare the spectral shift of the backscattered light. Although the backscatter spectrum appears random for a segment of fiber, it is actually determined by random fluctuations in the core index of refraction and is stable and repeatable. For a specific fiber segment *j*, the reflection spectrum is denoted as $U_j(\nu)$. If the fiber is exposed to a change in strain or temperature, the reflection spectrum will experience a shift in optical frequency $\Delta\nu_j$ and can be denoted $U_j(\nu - \Delta\nu_j)$. The shift in the reflection spectrum $\Delta\nu_j$ is computed by performing a cross correlation operation on $U_j(\nu)$ and $U_j(\nu - \Delta\nu_j)$. this spectral shift can then be related to a temperature or strain change.

as shown in the equation: $$\frac{\Delta\lambda}{\lambda} = -\frac{\Delta\nu}{\nu} = K_T\Delta T + K_\varepsilon \varepsilon$$,

Spectral Shift Quality

The Spectral Shift Quality is a measure of the strength of the correlation between the measurement and baseline reflected spectra. This value is calculated as:

$$\text{Spectral Shift Quality} = \frac{MAXIMUM(U_j(v) \star U_j(v - \Delta v_j))}{\sum U_j(v)^2}$$,

where U_j is the baseline spectrum for a given segment of data, $U_j(\nu - \Delta\nu_j)$ is the measurement spectrum under a strain or temperature change, and the symbol $\star$ is used to denote the cross-correlation operator. In other words, the **Spectral Shift Quality** is the maximum value of the cross correlation of the **baseline measurement** and measurement spectra normalized by the maximum expected value, i.e. the maximum of the baseline spectra autocorrelation.

Theoretically, the **Spectral Shift Quality** will be a value between 0 and 1, where 1 is a perfect correlation, and zero is uncorrelated. In practice the calculated value can exceed one due to small variations in the laser power. The data sets will be accurate if the **Spectral Shift Quality** is above about 0.15. If the **Spectral Shift Quality** is less than 0.15 it is likely that the strain or temperature change has exceeded the measurable range. Note that, as strain or temperature change increases, **Spectral Shift Quality** will decrease. This is expected since exposing a fiber to a change in strain or temperature induces a temporal shift as well as a temporal stretch or compression.

Temperature and Strain Change

Both temperature and strain cause a change in the light scattered from the fiber. Through judicious experimental planning the ODiSI can provide both temperature and strain measurements along the length of a sensor.

In the absence of strain the temperature change be written as:

Temperature Change = $\Delta T = -\dfrac{\bar{\lambda}}{cK_T}\Delta\nu$, where $\bar{\lambda}$ is the center wavelength of the scan and *c* is the speed of light. Similarly, in the absence of a temperature change, the strain can be written as:

Strain = $$\varepsilon = -\frac{\bar{\lambda}}{cK_{\varepsilon}}\Delta\nu$$.

Assuming a scan center wavelength of 1550 nm, we can substitute in the constants K_T and K_{ε} to yield the following conversion factors: ε = (-6.67 $\mu\varepsilon$ /GHz)$\Delta\nu$, and ΔT = (-0.801 ºC /GHz)$\Delta\nu$.

Thus the distributed temperature and strain curves are merely rescaled copies of the spectral shift distribution.

Gauge Length and Sensor Spacing

The spatial resolution of the **Spectral Shift**, **Spectral Shift Quality**, **Temperature Change**, and **Strain** measurements is determined by the **Sensor location** and **Gauge Length** settings in the **Fiber Config** window. The **Gauge Length** determines the segment size of the Rayleigh scatter that is used to determine the **Spectral Shift**, from which the other sensing parameters are calculated.

Temperature Change and Strain Coefficients

The temperature change and strain curves are generated by converting the spectral shift curve from values in GHz to degrees C or microstrain. This conversion is done using a 4th order polynomial fit. The default coefficients for this fit have been set for standard room temperature and zero strain. The user can customize these coefficients for other operating regimes by recording the **Frequency Shift** of a fiber over a region of interest, while measuring temperature or strain on that fiber externally.

Distributed Sensing References

D. Gifford, B. Soller, M. Wolfe, and M. Froggatt, “Distributed Fiber-Optic Sensing using Rayleigh Backscatter,” **WB 4**, p. 5, *European Conference on Optical Communications (ECOC) Technical Digest*, Glasgow, Scotland, 2005.

M. Froggatt, B. Soller, D. Gifford, and M. Wolfe, “Correlation and keying of Rayleigh scatter for loss and temperature sensing in parallel optical networks,” *OFC Technical Digest*, paper PDP 17, Los Angeles, March, 2004.

B. J. Soller, D. Gifford, M. Wolfe, and M. Froggatt, “High resolution optical frequency domain reflectometry for characterization of components and assemblies,” *Opt. Express*, **13**, pp.666-674, 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. Froggatt and J. Moore, “High resolution strain measurement in optical fiber with Rayleigh scatter,” *Appl. Opt.,* **37**, pp. 1735-1740, 1998.

K. O. Hill, G. Meltz, “Fiber Bragg grating technology—fundamentals and overview,” *Journal of Lightwave Technology*, **15**(8), pp.1263-1274, 1997.

A. Kersey, M. Davis, H. Patrick, M. LeBlanc, and K. Koo, “Fiber grating sensors,” *Journal of Lightwave Technology*, **15**(8), pp. 1442-1462, 1997.

A. Othonos, “Fiber Bragg gratings,” *Rev. Sci. Instrum.,* **68**(12), pp. 4309-4340, 1997.

Y. Roa, “In-fibre Bragg grating sensors,” *Meas. Sci. Technol.,* **8**, pp. 355-375, 1997.

Fiber Optic Interferometry

The ODiSI uses swept-wavelength coherent interferometry. 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 6-1.

(1) 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.

(2) 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.

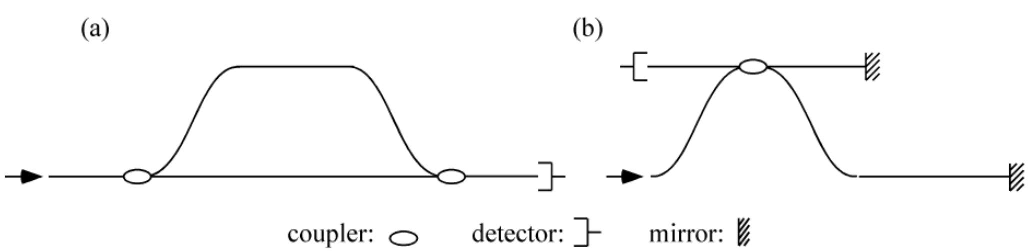


Figure 6- 1 Two basic types of fiber interferometers:

(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.

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:

$$I(\omega) = |E_0(t)|^2 + |E_0(t-\tau)|^2 + 2E_0(t)E_0(t-\tau)\cos[\omega(t)\tau],$$

where the time delay difference between the interferometer paths $\tau = \tau_1 - \tau_2$.

Optical Network for ODiSI

A schematic of Luna's ODiSI optical network is shown in Figure 6-2. The optical system is comprised of a tunable laser source (TLS), an interferometer (which includes the sensor), and a detector.

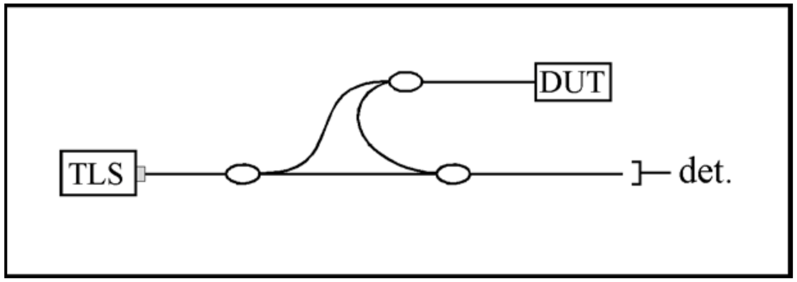


Figure 6- 2 ODiSI optical network

The basic idea from the previous section can be applied to device characterization by including a sensor in one arm of a Mach-Zender interferometer, We can describe the sensor 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 sensor 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

$$\begin{aligned} I = {} & |E_0(t)|^2 + |E_0(t-\tau)|^2\rho(\omega)^2 \\ & + 2\rho(\omega)E_0(t)E_0(t-\tau)\cos[\omega(t)\tau - \phi(\omega)] \end{aligned}.$$

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 ODiSI 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. The Fourier transform of a single, localized reflection is plotted in Figure 6-3. 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.

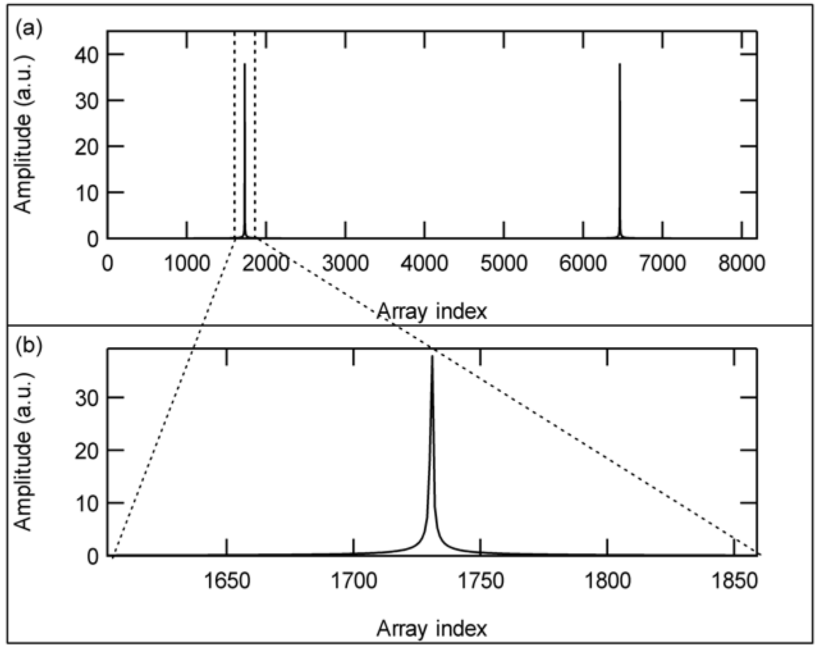


Figure 6- 3 (a) The Fourier transform of interference fringes.

(b) The segment of the time domain data that contains device information.

When measuring with the ODiSI he continually distributed scatter throughout the sensing fiber contribute to the interference pattern. The physical distance of the scatter location in the fiber is related to the array index in the Fourier transformed data. In order to more easily locate the temperature(strain) in the sensor, the time-domain data can be scaled in units of length, using the speed of light and the group index of the sensing fiber.

Fiber Interferometry References

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. 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.

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.

Chapter 7 Maintenance

Cleaning Connectors

It is extremely important to clean connectors before attaching optical fibers to the ODiSI for testing. Failure to do so may result in noisy data or damaged equipment.

Optical fiber connectors on cables should be cleaned before every connection to the ODiSI. The bulkhead connectors on the front panel of the ODiSI 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 ODiSI bulkhead connectors:

The cleaning supplies used with the ODiSI 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 ODiSI components.

Cleaning Optical Fiber Connectors

Important

Optical fiber connectors on devices should be cleaned before every connection to the ODiSI.

1 Expose the cleaning tape by pushing down the cover release lever.

Cleaning tape cover closed

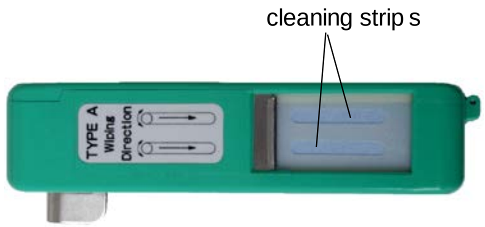
cover release lever

tape cover

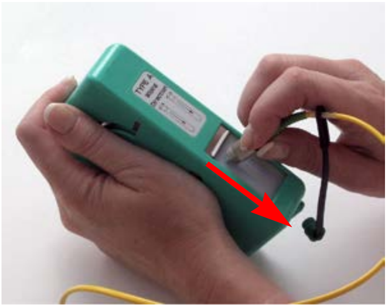
Cleaning tape cover open

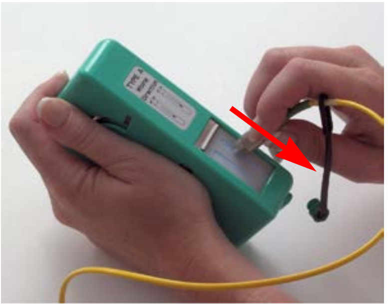
cleaning tape

The cleaner tape has two 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

Important

The bulkhead connector should be cleaned about once every 25 connections.

1. Turn off the ODiSI.
2. Make sure that no devices are connected to the ODiSI.
3. Open the protective cover. Gently insert one of the supplied mini swabs, as shown below. Twist the swab in one direction, and then remove. *Discard miniswabs after single use.*

Figure 9-1. Open the protective cover. Gently insert supplied mini swab, rotate in one direction, then remove.

Cleaning the Case

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.

Replacing Fuses

The fuse drawer is located on the power module on the instrument case back panel:

Warning

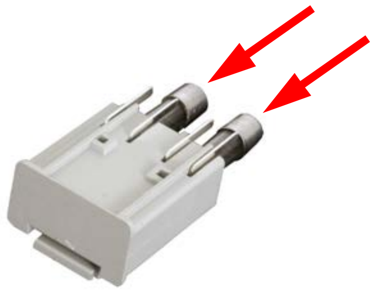
To avoid the risk of serious injury or death, ensure that the power cord is disconnected from the instrument when checking or replacing fuses.

To replace fuses

1 Disconnect the instrument power cord.

1 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.

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 ODiSI

The ODiSI 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 ODiSI system should always be shipped via air instead of ground, by a reputable shipping service provider.

Required Packing Materials

- ODiSI Shipping Box (#1)
- Desktop or Laptop PC Box (#2)
- PC Monitor Box (if do not have laptop)(#3)
- ODiSI Shipping Foam
- PC Monitor Shipping Foam

- PC Shipping Foam
- ODiSI Accessory Box
- PC Accessory Box
- Sturdy packaging tape to seal the boxes

Packing Procedure

1 Check that all materials to be shipped are ready to be packed using the “Components List” on page 7.

3 Obtain an ODiSI Shipping Box (#1).

4 Seal the bottom center and edges of the box.

5 Pack the ODiSI in the ODiSI Shipping Box using the original styrofoam insert on each side of the ODiSI.

7 Place the ODiSI Accessory Box on top of the ODiSI.

8 Seal the top of the box, taping the center and open edges.

9 Obtain a Luna Desktop or Laptop PC Shipping Box (#2), as applicable.

10 Seal the bottom center and edges of the box.

11 Pack the PC in the PC Shipping Box using the original styrofoam inserts on each side of the PC.

12 Pack the PC software and manuals, as well as the mouse, keyboard, and PC Power Cord in the PC Accessory Box.

13 Place the PC Accessory Box on top of the re-packaged PC.

14 Seal the top of the box, taping the center and open edges.

15 Obtain a Luna Technologies Monitor Shipping Box (#3), if applicable. Otherwise disregard the remaining steps.

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.

Chapter 8 Troubleshooting

This chapter describes how to troubleshoot ODiSI hardware and software errors.

If you have problems or error messages not listed here, or if the solutions provided here do not resolve a problem, please contact Luna Technologies toll free at (1-866-586-2682) or by e-mail at support@lunatechnologies.com.

General Troubleshooting

The ODiSI or PC will not power on

Cause(s)	Solution(s)
The ODiSI and/or the PC is not plugged in or turned on (and the laptop battery is dead, if applicable).	The ODiSI and the PC require separate power cords. Plug in the ODiSI and/or the PC, or replace dead batteries with charged ones if using a laptop PC. Instructions for the PC battery are located in the provided PC manual. Make sure to turn on the ODiSI power switch on the front of the instrument, and the PC according to its instructions.
Blown fuse.	Replace the fuse. For instructions, see “Replacing Fuses” in Chapter 7

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 ODiSI control software. If the problem persists, reinstall the ODiSI control software from the ODiSI software CD.
The ODiSI 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 ODiSI is restricted.	Move the ODiSI away from objects or surfaces that restrict air flow through the fan duct on the back of the ODiSI.

Laser overheated because of excessively high ambient temperature.	Move the ODiSI to a cooler environment or decrease the ambient temperature to within the ODiSI operating range of 10–35°C.

Control software will not load

Cause(s)	**Solution(s)**
Generally this occurs when other software is installed on the PC.	Remove any software not originally installed on the ODiSI PC, then restart. If the problem persists, reinstall the ODiSI control software from the ODiSI software CD.

Control software seems to lock up

Cause(s)	Solution(s)
Processing logged data with the wrong baseline range	Choose a baseline range that is the same as the range used to record the data.
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 ODiSI software, and click End Task.] Turn the instrument off and then back on again. Restart the ODiSI control software.
Multiple Luna Technologies software applications are running at the same time.	Ensure that you are only running one control software program at a time. Software applications cannot share the ODiSI 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 ODiSI control software.

	If the problem persists, reinstall the ODiSI control software from the ODiSI software CD.

Alignment unsuccessful

Cause(s)	Solution(s)
Normal alignment procedure occasionally fails.	Retry alignment

ODiSI will not scan

Cause(s)	Solution(s)
Optics not aligned. (The “Out of Alignment” indicator should be lit in this case.)	Realign

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)**
Baseline does not match fiber	Select a baseline that matches the fiber or record a new baseline
Mechanical vibration.	Move or shut down any sources of vibration. Isolate the ODiSI from those sources.
Loose fiber connection.	Tighten or reconnect the fiber (device under test) connections.
Dirty fiber or bulkhead connections.	Clean all connections. For instructions, see “Cleaning Connectors” in Chapter 7

ODiSI not aligned.	Align the Optics using Tools\Align in the ODiSI Control window
There is a strong reflection in the optical path.	Check the optical path using Tools\Check Path in the ODiSI control window. Then eliminate the strong reflection.
Patch cable too long	Shorten the leads to comply with the length limit of the ODiSI.
Cracks in bulkhead connector alignment sleeve.	Contact Luna Technologies at 1-866-LUNAOVA or support@lunatechnologies.com for service.

No data after scan

Cause(s)	**Solution(s)**
Incorrect graph range settings.	Rescale the plot axes.
Incorrect graph variable selected.	Make sure the graph is set to display the parameter that is in the active profile.

Instrument drifts out of Alignment

Cause(s)	**Solution(s)**
Temperature changes will cause the instrument to drift.	Tools\Align

Errors on Software Startup

The software goes into “Desktop Analysis” mode

Cause(s)	Solution(s)
The USB cable connections might 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.	Replace the cable

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.	Align the optics with Tools\Align

If any error occurs consistently, please contact Luna Technologies toll free at 866-LUNAOVA (866-586-2682) or by e-mail at support@lunatechnologies.com

Technical Support

If you have any problems with or questions about the information contained in this document, please contact our technical support staff by one of the following methods:

Luna Technologies, A Division of Luna Innovations Incorporated

3157 State Street

Blacksburg, VA 24060

Main Phone: (540) 961-5190

Toll-Free Support: 1.866.LUNA OVA (866.586.2682)

E-mail: support@lunatechnologies.com

www.lunatechnologies.com

Appendix A Specifications

Parameter	Specification	Units
Electrical		
Input Voltage Range	100-250	VAC
Input Frequency Range	50-60	Hz
Operating Power	100	VA
Optical Output		
Maximum Rated Output Power	9.0	mW
Internal Laser Module Maximum Rated Output Power	20.0	mW
Emitted Wavelengths	1510-1570	nm
PC I/O		

Input/Output Devices	• CD drive • USB ports • RS-232 port • Printer port • Ethernet port • IEEE-488/GPIB (optional) • Keyboard/Mouse • Display	
Environmental		
Operating Temperature Range[1]	10-35	ºC
Storage Temperature Range	0-40	ºC
Relative Humidity (non-condensing)	< 80	%

[1] Performance criteria can only be met if the unit is operated within the proper temperature range indicated. Maintenance of an acceptable internal operating temperature depends upon proper equipment ventilation. To ensure proper ventilation, never obstruct enclosure airflow openings.

For current performance specifications, check our website at www.lunatechnologies.com/products/ODiSI/ODiSI.html

Dimensions and Weight (Without PC)		
Weight (PC not included)	11.4 25	kg lbs
Case Size	366 X 345 X 165 14.42 X 13.6 X 6.5	mm in

Minimum PC Requirements

Important

Luna Technologies strongly advises using an instrument controller purchased from Luna. Luna Technologies makes no guarantees of performance if customers use some other instrument controller to operate the ODiSI.

Processor: Quad Core, 2.2 GHz minimum

Memory: 2 GB RAM

Operating System: Windows 7, 32-bit (Vista not supported)

Optical drive for installing the software

USB 2.0 port

17” LCD Monitor

Class 1 Laser Product

The Luna Technologies ODiSI is a **Class 1 Laser Product**, which meets the requirements of Class 1 in standards **IEC 60825-1: 2001** and **2007**, and complies with **21CFR1040.10**.

Maximum rated output power: 9.0 mW

Internal laser module maximum rated output power: 20.0 mW

Emitted wavelengths: 1510 to 1570 nm

Appendix B Using a fiber optics switch with ODiSI

Overview

The ODiSI system and ODiSI SDK if used in conjunction with a Luna Technologies’ FOS and FOS SDK allow the development of custom software utilities taking advantage of channel multiplexing. Two of the examples provided in the ODiSI SDK -- SDK_ODiSIExample_config.vi and SDK_ODiSIExample_wswitch.vi – work together to demonstrate the ODiSI SDK and FOS SDK integration. The example programs were written and tested using Visual Studio 2005 and LabVIEW 2010.

The example programs call functions contained in DLLs (primarily ODiSI.DLL and ltfos.dll) to control the ODiSI and FOS and perform calculation. It may be possible to call these same DLL functions from other programming languages; however C++ and LabVIEW are the only languages currently supported by the SDK.

Getting Started

Please refer to the ODiSI SDK Users Guide on how to setup the ODiSI SDK.

Using the ODiSI SDK with Switch

Before proceeding with the ODiSI SDK using the FOS SDK, the user is encouraged to gain familiarity with the ODiSI SDK by running the provided example programs. These programs demonstrate the various operations that can be performed with the SDK, and can serve as starting templates for writing your own programs. The user is then encouraged to review the examples presented herein.

LabVIEW *VIs* and Example Programs

The example LabVIEW code provided in the ODiSI SDK references the FOS SDK. The folders containing low level Vis are talked about in the respective SDK user guides. Each of these *VI*s has a simple and single purpose and should not be modified.

The folder *C:\ODiSI_SDK_v1.0\Labview\examples* contains an example program *"SDK_ODiSIExample_wswitch.vi"* that uses the low level VIs to control the ODiSI and FOS. The program demonstrates how to configure the ODiSI and Switch, connect to the ODiSI, retrieve and set fiber information, acquire measurements, log and load measurements, toggle the FOS to access a different port, as well as process and plot data. This document assumes that the user has reviewed and understood the examples provided in the ODiSI Users Guide and will primarily focus on switch integration into the work flow of the ODiSI code as a template for FOS utilization in conjunction with the ODiSI.

The figure below is the LabVIEW diagram for the example file. The data sequence flows from left to right, beginning with the ODiSI configuration and installed fiber retrieval, and FOS initialization and configuration. After configuration, the example code flows into an event structure within a *while* loop to enable data acquisition and display for any of the installed fibers. It is important to note that the when the program is terminated, the switch module has to be properly closed out by calling the "FOS Close Module" VI as illustrated below.

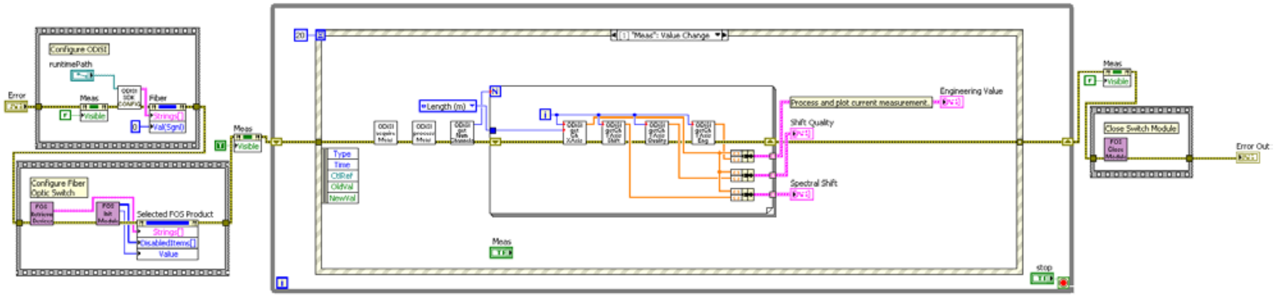


Figure 1: _Scan_DisplayCurves.vi

The event structure in the state machine has three events that illustrate integrated use of the ODiSI and the FOS. The figure below illustrates the "Meas" state where a measurement is acquired and displayed for the active fiber selected by the end user.

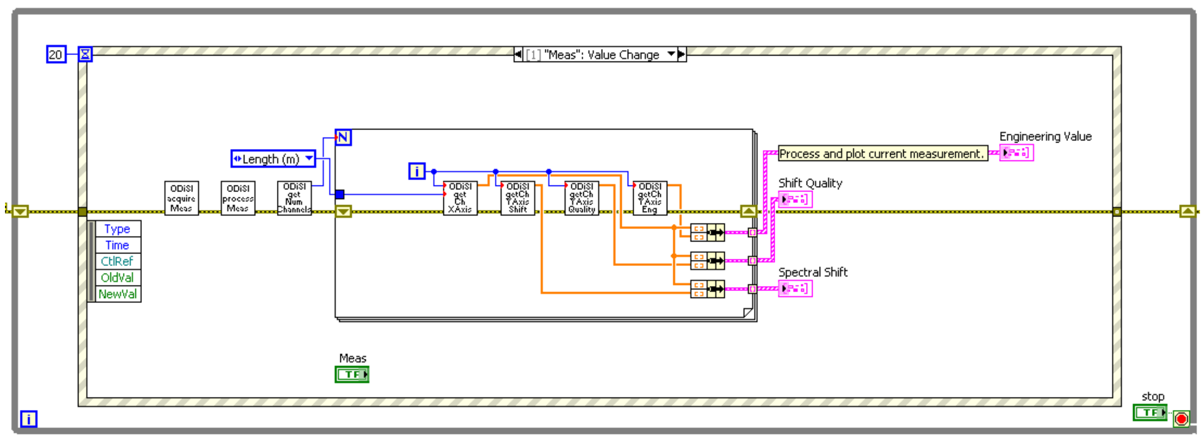


Figure 2: "Meas" State of event structure

The second state in the event structure called “*Fiber*” is used to configure the user selected fiber in the ODiSI as illustrated in the figure below. The fiber information is selected based on the user input. The corresponding switch port is retrieved from the fiber information. The ODiSI is then appropriately configured and the “*port*” state is then triggered to toggle the switch to match the user selection.

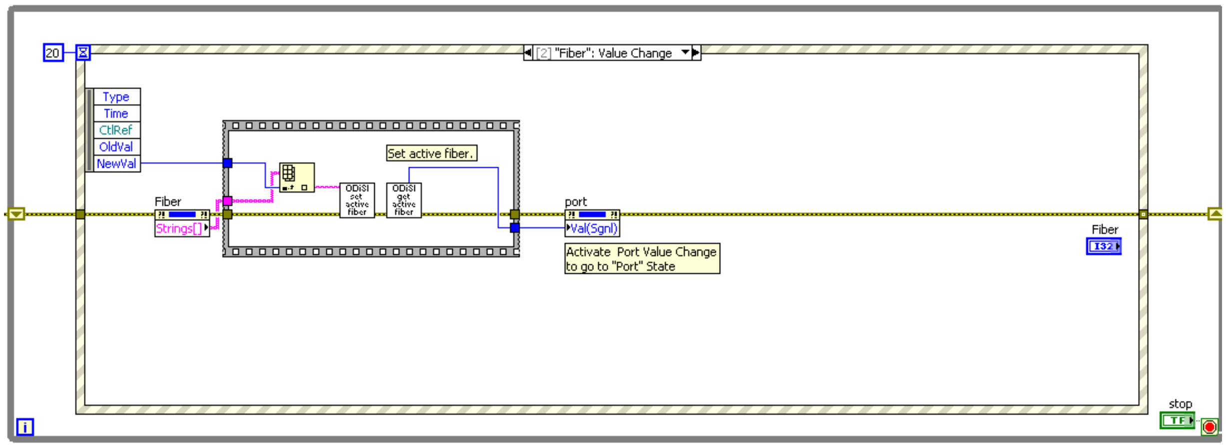


Figure 3: “Fiber” State of event structure

The “port” state simply toggles to switch to the port that matches the fiber path selected by the user, thus allowing for multi fiber measurement capability using the ODiSI and FOS

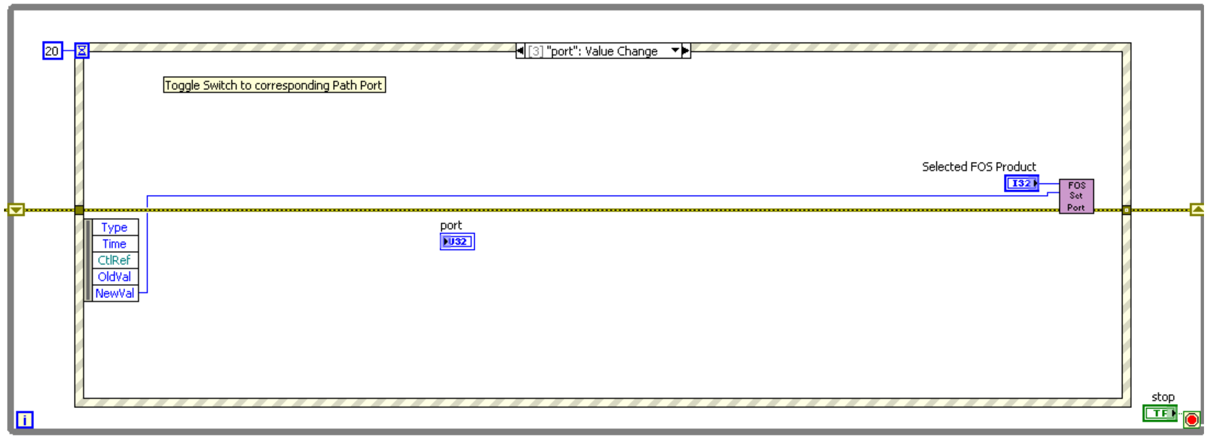


Figure 4: "Port" State of event structure