THORLABS

Swept Source OCT System

Operating Manual

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Part 1. Introduction

1.1. Important Notices

ATTENTION USER!

Please read the instruction manual carefully before operating the Swept Source OCT System.

All statements regarding safety and technical specifications will only apply when the unit is operated correctly.

WARRANTY WARNING

Do not open the microscope unit, the handheld scan probe, the swept source or the PC.

There are no user serviceable parts in this product. Opening the device will void your warranty.

Any modification or servicing of this system by unqualified personnel renders Thorlabs free of any liability.

Attention

This device can only be returned when packed into the complete original packaging, including all foam packing inserts. If necessary, ask for a replacement packing.

ATTENTION USER!

Check the supply voltage of the system before plugging in the CPU and Swept Source Laser.

Set the line select switch on the CPU to the appropriate setting. (See Appendix 7.1)

Make sure the included power cords for Swept Source Engine, PC and monitor are connected to a properly grounded power outlet (100V – 240V AC; 50Hz – 60Hz).

Transportation and delivery may cause the Swept Source OCT system to be warm or cool upon receipt. Please wait for the system to reach room temperature before attempting to operate.

Use a flat, dry, and stable surface to set up the system.

1.2. Safety and Warnings

WARNING High Voltage!

Before applying power to your system, make sure that the protective conductor of the 3 conductor mains power cord is correctly connected to the protective earth contact of the socket outlet. Improper grounding can cause electric shock resulting in severe injury or even death!

Make sure that the line voltage rating agrees with your local supply and that the appropriate fuses are installed. Fuses should only be changed by qualified service personnel. Contact Thorlabs for assistance.

Do not operate without cover installed. To avoid electrical shock the power cord protective grounding conductor must be connected to ground. Refer servicing to qualified personnel.

NOTE: Thorlabs provides the proper power input cable with each system for use in the United States. If using this unit anywhere else, the user will need to supply a properly grounded power cable to power the unit.

Attention!

Do not obstruct the air-ventilation slots in the computer housing!

Do not obstruct air-ventilation into the bottom of the swept source engine or out of the exhaust fan on the rear of the unit!

Mobile telephones, cellular phones or other radio transmitters are not to be used within the range of three meters of this unit since the electromagnetic field intensity may exceed the maximum allowed disturbance values according to EN50082-1.

WARNING Electrostatic Discharge (ESD)

All types of electronic components, particularly integrated circuits, are sensitive to Electrostatic Discharge (ESD). ESD is a general reason for failure of electronic equipment. The total operating time may be reduced if precautions against ESD-damage are not taken.

ALWAYS wear an ESD wrist strap connected to an ESD terminal whenever handling the swept source. See Figure 2.

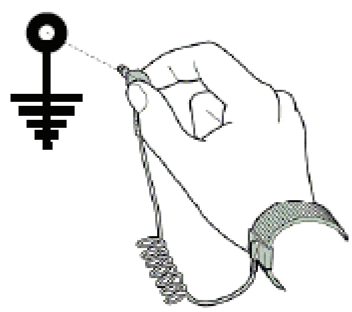


Figure 1: ESD wrist wrap. The wrist strap is connected to ground to ensure that no electrostatic field is built up.

WARNING

Do not, under any circumstances look into the optical output when the device is operating. The laser radiation is not visible to the human eye, but it can seriously damage your eyesight.

**VISIBLE AND INVISIBLE LASER RADIATION
DO NOT STARE INTO BEAM
OR VIEW DIRECTLY WITH
OPTICAL INSTRUMENTS.
CLASS 1M LASER PRODUCT**

1.3. *Care of the Swept Source OCT System*

Handle the system with care during transportation and unpacking. Banging or dropping the system can damage the unit or lower system performance.

Attention

If the system is mishandled during shipment, the optical components may become misaligned, which could lead to a decrease in the image quality. If this happens, the system will need to be realigned by qualified personnel.

If the system is dropped from a height greater than 15", it will be necessary for qualified Thorlabs' personnel to perform an electrical security check.

Please contact Thorlabs for more information.

- Do not store or operate in a damp, closed environment.
- Do not store or operate on surfaces that are susceptible to vibrations.
- Do not expose to direct sunlight.
- Do not use solvents on or near the equipment.
- Keep away from dust, dirt, and air-borne pollutants (including cigarette smoke). The system is not designed for outdoor use. Protect the equipment from rain and snow and humidity.
- Do not expose to mechanical and thermal extremes. Protect the equipment from rapid variation in temperature.
- Handle all connectors, both electrical and optical, with care. Do not use unnecessary force as this may damage the connectors.
- Handle the optical fiber with care; mechanical stress can decrease the performance and potentially destroy the fiber. Continual bending of the optical fiber can cause damage, it is important to keep the optical fiber patch cable as straight as possible to minimize bending.

NOTE: The most common cause of low signal intensity is contamination of the fiber due to airborne pollutants. To minimize exposure avoid unnecessarily disconnecting the optical fiber patch cable. In addition, it is advisable to check the fiber before making other adjustments to the optical system such as changing the focus, or optical path length. Be sure to check the patch cord for a loose connection, and make sure that the fiber is kept as straight as possible.

Attention

All lasers, especially lasers having resonator cavities defined by mechanical tolerances, are delicate precision instruments and they must be handled accordingly.

The Swept Source OCT system is designed to withstand normal transportation and normal operation conditions.

Do not move the system while it is connected and in operation.

Maintenance: Optical Cleaning

Good performance and image quality of the OCT microscope system relies on clean optical connections. Whenever using the Thorlabs OCM system, the following rules of thumb for optical fiber connection should be followed.

1. ALWAYS inspect and clean the fiber end before plugging it into a receptacle.
2. ALWAYS cover the fiber end that is not in use with a fiber cap or dust protection cover.

For the customer's convenience, a fiber cleaner and a fiber inspection scope (Thorlabs CL-200) is included with the system.

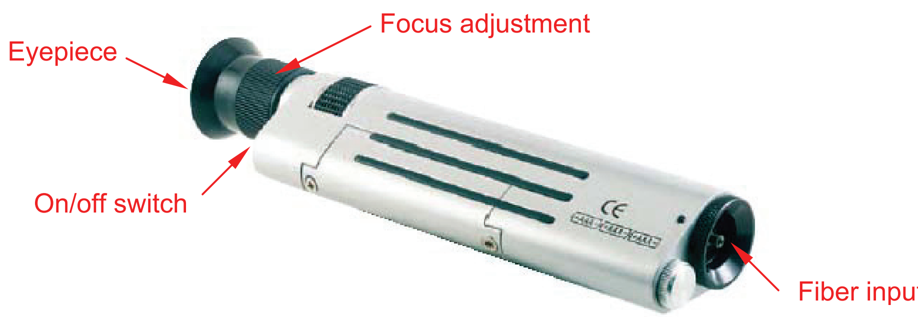


Figure 2: Fiber inspection scope (CL-200)

Please follow the steps below to inspect the fiber end:

Ensure that any source of Laser Radiation is TURNED OFF. This OCT system provides both IR and visible laser radiation, both sources must be disabled. The lasers are OFF when the "laser on" and "Aim on" indicator on the front panel of the Swept Source are not illuminated.

Figure 3: Laser Control Panel view. (a) Lasers disabled (OFF), (b) Lasers enabled (ON)

1. Insert the terminated fiber into the fiber input.
2. Look into the eyepiece and press the on/off LED switch.
3. Adjust the focus control, to find the clearest image.
4. Rotate the fiber end to make sure that no dirt is rotating in the view. Dirt that rotates with the fiber is attached to the tip of the ferrule.
5. If fiber tip is dirty, draw figure 8s with the ferrule on the cleaning reel. Re-inspect, and repeat if necessary.

Service

Only trained and approved Thorlabs' personnel should service the system. Please contact: techsupport@thorlabs.com

Accessories and Customization

Though the system is easily adapted for custom interfaces, to achieve the listed specifications, this system should only be used with accessories provided by Thorlabs. Any modification or servicing by unqualified personnel renders the warranty null and void, leaving Thorlabs free of liability. Please contact Thorlabs for questions on customization.

1.4. Swept Source Optical Coherence Tomography (SS-OCT) Theory

Swept Source Optical Coherence Tomography (SS-OCT) technology uses a rapidly tuned narrowband source to illuminate the interferometer and records the information with a single photodetector. SS-OCT technology, like optical frequency domain reflectometry, measures the magnitude and time delay of reflected light in order to construct depth profiles (A-scans) of the sample being imaged. Adjacent A-scans are then synthesized to create an image.

Advanced data acquisition and digital signal processing techniques are employed in the SS-OCT system to enable real-time video rate OCT imaging. This OCT system enables the generation of images similar to confocal microscopy by summing signals in the axial direction. High-speed 3D OCT imaging provides comprehensive data that combines the advantages of surface microscopy and structural OCT imaging in a single system.

SS-OCT has the advantage of generating high-speed depth profiles at the laser sweeping rate, as well as collecting interference signals from the sample using a high-efficiency balanced detection scheme. The 5-6 mm coherence length of the laser enables approximate 3 mm depth measurement range of the reflected signal without significant decay in the system detection sensitivity.

The Swept Source Optical Coherence Microscope (SSOCM) system utilizes the latest swept source based Fourier domain OCT technology to provide an OCT imaging system with detection sensitivity and imaging speeds much higher than conventional time-domain OCT (TD-OCT) systems. At the heart of the instrument is a swept laser source that tunes the lasing wavelength across a broad wavelength range at tens of kilohertz repetition rate. Each sweep of the laser wavelength provides a depth scan at a sample surface point that yields a detailed depth dependent reflectivity profile along the direction of the laser illumination path. The high-speed scan of the laser enables the real-time video rate imaging speed, which is one of the most important features of the SSOCM system.

The SSOCM system is capable of providing highly detailed 2D cross-sectional imaging of a sample's internal structure, as well as computer generated 3D reconstruction of a volume near the sample surface. If the sample is even slightly transparent to light in the range of 1200 to 1400 nm, as most biological samples and many industrial materials are, the internal structure of a sample can be accurately mapped via computer generated tomographic images.

The OCM1300SS provides simultaneous multiple imaging channels for microscopic viewing of the sample. The *en-face* images, similar to those obtained from a conventional microscope, can be acquired from the CCD channel while the cross-sectional images that show the sample's internal structure are acquired from the OCT channel. Due to the novel data acquisition and signal processing methods employed, real-time video-rate imaging speed has been achieved on both channels.

Part 2. System Description

2.1. Technical Specifications

Unless otherwise stated, all specs are typical

Optical	OCM1300SS	OCP1300SS	OCMP1300SS
Central Wavelength	1325nm		
Spectral Bandwidth	100nm		
Axial Scan Rate	16kHz		
Coherence length	6.0mm		
Average Output Power	10.0mW		
Electric			
A/D Conversion Rate	100MS/s		
A/D Resolution	14bit		
A/D Channels	2		
Analog Output Rate	1MS/s		
Analog Output Resolution	16bit		
Analog Output Channels	4		
Computer			
CPU	Dual-Core Intel Processor		
Memory	2GB SDRAM		
Operating System	Windows ® XP Professional, SP2		
Hard Drive	250GB SATA 3.0Gb/s		
Optical Drive	48X/32X CD-RW and 16X DVD+/-RW		
Monitor	Flat Panel, VGA/DVI		
Imaging			
2D Cross Sectional OCT Imaging Capability Imaging Speed (on 512 A-scans Per Frame)	25fps		
Maximum Imaging Size	4000(H) x 512 (D) Pixels		
Maximum Imaging Width	10mm		
Maximum Imaging Depth	3.0mm		
Transverse Resolution	15μm		
Axial Resolution (Air/Water)	12/9μm		
2D *en-face* Microscope Imaging Capability CCD Camera Pixel	2.0 Mega, 24 Bit RGB		
Maximum Resolution Pixel	1600 x 1200		
Imaging Speed	100fps @ 640 x 480 pixels; 20fps @ 1600 x 1200		
3D Volumetric Imaging Capability Maximum Volume Size	10 (L) x 10 (W) x 3 (D) mm		
Maximum Sampling Resolution	640 (L) x 640 (W) x 512 (D) pixels		
Imaging Time	~30 seconds		

General	OCM1300SS	OCP1300SS	OCMP1300SS
Supply Voltage for Swept Source Laser(1)	100 – 240VAC 50/60 Hz		
Supply Voltage for computer(1)	115/230VAC 50/60 Hz		
Storage/Operating Temperature	+10°C to +40°C		
Humidity	<26°C non condensing environment (RH 85%) @ 30°C		
External Magnetic Field at the surface	Less than 6μT at 30-200HZ (A/m)		
Dimensions of microscope (L x W x H)	280 x 229 x 381 mm		
Dimensions of swept source (L x W x H)	315 x 295 x 146 mm		
Dimensions of computer (L x W x H)	445 x 445 x 197 mm		

(1) Swept Source Engine has universal AC input; computer requires proper line select switch setting (See Appendix7.1)

2.2. Operating Principles

System Description

Figure 4 shows the schematic of Thorlabs' OCM1300SS OCT system. This system incorporates a high-speed frequency swept external cavity laser which has a 3dB spectral bandwidth (larger than 100nm) and an average output power of 10mW. The swept source has a built-in Mach-Zehnder Interferometer (MZI, Thorlabs INT-MZI-1300) that provides the frequency clock for the laser. The main output of the laser is coupled into a fiber-based Michelson interferometer and split into the reference and sample arms using a broadband 50/50 coupler (Thorlabs FC1310-70-50-APC).

In the reference arm of the interferometer, the light is reflected back into the fiber by a stationary mirror. In the sample arm, the light is fiber coupled into the microscope head, collimated and then directed by the XY galvo scanning mirrors towards the sample. The axial scans (A-scans) are performed at 16 kHz, which is the sweeping frequency of the laser. The transverse scan (B-scan) is controlled by the galvo scanning mirrors and determines the frame rate of the OCT imaging.

The light is then focused onto the sample surface by an objective with a long working distance. The long working distance of the objective provides a large clearance (>25 mm) between the optics and the sample, which enables easy handling of the sample. A dichroic mirror is inserted into the beam path to reflect the visible light from the sample onto a CCD camera that records the conventional microscope images of the sample. An aiming laser centered at 660 nm is coupled into the sample arm of the interferometer to visually indicate the scanning trace of laser.

The sample is placed on a stage, providing XY and rotational translation. An integrated CCD camera in the microscope head provides a conventional microscopic view of the sample, which aids sample alignment. A pair of XY galvo mirrors scans the beam across the sample surface, creating 1D, 2D, or 3D images. The optional handheld probe includes identical 2D and 3D imaging capabilities.

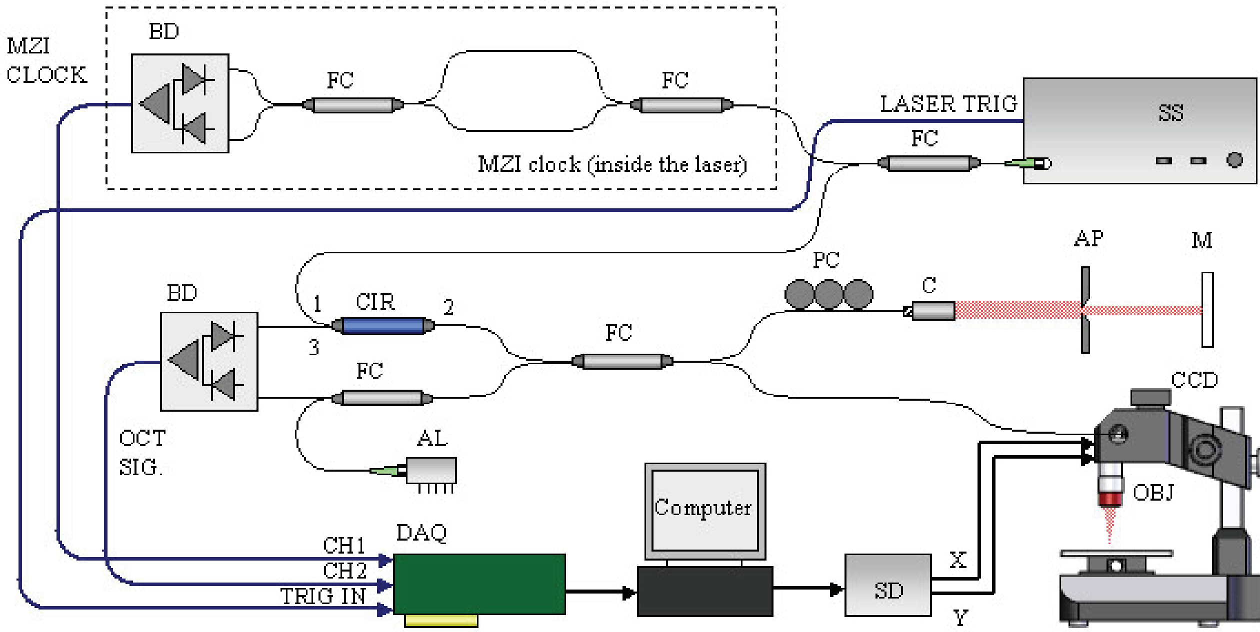


***Figure 4:** Schematic of SS-OCT System. Schematic of OCM1300SS swept source OCT microscope. SS: swept laser source, FC: fiber coupler, PC: polarization controller, CIR: circulator, C: collimator, AP: adjustable pinhole variable attenuator, M: mirror, BD: balanced detector, DAQ: data acquisition board, SD: XY scanners driver, CCD: CCD camera, OBJ, objective, MS: microscope*

Data Acquisition

In the Thorlabs SS-OCT, the interference signal is detected using a high-transimpedance gain-balanced photodetector (PDB145C) that suppresses the DC and autocorrelation noise in the interference signals. A 14-bit, high-speed digitizer is used to sample OCT interference fringe signals, which are first converted from time to frequency using a fast Fourier transform (FFT) and then recalibrated. The FFT of the interference signal yields the depth-dependent reflectivity profile for the OCT image.

All required data acquisition and processing is performed via the integrated software package, which contains a complete set of functions for controlling data measurement, collection, and processing, as well as for displaying and managing OCT image files.

Software

The software package within the SS-OCT system includes a library of parameters for sample applications. This system offers a high degree of flexibility by allowing the user to modify experimental parameters to suit experimental needs. For example, the lateral scanning range and the step width are both user controlled. In addition, the data sets are easily accessed off-line for further image processing and data analysis.

In the 1D imaging mode, there is no transverse scanning of the beam in the sample arm. The recalibrated interference fringe signals and the Fourier transformed point spread functions are displayed in real time, which aids optimization of the signal and system parameters. In the 2D imaging mode, the beam is scanned in one direction and cross-sectional OCT images are displayed in real time. The software provides flexible control of image size, brightness, contrast, and the A-line average. For the 3D imaging mode, the probe beam is sequentially scanned across the sample surface area, and the 3D volume data set under this area is acquired, processed, and stored. 3D volume display capability of the data is provided with the preinstalled software. The OCT data may be displayed in 2D or 3D mode.

The software allows real-time recording of 2D or 3D data into disk files at full imaging speed. The recorded binary data files can be exported into standard image files (jpeg, bmp) or converted to movie files (avi).

2.3. Components

Packing List

Please refer to the packing list below to ensure that the system is complete. Use only original parts. If any item is missing or damaged, contact Thorlabs for assistance.

Components	Quantity
Manual	1
Computer	1
OCT Microscope	1
Swept Source OCT Engine	1
19” Monitor	1
Keyboard	1
Mouse	1
Microscope Signal Cable (3 SMA to 2 SMA and 1 BNC)	1
Optical/DC Cable (1 SMF28 patch cord and 1 DC cable)	1
BNC/SMA cable (2 BNC to SMA)	1
6” BNC to SMA cable	1
IEEE 1394 fire wire cable	1
CL-200 Fiber Microscope(1)	1
Fiber Tip Cleaner	1
Power Cords(2)	3

(1) *standard Thorlabs product.*
(2) *power cords supplied for use in North America only.*

Microscope

The Microscope was specifically designed for use in the SS-OCT system. It holds the CCD camera, and the focusing optics required for the SS-OCT applications. The long working distance of the objective lens in the microscope allows the user to examine different types of sample (tissue or materials) with easy access and mobility. The microscope platform has X, Y and rotation translation and the microscope head assembled to the post has the Z translation capability.

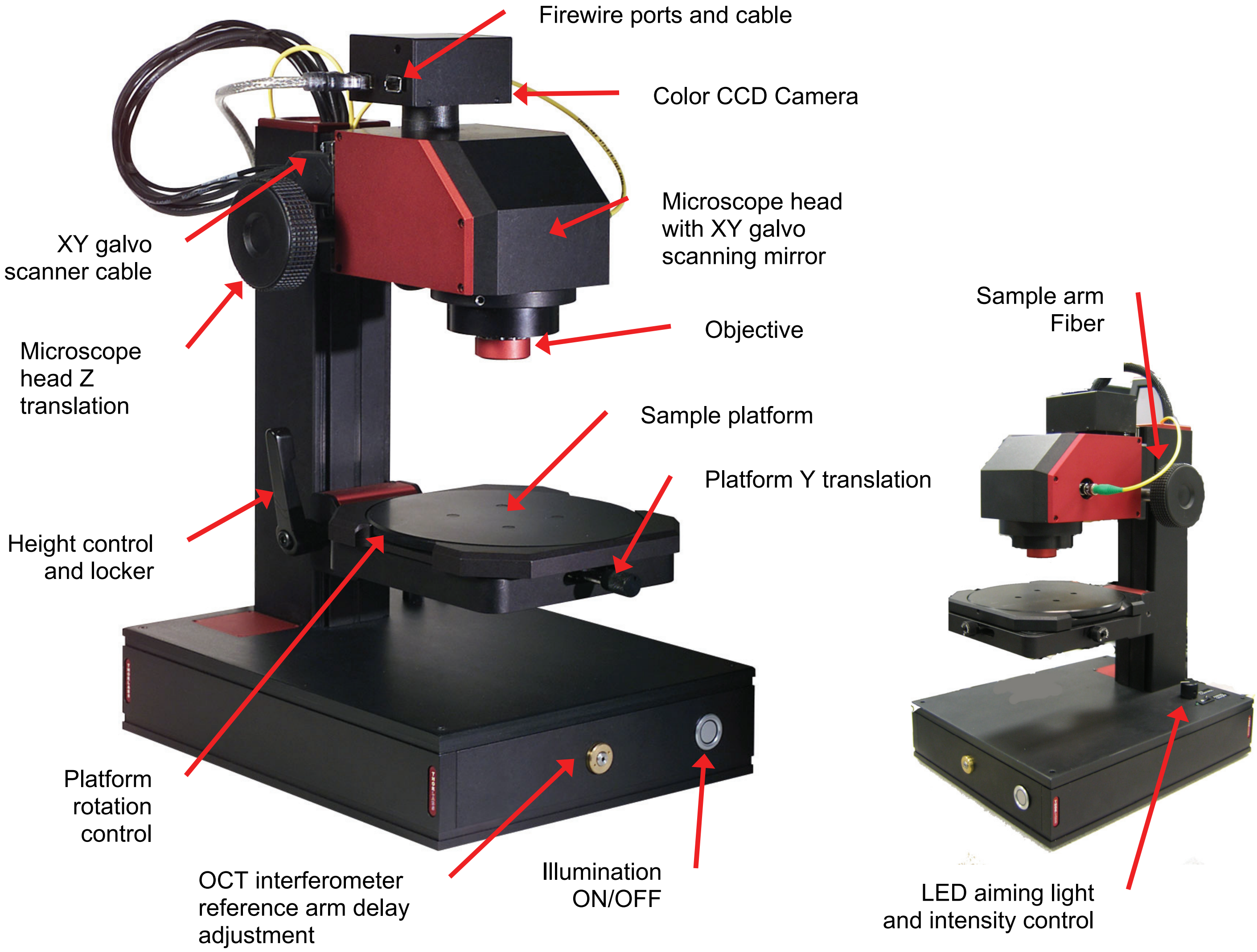


Figure 5: Microscope

Swept Source OCT Engine

SS-OCT applications require a laser that can be swept over a broad wavelength range with very high speed. The broad wavelength tuning range is required for obtaining high image resolution while the high tuning speed is needed for video rate imaging speed higher than 20 fps.

Thorlabs' Swept Source Laser is specifically designed for SS-OCT applications. It sweeps across at least 100nm at a 16 kHz repetition rate, offers a coherence length of 6mm, and delivers more than 10mW of average optical power out of an SMF28 single mode fiber. The Swept Source Engine is based on a patented external cavity laser diode design.

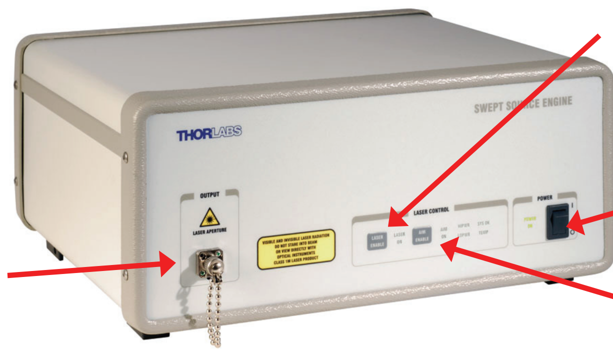


Figure 6: ***Swept Source OCT Engine***

Computer

The computer (PC) contains an NI analog control card and a digitizer card, and controls all data acquisition including parameters for controlling the scan probe and data collection. All required data acquisition and analysis is performed within the SS-OCT software package and the resulting 1D, 2D or 3D images are displayed on the PC monitor. The data can be saved, analyzed, and exported for further use.

Figure 7: ***Computer***

Handheld Probe

The Swept Source OCT system can be run using the microscope option or using a handheld probe designed to work with the system. This handheld probe contains the optics necessary to replace the microscope in the system. It will also give more accessibility to the system, since the probe can be moved from one place to another easily. The handheld probe can be used with the Swept Source OCT System independently of the microscope unit (OCP1300SS) or it can be adapted as a combo system with the microscope (OCMP1300SS).

Figure 8: Handheld Probe for the Swept Source OCT System

2.4. Installation of Swept Source OCT Systems

Swept Source Connections

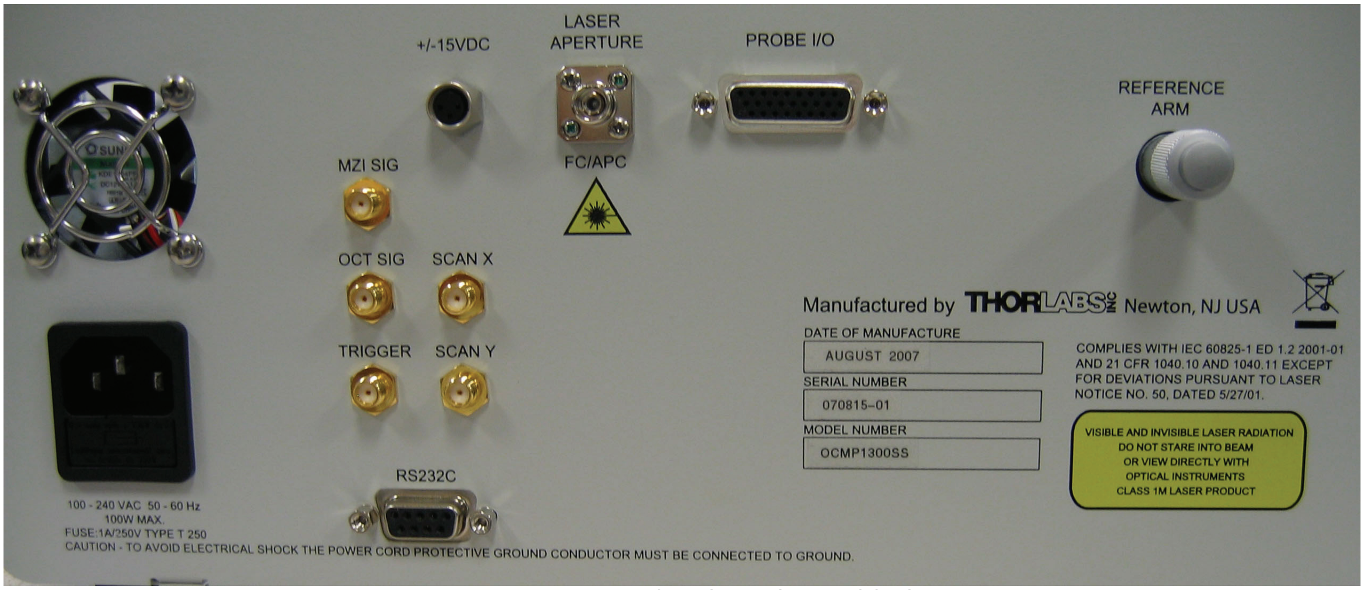
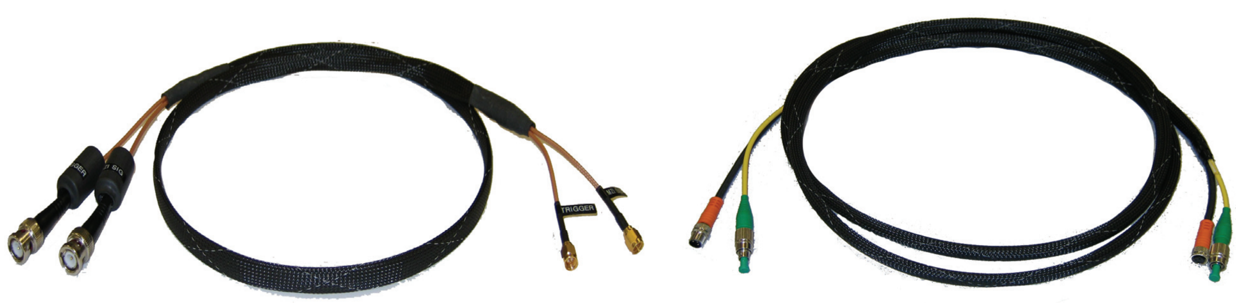


Figure 9: Rear View of the Swept Source OCT System

For the following steps, please refer to Figures 9, 10 and 11:

1. Insert the "MZI SIG" SMA connector of the BNC/SMA cable into the MZI SIG port on the laser.
2. Insert the "TRIGGER" SMA connector of the BNC/SMA cable into the TRIGGER port on the laser.
3. Insert the male end of the 3-pin DC cable of the Optical/DC cable into the +/- 15VDC port.
4. Remove the cap from the fiber connector on the Optical/DC cable. Inspect the FC/APC connector with a fiber microscope to **make sure the fiber tip is clean**. Do not touch the fiber tip. Insert the FC/APC connector of the Optical/DC cable into the LASER APERTURE port.
5. Insert a power cord into the back of the Swept Source unit, and plug the other end into a 100-240 VAC wall outlet.



BNC/SMA Cable *Optical/DC Cable*

Figure 10: Cables Used in Installation of Swept Source

BNC connectors end *SMA connectors end*

Figure 11: BNC/SMA cable labels

Computer Connections

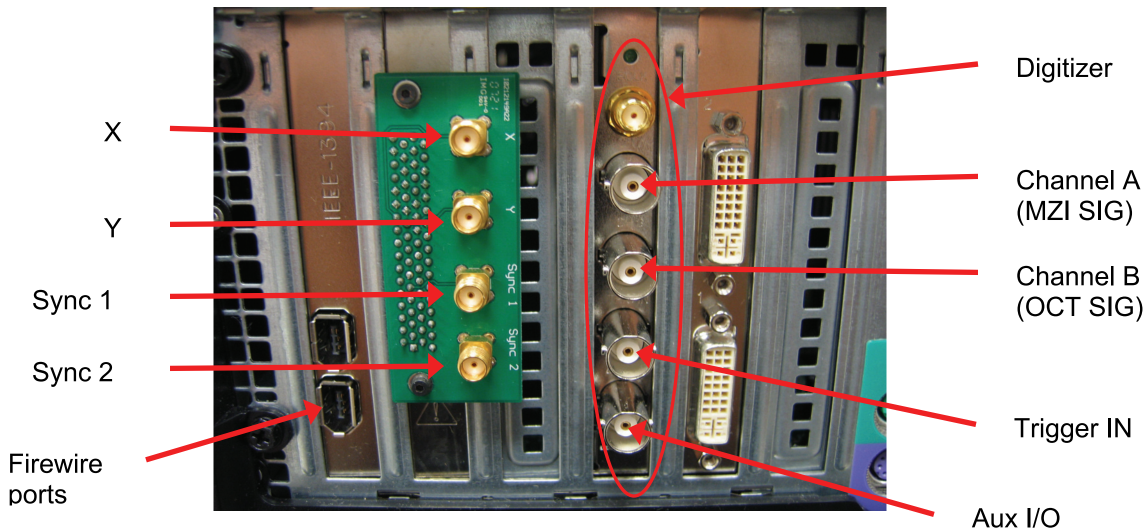


Figure 12: Rear View of the Computer

For the following steps, please refer to Figure 10, 11, 12, 13 and 14:

1. Take the “MZI SIG” BNC connector of the BNC/SMA cable attached to the MZI SIG port of the Swept Source and connect it to the Channel A port (Ch A) of the digitizer.
2. Take the “TRIGGER” BNC connector of the BNC/SMA cable attached to the TRIGGER port of the Swept Source and connect it to the Trigger IN port (Trig IN) of the digitizer.
3. Take the SMA/BNC end of the Microscope Signal Cable and connect the SMA connector labeled as “SCAN X” into the X port on the green board at the back of the PC.
4. Take the SMA/BNC end of the Microscope Signal Cable and connect the SMA connector labeled as “SCAN Y” into the Y port on the green board at the back of the PC.
5. Take the SMA/BNC end of the Microscope Signal Cable and connect the “OCT SIG” BNC to the Channel B port (Ch B) of the digitizer.
6. Insert the SMA connector of a CA2806 (Short SMA to BNC) into the Sync 1 port on the green board at the back of the PC and connect the other end (BNC connector) into the TRIGGER IN port of the digitizer.
7. Insert one end of the Firewire cable into one of the Firewire ports at the back of the PC.
8. Insert the mouse, keyboard and monitor in the designated standard ports.

9. **IMPORTANT**!. Check that the red switch near the AC input of the PC is on the right AC setting. The PC can be damaged if plugged into the incorrect wall voltage, even if it is not powered on. Insert a power cord into the back of the PC, and plug the other end into the appropriate 110/230 VAC wall outlet.

Microscope Signal Cable

6" BNC/SMA cable

Firewire Cable

Figure 13: Cables used in installation of Computer

3 SMA connectors end

2SMA/1BNC connectors end

Figure 14: Microscope signal cable labels

Microscope Connections

Figure 15: Rear View of the microscope panel

For the following steps, please refer to Figure 10, 13 and 15:

1. Take the "SCAN X" SMA connector of the Microscope Signal Cable and connect it to the SCAN X port at the back of the microscope.
2. Take the "SCAN Y" SMA connector of the Microscope Signal Cable and connect it to the SCAN Y port at the back of the microscope.
3. Take the "OCT SIG" SMA connector of the Microscope Signal Cable and connect it to the OCT SIG port at the back of the microscope.
4. Take other end of the Optical/DC cable and connect the 3-pin DC connector into the ±15VDC INPUT port at the back of the microscope.
5. Remove the remaining cap off the fiber connector of the Optical/DC cable. Inspect the FC/APC connector with a fiber microscope to **make sure the fiber tip is clean**. Do not touch the fiber tip. Insert the FC/APC connector of the Optical/DC cable into the FC/APC INPUT port.

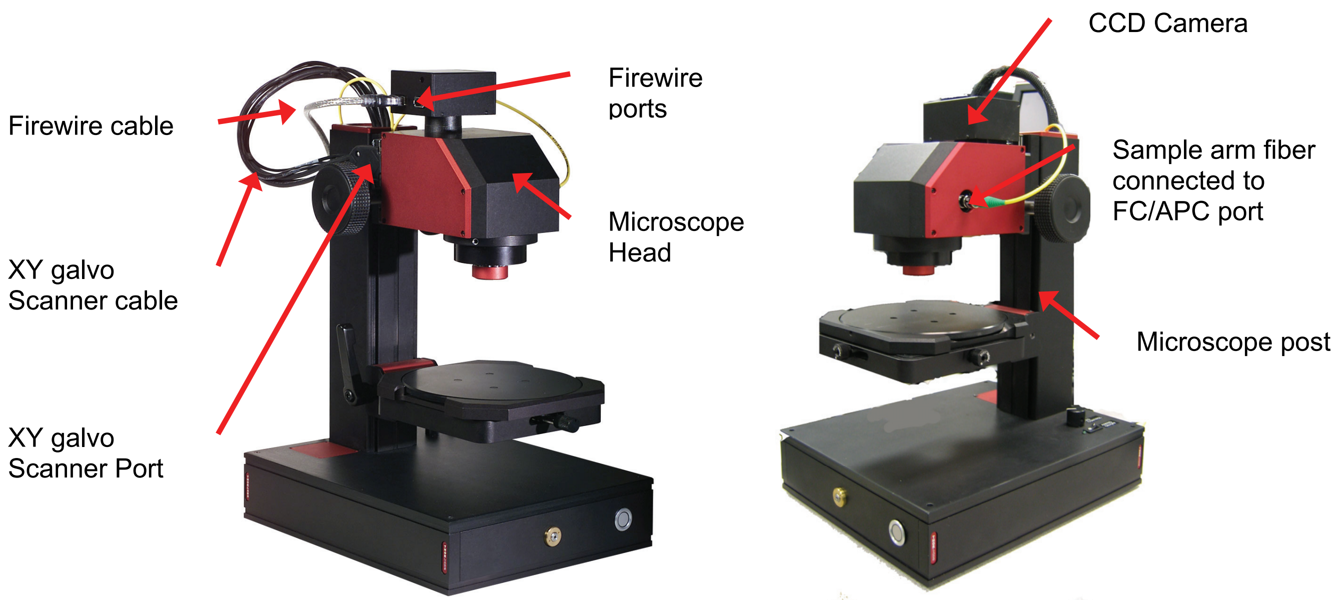


Figure 16: Microscope side views

For the following steps, please refer to Figure 16:

1. Take the Firewire cable connected to the back of the PC and insert it into the cable clips on the back of the microscope post. Connect the cable to either of the Firewire ports located on the CCD camera.
2. Take the XY Scanner cable (26-pin cable) coming out of the microscope post and connect it to the XY Scanner Port at the back of the microscope head. Be sure to fasten the screws into the D-SUB connector on the microscope head.
3. Remove the cap off the fiber connector coming out of the microscope post. Inspect the FC/APC connector with a fiber microscope to **make sure the fiber tip is clean**. Do not touch the fiber tip. After inspecting the fiber tip connect the fiber to the FC/APC port located on the microscope head.

Probe Connections (optional for the OCMP1300SS system)

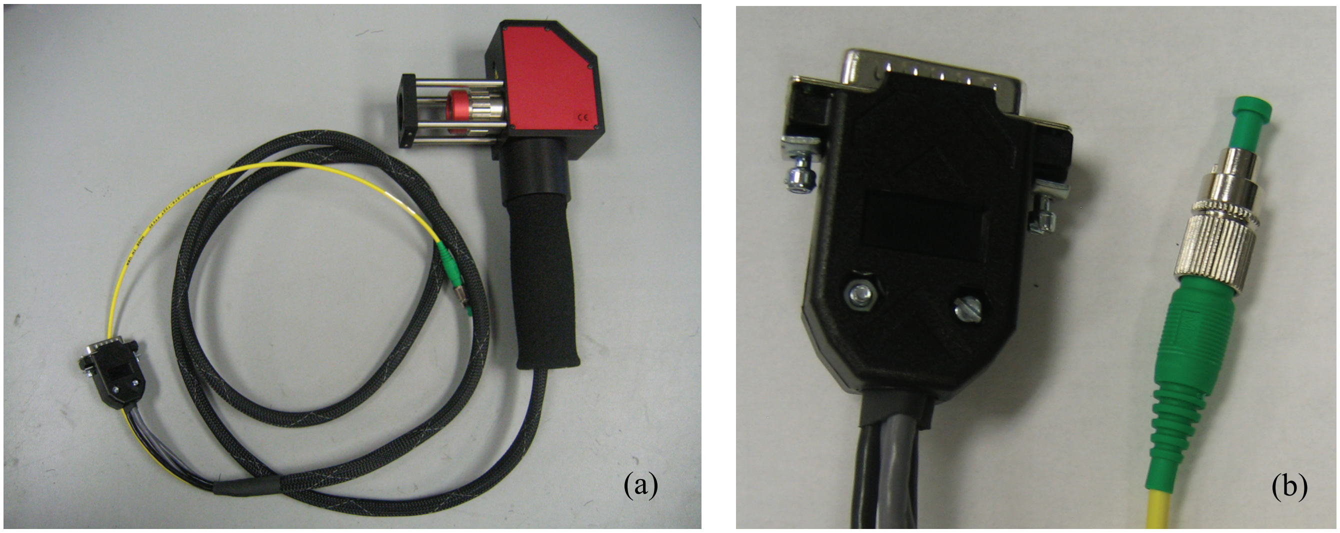


Figure 17: ***(a) Handheld Probe, (b) Probe connectors***

To use the Probe instead of the microscope follow the steps and refer to Figure 9 and 17:

1. Disconnect the SMA connectors "SCAN X", "SCAN Y" and "OCT SIG" connected at the microscope rear panel and connect them into the SCAN X, SCAN Y and OCT SIG ports located on the rear panel of the Swept Source Engine.
2. Take the 26-pin connector at the end of the Probe and connect it to the PROBE I/O port at the back of the Swept Source.
3. Disconnect and cap the fiber patch cord from the LASER APERTURE port on the Swept Source.
4. Remove the cap off the fiber connector at the end of the Probe. Inspect the FC/APC connector with a fiber microscope to **make sure the fiber tip is clean**. Do not touch the fiber tip. Insert the FC/APC connector of the Probe cable into the LASER APERTURE port.

2.5. Swept Source OCT System Cart (Optional)

Thorlabs offers an optional Swept Source OCT System Cart. This Cart allows you to place the Swept Source OCT System which includes the Microscope, the Computer and the Swept Source Engine, all in one spacious Cart that will make the system easy to move from one place to another. The Cart comes completely assembled for your convenience.

Note: The Cart (OCM-CART) is sold separately. Please contact our sales department to order.

Figure 18: ***SS-OCT Cart (OCM-CART, sold separately)***

Part 3. System Software

3.1. Starting the System

ATTENTION!

Check the supply voltage of the system BEFORE plugging in the CPU and Swept Source Engine. Set the line select switch on the CPU to the appropriate setting.

Make sure the power cords for Swept Source Engine, PC and monitor are connected to a properly grounded power outlet (100V – 240V AC; 50Hz – 60Hz).

Transportation and delivery may cause the Swept Source OCT system to be warm or cool upon receipt. Please wait for the system to reach room temperature before attempting to operate.

Use a flat, dry, and stable surface to set up the system.

System Components Start-up

Follow the steps for a proper initiation of the system:

1. Start the Swept Source laser by switching on the POWER to |, and check that the “POWER ON” indicator turns green.
2. Wait until the “SYS OK” indicator turns green, the “TEMP” indicator should turn off at that time.
3. Turn the OCT IR laser ON using the “LASER ENABLE” button.
4. Turn on the computer and monitor.
5. If required turn on the visible Aiming laser as follows:
    - For OCP and OCMP systems press the AIM ENABLE button on the front of the Swept Source Engine.
    - For OCM systems use the controls located at the Microscope base unit.

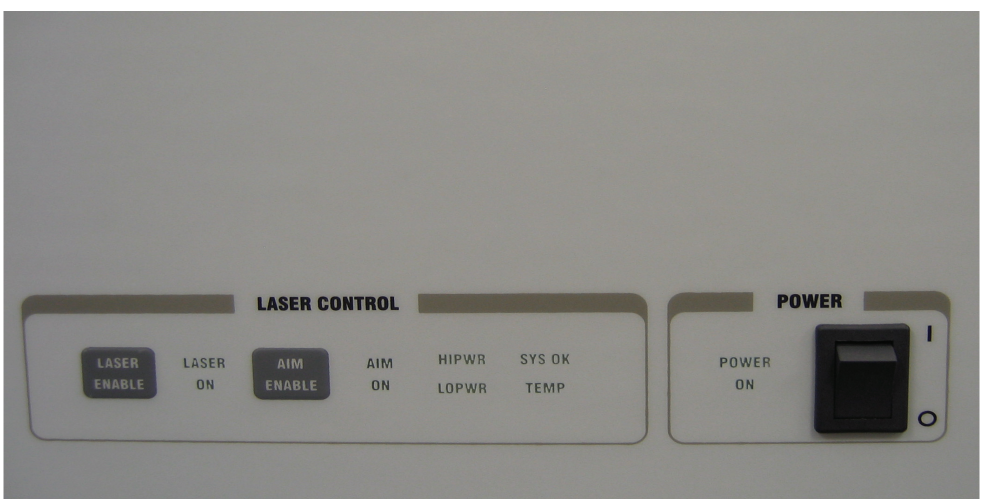


Figure 19: Swept Source front panel view

Software Start-up

Start the software by double clicking on the Desktop Icon **Thorlabs OCM** or use the following path, folder, and application program:

Start menu -> "All Programs" -> "Thorlabs OCM" to find the program shortcut to "Thorlabs OCM"

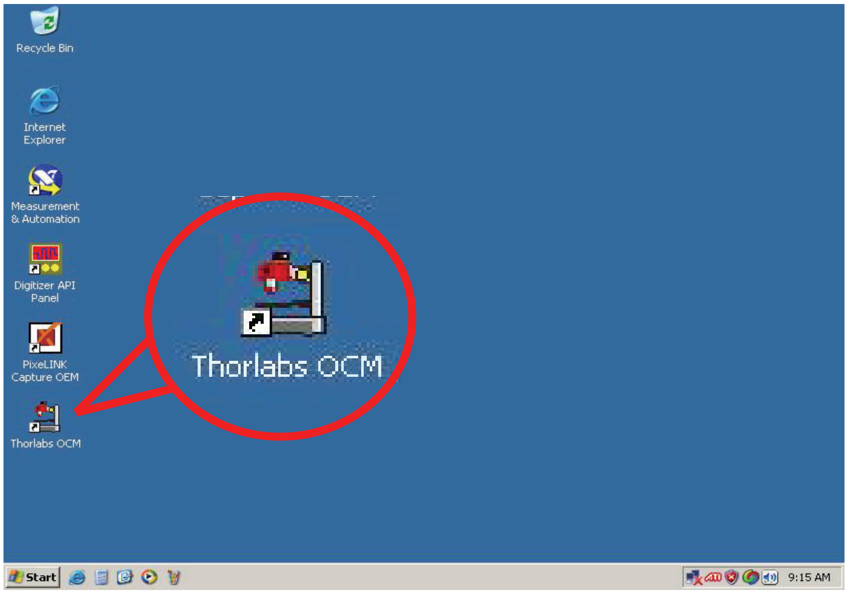


Figure 20: System Desktop

There are some other test programs on the windows desktop:

- The "Measurement & Automation" program: for the configuration and testing of the NI-67xx analog output card.
- The "Digitizer API Panel": test program for the high-speed digitizer card.
- The "Pixelink Capture OEM": test program for the CCD camera.

After starting the Thorlabs OCM program, the software shows the system initialization window:

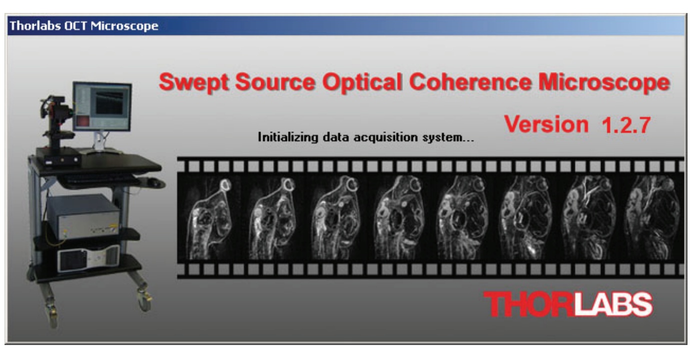


Figure 21: Software initialization window.

3.2. *Thorlabs OCM program*

Main Software Interface

The software interface can be divided into five major regions: (see screen capture below):

1. Across the top is the Menu bar
2. Below the Menu bar is the Tool bar, with icons that allow easy access to different functions.
3. The middle region is the primary image window which displays the different visualization modes.
4. The bottom left corner displays the secondary image.
5. The bottom right corner is the OCT control panel, containing tabs for the different modes of operation (1D, 2D, 3D, Doppler and Replay) and also the DAQ set up tab.

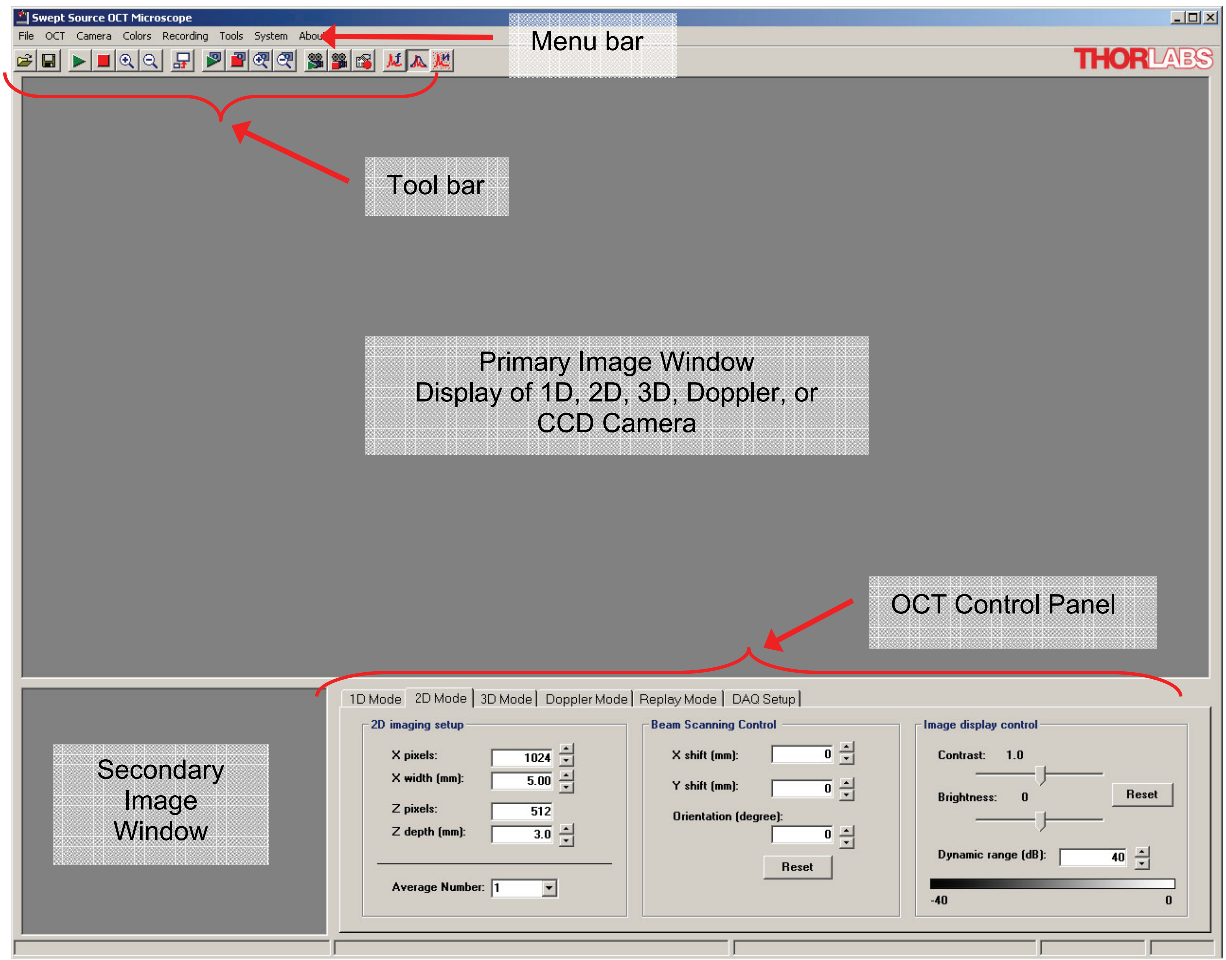


Figure 22: Main Software Screen

Menu Bar

Figure 23: Screen shot of the Menu bar

The “File” menu group provides file operation functions:

- “Open”: Open a previously saved OCT data file for review or replay.
- “Save”: Save the current image window onto disk.
- “Export 3D Data”: Export a 3D data set into multiple image files.
- “Export A-Line Data”: Export one line of A-Line data into txt files.
- “Close”: Quit current program.

The “OCT” menu group provides control of the OCT channel:

- “Play OCT”: Start acquiring and displaying OCT images.
- “Stop OCT”: Stop acquiring OCT images.
- “Fit Screen”: Fit the OCT image to the primary display window.
- “Fit Original”: Fit the OCT image to the original size.

The “Camera” menu group provides control of the CCD camera:

- “Play Camera”: Start acquiring and displaying CCD images. It also displays the CCD camera control panel.
- “Stop Camera”: Stop acquiring CCD images.
- “Camera Zoom In”: Zoom in the CCD camera.
- “Camera Zoom Out”: Zoom out the CCD camera.

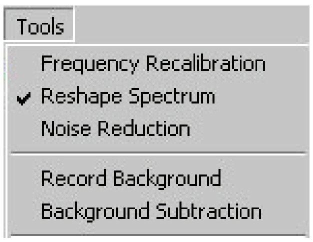
The “Color” menu group provides color control of OCT images:

- “Gray Scale”: Display the OCT images in gray scale.
- “Colorize”: Display the OCT images in preset color map.
- “Positive Color”: Display the OCT images in positive color.
- “Negative Color”: Display the OCT images in negative color.

The “Recording” menu group provides data recording functions:

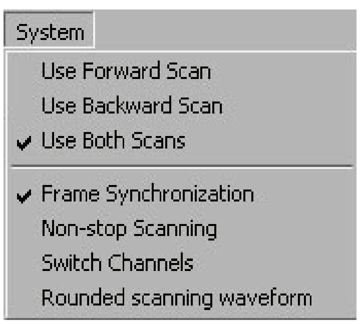
- “Setup”: Setup data file recording options (format and filename).
- “Start”: Start recording data file.
- “Stop”: Stop recording data file.

The “Tools” menu group provides image-processing tools:



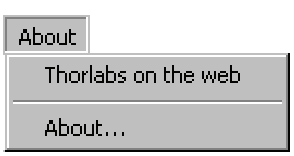
- “Frequency Recalibration”: Rebuild the laser frequency clock table.
- “Reshape Spectrum”: Enable/disable the Gaussian spectral window.
- “Noise Reduction”: Enable/disable the vertical noise reduction feature.
- “Record Background”: Stores values for background noise when no sample is in the beam path
- “Background Subtraction”: Subtracts out the recorded background noise from the image for a clearer cross-section.

The “System” menu group provides system functions:



- “Use Forward Scan”: Construct OCT images only from the forward laser scans. 2D and 3D only.
- “Use Backward Scan”: Construct OCT images only from the backward laser scans. 2D and 3D only.
- “Use Both Scans”: Construct OCT images from both the forward and backward laser scans. 2D and 3D only.
- “Frame Synchronization”: Enable/disable the synchronization between transverse scan (B-Scan) and axial A scan (A-Scan).
- “Non-stop Scanning”: Enables non-stop scanning in 3D mode.
- “Switch Channels”: Switch the OCT and CCD imaging channels between the primary and secondary image windows.
- “Rounded Scanning Waveform”: Changes the scanning waveform from sawtooth to sinusoid.

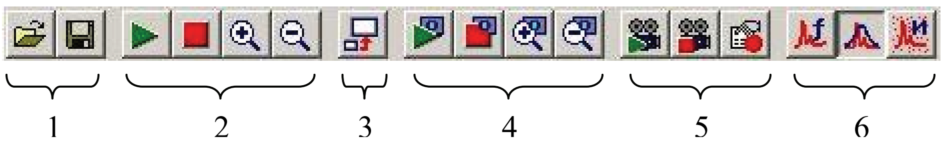
The “About” menu group provide the information about the software.



- “Thorlabs on the web”: Visit the Thorlabs website for information about new products and services.
- “About”: Software version and copyright information.

Tool Bar

The software tool bar is divided into six groups:



Group 1 is the “file operations” group and has two buttons:

- The “Open Files” button opens any image data file saved by this software for display.
- The “Save Files” button saves the current image being displayed into a disk file with standard picture file formats of “*.bmp” or “*.jpg”.

Group 2 is the “OCT imaging channel control” group and has four buttons:

- The “Play OCT” button starts acquiring OCT data (continously for 1D, 2D, and doppler modes).
- The “Stop OCT” button stops acquiring and displaying the OCT images.
- The “Zoom In OCT” button resizes the OCT image size to fit into the primary image window. Note this button has no effect when OCT images are displayed in the secondary image window.
- The “Zoom Out OCT” button resizes the OCT image to its original size. The width of the image is the number of A-lines per frame and image height is always 512.

Group 3 has only one button, “Switch Channels,” that switches the OCT and CCD imaging channels between the primary and secondary image windows.

Group 4 is the “CCD imaging channel control” group and has four buttons:

- The “Play CCD” button starts acquiring and displaying CCD (En-face view) images of the sample in either the primary or secondary image window. Pressing this button at any time will bring up the camera control panel.
- The “Stop CCD” button stops acquiring and displaying the CCD images.
- The “Zoom In CCD” button uses a digital zoom function of the CCD camera to zoom into more detailed view (smaller view area) of the sample.
- The “Zoom Out CCD” button uses a digital zoom function of the CCD camera to zoom into less detailed view (larger view area) of the sample.

Group 5 is the “Data recording” group and has three buttons.

- The “Start recording” button toggles the data-recording mode. If there is image data being acquired and displayed, the software starts recording data immediately (using default recording option or using options as specified in the “Recording setup” dialog). If there is no image data being acquired and displayed, the software starts recording data right after the user initiates image data acquisition by clicking “Play OCT” or “Play CCD” buttons.

- The "Stop recording" button stops the data-recording mode and any data recording operations that are in progress.
- The "Recording Options" button allows the user to choose different recording modes from the "Data recording options" dialog.

Group 6 is the "Image tools" group and has three buttons.

- The "Frequency Recalibration" button refreshes the "Time to frequency look-up table" of the system. This table is used for recalibrating the OCT interference fringe signals from time to optical frequency space that is usually a nonlinear conversion. This operation needs to be done only when severe degradation in image resolution is observed.
- The "Spectrum Reshaping" button applies a windowed Gaussian function to the raw interference signals to reshape the laser output spectrum. This function can suppress unwanted side-lobes in the OCT point spread functions and sometimes makes the images cleaner or sharper.
- The "Noise Reduction" button applies some noise reduction algorithms to remove the noisy vertical streaks from the images. Enabling this function sometimes improves images quality or makes the images easier to view.

OCT Control Panel

The OCT imaging channel can be controlled through the OCT control panel and has three modes of operation. The panel is located below the primary image window and can be adjusted in real-time to find out how OCT images are affected by different settings.

1D Mode

1D mode is the point spread function measurement mode of the system. The probing laser beam is parked at one spot on the sample and the depth profile of the location can be calculated and displayed. To run the system in 1D mode, click the "1D Mode" tab and then click "Play OCT" button from the tool bar.

The 1D mode is also important for the initialization of the system as well as optimization of the performance, since it provides a tool for directly monitoring the raw fringe signals from the OCT interferometer and frequency clock.

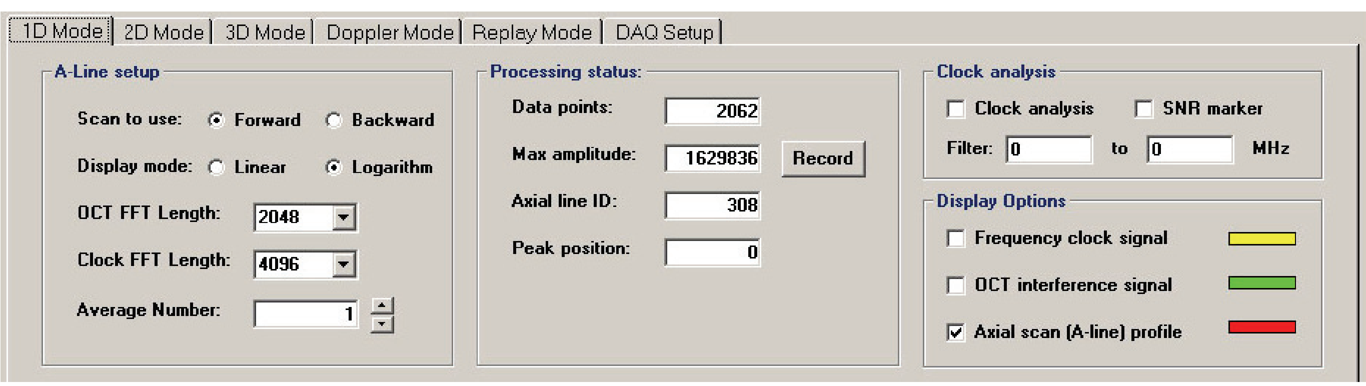


Figure 24: Screenshot of 1D Mode tab

The “**A-line set up**” group contains different settings for obtaining the 1D data information.

- “Scan to use”: select either the forward or backward laser scan to be display and analyzed. 1D mode only.
- “Display mode”: select the data to be displayed in either linear or logarithmic scale.
- “OCT FFT Length”: select 1024 or 2048 length. Standard OCT FFT length is 1024 points.
- “Clock FFT Length”: select from 1024 to 8192. Standard Clock FFT length is 4096 points.
- “Average Number”: Sets the number of averages performed, to smooth out the data being displayed. This will factor into the framerate of the system as well.

The “**Processing status**” group contains text boxes showing the processing status of the current A-line.

- “Data points”: displays the number of data points extracted from the clock signal at pass-zero points.
- “Max amplitude”: displays the maximum amplitude signal after the Fourier transform of the recalibrated interference fringes. After the user clicks the “record” button beside the text box, the software records the maximum amplitude value and uses it as the reference value for 0 dB. The peak of the PSF is then shifted to 0dB on the display as well.
- “Axial line ID”: the number of A-lines acquired and processed by the software since the last start.
- “Peak position”: the position of the peak value of one A-line, between 1 and 1024.

The “**Clock analysis**” group allows the user to view the frequency clock signal from the laser and define some parameters for processing the clock signal.

- “Clock analysis” checkbox: Checking this box enters the clock analysis mode. Detailed information about this mode can be found in section 3.3, OCT Imaging.
- “SNR marker” checkbox: Checking this box will show the SNR level cursor (orange horizontal line) on the clock analysis mode display
- “Filter”: Display the values of high and low pass band of the software bandpass filter used in clock signal analysis

The “**Display options**” group allows the user to choose different signal traces to view. The signals that can be displayed include:

- “Frequency clock signal” (time domain): This is the signal from the Mach-Zehnder interferometer inside the laser.
- “OCT interference signal” (time domain): This is the raw signal from the OCT interferometer.
- “Axial scan (A-line) profile” (frequency domain): This signal is the depth profile of the sample from one laser scan. The signal is calculated after the Fourier transform of the frequency calibrated OCT fringe signals.

2D Mode

2D mode is the imaging mode for OCT that acquires and displays cross-sectional 2D images. To run the system in 2D mode, click the “2D Mode” tab and then click “Play OCT” button from the tool bar.

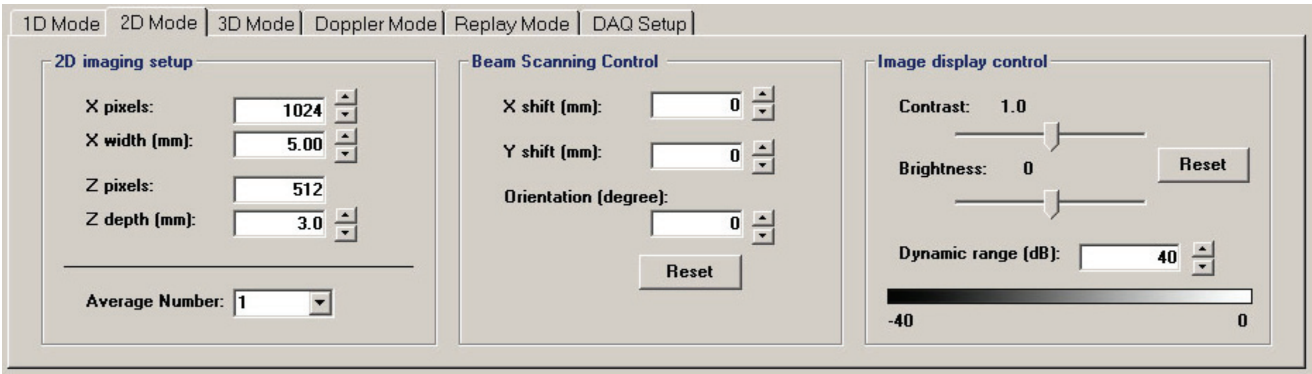


Figure 25: ***Screenshot of 2D Mode tab***

The “**2D imaging setup**” group controls the width, depth and number of pixels of the image.

- “X pixels”: The number of pixels/data points in transverse (X) direction is the same as the number of A-lines for every frame of OCT image. This parameter is adjustable through the up/down buttons beside the text box, from 64 to 4096 with a step size of 32.
- “X width (mm)”: The physical distance of the beam scan across the sample surface at the focusing plane of the objective. It is the width of the sample to be imaged. This parameter is adjustable from 0 to 10 mm with a step size of 0.05 mm.
- “Z pixels”: The number of pixels/data points in depth (Z) direction for every OCT image. This parameter is fixed to be 512 because of the fixed Fourier transform window size of 1024.
- “Z depth (mm)”: The depth (in air) of the sample to be imaged. This parameter is adjustable from 3.0 to 0.1 with a step size of 0.1 mm.
- “Average Number”: Sets the number of averages performed, to smooth out the data being displayed. This will factor into the X pixels and framerate of the system as well.

The “**Beam Scanning Control**” group controls the shift and orientation of the beam.

- “X shift (mm)”: The shift of the scanning center position in X direction. This parameter is adjustable from –10 to 10 mm with a step size of 0.1 mm.
- “Y shift (mm)”: The shift of the scanning center position in Y direction. This parameter is adjustable from –10 to 10 mm with a step size of 0.1 mm.
- “Orientation (degree)”: The angle of the beam scanning trace that can be rotated about its center axis. This parameter is adjustable from 0 to 180 degrees with a step size of 3 degrees.
- The “Reset” button brings all beam scanning control values to zero.

The “**Image display control**” group contains a number of controls for the user to change and adjust the image display properties.

- “Contrast”: The control for adjusting the contrast value of the OCT images being displayed.
- “Brightness”: The control for adjusting the brightness of the OCT images being displayed.
- “Reset”: This button returns the contrast and brightness to the default values.
- “Dynamic range”: The dynamic range of the OCT signal in logarithmic scale is displayed. The 0 dB reference is the maximum amplitude recorded in PSF mode. This parameter has a default value of 55 dB and can be adjustable from 30 to 66 dB with a step size of 1 dB. A gradient/color map showing the gradient/color coding of the images is provided under this control.

3D Mode

In 3D mode, the software controls the XY scanning mirrors to scan the laser beam across an area of the sample surface. With the depth ranging capability inherent to the OCT axial scan, the software records a data set that contains three-dimensional structural information of the sample, and displays the 3D data as multiple 2D image slices from any planes along the X, Y, or Z-axis.

To run the system in 3D mode, click the "3D Mode" tab and then click "Play OCT" button from the tool bar.

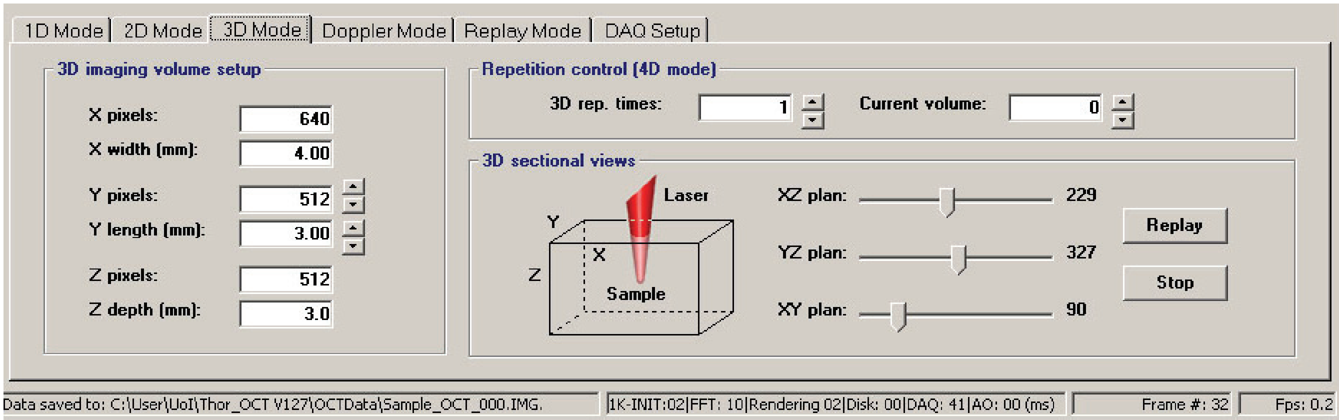


Figure 26: Screenshot of 3D Mode tab

The "**3D imaging volume setup**" group allows the user to setup the parameters that define the 3D volume to be imaged.

- "X pixels": The number of pixels/data points in transverse (X) direction of the imaging volume. This parameter is the number of A-lines per frame. It cannot be adjusted in 3D mode but is always the same as defined in 2D mode.
- "X width (mm)": The beam scanning width in the X direction of the imaging volume. The parameter cannot be adjusted in 3D mode but is always the same as defined in 2D mode.
- "Y pixels": The number of pixels/data points in length (Y) direction. In 3D mode, this parameter specifies number of cross-sectional OCT images (XZ plane) to be acquired. This parameter is adjustable from 16 to 640.
- "Y length (mm)": The beam scanning length in Y direction of the imaging volume. This parameter is adjustable from 0 to 10 mm with a step size of 0.05 mm
- "Z pixels": The number of pixels/data points in depth (Z) direction for every OCT image. This parameter is the same as used in 2D mode.
- "Z depth (mm)": The depth (in air) of the sample to be imaged. This parameter is the same as used in 2D mode.

The "**Repetition control (4D mode)**" group provides the function of multiple 3D scans of the same sample area using time as another dimension.

- "3D rep. times": The number of 3D scans to perform. The software will repeat the 3D scan at full speed for the given times.
- "Current volume": The number of 3D scans that has been finished.

The "**3D sectional views**" group provides controls to display the recorded 3D OCT data set from different viewing planes.

- "XZ plan": The slider control to display the XZ sectional slices of the 3D data at different Y locations.
- "YZ plan": The slider control to display the YZ sectional slices of the 3D data at different X locations.
- "XY plan": The slider control to display the XY sectional slices of the 3D data at different Z locations.
- "Replay" button: Plays the slides like a movie, relative to the last plane selected.
- " Stop" button: Stops the replay.

Doppler Mode

Doppler OCT velocimetry is a noninvasive technique that includes flow velocity measurements in the sample. The Doppler mode can measure the velocity of particles at the same time it creates standard OCT images of the sample.

To run the system in Doppler mode, click the "Doppler Mode" tab and then click "Play OCT" button from the tool bar.

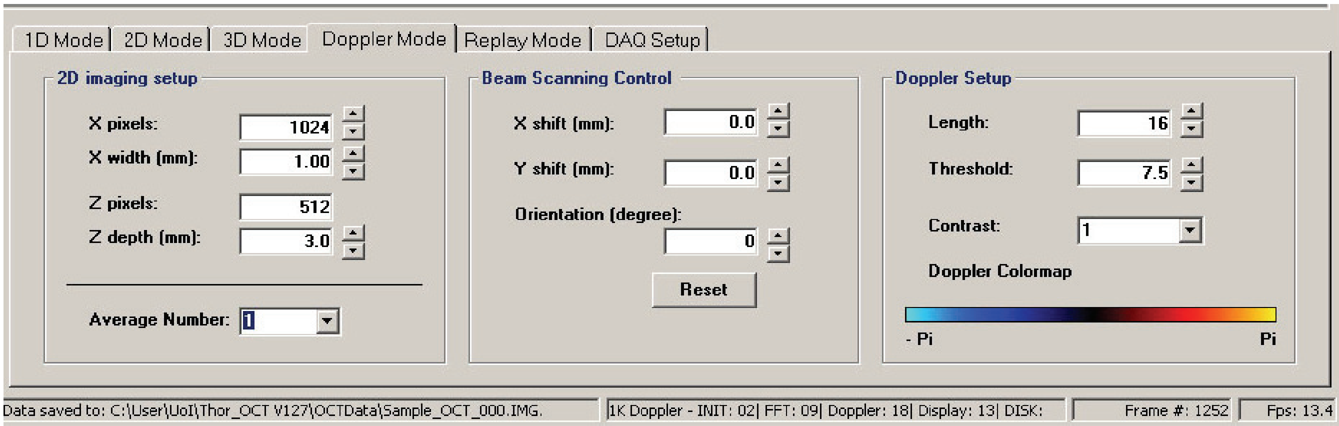


Figure 27: Screenshot of Doppler Mode tab

The "2D Imaging Setup" and the "Beam Scanning Control" group of the Doppler Mode tab are exactly the same as the ones included in the 2D Mode tab. Additionally, the Doppler Mode tab contains the "Doppler Setup" group. This group allows the user to setup the parameters that control the Doppler image.

Replay Mode

In Replay mode, the user can view and export the data already acquired by the system.
To run the system in Replay mode, click the "Replay Mode" tab and then click "Play OCT" button from the tool bar.

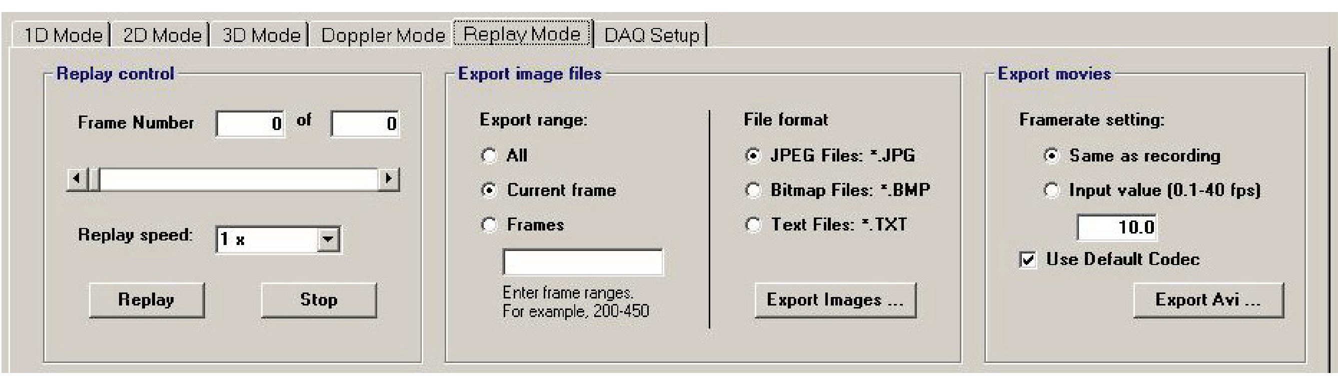


Figure 28: Screenshot of Replay Mode tab

The "**Replay Control**" group allows the customer to display the recorded images.

- "Frame number": The total number of frames in the movie file and the frame number being displayed.
- "Replay Speed": The speed of the movie file being replayed.
- "Replay" button: Replay the movie file that has been loaded.
- "Stop" button: Stop the playing of movie file.

The “**Export Image files**” group provides the ability to export selected frames to disk image files with different file format.

- “Export Range”: The range of the image frames in the movie file to be exported.
- “File Format”: The file format of the image frames to be saved into disk files.
- “Export Images” button: This button opens a file saving dialog to let the user select the disk path of the image files to be saved to.

The “**Export Movies**” group provides the ability to export a movie.

- “Framerate setting”: Choose either to match the framerate of the recorded images, or specify a custom value.
- “Use default codec” checkbox: Use the default video compressor setting to compress the *.avi file which has optimal video quality and file size.
- “Export Avi” button: This button opens a file saving dialog to let the user select the disk path of the *.avi files to be saved to.

DAQ Setup Tab

To run the system in Replay mode, click the “Replay Mode” tab and then click “Play OCT” button from the tool bar.

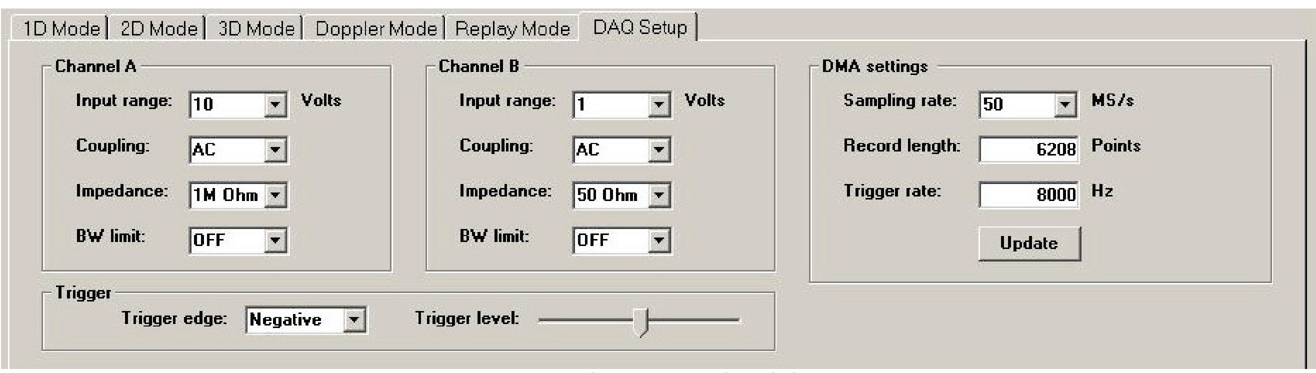


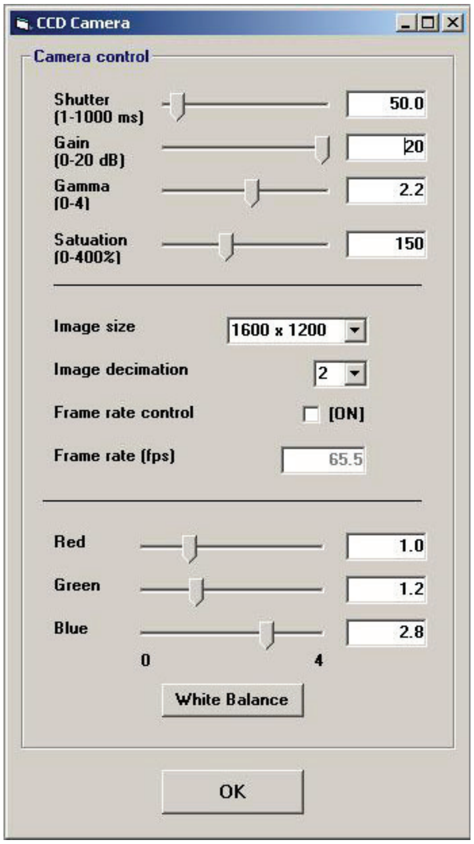
Figure 29: Screenshot of DAQ Setup tab

The “Channel A”, “Channel B” and DMA groups provide settings for the digitizer.

NOTE: These settings should not be altered for typical operation.

Camera control panel

The “CCD Camera” control panel has all the controls required for controlling the parameters of the CCD camera. This window appears by clicking



- “Shutter”: The shutter value controls the exposure time of the sensor. The shutter can be controlled manually from 1 to 1000 ms. When the “Frame rate control” is active (ON), the Shutter control is limited by the Frame Rate control setting. For example, if the Frame Rate control is set to 50 fps, the maximum value of the Shutter control will be limited to 20ms. For unlimited control of the Shutter feature, the “Frame rate control” must be turned off.
- “Gain”: The gain value controls the amplification of the image for the camera, and can be adjusted from 0 to 20 dB. Increasing gain will increase the image intensity but will also increase the noise in the image. The lowest Gain setting will produce the highest quality image.
- “Gamma”: The gamma value controls the contrast in the image by translating pixel values according to a logarithmic curve. A value of one is a linear translation. Higher or lower values of gamma will result in missing codes in the image histogram.
- “Saturation”: The saturation value controls the intensity of the hues in the image. The saturation control allows the hue to be changed from full mono to more than twice the normal
- “Image size”: The image size value controls the actual area size in the sensor to be displayed in the software window. It is used as the software zoom function of the software and has seven values from 1600 × 1200 to 320 × 240. Choosing a smaller value will have a small imaging area fill the whole display window in the software.
- “Image decimation”: The image decimation value controls the pixel-addressing option used by the camera. If the decimation value is 1, all pixels in the camera region-of-interest (ROI) will be returned. If the decimation value is 2, the camera read out every two pixels and skips the following two pixels. The pixel-addressing mode reduces the number of pixels to be transferred and processed during imaging mode and lowers the load on the CPU.

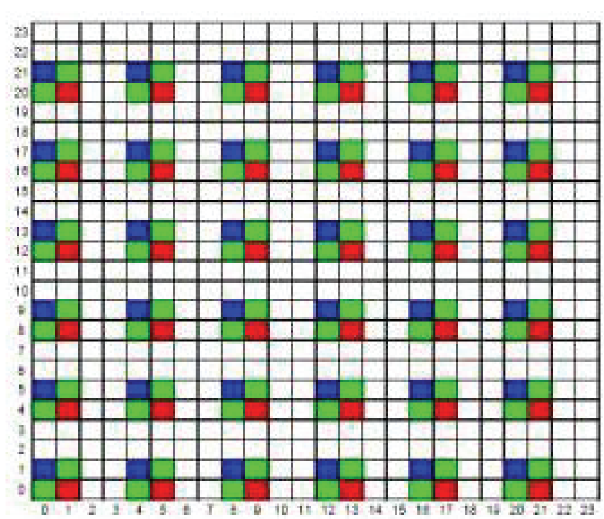


Figure 30: Pixel decimation value of 2

- "Frame rate": The frame interval and the required bandwidth on the FireWire bus are fixed by the Frame Rate value. The available frame rate range depends on the current video format, ROI value and video mode.
- When the Frame Rate feature is ON, the exposure time (Shutter) is limited by the frame rate value dynamically. When the Frame Rate value is changed, the minimum and maximum limits on the Shutter control will change accordingly. The Shutter value will be forced to lie within these limits.
- After a change to ROI, video format or video mode, the Frame Rate control will attempt to maintain the same frame rate. If this is not possible, the Frame Rate control will be turned OFF.
- When the Frame Rate control is OFF, the frame rate value defaults to the maximum isochronous frame rate. The frame rate is then a function of the exposure time for exposures longer than the inverse of the frame rate value. For shorter exposure times, the frame rate will be constant.
- "Red/Green/Blue": The red/green/blue values define the gain values for the corresponding color channels.
- "White balance": White Balance defines the color temperature of the light source. The camera uses this information to select form one of a number of possible color correction matrices. Turning the White Balance off disables the color correction. The camera has color correction settings for 3200ºK (incandescent), 5000ºK (daylight 1) and 6500ºK (daylight 2).

3.3. *OCT Imaging*

1D Mode

To run the software in 1D measurement mode, follow the steps below. If the software is running for the first time after the installation, or if any hardware changes have been made to the system, the software needs to be initialized, please start from step 1. For the routine daily use of the software, the software does not need to be initialized every time, and the user can start directly from step 3.

Step 1: Enter the "Clock analysis" mode

- Choose the "1D" tab in the OCT control panel
- Check the "Clock analysis" checkbox in the "Clock analysis" group.
- Click "Play OCT" from the tool bar

The software screen capture is like below.

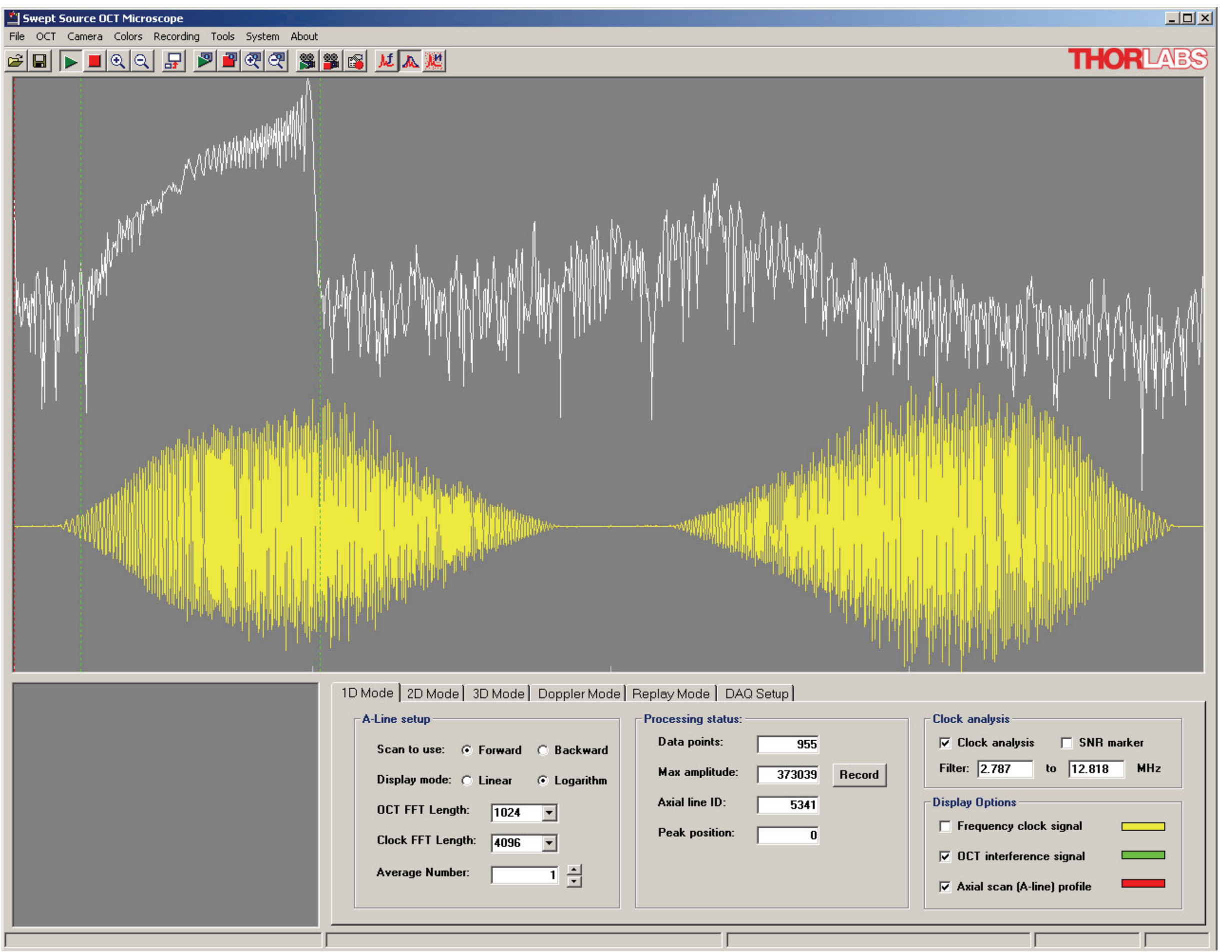


Figure 31: Screenshot of clock analysis mode

In the primary OCT window there are two color traces.

- The yellow trace is the frequency clock signal (time domain) from the laser. There are two major envelopes that correspond to the forward and backward scans of the laser. Selecting the "trigger edge" options in the "DAQ setup" group changes the order of the two scans in the trace.
- The white trace is the Fourier transformed electric spectrum of the clock signal (frequency domain). The horizontal frequency display range is from 0 to 50 MHz.

Step 2: Set the frequency window and time window of the clock signal.

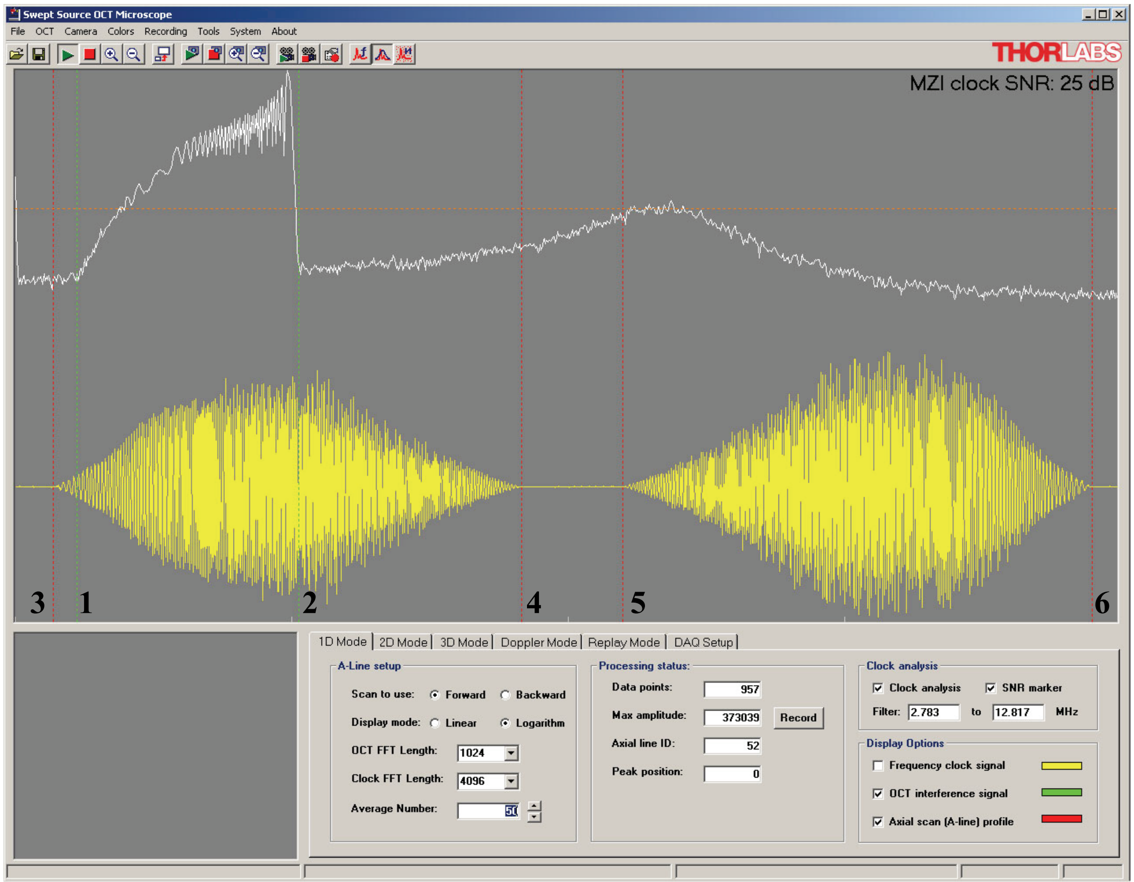


Figure 32: Screenshot of cursors positioning

- Increase the number of averages in the “A-line setup” group to smooth out the signal.
- Right click on the primary display window and the first cursor (green) will appear, attached to the mouse pointer.
- Situate the first cursor at the prominent rising edge of the white signal (1). This will set the lower value of the software bandpass filter. Left-click once to place the cursor. The next cursor (green) will automatically appear, attached to the mouse pointer.
- Situate the second cursor at the prominent falling edge of the white signal (2). This will set the upper value of the software bandpass filter. Left-click once to place the cursor. The next cursor (red) will automatically appear, attached to the mouse cursor.
- Situate the third cursor at the very beginning of the first scan of the clock signal (3). This, along with the next 3 cursors, will set the “on-time” that the software will use to ignore the “off-time” of the laser. Left-click to place the cursor. The next cursor will automatically appear, attached to the mouse pointer.
- Repeat the previous step to set the “on-time” of the yellow clock signal (4, 5, 6)

Step 3: Enter "1D mode"

Un-checking the "Clock analysis" checkbox brings the system to the interference signal point spread function analysis mode (1D mode).

Shown below is the system running in PSF mode. The green trace is the OCT interference fringe signal after frequency recalibration, displayed in linear scale. The red trace is the point-spread function of the sample depth profile after Fourier transform of the interference fringe signal. The depth profile is displayed in logarithmic scale with display range from 0 dB (top of the window) to -100 dB (bottom of the window) and -20 dB per division.

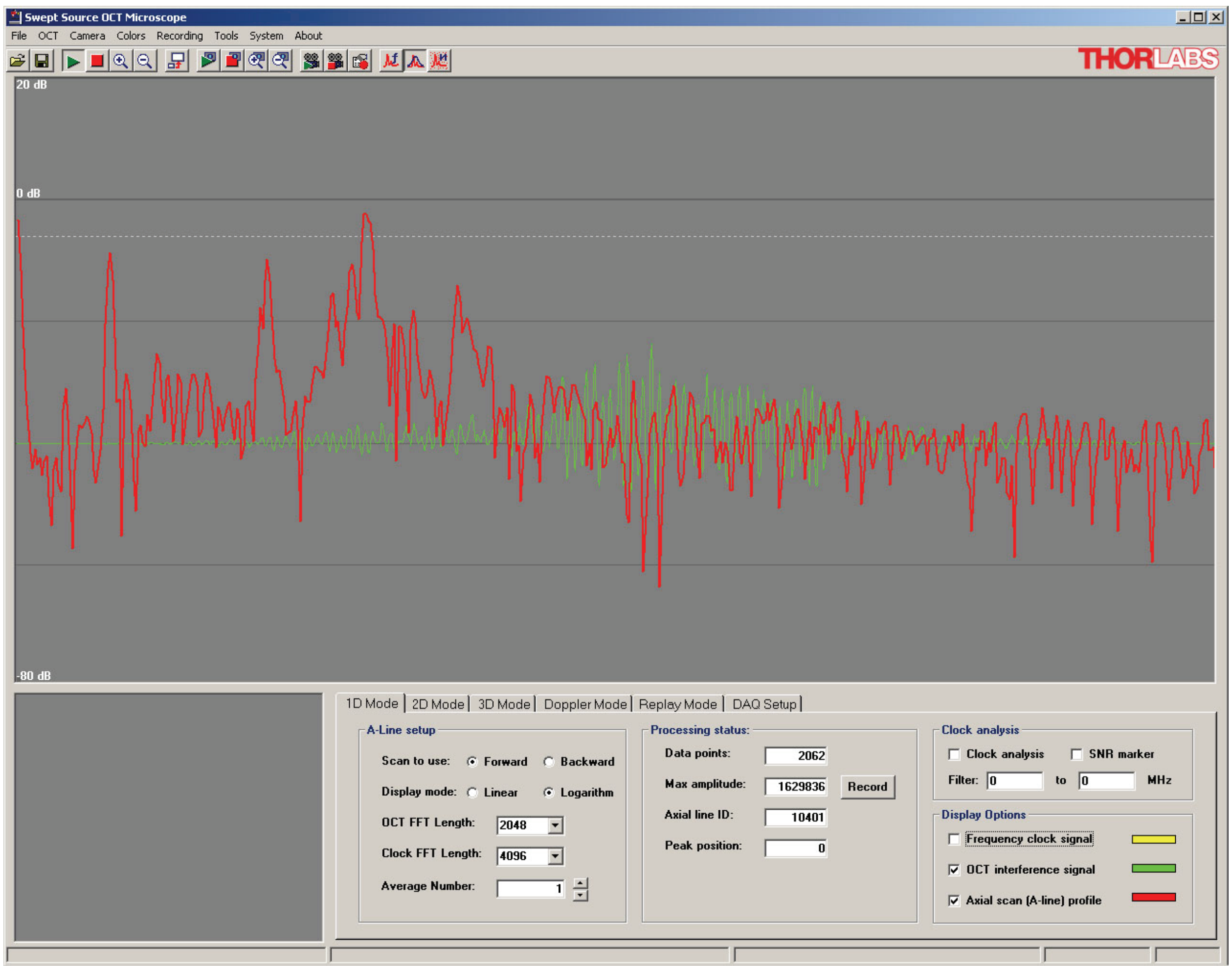


Figure 33: Screenshot of Axial scan and OCT interference signal

If the point spread function of the sample depth profile has data points larger than 0 dB, the user needs to click the "Record" button to record the new maximum signal amplitude for future reference.

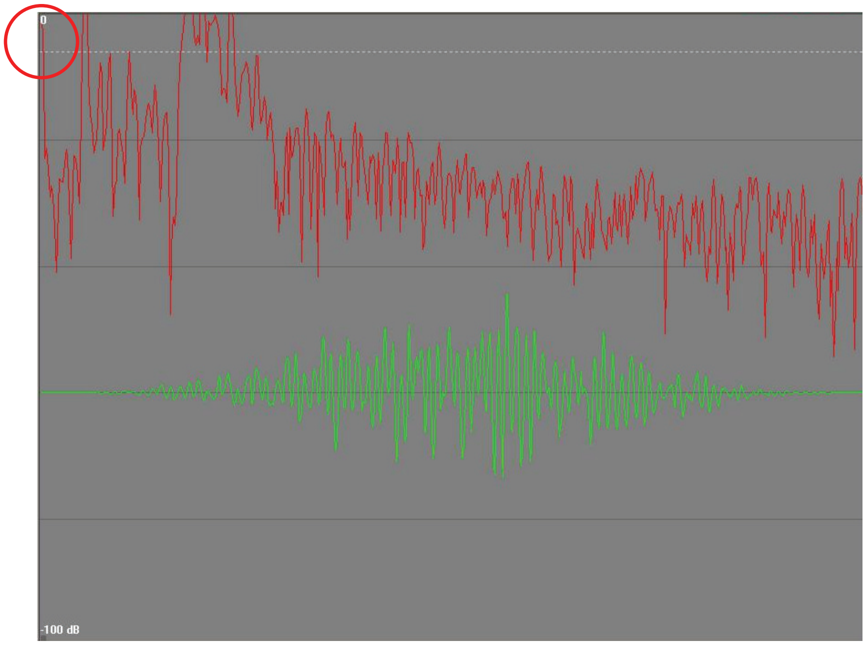


Figure 34: Inappropriate Maximum Amplitude

The "display mode" allows the PSF of sample depth profile to be displayed in logarithmic scale (-100 dB – 0 dB) or linear scale (0 - 1).

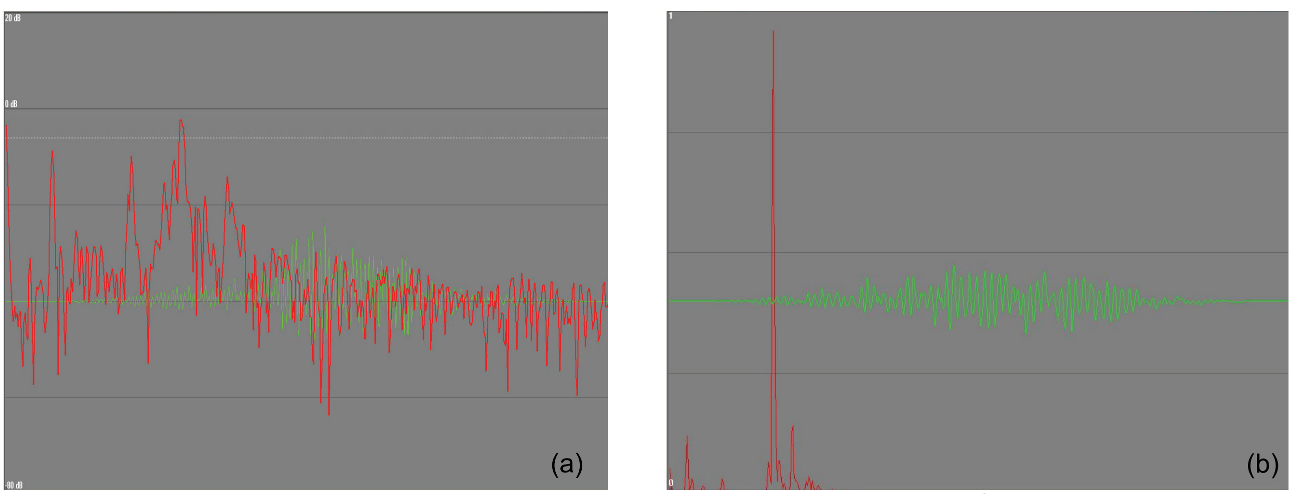
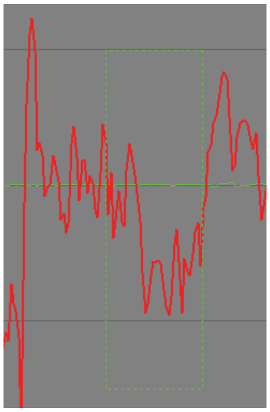


Figure 35: Display Modes. (a) Logarithmic scale (b) Linear Scale

Adjusting gain and dynamic range visually

If using the "Record" button to bring the signal peak to 0dB is not giving the best image quality, it is also possible to control the "gain" of the PSF and also the dynamic range of the system. There is added functionality given to the mouse cursor in 1D mode, and it is outlined below.



Anytime the mouse cursor is over the primary image window, it is possible to draw a box with two clicks – 1 left-click to start the box (at the upper left corner), and 1 more left-click to complete the box (at the lower right corner). This box has several properties associated with it:

- The horizontal position and length do NOT matter.
- The vertical *distance* will set the dynamic range.
- The first click (top left corner of the box) will always be adjusted to 0dB (similar to the record button, but the user chooses the "peak").

For example, we'll look at the following three screenshots. Figure 36 shows the image window before any clicks. The goal here is to move the PSF up towards 0dB so that there is about 40dB signal-to-noise. This is estimated by the noise floor, then the first click to draw the box should be about 40dB above this noise floor. Figure 37 shows one left-click to begin the box at the top left, then the screenshot was taken after the mouse was moved down and to the right. The vertical distance of this box (estimated to be 50dB) will be the dynamic range. Figure 38 is the result after the second left-click of the mouse to place the lower right corner of the box. The PSF is shifted to 0dB from where the box was started.

This procedure can be followed to lower the gain in 1D mode as well, by starting the box above 0dB. The dynamic range is also adjustable in 2D mode during imaging.

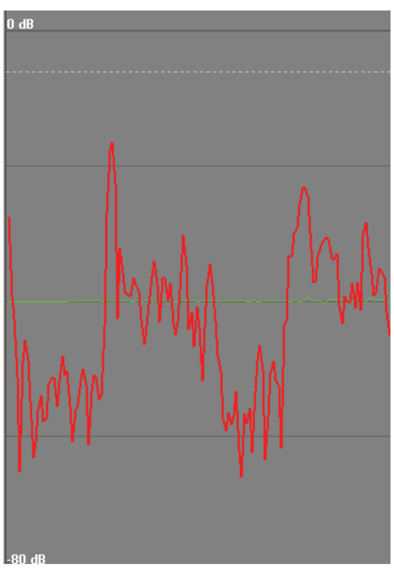


Figure 36

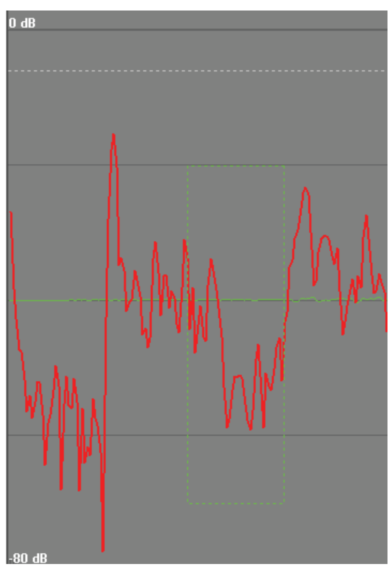


Figure 37

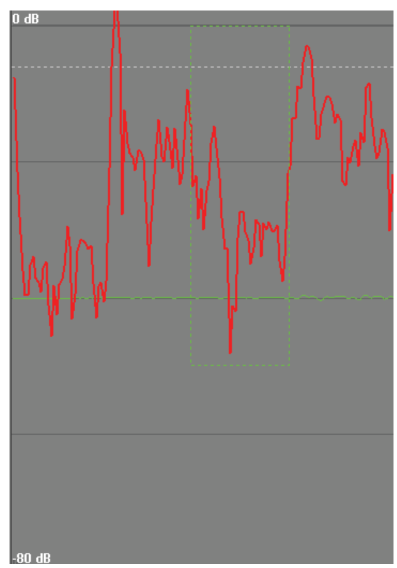


Figure 38

2D Measurement Mode

2D mode of the system is the OCT imaging mode where the software acquires and displays the image data in real-time. 2D mode is the default mode of the software. Clicking the "Play OCT" button runs the system in this mode. If the software is running for the first time after a new installation or changes have been made to system configurations since last run of the software, it is recommended that the user run the system in PSF mode first to make sure the DAQ and clock settings are correct. Below is the software screen shot of the system imaging an infrared senor card (Thorlabs IRC3). Cross-sectional structural information of card can be displayed.

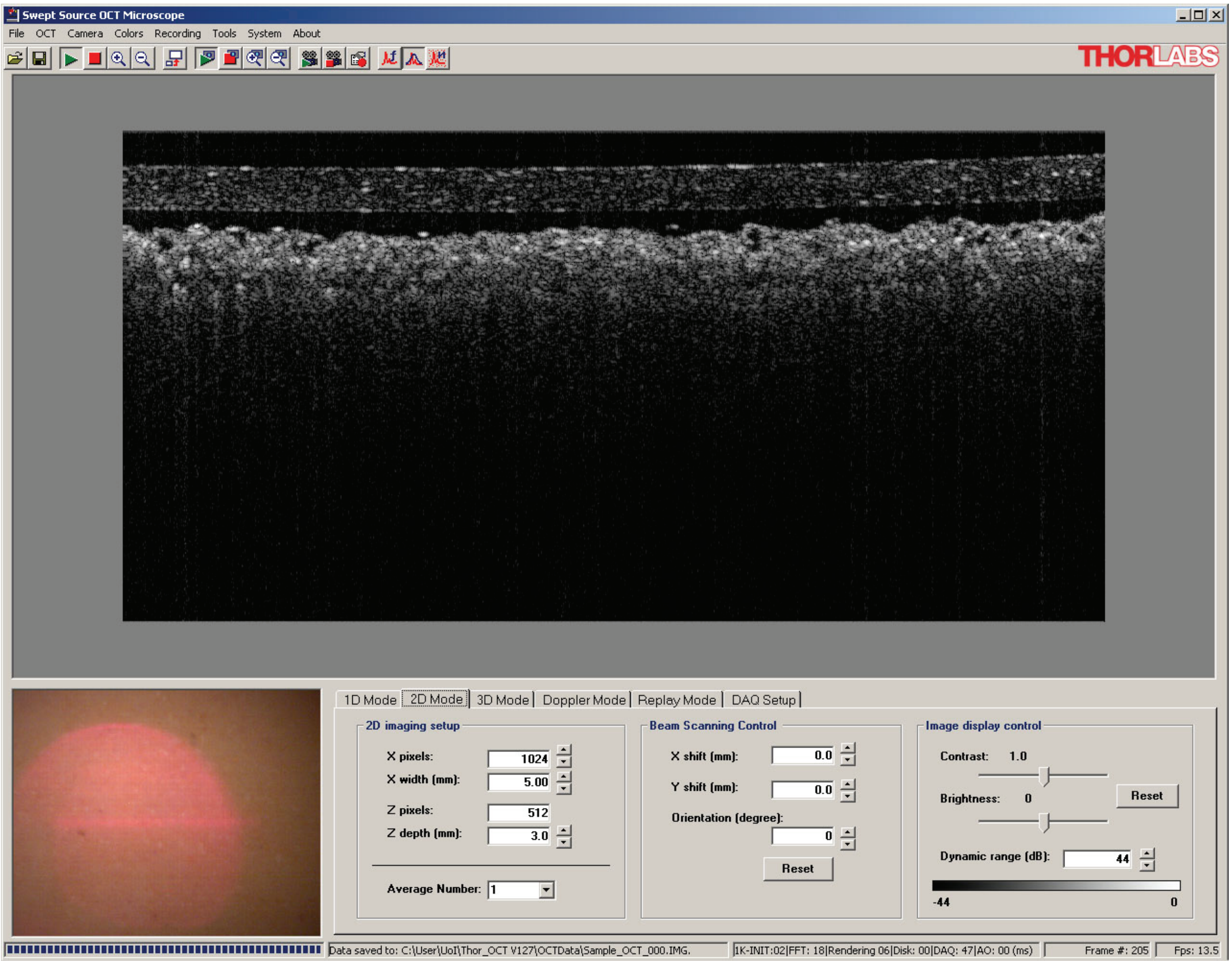


Figure 39: Screenshot of the 2D mode image display

By default, the OCT image size is 1024 (W) × 512 (H) pixels, which means there are 1024 OCT A-lines per frame. The number of A-lines per frame can be adjusted by the "X pixels" value. Since the laser sweeping speed is fixed at about 16 kHz, changing of the X pixels value also changes the actual frame rate of the system, which is displayed in the "frame rate" text box on the very bottom right of the window.

The "2D imaging setup" control group allows the user to change the imaging area and adjust the image size in real time. For detailed explanation of the parameters, please refer to 4.5.2 "2D imaging setup".

The "Image display control" control group allows the user to adjust the contrast and brightness properties, as well as the dynamic range, of the images being displayed. For detailed explanation of the parameters, please refer to 4.5.2 "Image display control".

Reference Delay Adjustment

The reference delay adjustment gives the user access to the reference arm path length. In the microscope base there is a translation stage with the reference mirror mounted on it which can be moved with the adjuster on the front panel. For the handheld, the reference arm mirror is in the laser enclosure, and there is a micrometer on the rear panel to adjust this delay.

If the image appears fuzzy or out-of-focus, the reference delay might need to be adjusted. In order to do this, refer to the following steps:

- Set up 2D imaging.
- Move the sample into a position where the image looks the sharpest, regardless of its position on the screen (either move the sample, or translate the microscope head). This is the optical focus of the objective.
- Adjust the reference delay to move the picture to the optimum viewing location.
- Repeat until image quality is maximized.

3D Measurement Mode

In "3D Mode" of the system, the software controls the beam to scan across a 2D sample surface using the XY galvanometers inside the microscope head. With the depth ranging capability provided by OCT, the software acquires a data set that contains the 3D structure information of the sample near its surface. In this mode, the software acquires multiple adjacent 2D OCT frames in XZ plane and forms a stack of images in Y direction as a 3D data set.

To run the system in this 3D imaging mode, the user need to click on the "3D Mode" tab of the OCT control panel, and then adjust the parameters that define the beam scanning area, and click the "Play OCT" button.

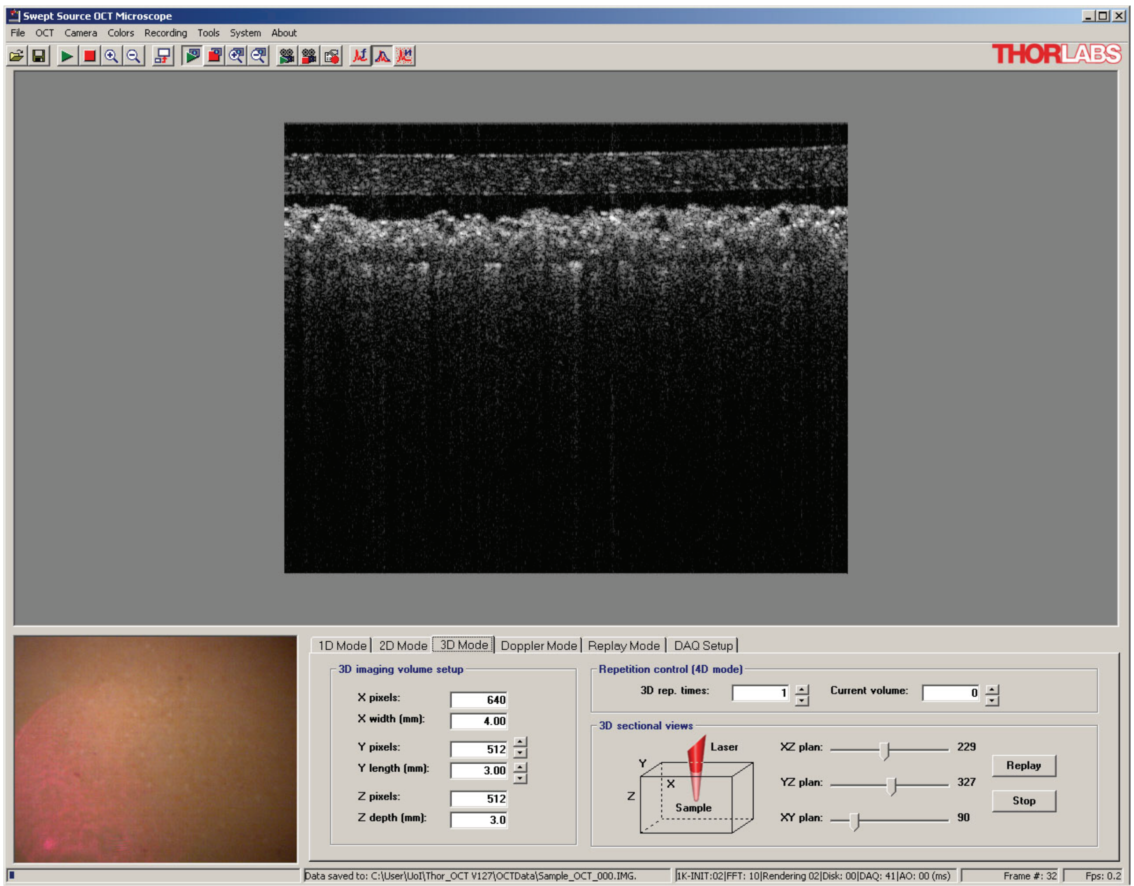


Figure 40: Screenshot of 3D Mode image display

During the 3D imaging process, the multiple adjacent OCT frames are acquired and displayed in real-time like a movie being played. The OCT control panel is disabled and all the controls cannot be adjusted until the 3D scan is finished. There is a progress bar showing the current progress in the whole imaging process. The 3D imaging process can be terminated any time by click the "Stop OCT" button.

After the 3D imaging process finishes successfully, the 3D OCT data set is available for display as 2D images from multiple directions. This function is provided by the "3D sectional control" group. By changing the corresponding slider bar position, the sectional images at different position in XZ, YZ, or XY plane can be displayed. Note that the XZ plane is the original OCT imaging plane as in 2D mode, and XY plane provides the en-face view of the sample at different depth, similar to the views provided by con-focal microscopes.

The software also provides repetition control for the 3D imaging mode, which is also called 4D imaging mode. In this mode, the user needs to set the number of 3D scans to be performed, and the software will scan the same 3D area that many times.

Doppler Mode

Doppler OCT is an optical phase sensitive measurement technique that detects the laser frequency shift proportional to the velocity of moving optical scattering. The principle of this measurement is shown in Figure 41.

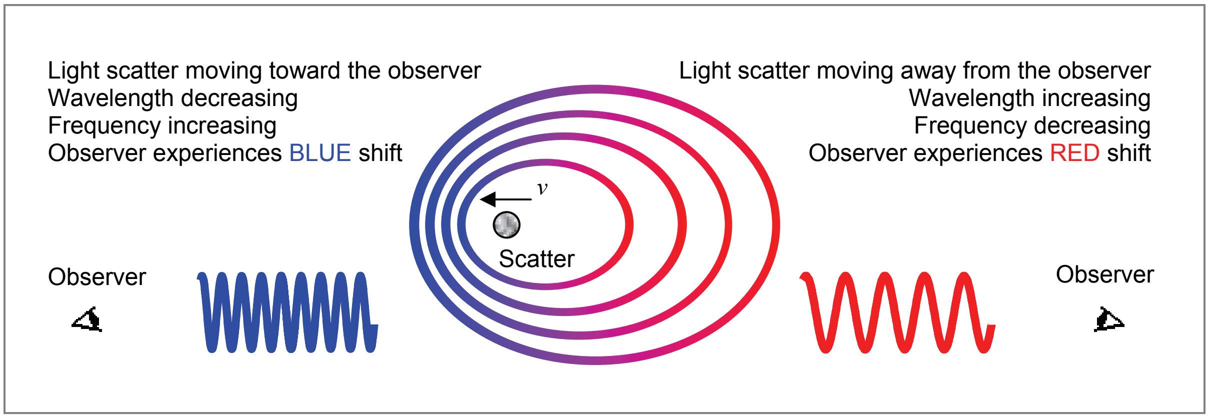


Figure 41: Doppler Effect for a light wave reflected from a moving scatter. By detecting the small frequency shift in the OCT interference fringe signals, the moving scatter velocity projected to the light propagation direction can be measured.

Doppler OCT measures the velocity component projected to the light propagation direction, and can not detect the sample velocity that is perpendicular to the light propagation detection. Therefore in many Doppler OCT experiments, a measurement angle is required. For blood vessel imaging applications, because of the nature of vascular matrix in live tissue samples, this imaging angle requirement is not critical, and Doppler OCT signals can be observed even when the optical beam is perpendicular to the sample surface.

Software Interface

After starting the Swept Source OCT (SS-OCT) software, and successfully acquiring OCT images in 2D mode, the user can click on the “Doppler Mode” tab in the software control panel to enter the Doppler OCT imaging mode as shown in Figure 42.

The software controls in Doppler Mode are organized in three groups:

- **2D Imaging Setup**
  - **X Pixels:** Number of A-scans per frame that equal to the number of pixels in the X directions of one image. This control can be changed from 64 to 4000.
  - **X Width (mm):** The beam scanning width on sample surface. Combining the two controls of **X Pixels** and **X width** determines how many A-scans to represent the physical beam scanning width in one OCT image. Note the **X width** is calibrated to the standard OCT objective used on the microscope, and may not be accurate if the objective has been changed. This control can be changed from 0 to 20 mm.
  - **Z Pixels:** The number of pixels (data points) in the depth (Z) direction. This number is currently fixed to be 512.
  - **Z Depth (mm):** The depth (Z) range of the OCT image being displayed. This control can be changed from 0 to 3 mm.
  - **Average Number:** The number of adjacent A-lines that are averaged to be displayed as one line in final OCT image. This control is useful if the application needs to average multiple A-lines to improve the image signal-to-nosie ratio (SNR), but at the cost of slowing down the beam scan and frame rate. The **Average Number** can be chosen from a dropdown list with the following numbers: 2,4,8,16.
- **Beam Scanning Control**
  - **X shift (mm):** The distance in X direction from actual beam scanning center position to the original center position. The value is in millimeter.
  - **Y shift (mm):** The distance in Y direction from actual beam scanning center position to the original center position. The value is in millimeter.

- **Orientation (degree):** The angle between actual beam scanning trace and the default beam scanning trace along X direction.
- **Reset:** Restore the beam scanning trace to the default settings. The beams scans in X direction across the original center position, with the scanning width defined by **X Width**.

- **Doppler Setup**
  - **Length:** The ensemble length (number of A-scans) that Doppler OCT algorithm uses to average the phase difference across a number of A-scans and calculate the Doppler frequency shift. The default value for this parameter is 16 and can be changed from 2 to 32. Larger numbers show better average effect and improved SNR, while smaller numbers show better details about local Doppler frequency shift.
  - **Threshold:** The threshold value that the Doppler OCT algorithm uses to determine to show a pixel in Doppler OCT image or not. By comparing this threshold value with the OCT intensity value, the pixels with OCT intensity value equal or larger than the threshold are displayed using the Doppler color map; while pixels with OCT intensity value smaller than the threshold are displayed using black color (RGB[0,0,0]).
  - **Contrast:** The scale factor in the Doppler color map used to display a pixel in the Doppler OCT image. For example, if the contrast value is 1 (default), then the Doppler color map is used for display the Doppler phase shift value from $-\pi$ to π. If the contrast value is ½ then the color map is used to display Doppler phase shift value from $-\pi/2$ to $\pi/2$.
  - **Doppler Colormap:** The color map used to display the Doppler frequency shift, representing blue shift (light scatter moving toward the detector) and red shift (light scatter moving away from the detector) of the center frequency.

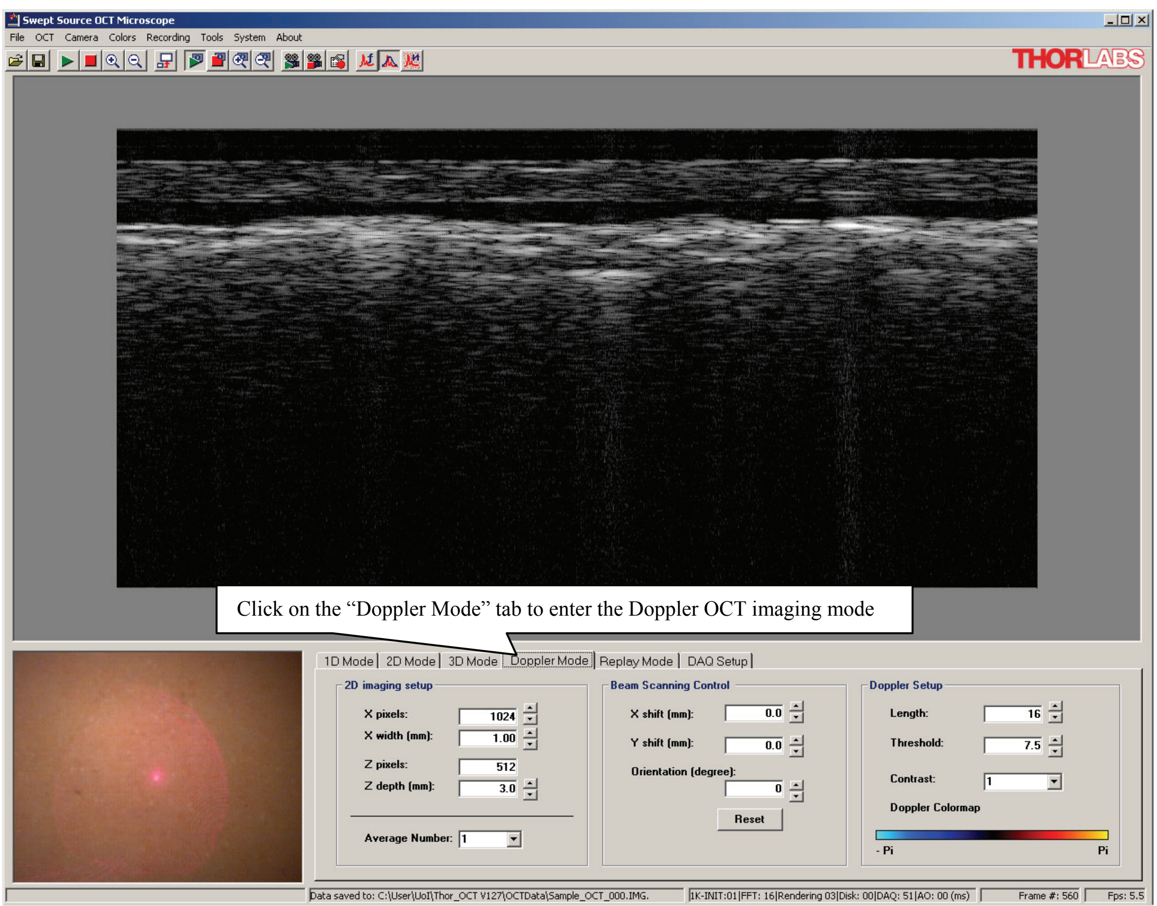


Figure 42: Doppler OCT imaging mode

1. **Preparing the Experiment**

Doppler OCT imaging experiments require very stable conditions for producing optimal imaging results. The following conditions are considered critical for the Doppler OCT imaging experiments.

- **Low vibration**
  Control of the sample vibration is essential for Doppler OCT measurement. It is highly recommended to put the OCT microscope/interferometer on a separate table from the swept source and computer sub-systems, since the vibrations caused by the computer fan and power supply causes very noticeable artifacts in the Doppler OCT images. Figure 43a (OCT microscope on the same cart as the computer and laser) and 43b (OCT microscope on a separate table) compare the Doppler OCT imaging of the same IR card sample under different vibration conditions.

- **Low air turbulence**
  Low air turbulence and pressure change are also important for Doppler OCT imaging, since these effects cause optical path length changes in the sample arm and are detected as Doppler frequency shift.

- **Constant temperature**
  For the same reasons as above, constant temperature is required for Doppler OCT imaging. However, since the temperature changes are typically much slower than Doppler OCT imaging frame rate, it only adds a background phase drift on the final images.

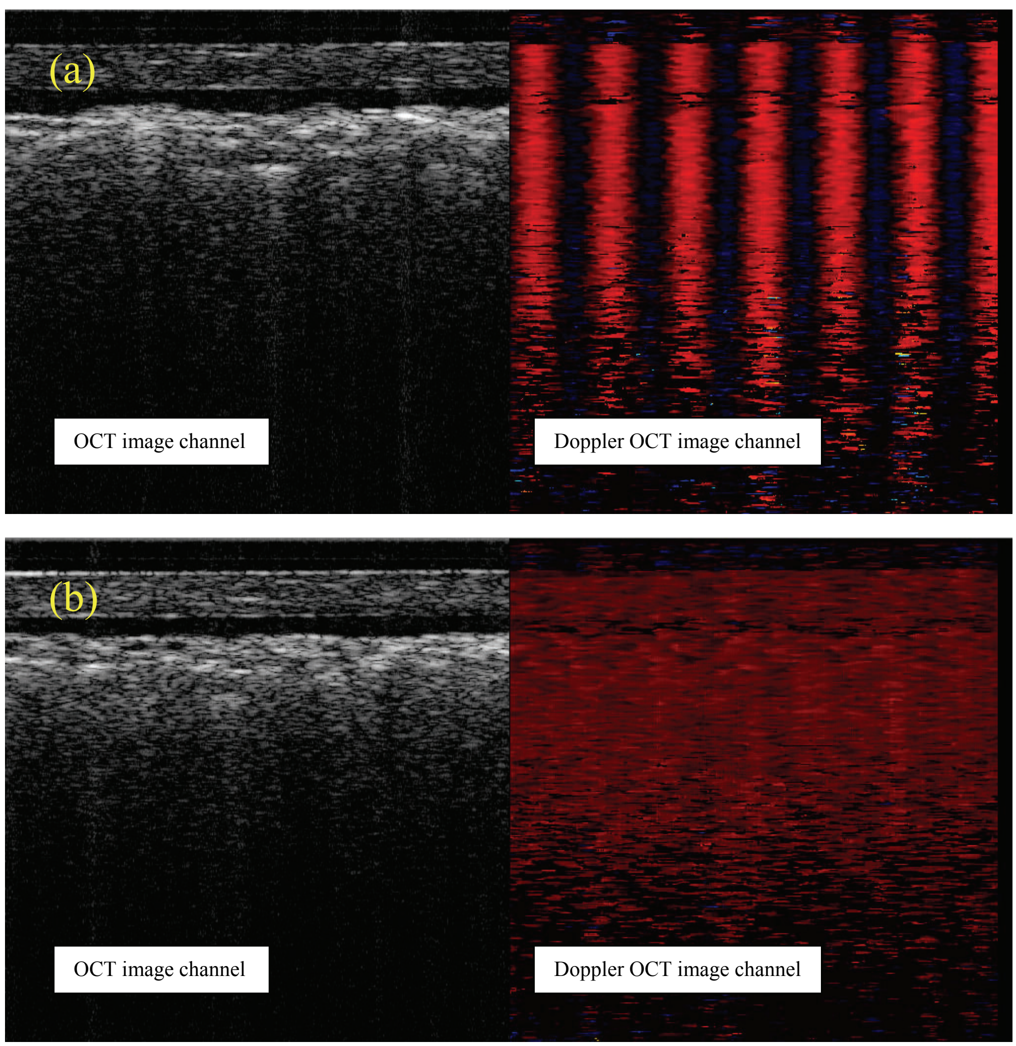


Figure 43. Comparing Doppler OCT imaging under different vibration conditions. (a) OCT interferometer on the same cart as the computer and laser, where the vibrations of the fans cause very noticeable vertical color bands in the Doppler OCT image. (b) OCT interferometer on a separate table where the color bands disappear. The residual dark-red background on the Doppler OCT image is caused by the motion of galvo scanning mirror.

The following software parameters are recommended to produce optimal Doppler OCT images.

- X Pixels: Using a larger number of A-scans to measure the Doppler frequency shift increases measurement accuracy. This number is typically 2000-4000 for Doppler OCT imaging.
- X Width: Reducing the beam scanning width also improves probability of detecting small vessels. 1 or 2 mm is the typical setting.
- Average Number: Average number of 2 or 4 is typically used.
- Length: Values between 10 and 16 are typically used.
- Threshold: Typically set above 6.8.

2. Sample Images from Skin

Showing below are some example Doppler OCT images acquired from human skin samples.

Example 1: Nail folder
The nail folder region is full of blood vessels close to skin surface. With some efforts the Doppler OCT images of blood flow in this skin region can be observed. Figure 44 and 45 show some example images. Note the real-time frame rate is limited to about 2.3 fps due to the large number of A-scans and line average used to improve the image quality.

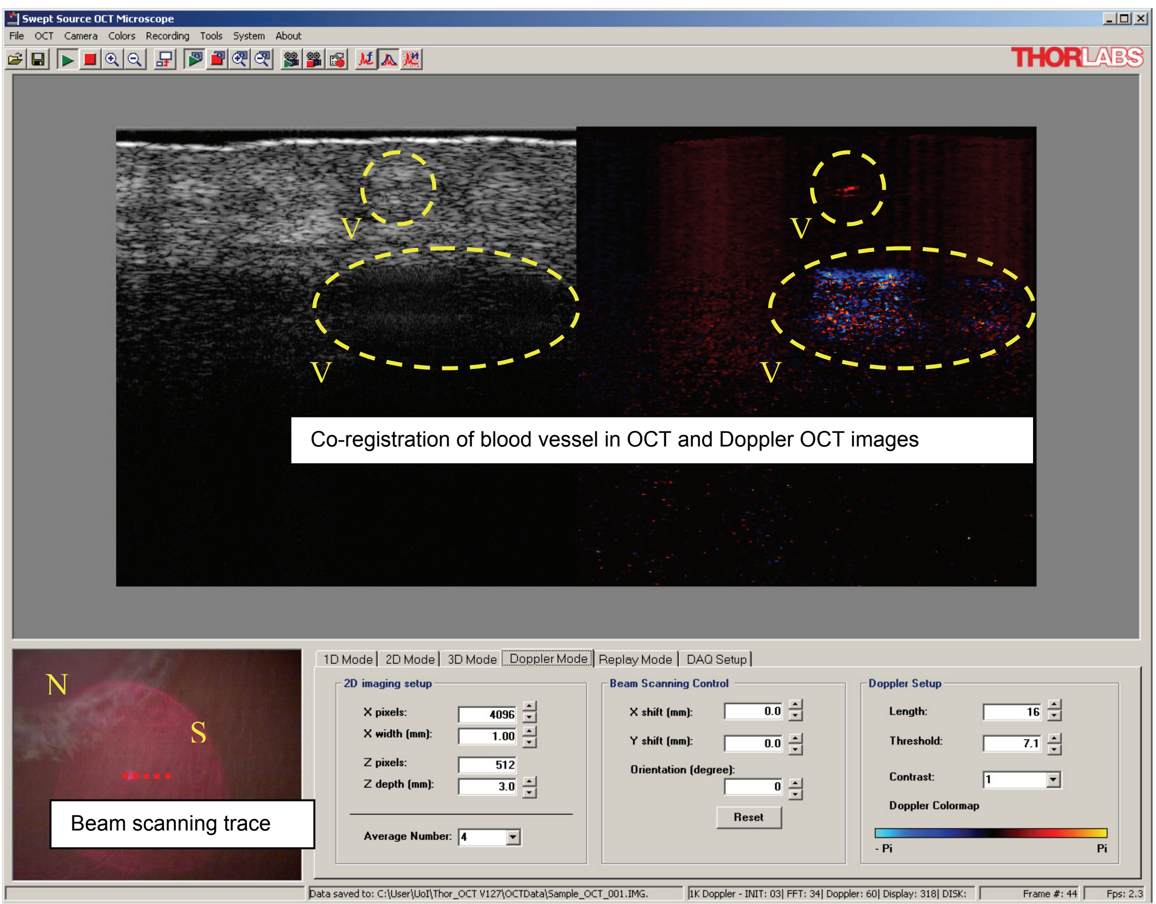


Figure 44: Doppler OCT imaging of human nail folder region

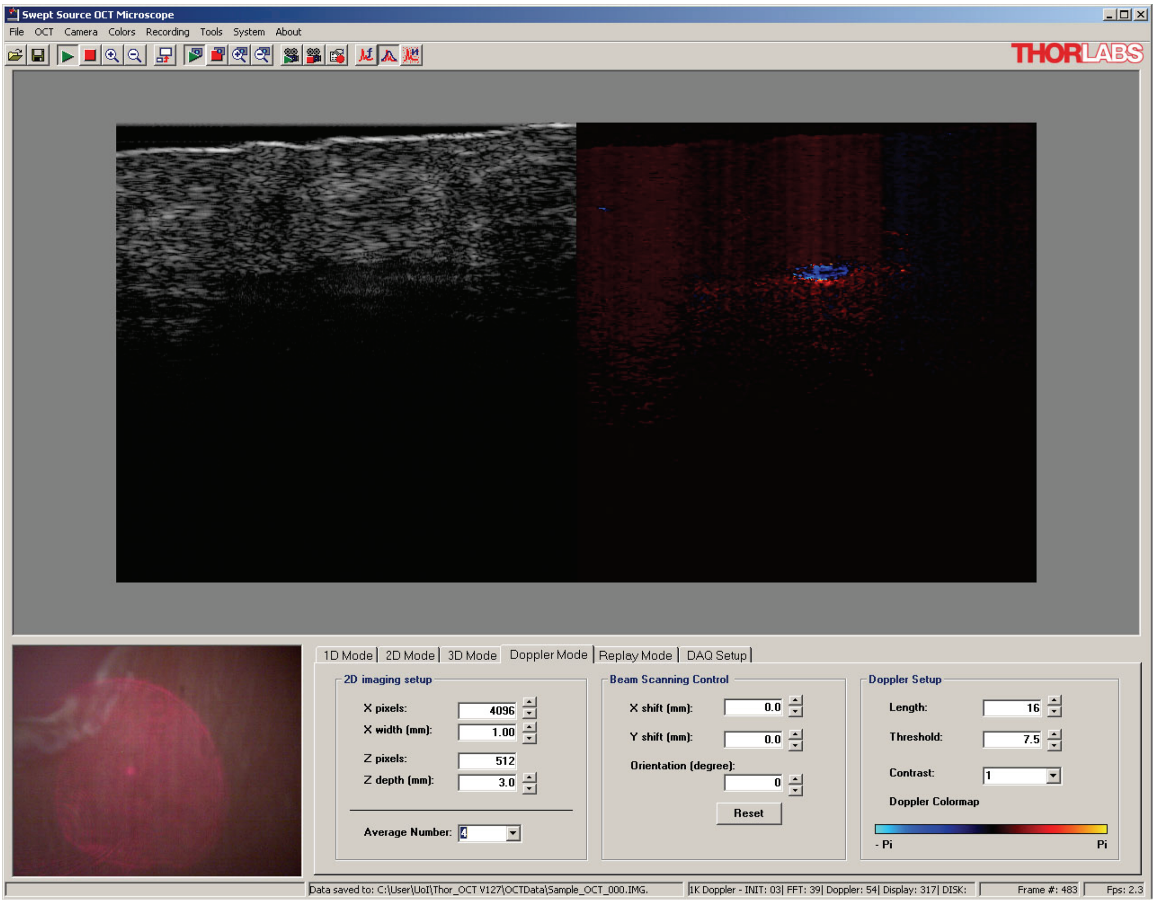


Figure 45: Doppler OCT imaging of human nail folder region

3.4. Data Recording

The software supports real-time image data recording from both the OCT and CCD channels. Clicking the "Start Recording" button starts recording data from the next available image frame. Clicking the "Stop Recording" button stops data recording immediately.

To view or change the data recording settings, select "Setup" from the Recording menu. The File name text box shows the name of the OCT data file to be recorded. The default filename is "Sample_OCT.img", and the default file path is "App.path\OCTData\". The "App.path" is the path of this application software.

The file name and path can be changed by clicking the button beside the text box.

The software supports four file types for the OCT data file to be saved as:

- *.IMG: The OCT data is saved as processed image data, the same as what is being displayed, in binary file format. Every pixel is in 8-bit grayscale and takes one byte of disk space. Every A-line in the OCT image takes 512 pixels, or 512 bytes. For more detailed file structure of the *.IMG file type, please refer to the next section.
- *.FRG: The OCT data is saved in raw fringe data points from the data acquisition card, after frequency recalibration but before Fourier transform. Every data point is a 16-bit integer and takes two bytes of disk space. Every A-line in the OCT image takes 1024 data points, or 2048 bytes. Therefore, the *.FRG file size is four times larger than *.IMG file size. For more detailed file structure of the *.FRG file type, please refer to the section.
- *.JPEG: The OCT data is saved frame by frame as JPEG files, with the filenames increasing numerically. Due to the intensive calculation used in JPEG compression engine, the OCT imaging speed degrades about 20-50% when saving files in this mode.
- *.BMP: The OCT data is saved frame by frame as Bitmap files, with the filenames increasing numerically. This file saving mode does not slow down the OCT imaging speed but the total file size is larger than using other modes.

The "CCD channel" checkbox can enable or disable the data recording on CCD channel.

The software supports two file types for the CCD data file to be saved as:

- *.JPEG: The CCD image data is saved frame by frame as JPEG files.
- *.BMP: The CCD data is saved frame by frame as Bitmap files.

3.5. Data File Format

*.IMG file

"*.IMG" file type – data saved as processed images in log scale, 256 gray levels, one byte per pixel.

Start byte	Length in byte	Type	Description
1	16	String	File identification string.
17	4	Long integer	Number of images saved in the file
21	4	Long integer	Image width
25	4	Long integer	Image depth
29	4	Long integer	Number of frames in each 3D volume
33	4	Long integer	Number of 3D volumes
37	4	Long integer	FFT length (1024 or 2048)
41	472		Reserved
513	Frame data length		Frame data (processed images)

Starting from byte 513, the image data is saved frame by frame, with equal data length for every frame. The frame data has the following format

Start byte	Length in byte	Type	Description
1	4	Long integer	Time elapsed between previous and current frame
5	4		System time of current frame
9	32		Reserved
41	Frame size		2 dimensional array of the image data

Frame size is calculated as: **Image Width × Image Depth × 1** bytes

The **image width** equals number of a-scans per frame and **image depth** is always 512, regardless of FFT length to be 1024 or 2048.

*.FRG file

"*.FRG" file type – Calibrated fringe data from the digitizer (14 bits) saved as integers.

Start byte	Length in byte	Type	Description
1	16	String	File identification string.
17	4	Long integer	Number of images saved in the file
21	4	Long integer	Image width
25	4	Long integer	Image depth
29	4	Long integer	Number of frames in each 3D volume
33	4	Long integer	Number of 3D volumes
37	4	Long integer	FFT length (1024 or 2048)
41	472		Reserved
513	Frame data length		Frame data (raw fringes)

Starting from byte No.513, the image data are saved frame by frame, with equal data length for every frame. The frame data has the following format

Start byte	Length in byte	Type	Description
1	4	Long integer	Time elapsed between previous and current frame
5	4		System time of current frame
9	32		Reserved
41	Frame size		2 dimensional array of the fringe data

Frame size is calculated as: **Image Width × FFT Length × 2** bytes

*.RAW file

"*.RAW" file type – raw data from the digitizer (14 bits, 2 channels) saved as integers.

Start byte	Length in byte	Type	Description
1	16	String	File identification string.
17	4	Long integer	Number of images saved in the file
21	4	Long integer	Image width
25	4	Long integer	Image depth
29	4	Long integer	Number of frames in each 3D volume
33	4	Long integer	Number of 3D volumes
37	4	Long integer	FFT length (1024 or 2048)
41	4	Long integer	Data length per frame
45	4	Long integer	Data length per line
49	464		Reserved
513	Frame data length		Raw data from digitizer for each frame

Starting from byte No.513, the image data are saved frame by frame, with equal data length for every frame. The frame data has the following format

Start byte	Length in byte	Type	Description
1	4	Long integer	Time elapsed between previous and current frame
5	4		System time of current frame
9	32		Reserved
41	Frame size		Raw frame data

Frame size is calculated as (in bytes): **Image width × Data length per line 2 × 2 (Channels)**

Frame data length is calculated as: **Frame size + 40 (frame header)**

In the "**Raw frame data**", the channel 1 (MZI clock) and channel 2 (OCT signals) data are interleaved line by line with length of each line specified by the "**Data length per line**" parameter.

For example:
The i^{th} line of MZI clock data starts from: (2 **×** ***i***) **× Data length per line**
The i^{th} line of OCT data starts from: (2 **×** ***i*** + 1) **× Data length per line**

3.6. Data File Management

Data Movie Replay

The "Image Library" control panel provides replay and exporting functions to the saved OCT data file.

The "Replay control" group allows the user to browse and replay a saved OCT data file.

- After loading a saved OCT data file, the number of image frames inside the file will be shown in the "Frame No." text boxes as 0 of numberofframes.
- The user can slide the horizontal scroll bar to browse the frames or click the "Replay" button to start the automatic replay of the data file. The "Stop" button stops the replay progress.
- The user can also set the replay speed as original speed or higher speed by choosing from the "Replay speed" option box.

3.7. Exporting Data Files

The "Export images" group allows the user to export the specific image frames into separate disk files.

- The "Export range" provides some options for the user to choose the specific range of frames to export.
- The "Export format" options let the user choose the image file format types to save as. Two file types of JPEG file and Bitmap file are supported.
- The "Export Images" button brings up a file saving dialog to allow the user to choose the path of the files to save to.

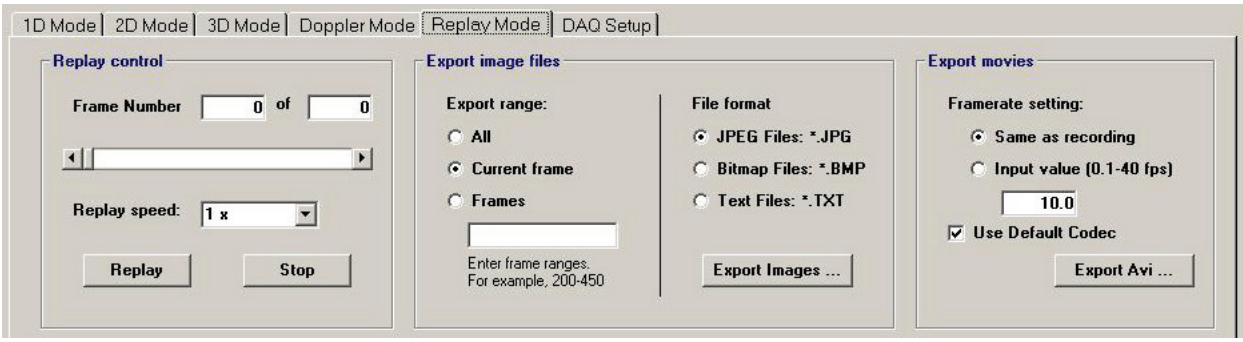


Figure 46: Replay Mode Tab

3.8. 3D model reconstruction

Multiple adjacent 2D cross-sectional images can be synthesized into a computer generated 3D model using the latest 3D rendering software like *Amira*. Please refer to the user manual of Amira for more detailed information about the construction of 3D models.

3.9. Shutting Down the System

The following steps should be followed when shutting down the system:

1. Save any important data.
2. Close the "Thorlabs OCM" software.
3. Shut down the PC.
4. Turn the laser off by pressing the Laser Enable switch.
5. Turn the power switch on the Swept Source Engine to 0.

Part 4. Warranty Information

General Product Warranty

Thorlabs warrants that all products sold will be free from defects in material and workmanship, and will conform to the published specifications under normal use, when correctly installed and maintained.

Optomechanics

Lifetime Warranty: Thorlabs offers a lifetime warranty on all optomechanical components. Thorlabs will repair or replace any optomechanical product which, after evaluation, has been shown to not meet specifications under the conditions listed above.

Optical Tables and Breadboards

Lifetime Warranty: Thorlabs provides a lifetime guarantee that all of our passively damped optical tables and breadboards will meet all originally stated performance specifications under normal use and proper handling. We additionally guarantee that all our table tops and breadboards, both active and passive, will be free from defects in workmanship, including delamination of the skins under normal use and handling.

Lasers and Imaging Systems

Thorlabs offers a one year warranty on all lasers and imaging systems, with the exceptions of laser diodes. Some products are warranted for the number of hours specified in the operating manual of each laser.

Opto-Electronics, Control Electronics, Optics, and Nano-Positioning Product Lines

Thorlabs offers a two year warranty on the above mentioned product lines, provided normal use and maintenance of the products and when properly handled and correctly installed.

Thorlabs shall repair or replace any defective or nonconforming product as detailed above. We ask that buyer contact Thorlabs for a Return Material Authorization number (RMA #) from our Customer Service/Returns department in order to most efficiently process the return and/or repair.

Non-Warranty Repairs

Products returned for repair that are not covered under warranty, will incur a standard repair charge, in addition to all shipping expenses. This repair charge will be quoted to the customer before the work is performed.

Warranty Exclusions

The stated warranty does not apply to Products which are (a) specials, modifications, or customized items (including custom patch cables) meeting the specifications you provide; (b) ESD sensitive items whose static protection packaging has been opened; (c) items repaired, modified or altered by any party other than Thorlabs; (d) items used in conjunction with equipment not provided by, or acknowledged as compatible by, Thorlabs; (e) subjected to unusual physical, thermal, or electrical stress; (f) damaged due to improper installation, misuse, abuse, or storage; (g) damaged due to accident or negligence in use, storage, transportation or handling.

Part 5. Certifications and Compliance

Konformitätserklärung
Declaration of Conformity
Declaration de Conformité

Thorlabs Inc
435 Rt 206
Newton, NJ
USA

erklärt in alleiniger Verantwortung, dass das Produkt:
declares under it's own responsibility, that the product:
declare sous notre seule responsabilité, que le produit:

OCM1300SS/OCP1300SS/OCMP1300SS

mit den Anforderungen der Normen
fulfills the requirements of the standard
satisfait aux exigencies des norms

72/73/EEC	Low Voltage Directive 19.02.1973
93/68/EEC	Change of Low Voltage Directive
DIN EN 61010-1:2001	Safety of Test and Measurement Equipment
DIN EN 61326:97+A1:98+A2:01+A3:03	EMC of Test and Measurement Equipment
DIN EN 61000-3-2:2000	Harmonic Current Emission
DIN EN 61000-3-3:95 + A1:2001	Voltage Fluctuations and Flickers
DIN EN 61000-4-2	Electrostatic Discharge Immunity (Criteron C)
DIN EN 61000-4-3	Radiated RF Electromagnetic Field Immunity (Criterion B)
DIN EN 61000-4-4	Electrical Fast Transient/Burst Immunity (Criterion B)
DIN EN 61000-4-5	Power Line Surge Immunity
DIN EN 61000-4-6	Conducted RF Immunity
DIN EN 61000-4-11	Voltage Dips and Interruptions Immunity

übereinstimmt und damit den Bedingungen entspricht.
and therefore corresponds to the regulations of the directive.
et répond ainsi aux dispositions de a directive.

Dachau, 29. August 2007 ....

Ort und Datum der Ausstellung
Place and date of issue
Lieu et date d'établissement

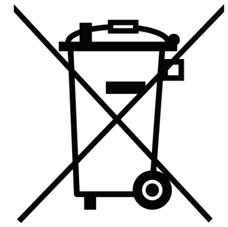
Name und Unterschrift des Befugten
Name and signature of authorized person
Nom et signature de la personne autorisée

Part 6. Regulatory

As required by the WEEE (Waste Electrical and Electronic Equipment Directive) of the European Community and the corresponding national laws, Thorlabs offers all end users in the EC the possibility to return "end of life" units without incurring disposal charges.

This offer is valid for Thorlabs electrical and electronic equipment:

- Sold after August 13th 2005
- Marked correspondingly with the crossed out "wheelie bin" logo
- Sold to a company or institute within the EC
- Currently owned by a company or institute within the EC
- Still complete, not disassembled and not contaminated



Wheelie Bin Logo

As the WEEE directive applies to self contained operational electrical and electronic products, this end of life take back service does not refer to other Thorlabs products, such as:

- Pure OEM products, that means assemblies to be built into a unit by the user (e. g. OEM laser driver cards)
- Components
- Mechanics and optics
- Left over parts of units disassembled by the user (PCB's, housings etc.).

If you wish to return a Thorlabs unit for waste recovery, please contact Thorlabs or your nearest dealer for further information.

Waste treatment is your own responsibility

If you do not return an "end of life" unit to Thorlabs, you must hand it to a company specialized in waste recovery. Do not dispose of the unit in a litter bin or at a public waste disposal site.

Environmental Impact

It is well known that WEEE directive was established because electronic products are known to pollute the environment by releasing toxins during decomposition. The aim of the European RoHS directive is to reduce the content of toxic substances in electronic products in the future.

The intent of the WEEE directive is to enforce the recycling of WEEE. A controlled recycling of end of live products will thereby avoid negative impacts on the environment.

Part 7. Appendix

7.1. Setting the Line Select Switch

The Swept Source Engine will operate from AC line voltages ranging from 100-240 VAC at 50-60Hz. There is no need to configure the unit for specific line voltages.

The computer's line select switch is located next to the AC input port at the rear panel of the computer. Select the proper AC line voltage **before installing the AC line cord**.

Figure 47: PC Line Select Switch

7.2. Changing the Input Fuses

If for some reason you need to replace an open fuse in the Swept Laser Source, you must perform the following procedure:

- Remove the AC input cable that may be connected to the unit.
- Slide open the cover of the fuse holder located at the rear panel of the Swept Laser Source as shown in figure 48. Remove the existing fuse and install the appropriate replacement fuse for Swept Laser Source.
  Use only is 1A 250VAC Type T 5x20mm style fuse
  (IEC 60127-2/III, Low Breaking Capacity, slow blow)
- Slide the fuse cover closed.

Figure 48: Fuse cover located on the Swept Source rear panel

Refer to CPU user's manual for computers fuse information.

Part 8. Thorlabs Worldwide Contacts

For technical support or sales inquiries, please visit us at www.thorlabs.com/contact for our most up-to-date contact information.

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