Swept Source Optical Coherence Tomography

Swept Source OCT Imaging System shown on a Thorlabs ScienceDesk™. See page 26 for details on Thorlabs' ScienceDesks.

SS-OCT Features

- 1040 or 1325 nm Center Wavelength
- Ideal for Imaging Small Animals, Tissue, and Other Highly Scattering Material
- Video Microscopy Imaging with Integrated CCD Camera in Handheld Probe
- Doppler Flow Imaging Included
- Compact System Design Ready for OEM Applications
- 3D Imaging Capability
- Sub-Surface Imaging up to 3 mm in Tissue

Optional Features

- Family of Objective Lenses to Optimize Imaging Performance
- Polarization-Sensitive OCT
- High-Power Light Sources
- Special Center Wavelength Sources for Industrial Samples

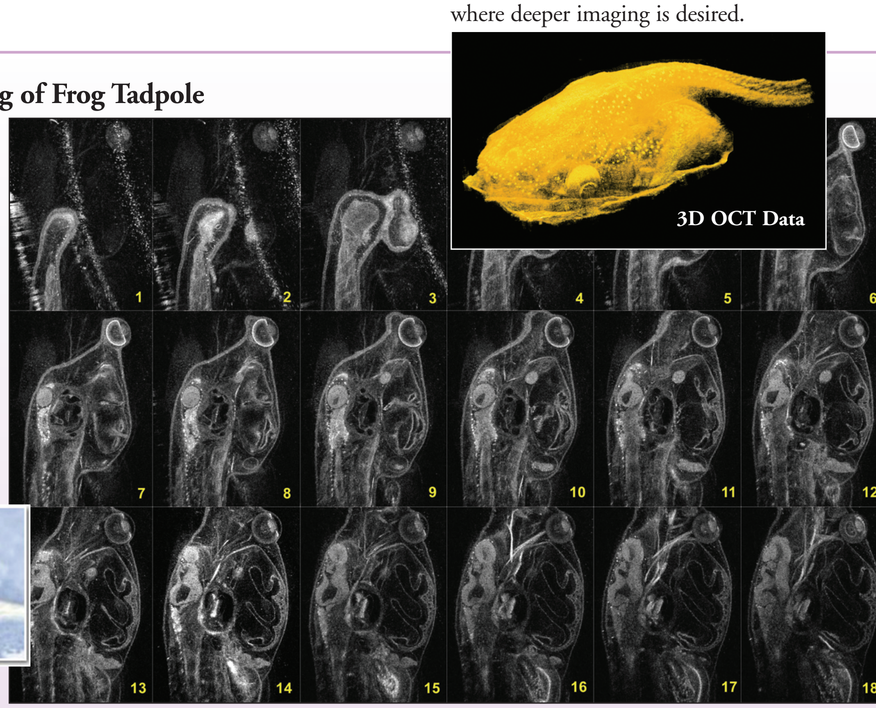
Swept Source Optical Coherence Tomography (SS-OCT) is a Fourier Domain OCT technique that utilizes a frequency-swept, broadband tunable laser and balanced detection scheme to generate and measure frequency-based interferometric signals. With SS-OCT the spectral components of the interferogram is encoded in time as the laser source tunes across a broad bandwidth. Compared to Spectral Domain OCT technology, SS-OCT systems do not suffer from inherent sensitivity degradation at greater depths. Therefore, SS-OCT is preferred for applications where deeper imaging is desired.

Biological Imaging

Three-Dimensional Imaging of Frog Tadpole

The data shown here represents a series of *en face* images of an African frog tadpole and a 3D image reconstruction. The data was acquired using the Thorlabs OCS1300SS OCT microscope system. All images are 6 mm x 8 mm and were taken from the posterior to the anterior of the tadpole in 100 µm increments.

Reference: R. Huber, *et al.*, *Optics Express* **13**, 10523 (2005)



Swept Source OCT Systems

OCS1300SS: Deep Imaging
The OCS1300SS is our most popular OCT imaging system. Utilizing a 55 kHz swept laser source with a center wavelength of 1325 nm (SL1325-P55), this system provides deep imaging (up to 3 mm) in highly scattering tissue. The OCS1300SS comes with three-dimensional, as well as Doppler imaging capabilities bundled into a complete data control and acquisition software package. The OCS1300SS Imaging System includes a 3D imaging capable handheld probe with articulating stand. Imaging performance is enhanced by using an OCT-optimized objective lens (Thorlabs' Item# LSM03). Details on this and other OCT objectives can be found on page 1386.

OCS1050SS: High-Resolution Imaging
The OCS1050SS builds upon the standards set by our 1300 nm system by offering high-resolution swept-source OCT images while utilizing a wavelength band that is less susceptible to water absorption. It is capable of imaging depths up to 2.5 mm, with an axial resolution of 12.5 µm (in air). The system includes the same 3D imaging handheld probe; when coupled with an LSM02-BB scan lens, the OCS1050SS is Thorlabs' highest resolution swept source OCT system. Our new 1050 nm swept laser source (SL1050-P55) has an 80 nm bandwidth, 5 mm coherence length, and 10 mW output power. See page 1368 for details on our high-speed, 55 kHz swept laser sources.

SS-OCT Systems	**1300 nm** ■ Deep Imaging ■ A-Scan Rate: 55 kHz ■ Image Acquisition Rate: 50 Frames per Second**	**1050 nm** ■ High Resolution ■ A-Scan Rate: 55 kHz ■ Image Acquisition Rate: 50 Frames per Second**
Center Wavelength	1325 ± 15 nm	1040 ± 15 nm
Spectral Bandwidth (20 dB)	120 ± 10 nm	80 ± 10 nm
Axial Resolution (Air/Water)	12 µm / 9.0 µm	10 µm / 7.5 µm
Lateral Resolution	15 µm	12.5 µm
Maximum Imaging Depth*	6.0 mm	5.0 mm
Maximum Pixels per A-Scan	1024	1024
Optical Power on Sample (Average)	5.0 mW	4.0 mW

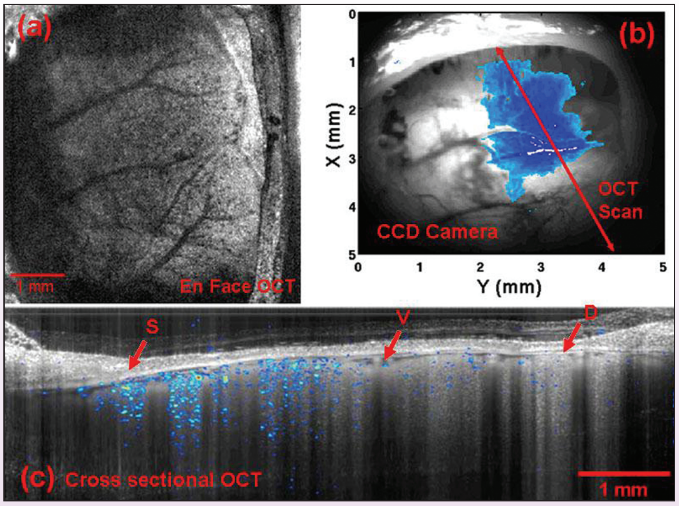
*Maximum Imaging Depth that is supported by the data acquisition system and software. 6.0 mm (5.0 mm for 1050 SS-OCT) imaging depth is susceptible to signal degradation due to finite coherence length of the swept laser source. Actual Imaging Depth will vary based on absorption and scattering properties of the sample. **Image Aquisition Rate based on 1024 lines per frame.

Brain Functional Imaging

The pictures to the right show OCT images representing the functionally active region of a rat brain. Images were taken by researchers at MIT and Massachusetts General Hospital using a modified Thorlabs Swept Source OCT system.

The OCT scan is directed to the region of interest using a video microscope. The OCT image enables identification of the skull (S), surface vasculature (V), and meningeal layers, including the dura mater (D). The blue-colored areas show the functionally active regions of the cortex, which were co-registered on the CCD camera and OCT channels.

Reference: A.D. Aguirre Y. Chen, J.G Fujimoto, L. Ruvinskaya, A. Devor, and D.A. Boas, "Depth-resolved imaging of functional activation in the rat cerebral cortex using optical coherence tomography." *Optics Letters* **31**, 3459 (2006).

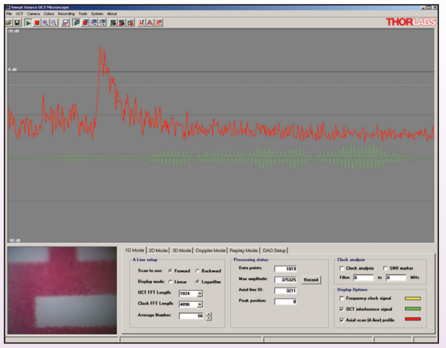


Swept Source OCT Software

1D Mode

OCT A-Scan Display and System Diagnostics

In the 1D imaging mode, there is no transverse scanning of the probe beam in the sample arm. Real-time display of the calibrated OCT interference fringe, Fourier Transform point spread function (A-Scan), and frequency clock are provided to aid optimization of the signal and system parameters. In this mode, the user can control the dynamic range and gain settings, save A-Scans, as well as measure the coherence length and axial resolution of the system. An *en face* CCD camera view is provided to aid in alignment of the sample relative to the OCT probe beam.

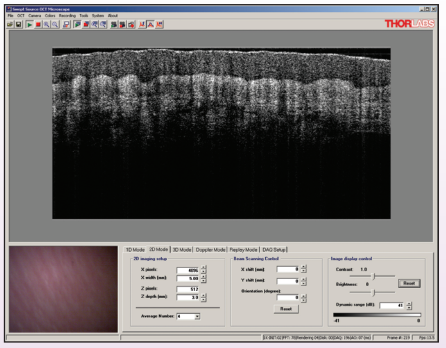


1D Mode: OCT A-Scan Display and System Diagnostics

2D Mode

Cross-Sectional (B-Scan) Imaging

In the 2D imaging mode, the probe beam is scanned in one direction and cross-sectional OCT reflectivity images are displayed in real time. The software provides flexible control of scanning parameters such as distance, offset, and angle as well as the number of lines per image. Line averaging and image display parameters such as brightness and contrast can also be controlled in this mode. The user can export 2D data as either recalibrated fringe data or 8-bit pixel images. The fringe or image data can also be converted into .jpg, .bmp, .tif, or .avi file formats. As in the 1D mode, the *en face* CCD camera view from the probe is provided to aid in alignment of the sample to the scanning OCT probe beam.

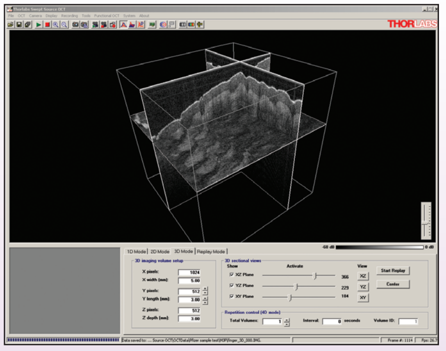


2D Mode: Cross-Sectional (B-Scan) Imaging

3D Mode

Volume Imaging

In the 3D imaging mode, the probe beam sequentially scans across the sample as a series of 2D cross-sectional images are acquired and built into a 3D image. The user can control the X and Y scanning parameters for volume acquisition. Display of the cross-sectional images are provided as they are being acquired to build the 3D volume dataset. In this mode, the 3D volume dataset can be displayed in one of three orthogonal planes (XY, YZ, or XZ) or a combination of the three planes. The user can zoom, rotate, and define the orthogonal planes in which to display. 3D datasets are saved as a series of 2D cross-sectional scans. Additional software support is provided that enables 3D graphic rendering of the acquired OCT data.

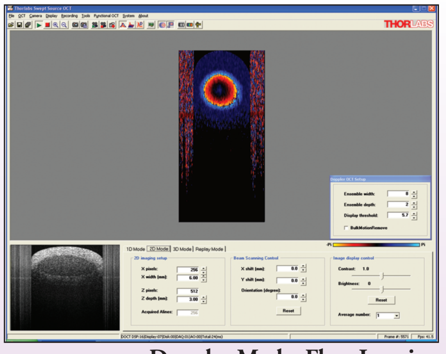


3D Mode: Volume Imaging

Doppler Mode

Flow Imaging

Doppler OCT imaging comes standard with all Swept Source OCT systems. In the Doppler mode, phase shifts between adjacent pixels are averaged to calculate the Doppler frequency shift induced by particle motion or flow. Doppler mode is activated by a button on the software toolbar. The user can control the number of lateral and axial pixels over which to average to calculate Doppler frequency shifts as well as threshold values for the Doppler OCT image display. The Doppler images are displayed in the main window with a colormap indicating forward- or backward-directed flow, relative to the OCT beam. Additionally, in a secondary window, the user can choose to view either the standard *en face* CCD camera view or, by switching to "dual display", simultaneous OCT structural images.



Doppler Mode: Flow Imaging

Doppler OCT Imaging

Doppler OCT is an extension of OCT that enables imaging of particle motion within a sample. In Fourier Domain OCT (FD-OCT) systems, there are no additional hardware requirements for implementation of Doppler imaging. Doppler OCT imaging capability is embedded in the software provided with all Thorlabs' SS-OCT systems and is ideal for studying embryonic cardiac dynamics, functional vascular imaging, or monitoring vascular treatment response. It is also useful for general flow velocimetry used in microfluidic channel monitoring.

Principles of Doppler OCT

The Fourier transform of the interferogram acquired in FD-OCT imaging (A-scan) produces a complex signal [I(z) + iQ(z)], where the magnitude of that signal is used to create the structural OCT image. The complex portion of the signal contains information based on the phase of the interferogram. Any change in phase between consecutively acquired A-scans can be attributed to a Doppler frequency shift induced by particle motion. In Thorlabs' implementation of Doppler OCT, Doppler frequency shifts are calculated based on spatially averaging phase shifts within a sliding 2D window and using a Kasai autocorrelation function (see Ref. 1). The Doppler frequency shift f_D caused by moving particles is related to the phase shift between A-scans, as described in the following expression:

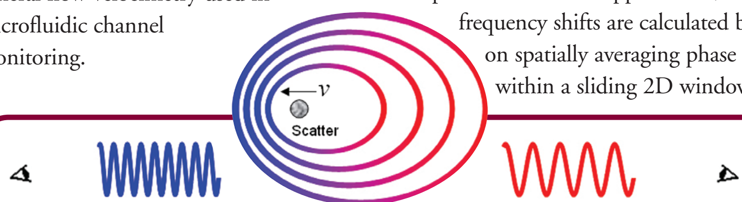
$$f_D = \frac{\Delta\varphi}{2\pi} f_A$$

where Δφ is the average phase shift within the sliding 2D window and f_A is the A-scan rate of the OCT system. The Thorlabs Doppler Imaging Mode displays the phase shift induced by moving particles using a standard Doppler colormap where red to yellow (violet to blue) indicates flow in the direction toward (away from) the OCT sample beam.

The mean velocity <v> of the moving particles, at any depth, can be quantified by knowing θ, the angle between the OCT sample beam and flow vector:

$$\langle v \rangle = \frac{\lambda_o f_D}{2n\cos(\theta)}$$

Here, λ_o is the center optical wavelength of the OCT sample beam and n is the index of refraction of the sample.



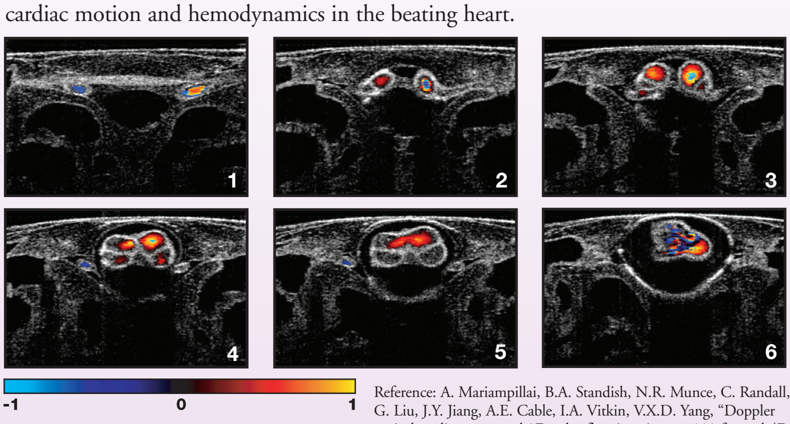
Doppler Effect

A stationary observer will observe a Doppler shift in the frequency of light emitted from a source moving toward or away from the observer. When the light source is moving toward the observer, the observed frequency of light will be blue-shifted, meaning the perceived frequency of the light will be higher than the actual frequency emitted by the source. Higher frequencies correspond to shorter wavelengths. Conversely, if the light source is moving away from the observer, the observed frequency of light will be red-shifted to lower frequencies. In Doppler OCT, the Doppler effect caused by moving particles in a sample is determined by measuring a shift in the phase between consecutive OCT interference fringe signals.

[1] C. Kasai, K. Namekawa, A. Koyano, R. Omoto *et al.* "Real-time two-dimensional blood flow imaging using an autocorrelation technique," IEEE Trans. Sonics. Ultrason. **32** 458-464 (1985).

Developmental Biology

Thorlabs' Swept Source OCT Imaging System (OCS1300SS) with Doppler Imaging was used by researchers at the University of Toronto to study the cardiovascular system of living tadpoles. The series of images below show *in vivo* cross-sectional SS-OCT images of a beating tadpole heart superimposed with Doppler blood flow images. An optical Doppler cardiogram was obtained using a gated technique to increase the effective frame rate and improve the signal-to-noise ratio. The gating technique provides ultra high-speed visualization of the heart blood flow pattern in developing African frog embryos in both 3D and 4D (i.e., 3D + time) modes. This allows detailed visualization of the complex cardiac motion and hemodynamics in the beating heart.



Normalized Flow Velocity

Reference: A. Mariampillai, B.A. Standish, N.R. Munce, C. Randall, G. Liu, J.Y. Jiang, A.E. Cable, I.A. Vitkin, V.X.D. Yang, "Doppler optical cardiogram gated 2D color flow imaging at 1000 fps and 4D *in vivo* visualization of embryonic heart at 45 fps on a swept source OCT system", *Optics Express* **15**, 1627 (2007).

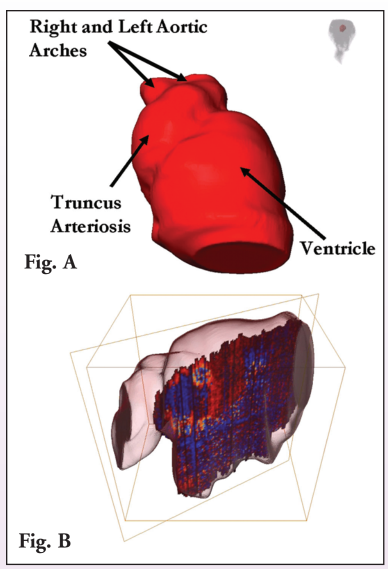


Fig. A shows the 3D surface reconstruction of the tadpole heart, while Fig. B demonstrates the complex blood flow pattern of the heart via a 3D color Doppler map.

Swept Source OCT System Specifications

NEW product

Due to rapid improvements to our systems, all specifications presented here are subject to change. Please refer to our website, www.thorlabs.com, for or call for the latest specifications

Optical*	OCS1300SS	OCS1050SS
Center Wavelength	1325 nm	1040 nm
Spectral Bandwidth (20 dB)	120 nm	80 nm
A-Scan Rate	55 kHz	55 kHz
Average Optical Power at Sample	5.0 mW	4.0 mW
Electronics		
A/D Conversion Rate	180 MS/s	
A/D Resolution	16 Bit	
A/D Channels	2	
Analog Output Rate	1 MS/s	
Analog Output Resolution	16 Bit	
Analog Output Channels	4	
Imaging Specifications		
2D Cross-Sectional OCT Imaging		
Imaging Speed (1024 A-Scans/Frame)	50 frames per second	
Maximum Sampling Resolution	8192 (W) x 1024 (D) Pixels	
Maximum Scan Range	10 mm	
Maximum Imaging Depth**	6.0 mm	5.0 mm
Lateral Resolution with LSM03 Objective	15 µm	12.5 µm
Axial Resolution in Air (Water)	12 µm (9.0 µm)	10 µm (7.5 µm)
3D Volume OCT Imaging		
Maximum Volume Size**	10 mm x 10 mm x 6.0 mm	10 mm x 10 mm x 5.0 mm
Maximum Sampling Resolution	1024 (W) x 1024 (L) x 1024 (D)	
Volume Acquisition Time	5 s (512 x 512 x 1024)	
***En Face* Video Microscopy**		
CCD Camera	0.25 Megapixels (Effective)	
Maximum Pixel Resolution	328 x 256	
Imaging Speed	29 Frames/s	

*Longer coherence length system configurations are available with shorter turning ranges, please call for details.
**Imaging Depth is software selectable up to the maximum range.

Handheld Probe (above) and Articulated Probe Mount (below) Included with all OCT Systems

ITEM#	$	£	€	RMB	DESCRIPTION
OCS1300SS	$ 60,000.00	£ 41,594.00	€ 53.269,00	¥ 506,642.00	1300 nm SS-OCT Imaging System
OCS1050SS	$ 60,000.00	£ 41,594.00	€ 53.269,00	¥ 506,642.00	1050 nm SS-OCT Imaging System