TELESTO II

Spectral Domain OCT System

Operating Manual

Table of Contents

Table of Figures

Part 1. Introduction

ATTENTION

Please read the instruction manual carefully before operating the SD-OCT system.

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

This equipment is intended for laboratory use only and is not certified for medical applications, including but not limited to life support situations.

Refer to this manual whenever the following symbols are encountered on the SD-OCT system:

Attention symbol indicates that additional information is given in this manual.

Laser Safety symbol indicates that laser radiation is present.

ATTENTION

Check the supply voltage of the system before plugging in the computer. Make sure the included power cords for the base unit, computer and monitor are connected to a properly grounded outlet (100 – 240 VAC; 50 – 60 Hz).

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

Operate this system on a flat, dry, and stable surface only.

WARRANTY WARNING

Do not open the Base Unit, Imaging Probe or 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. This device can only be returned when packed into the complete original packaging, including all foam packing inserts. If necessary, ask for replacement packaging.

1.1. Safety

SHOCK WARNING – HIGH VOLTAGE

Before applying power to the system, make sure that the protective conductor of the three-conductor mains power cord is correctly connected to the protective earth contact of the socket outlet. Improper grounding can cause electrical 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. Refer servicing to qualified personnel.

ATTENTION

Do not obstruct the air-ventilation slots in the computer housing. Do not obstruct air-ventilation into the bottom of the base unit 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 IEC 61000-6-1:2005.

LASER RADIATION WARNING

Laser emission may be emitted

a) from the scan lens of the Imaging Probe (intended use)

b) from the back of the base unit when the fiber cap is removed and the fiber disconnected

c) from the output of the fiber when the fiber is not connected to the Imaging Probe

Do not look into the optical output when the device is operating. The laser radiation is not visible to the human eye and can cause serious damage to your eyesight.

UNSICHTBARE LASERSTRAHLUNG

NICHT DIREKT MIT OPTISCHEN INSTRUMENTEN BETRACHTEN

LASER KLASSE 1M

KLASSIFIZIERT NACH DIN EN 60825-1:2008

INVISIBLE LASER RADIATION

DO NOT STARE INTO BEAM OR VIEW DIRECTLY WITH OPTICAL INSTRUMENTS

CLASS 1M LASER PRODUCT

CLASSIFIED ACCORDING TO DIN EN 60825-1:2008

1.2. Care and Maintenance

Handle the system with care during transportation and unpacking. Banging or dropping the system can damage the unit or lower system performance. If the system is mishandled during shipment, the optical components may become misaligned, which could lead to a decrease in image quality. If this occurs, the system will need to be realigned by qualified personnel. If the system is dropped from a height greater than 15", Thorlabs will need to perform an electrical security check. Please contact Thorlabs Technical Support 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, 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 performance and potentially destroy the fiber. Continual bending of the optical fiber can cause damage. It is important, therefore, 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.

All lasers, especially lasers with resonator cavities that are defined by mechanical tolerances, are delicate precision instruments and must be handled accordingly. The SD-OCT system is designed to withstand normal transportation and operating conditions. Do not move the system while it is connected and in operation.

1.2.1. Optical Cleaning

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

1) <u>Always</u> inspect and clean the fiber end before plugging it into a receptacle.
2) <u>Always</u> cover the fiber end that is not in use with a fiber cap or dust protection cover.

1.2.2. Fiber Cleaning Techniques Using the FBC1

This section details how to clean fiber bulkheads and fiber connectors using the FBC1 one-step cleaner.

Using Extended Mode

Figure 1 FBC1 Extended Mode

To use extended mode, pull the tip outward while simultaneously pushing down on the lock button. Extended mode is useful for panels with multiple bulkhead connectors or other tight spaces.

Cleaning Fiber Bulkheads

Figure 2 Cleaning Fiber Bulkheads

Remove the guide cap completely from the device, and insert the tip of the cleaner into the bulhead connector. Push the case to start the cleaning process; a click indicates that the cleaning is complete.

Cleaning Fiber Connectors

Figure 3 Cleaning Fiber Connectors

Open the cover on the guide cap, and insert the fiber connector over the guide cap. Push the case to start the cleaning process; a click indicates that the cleaning is complete.

1.2.3. Service

Only trained and approved Thorlabs personnel are allowed to service the system. Please contact Thorlabs Technical Support for more information.

1.2.4. Accessories and Customization

The TELESTO II Spectral Domain OCT System can easily be adapted for custom interfaces. To achieve the listed specifications however this system should only be used with the accessories that Thorlabs provides. Any modification or maintenance by unqualified personnel will render the warranty null and void, leaving Thorlabs free of liability. Please contact Thorlabs Technical Support for questions on customization.

Part 2. Description

2.1. Theory

2.1.1. Spectral Domain OCT Technology

Spectral Domain Optical Coherence Tomography (SD-OCT) is a measurement method based on the detection of optical path length differences. It incorporates a broadband light source with a high-speed spectrometer to provide depth profiles that can be added to cross-sectional images. These cross-sectional images can be used for 3-dimensional reconstructions.

SD-OCT uses Fourier Domain technology to determine the optical properties of an unknown sample by analyzing the back-reflected and scattered light from an illuminated volume of the sample. The light of a broadband source travels to the sample and illuminates it perpendicularly and with a small focus that provides a good lateral resolution. The back-scattered light travels to the spectrometer where the unique phase delay for each wavelength is detected. The depth information is acquired using a Fast Fourier Transformation (FFT).

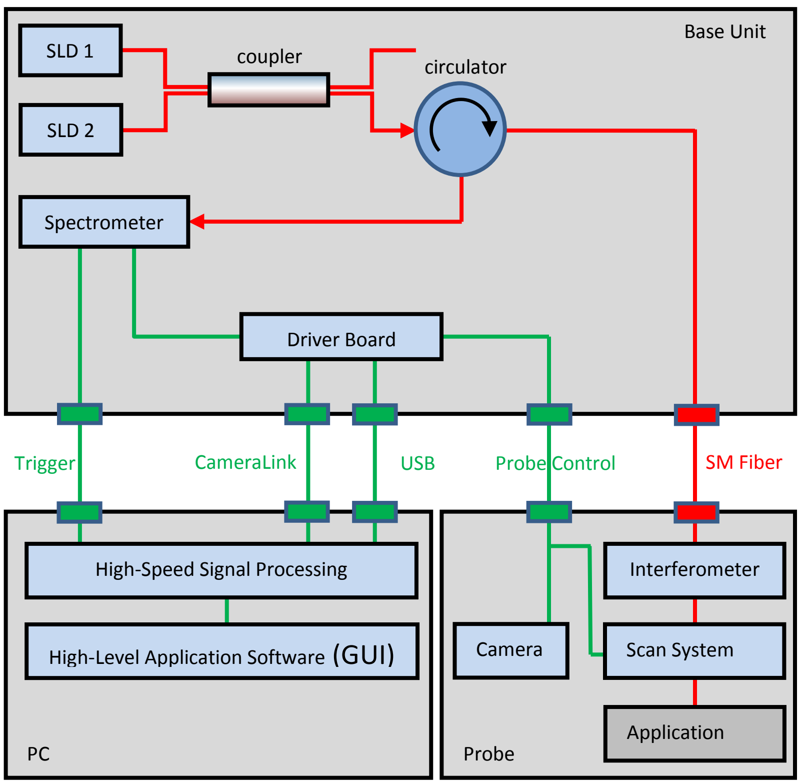

Figure 4 Schematic Diagram of the SD-OCT System

When added to a 2-dimensional image, the two main features of the scanned image are the axial and lateral resolutions. The axial resolution does not depend on the optics; it is driven by the spectral bandwidth of the light source. The lateral resolution, on the other hand, is affected by the chosen application optics.

The SD-OCT system has four main parts: the base unit, a PC, an imaging probe and a probe stand (see Figure 4 above for a schematic diagram of the SD-OCT system).

2.1.2. Nomenclature in OCT imaging

As described before, the SD-OCT engine creates a depth profile from the interference of photons sent into the sample and received back with photons reflected in the reference arm. This depth profile is referred to as A-scan. Figure 5 shows a tomato's A-scan data.

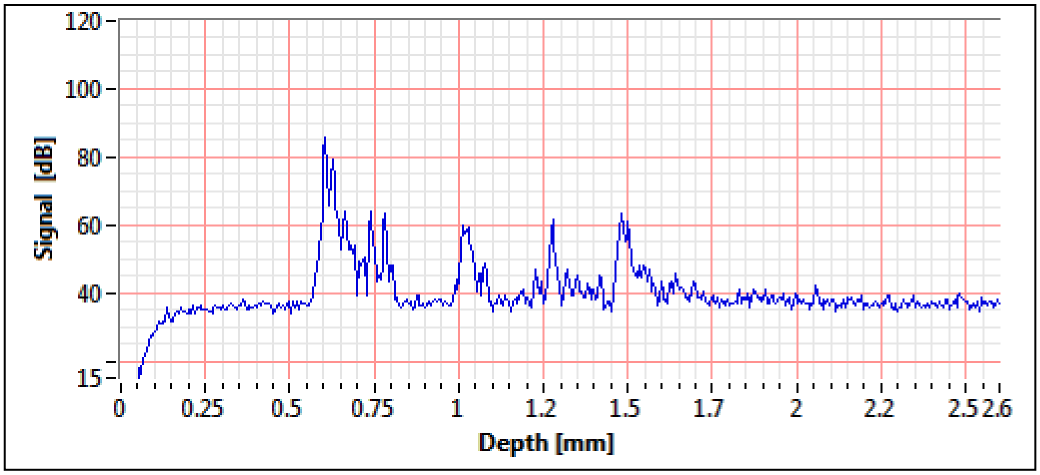

Figure 5 A-scan data set

The imaging probe is equipped with two galvanometer driven scanners. When scanning one mirror while collecting multiple A-scans, a 2-dimensional image is created. This is referred to as a B-scan. Here, the depth information is typically displayed from top to bottom, while the scan axis in Figure 2 is from left to right. Figure 6 shows a B-scan data set.

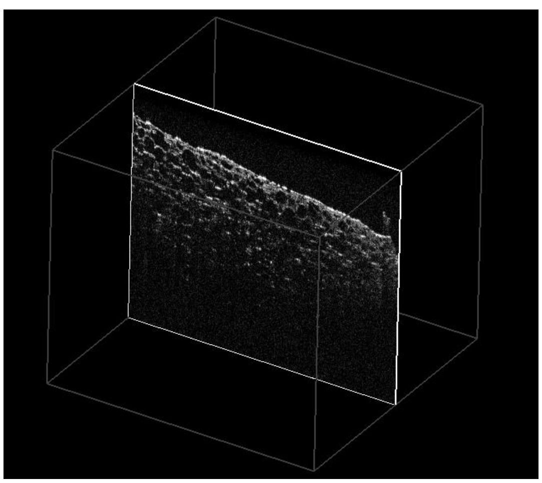

Figure 6 B-scan data set

When scanning both galvanometer mirrors, a volume can be acquired. This can be imaged by movable sections through the volume or by 3D rendering (see Figure 7). Please refer to the SD-OCT Software Manual for all features available.

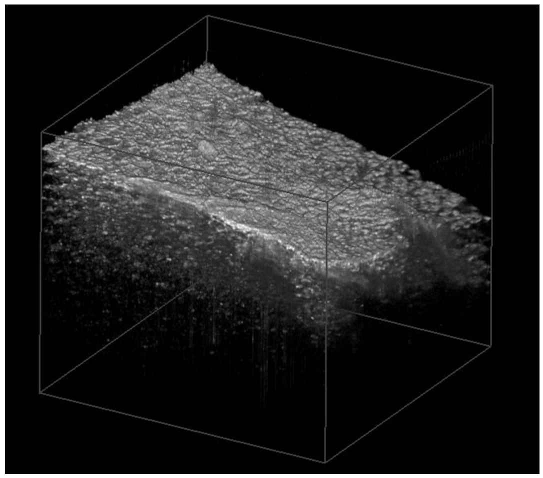

Figure 7 Rendered volumetric data set

When displaying a plane with both scan directions as axes, an en-face image is created. Here, the viewing plane is parallel to the image plane of the color camera inside the imaging probe. This plane is referred to as C-scan.

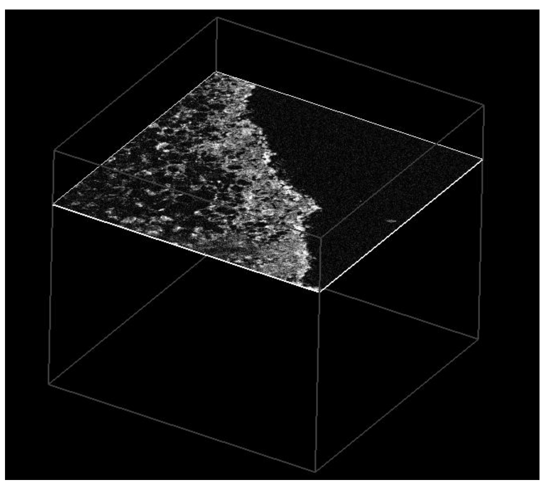

Figure 8 En-Face view or C-scan

2.2. System Components

2.2.1. Packing List

Refer to the packing lists below to ensure that the system is complete. If any item is missing, contact Thorlabs for assistance. Do not use your own spare parts. Please use the appropriate tools when assembling a Spectral Domain SD-OCT system and handle all components of the system with care.

The system is shipped in three carton boxes containing the OCT engine, the computer system and the OCT probe stand

TELESTO II System Box

This box should contain:

Qty	Part
1	OCT Base Unit TELESTO II
1	OCT 3D Imaging Probe LSM03 (1300nm)
1	Distribution DVD -- OCT System Software
1	Manual SD-OCT Software
1	Manual SD-OCT TELESTO II
1	Power Cord ………………….
1	USB-Cable, 2m, A-B, USB 2.0
2	Fuse 2A (T), 5x20mm, Littlefuse 218P
1	Viewing Card for 400-640nm & 800-1700nm
1	connection cable set 2m,NIR-b, Base unit ↔ Imaging Probe
1	Fiber Patch Cord 2m, single mode 1310nm, FC/APC
1	CameraLink Cable 2m
1	Trigger Cable SMB-SMB 2m

Computer Box

This box should contain:

Qty	Part
1	Computer for operating TELESTO II
1	CameraLink data acquisition card
1	Power Cord, for Computer ………………
1	TFT Display for OCT-Computer
1	Power Cord, for TFT Display ………………
1	Dell Tastatur Quietkey USB (……..)
1	Dell Laser Mouse (6 buttons)
1	Cable, Dell

Probe Stand Box

This box should contain:

Qty	Part
1	Baseplate with translation & rotation stage
1	Post
1	Fokus Block
1	Safety Ring
1	1/4"-20 Cap Screw
1	#8-32 Cap Screw
1	3/16" Hex Key
1	9/64" Hex Key

Note: Before operating the system, check to see if any parts have been damaged during transportation. If so, please contact Thorlabs for further assistance.

2.2.2. Base Unit

The base unit is the main component of the SD-OCT system. This unit sends light to the application, communicates with the PC through a USB connection, triggers the camera of the spectrometer and delivers the measurement data to the frame grabber card of the PC via CameraLink interface. The base unit contains two broadband super luminescent diodes (SLD) which are combined by a fiber optic coupler and directed through an optical circulator to the probe port at the backside of the device. The back-scattered and reflected light from the application is returned through the circulator, which directs the light to a spectrometer (as described in Figure 4). Other components in the base unit include a high-speed linear imaging sensor, analog and digital timing circuitry, analog control signals for the application, and data acquisition hardware.

Figure 9 Base Unit

The central wavelength of the SLD in this system is 1310nm. The use of near-IR broadband sources balance the desire for low scattering losses with the need to operate within the wavelength range that will provide higher penetration depth into the sample. Near-IR broadband sources are a perfect compromise between sufficient transparency and a significantly reduced scattering coefficient.

2.2.3. Imaging Probe

Thorlabs SD-OCT systems use a common path OCT setup in which the interferometer is located within the imaging probe (see Figure 10). This integration of the interferometer eliminates the problems associated with chromatic and polarization mode dispersion that are introduced by differences between individual fibers in the sample and reference arms. The imaging probe is equipped with a white light illumination ring.

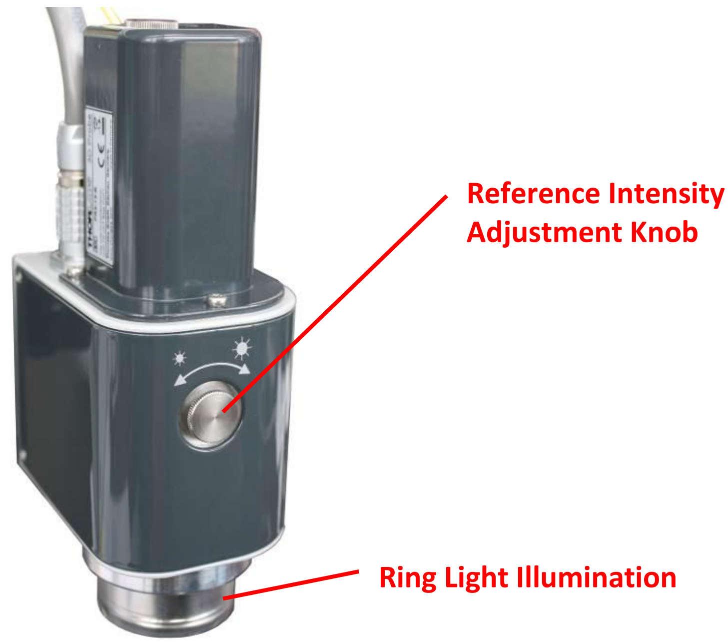

Figure 10 Imaging Probe (front view)

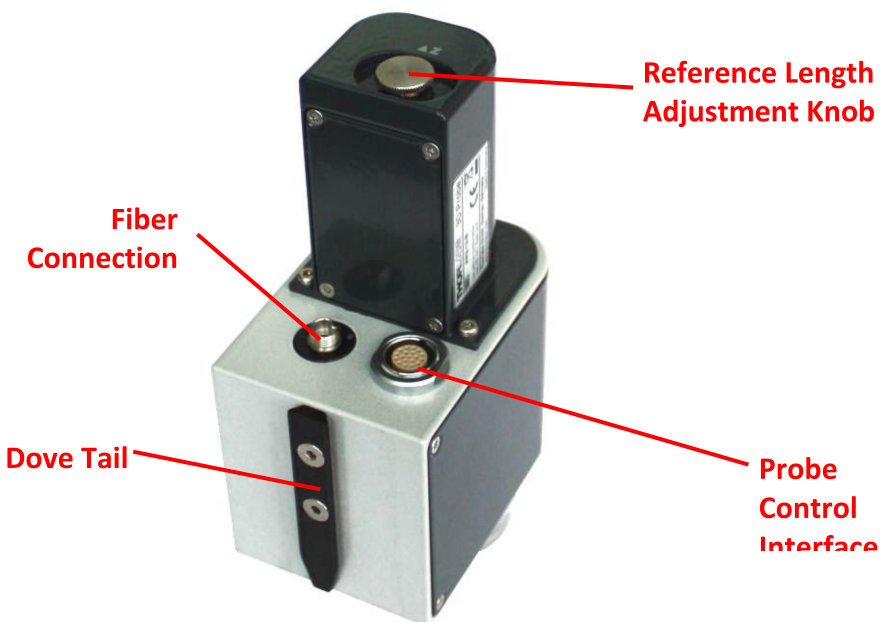

Figure 11 Imaging Probe (rear view)

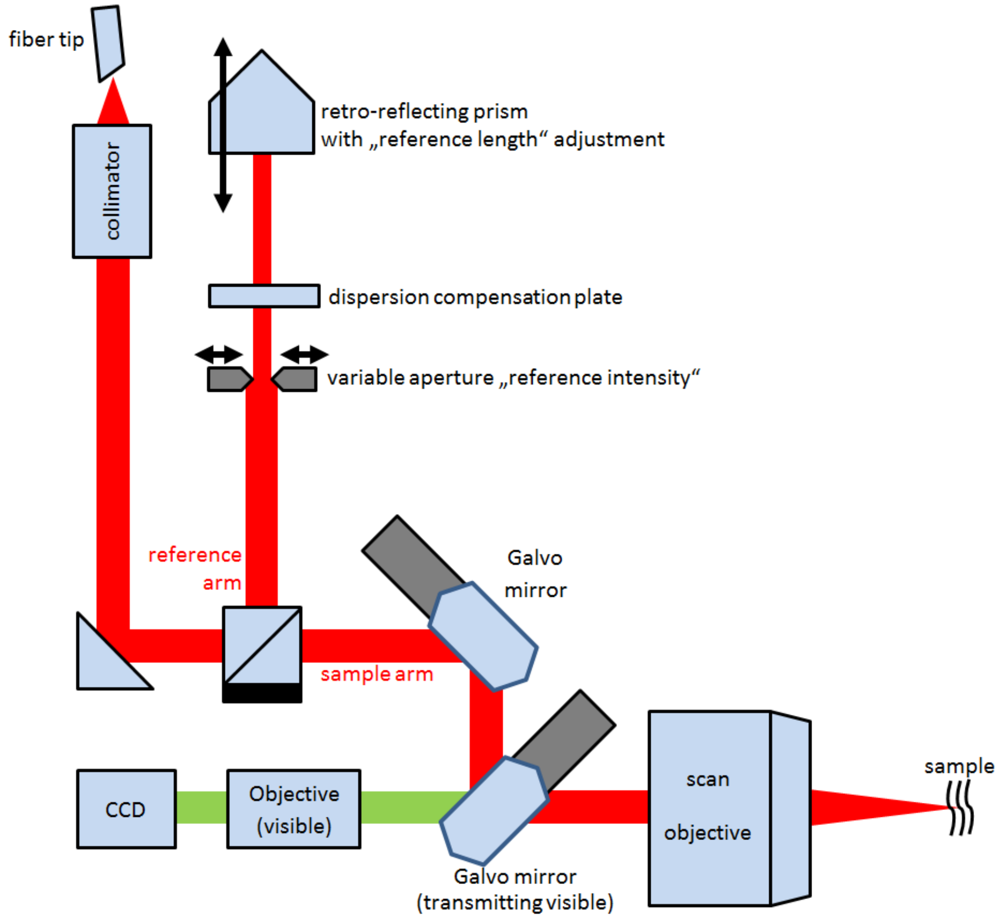

Figure 12 Optical Layout of Imaging Probe

Figure 12 illustrates the optical layout of the imaging probe. The output of an FC/APC fiber is collimated and routed to a beam splitter cube. Here the beam is divided into a sample beam and a reference beam, similar to a Michelson Interferometer. The sample beam is routed over two galvanometer actuated mirrors to allow for scanning in two axes. The scan objective then focuses the beam in the sample. Back-scattered and back-reflected light is collected by the scan objective again and travels back to the fiber. The light reflected into the reference arm is retro-reflected back into the fiber. There is an optimum intensity for the reference light that can be adjusted using the reference intensity adjustment knob which will open or close the variable aperture inside the imaging probe.

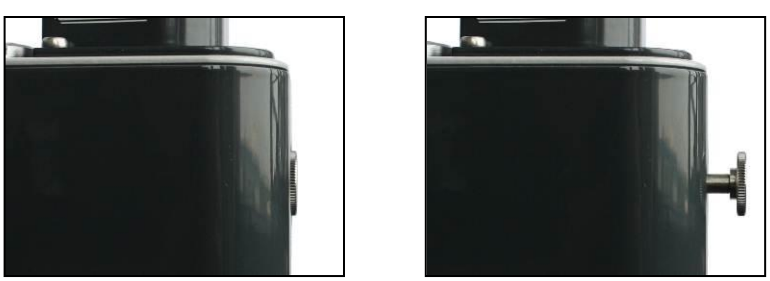

Figure 13 Reference Intensity Adjustment

In order to adjust the reference intensity adjustment knob, pull the knob approximately 5mm outwards (see fig. 10) until you feel the knob coming to a rest. A clock-wise rotation will increase the amount of reference light. As a qualitative indication, observe the reference intensity bar in the OCT software. Please refer to the Software Manual and chapter 5.1 for additional guidance.

The length of the reference arm can be adjusted with the reference length adjustment knob (see Figure 14). Adjustment of the reference length may be done in combination with focus height adjustment (using the OCT stand), so that the focus position in the OCT data is shifted. Also, this adjustment is necessary when imaging in refractive medium.

Figure 14 Reference Length Adjustment

In order to adjust the reference length adjustment knob, pull the knob approximately 5mm outwards (see fig.11) until you feel the knob coming to a rest. A clock-wise rotation will increase the reference length

2.2.4. Probe Stand

The Thorlabs SD-OCT system is shipped with a probe stand. For setting up the probe stand, please consult the instructions that you find in the probe stand box. The probe stand is equipped with a dove tail slide for holding the imaging probe.

Figure 15 Probe Stand with Imaging Probe

The focus block of the probe stand is fixed on the stand by securing the locking handle, while a safety ring prevents the block from falling. Also, this safety ring centers the focus block above the rotation stage. Please refer to the figures below.

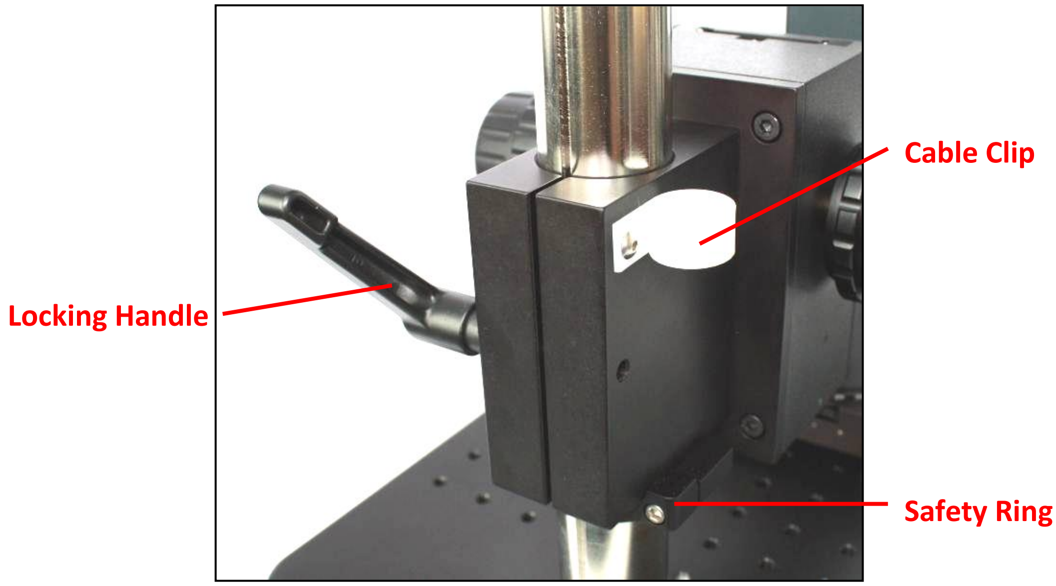

Figure 16 OCT Stand Coarse Adjustment and Cable Clip(rear view)

Finer focus adjustment can be done using the adjustment knobs as depicted in Figure 17.

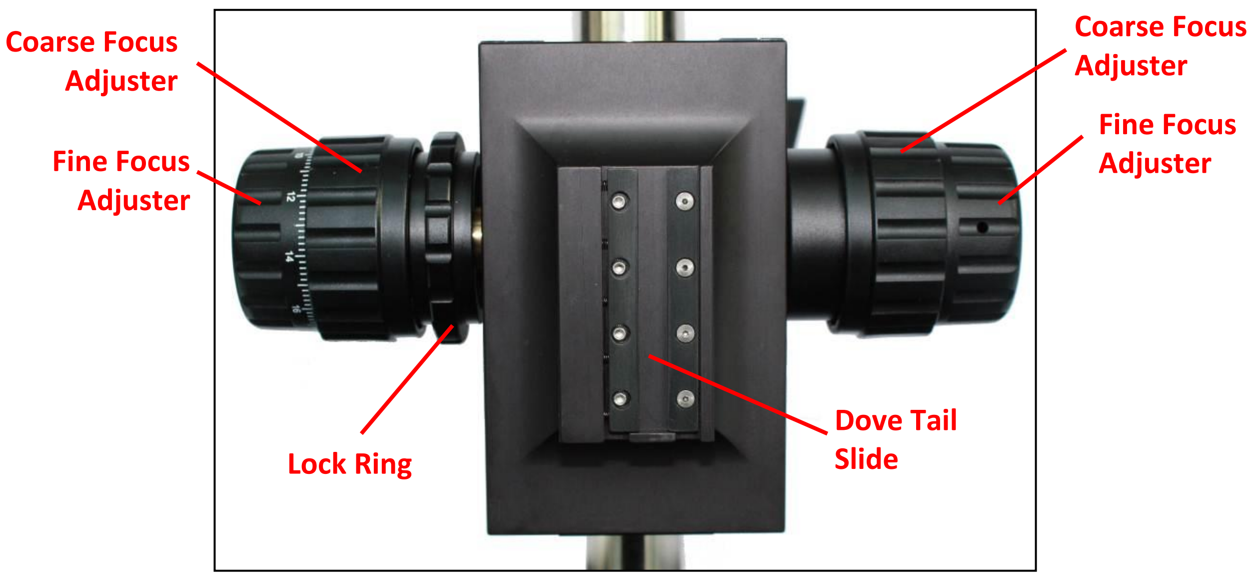

Figure 17 OCT Stand Adjusters and Dove Tail Slide

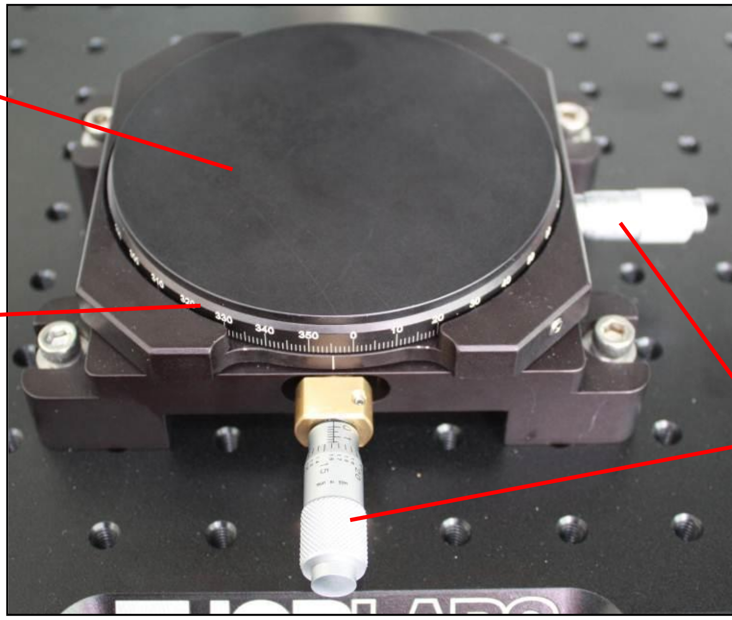

Figure 18 OCT Stand Sample Station

The sample plate of the sample station can be removed by counter-clockwise rotation with the rotation stage underneath being held in place. The bores of the rotation stage underneath allow for mounting of individual sample holders. A drawing of the rotation stage bores is shown in Figure 64.

2.2.5. Graphical User Interface

This SD-OCT system is delivered with application software made for the imaging probes provided by Thorlabs. All required data analysis as well as 2D and 3D display can be performed within the software package. The data can be saved, analyzed and exported for further use.

Detailed operating instructions for the SD-OCT software are provided in the SD-OCT Software User's Manual.

2.2.6. SDK

A software development kit (SDK) is provided with the system. The SDK gives access to all software routines used to control the units and to process the acquired data. It allows a quick start for application specific software development. The SDK is implemented in two programming languages, C and LabVIEW. For professional and advanced users the C interface guarantees a seamless integration into their own object oriented software. For easy access to the functionality we also provide a LabVIEW Interface. The LabVIEW interface has the same functionality as the C interface and maintains the same high processing speed achieved with the C interface.

Hardware control through the SDK ranges from low level functions such as setting the galvo scanners to a desired position, to very powerful functions such as initiating full 3D measurements. The programmer can:

- define either a standard probe provided by Thorlabs or create a software representation of a custom-built probe.
- Define simple or complex scan patterns.
- Acquire simple A-Scans, B-Scans or complete volumetric measurements.

Processing of acquired OCT data ranges from simple A-Scan processing to advanced routines for Doppler speed measurements. The programmer can:

- Take the standard processing steps necessary to convert a spectrum measurement into an A-Scan
- Set the color scheme, brightness and contrast of images
- Calculate the speed of particles in the sample via Doppler OCT
- Import and export the different file formats data types

The function library also contains the source code for the LabVIEW software applications supplied with the instrument and other example programs. Often these can be used as a starting point for software development projects.

The SDK can be installed from the DVD which ships with the system.

A complete documentation of the SDK with a description of all functions can be found in PDF format in the SpectralRadar SDK program group after installation of the SDK.

2.3. Warning Text

Figure 19 Laser Emission Warning Labels

Figure 20 Base Unit Warning Labels

Figure 21 Imaging Probe Warning Label

Part 3. Installation

3.1. Unpacking

Carefully unpack the components from the transport boxes. Make sure that all components are delivered according to the packing list on page 14. Packing lists are also included in every transport box. After unpacking, store the packing cartons and inserts. You may need them in case of a service or upgrade of your OCT system.

3.2. System Connections

Base Unit Connections

All of the base unit connections are located in the rear (see below). Please see Figure 4 on page 11 for a schematic description of the necessary interconnections.

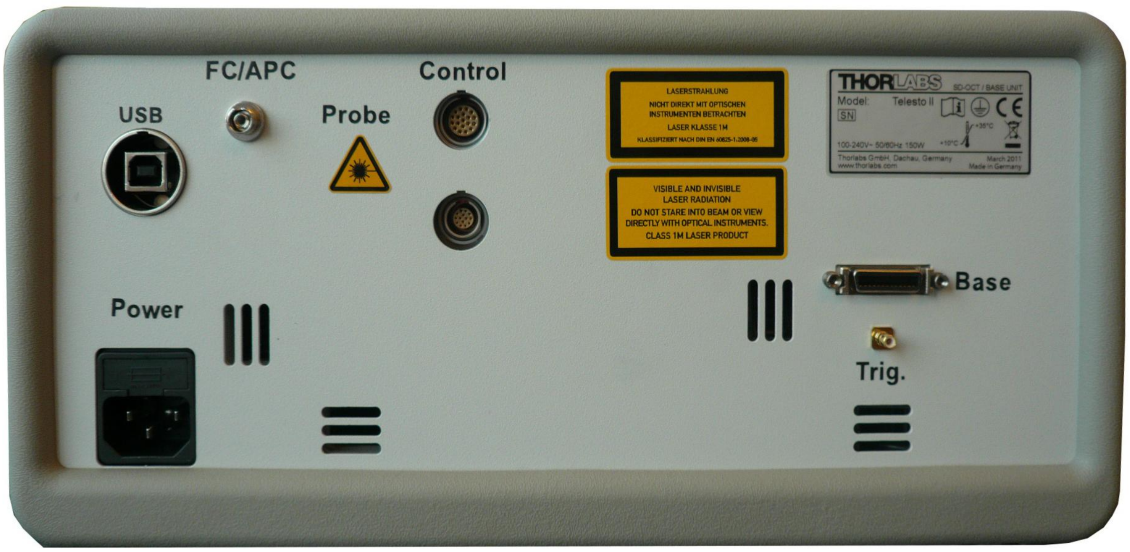

Figure 22 Rear View of Base Unit

From left to right:

- Power Plug
- USB Data Port to Connect PC (USB 2.0 Type B Interface)
- Fiber Plug (FC/APC)
- Probe Connection Port (LEMO, 19 Pin)
- Auxiliary Connection Port (LEMO, 14 Pin) – not used
- CameraLink trigger (SMB)
- CameraLink Base (MDR 26)

Imaging Probe Connections

All of the probe's connections are located on top of the probe (see below). Please see Figure 4 on page 11 for a schematic description of the necessary interconnections.

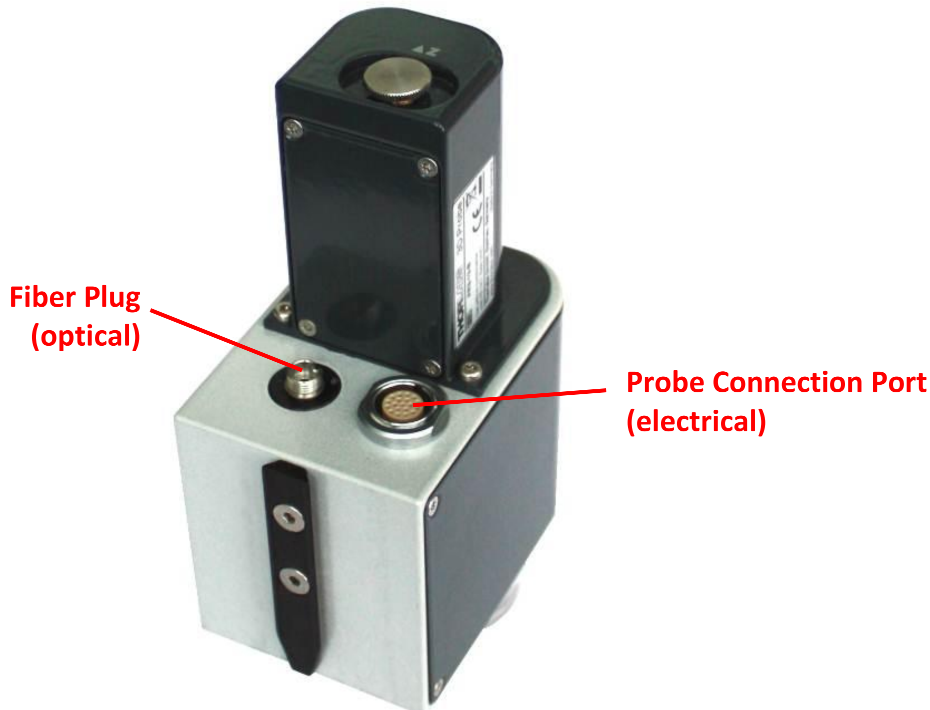

Figure 23 Interconnections of the Imaging Probe

PC Connections

The PC is equipped with a CameraLink frame grabber card, as shown in Figure 24.

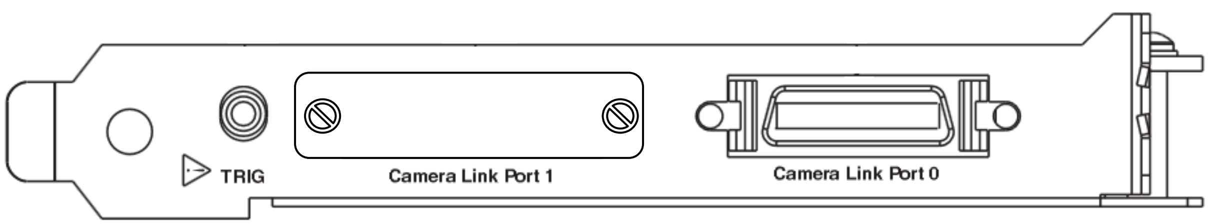

Figure 24 Connections of the CameraLink frame grabber card

- CameraLink trigger connector (SMB)
- CameraLink Port O connector(MDR 26)

For location of USB connectors, Monitor connections and AC plugs, please refer to the hardware manual shipped with the PC system.

3.3. System Installation

ATTENTION

Make sure the included power cords for the base unit, computer and monitor are connected to a properly grounded outlet (100 – 240 VAC; 50 – 60 Hz).

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

Operate this system on a flat, dry, and stable surface only.

1) Install the PC, monitor, mouse and keyboard according to the documentation provided by the PC manufacturer.

2) Assemble the probe stand as described in the documents provided in the probe stand box.

3) Mount the probe in the probe stand by sliding the dove tail (see Figure 11) at the back of the Probe into the dove tail slide (see Figure 17) of the probe stand.

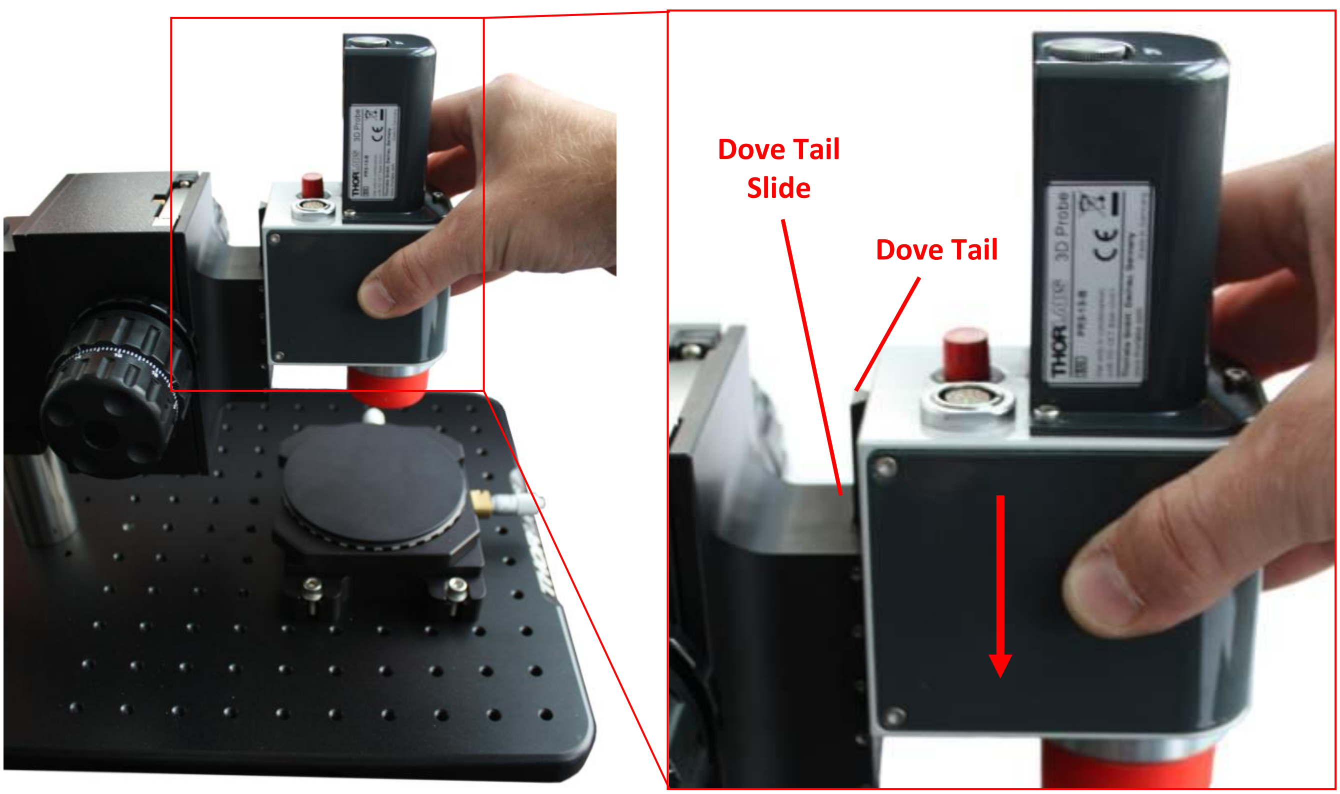

Figure 25 Mounting the Imaging Probe into the dove tail slide of the OCT Stand

4) CameraLink and trigger connections:

Identify the CameraLink frame grabber card connections at the back of the PC (see Figure 26). There are two connectors: one for the trigger cable and one for the CameraLink data connection.

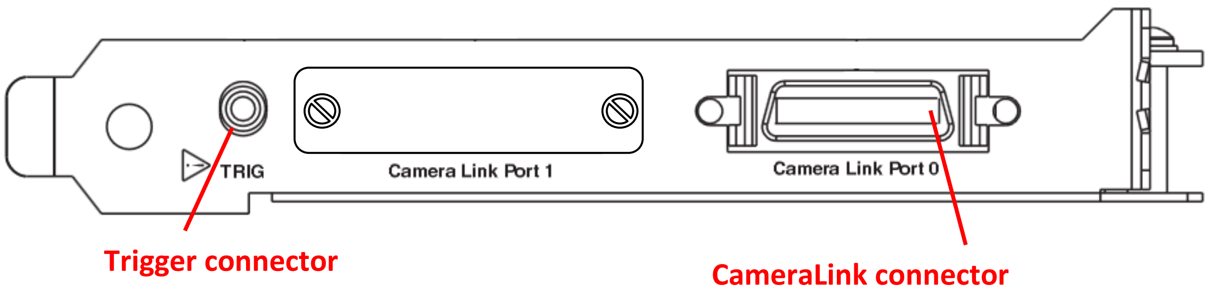

Figure 26 CameraLink frame grabber card inside the PC

Connect trigger and CameraLink data cable to the frame grabber card as shown in Figure 27. Secure the CameraLink plug with the screws attached to the connector.

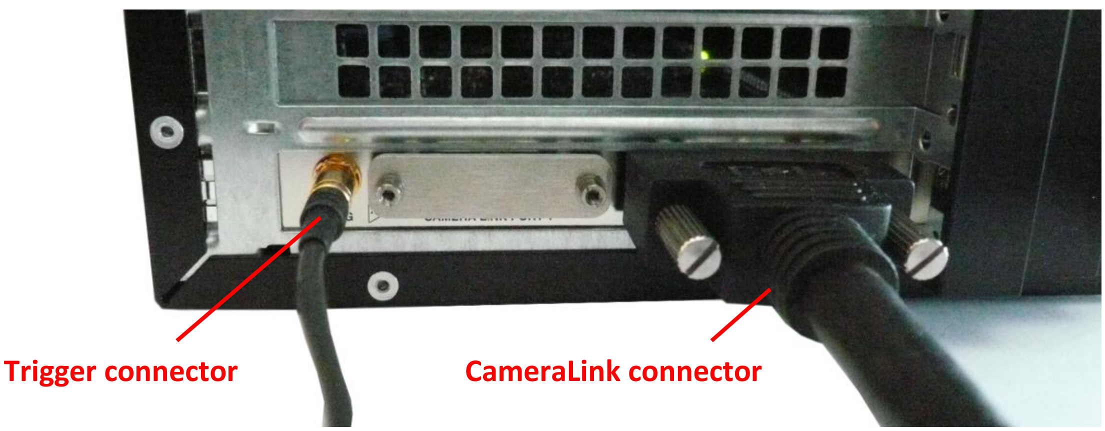

Figure 27 Trigger and CameraLink cable attached to the PC

Attach the Trigger cable to the base unit as shown in Figure 28.

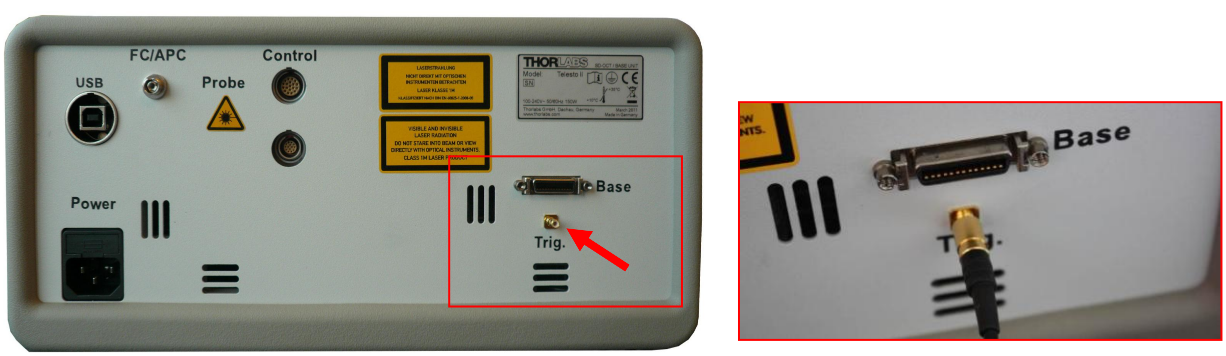

Figure 28 Attaching trigger cable to base unit

Now connect the CameraLink cable to the base unit and secure it.

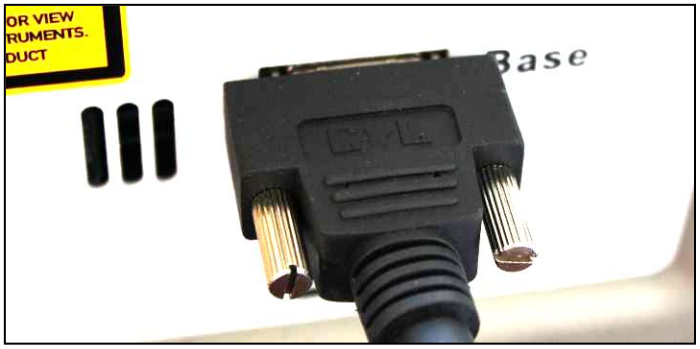

Figure 29 CameraLink cable base unit attached to base unit

5) Attach the USB cable to the base unit and to the PC.

6) Connect the power supply plug to the socket of the base unit and connect the other end to a wall plug.

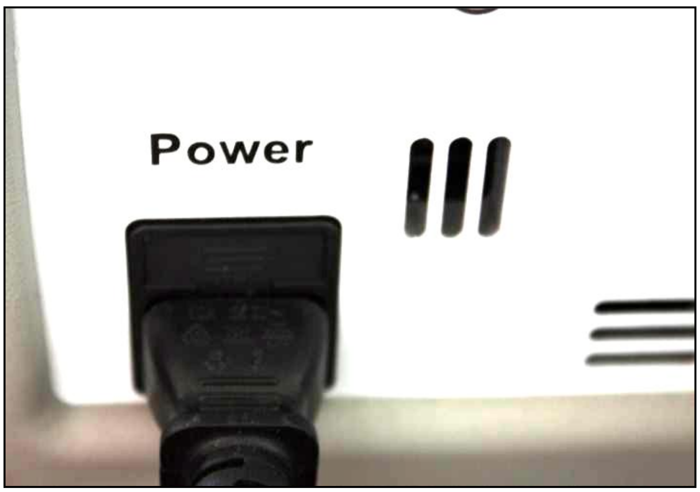

Figure 30 Power Supply Plug connected to the Base Unit

7) Attach the probe cable to the imaging probe.

   You may use either side of the interconnection cable set, which also includes the interconnection fiber (not shown below). Align the red dot of the plug to the alignment mark of the probe connection port.

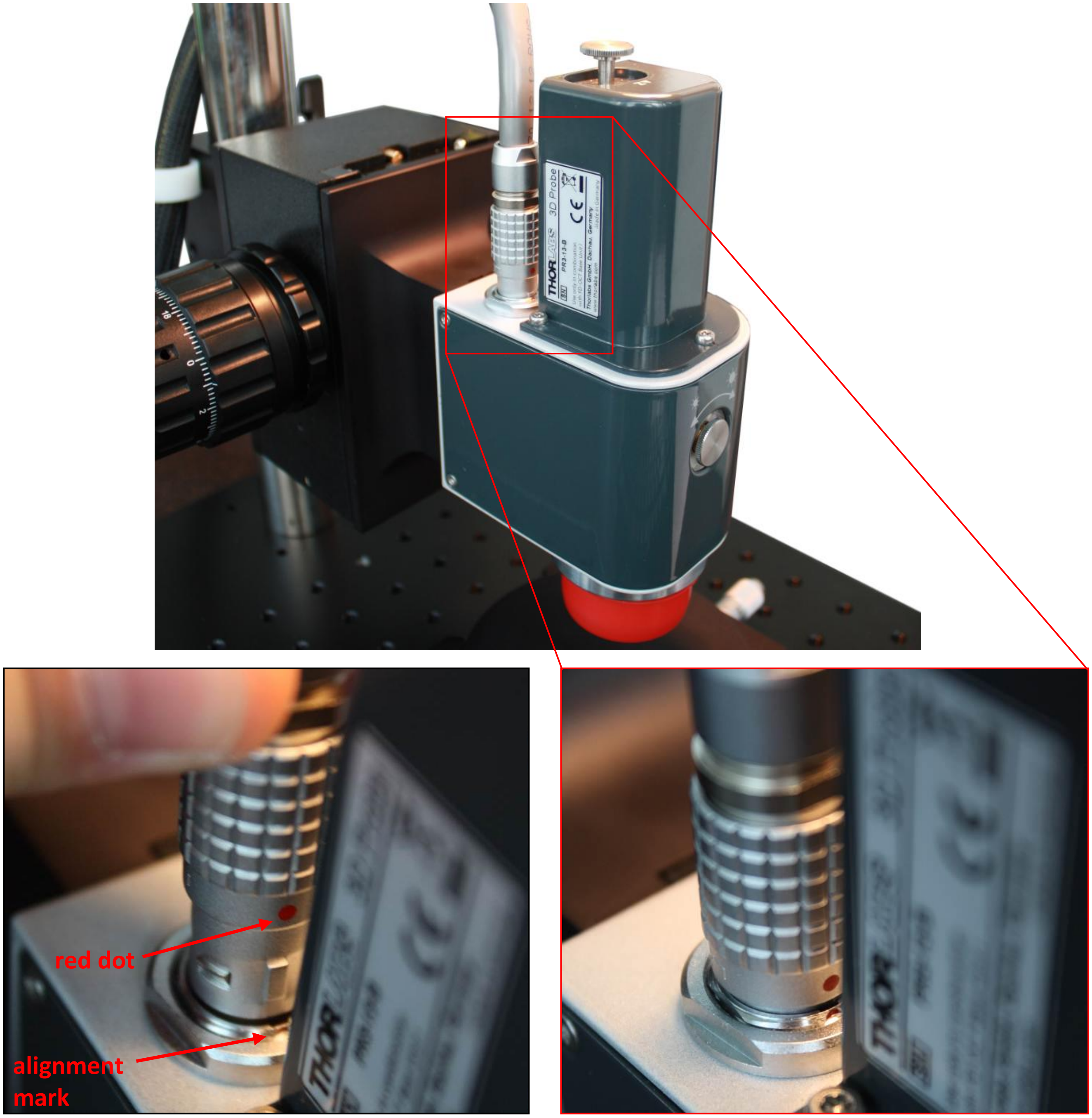

Figure 31 Plugging the probe connector into the imaging probe

Push the connector into the plug until a “click” sound is heard.

8) Fiber connection to the imaging probe

ATTENTION

When installing the fiber, make sure that the fiber tip does not get contaminated by dust. To clean the fiber tip, follow the instructions in chapter 1.2.2

Do not touch the fiber tip!

Remove the dust caps from one fiber end and from the FC/APC fiber connection at the imaging probe. Store these with the system packaging.

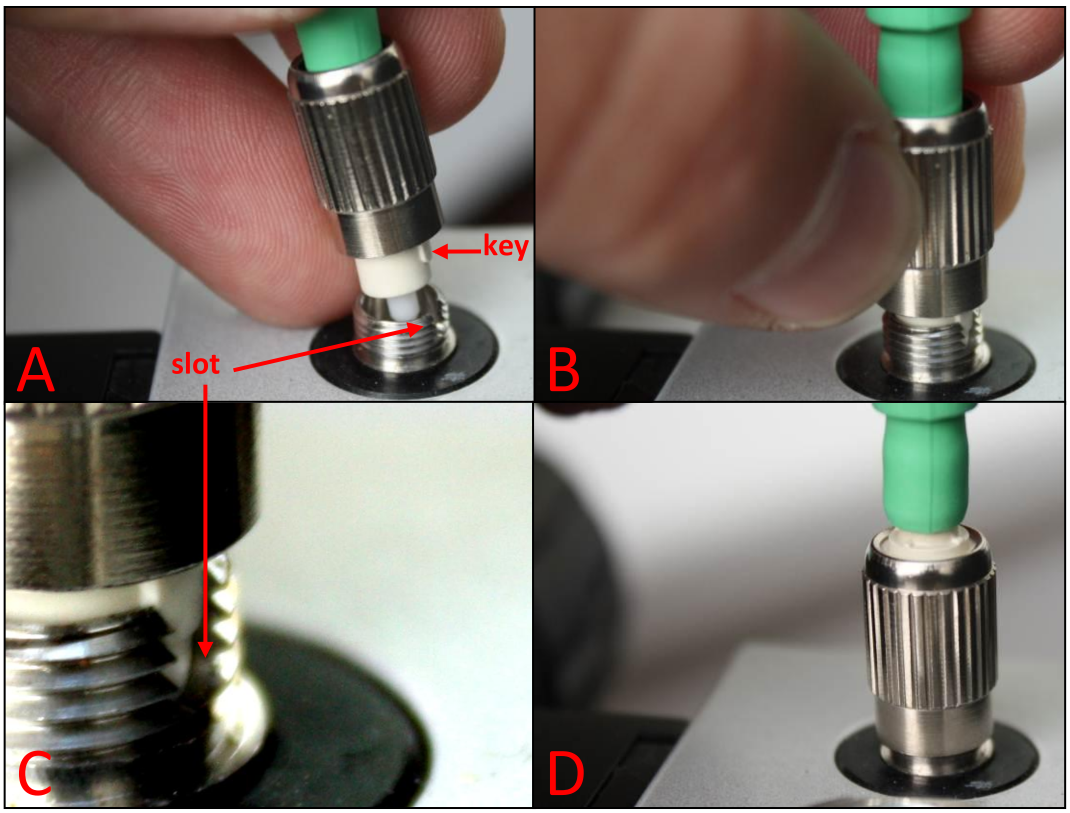

Figure 32 Installation of the fiber at the Probe fiber connector

A) Slide the fiber tip into the center bore of the fiber connection.

B and C) The fiber needs to be oriented in rotation, so that the alignment key slides into the mating part of the probe connector as show in Figure 32C.
NOTE: If the key is not properly aligned with respect to the slot, you will still be able to secure the fiber but there will be significant light loss produced by this incorrect connection. Also, the OCT focus position is affected by this.

D) Secure the fiber connection by turning the lock cap clockwise. No force is needed for this operation.

Attach the remaining plug of the probe connection cable to the base unit. The probe connection is located at the rear of the base unit. For installation, align the red dot upwards, facing the alignment mark in the base unit. Push the connector into the plug until a “click” sound is heard. After installation, the connector should be locked.

Figure 33 Installing the probe connection at the base unit

9) Fiber connection to the base unit.

ATTENTION

When installing the fiber, make sure that the fiber tip does not get contaminated by dust. To clean the fiber tip, follow the instructions in chapter 1.2.2

Do not touch the fiber tip!

Remove the dust caps from the fiber end and from the FC/APC fiber connection at the base unit.

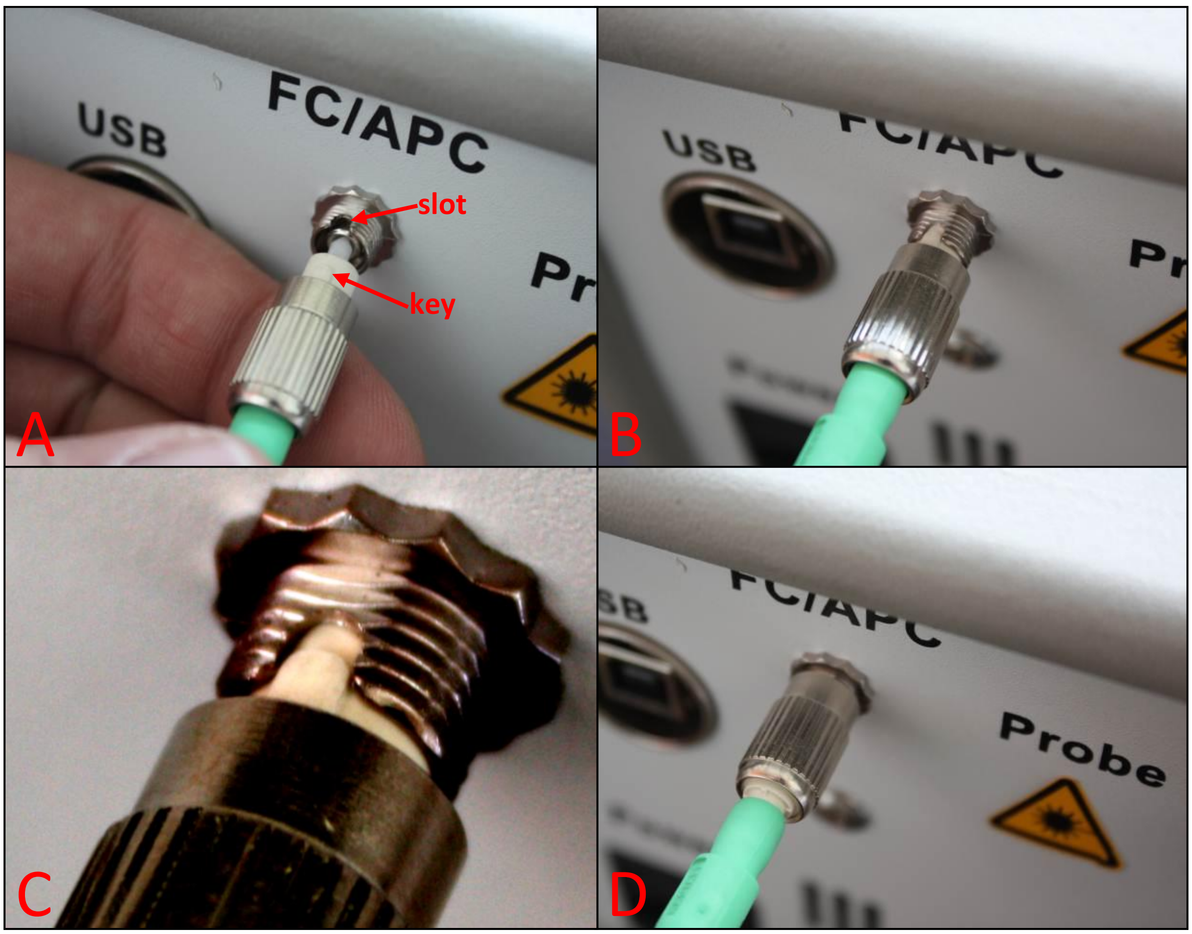

Figure 34 Installation of the fiber at the base unit Connector

B) Slide the fiber tip into the center bore of the fiber connection.

B and C) The fiber needs to be oriented in rotation, so that the alignment key slides into the mating part of the probe connector.
NOTE: If the key is not properly aligned with the slot, you will still be able to secure the fiber but there will be significant light loss produced by this incorrect connection.

D) Secure the fiber connection by turning the lock cap clockwise. No force is needed for this operation.

ATTENTION

The fiber is slightly longer than the interconnection cable to avoid stress to it. Please be careful not to pull the loop of the fiber at the back of the base unit!

Figure 35 Fiber loop at the base unit

10) Pull the protection cap off the scan objective

Do not rotate the protection cap, as this might loosen the fit of the illumination tube.

Figure 36 Protection Cap Removal

Part 4. System Operation

4.1. *Starting the System*

Follow these steps for proper initialization of the system:

1) Start the base unit by placing the POWER switch to the "|" Position. Verify that the "POWER ON" indicator turns green. Wait for 30 seconds until the PC has recognized the hardware.

2) Start the Thorlabs SD-OCT software (see Software User's Manual for details). The system will be switched on via remote control from the computer. After starting the user software, the green "SYS OK" LED on the base unit will illuminate.

3) After loading the program, the software performs a warm up and initial calibration procedure. During the warm up, the system performs a dark current measurement. Next, the light source is switched on ("SLD ON" LED will illuminate) and stabilized with respect to temperature and the related performance parameters. The warm up takes approximately 10 seconds to complete.

4.2. *Basic Adjustments*

When receiving the SD-OCT system from Thorlabs, the reference length is adjusted, so that OCT imaging in air is possible simply by adjusting the focus right. Once the probe is significantly misadjusted, the following procedure will aid you to a good basic adjustment.

4.2.1. Adjusting the Focus

For adjusting the focus, place a suitable sample, for example the IR viewing card delivered with the system, underneath the probe. Using the OCT software, a fraction of the card can be seen. Now adjust the height of the imaging probe with respect to the card by adjusting the focus block of the probe stand (see Figure 16 and Figure 17).

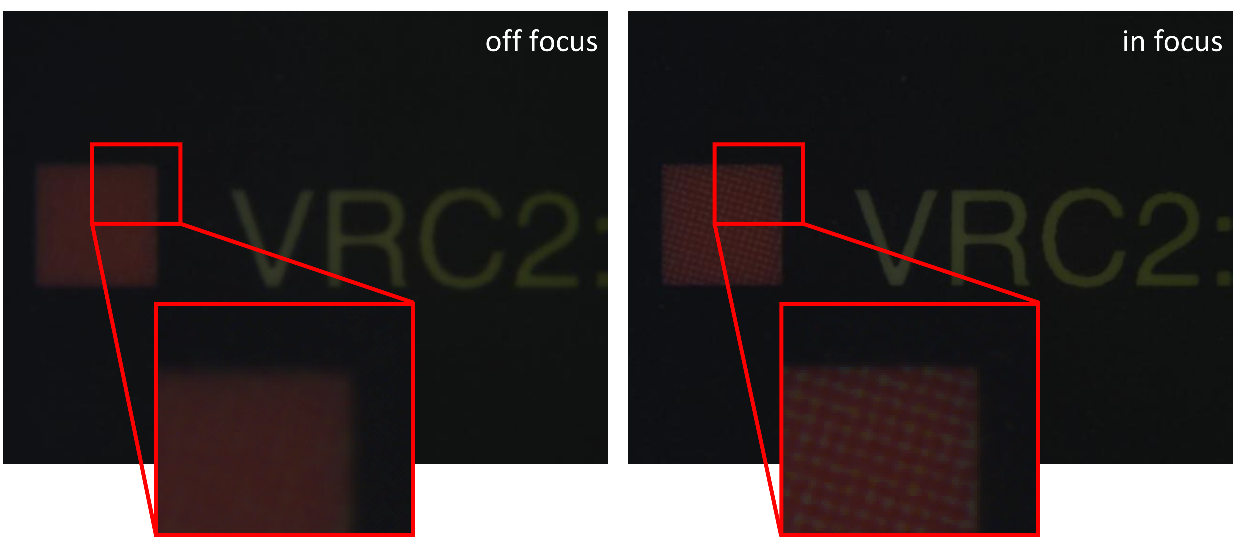

Figure 37 Basic focus adjustment

4.2.2. Adjusting the Reference Intensity

For optimum imaging quality it is necessary to ensure that the reference intensity is set into the correct range. The reference intensity is displayed by the SD-OCT software, as shown below. For optimizing the reference intensity pull out the reference intensity adjustment knob (see Figure 13). Clockwise rotation will increase the reference intensity.

After start of B-scan acquisition, the reference intensity is displayed in the upper portion of the imaging software.

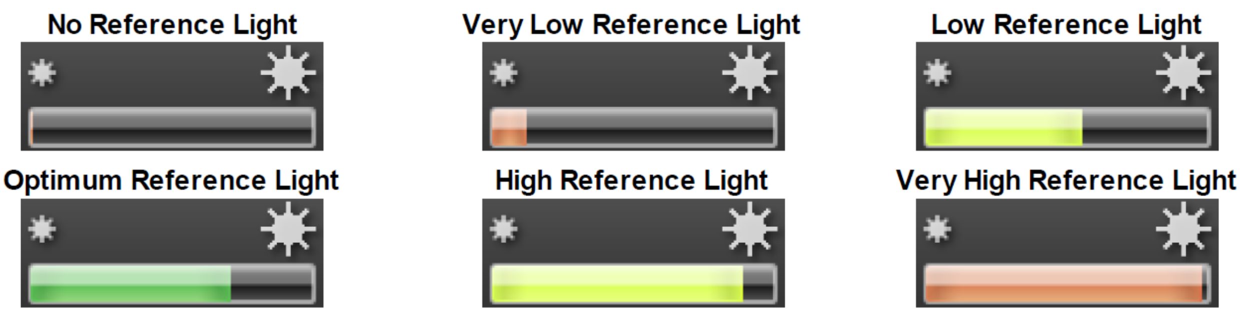

Figure 38 Different states of reference intensity adjustments

4.2.3. Adjusting the Reference Length

The following steps will guide you to a basic adjustment of the reference length:

- Start B-scan acquisition. When significantly misadjusted, you will get an incorrect OCT image.
- Turn the reference length adjustment knob (as shown in Figure 14) on the imaging probe **counter-clockwise**, until the force needed for turning significantly increases.
- Now slowly turn the reference length adjustment knob clockwise until you see the signal from the sample coming into the displayed B-scan from the bottom.
- Hit the auto-adjust button (see Software Manual) to adjust the dynamic range of your B-scan
- When using the IR card for adjustment, your B-scan image should look as shown in Figure 39.

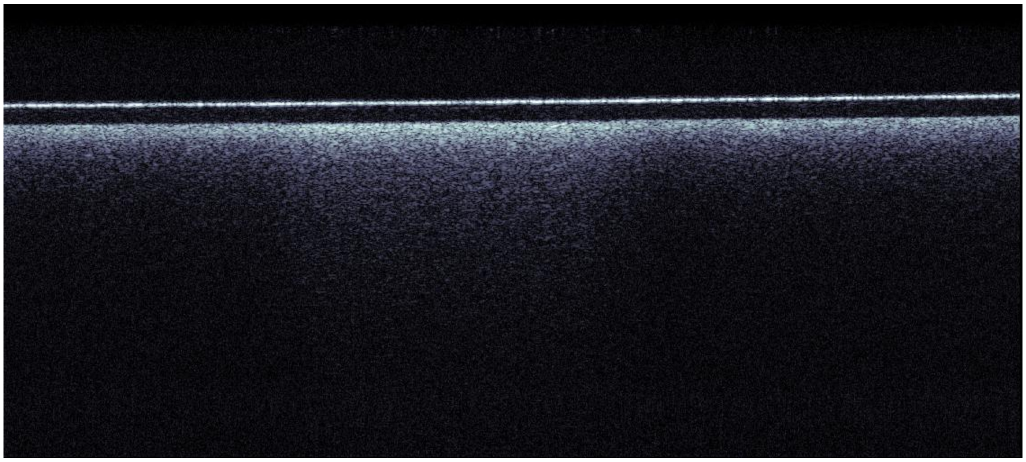

Figure 39 B-scan of an IR viewing card

After basic alignment, you need to adjust the focus position inside your sample by use of the fine focus adjuster (see Figure 17) of the probe stand. Then, the final position of the OCT image in the B-scan or volume can be set using the reference length adjustment knob, which will move the image up and down until you achieve desire location.

4.3. Shutting Down the System

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

1) Save any important data.
2) Close the Thorlabs software.
3) Shut down the PC.
4) Turn the power switch on the base unit to “0”.

4.4. Example Images

Spectral Domain OCT can be used for a wide range of real-time monitoring applications in biological and clinical fields as well as in manufacturing and materials science. This technology is ideal for in-line industrial imaging applications ranging from laminated packaging films to 3D visualization of mechanical parts.

Skin Imaging

SD-OCT provides real-time high resolution surface and sub-surface imaging of human skin, making this system ideal for many dermal and sub-dermal applications, including burn-depth monitoring, wound healing, and cancer detection.

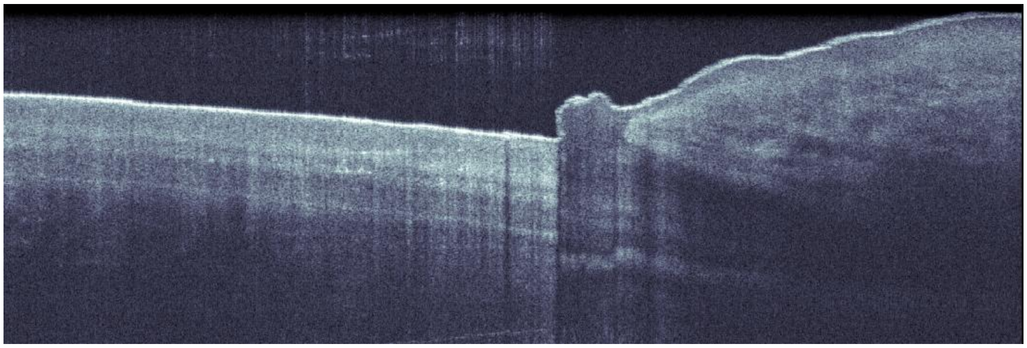

Figure 40 B-scan of a nailfold, imaged at 28kHz A-scan rate

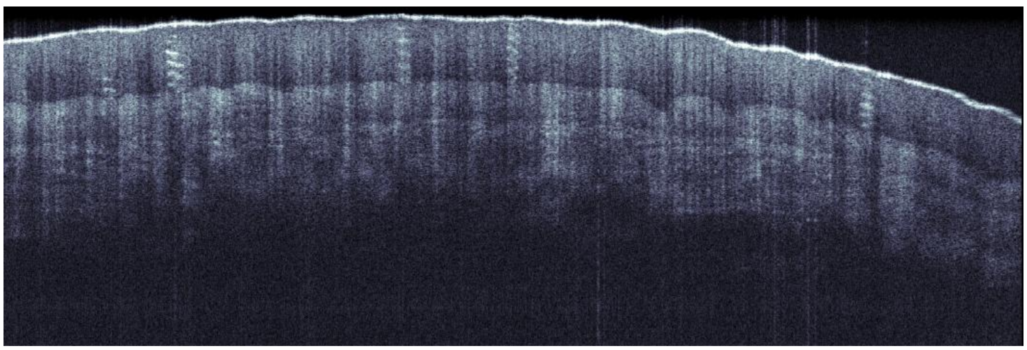

Figure 41 B-scan of a fingertip, imaged at 28kHz A-scan rate

Material Imaging

SD-OCT can also be used for non-biological material science applications. SD-OCT is ideal for monitoring surface topography and layered structures.

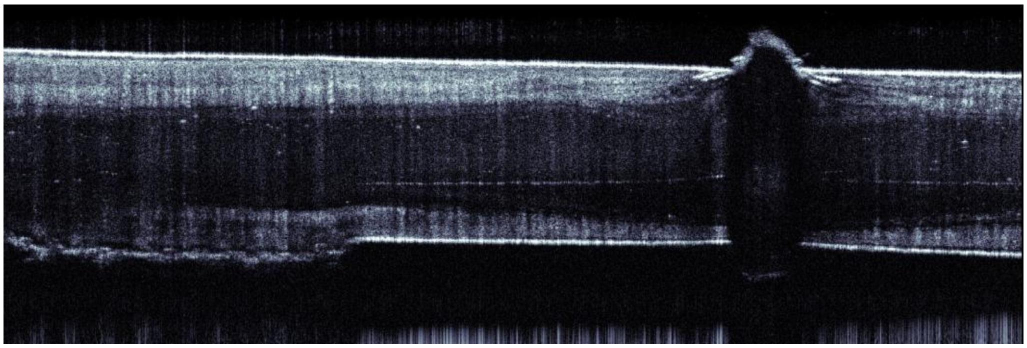

Figure 42 B-scan of a semi-transparent molded plastic cap

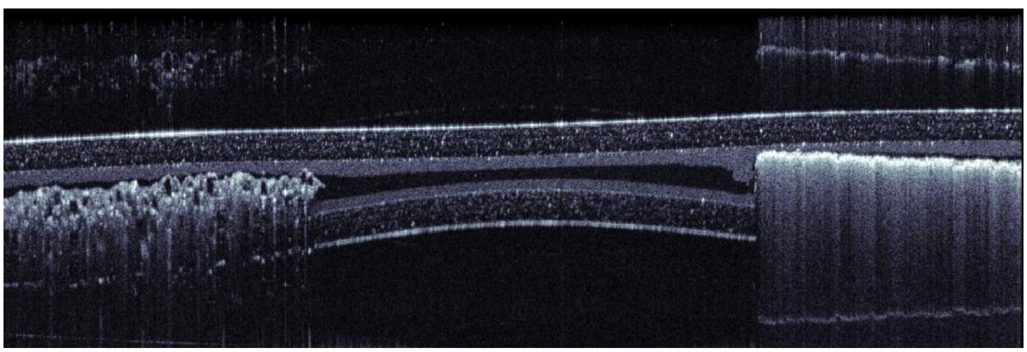

Figure 43 B-scan of a laminated IR card (not included)

Biological Imaging

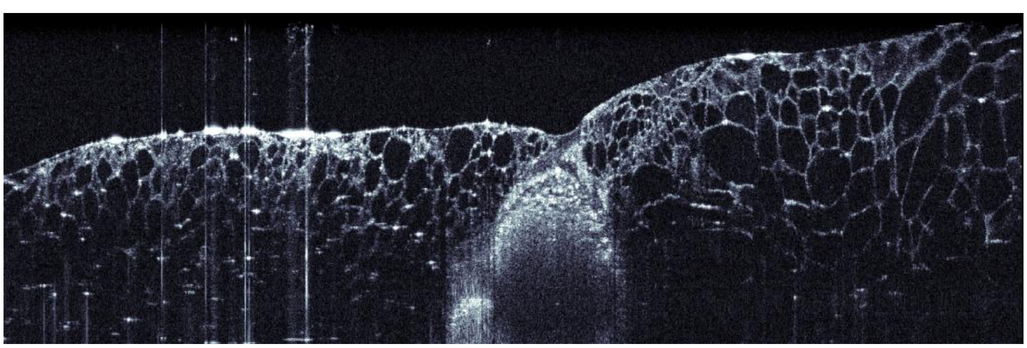

Figure 44 B-scan of a section of a grape

Part 5. Imaging Artifacts

5.1. Saturation and Non-Linearity

The OCT A-scan data is created by frequency analysis of the spectral data generated by the spectrometer. Intense reflection from the sample can saturate the sensor of the spectrometer or illuminate very close to saturation. This effect broadens the signal and leads to a nonlinear response. For example, a sinusoidal optical signal is interpreted as partially rectangular. Consequently, additional harmonic frequencies of the root signal appear.

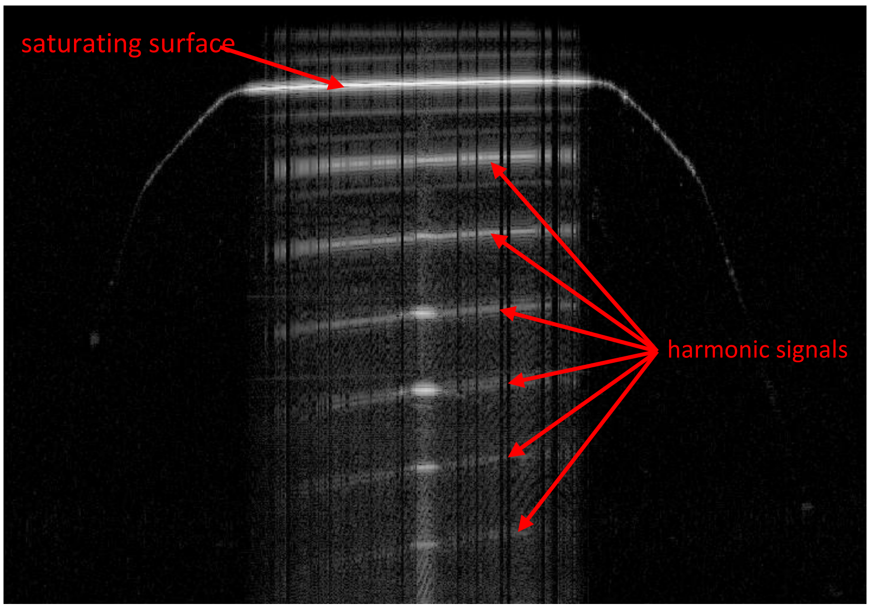

Figure 45 High surface reflection causing saturation and nonlinear response of the spectrometer

A typical example of this effect is shown in Figure 45. Saturation can be reduced or avoided by:

- increasing A-scan rate (see software manual for details)
- changing focus position
- tilting the sample with respect to the A-scan axis
- introduction of a wedge into the optical path (first reflex reflecting outside of NA) and immersion (see Figure 46)

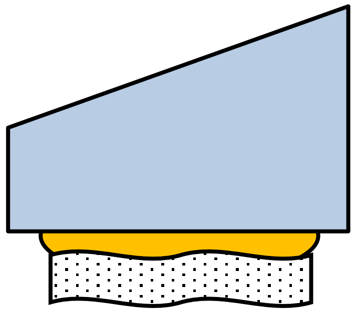

Figure 46 Avoiding strong surface reflection by use of an immersed wedge

When operating with a wedge, the image will be tilted in the direction of the wedge angle. When scanning in the orthogonal direction, no tilt occurs.

5.2. Wrong Reference Intensity Setting

The OCT image is created by interferometry as shown in Figure 12. For good image acquisition the intensity of the reference light needs to be well above noise level and well below saturation. In the SD-OCT software a colored bar indicates if the reference intensity is set properly. For adjustment of the reference intensity, please refer to chapter 2.2.3. Especially when changing the integration time of the spectrometer (or A-scan rate respectively) the reference intensity needs to be adjusted.

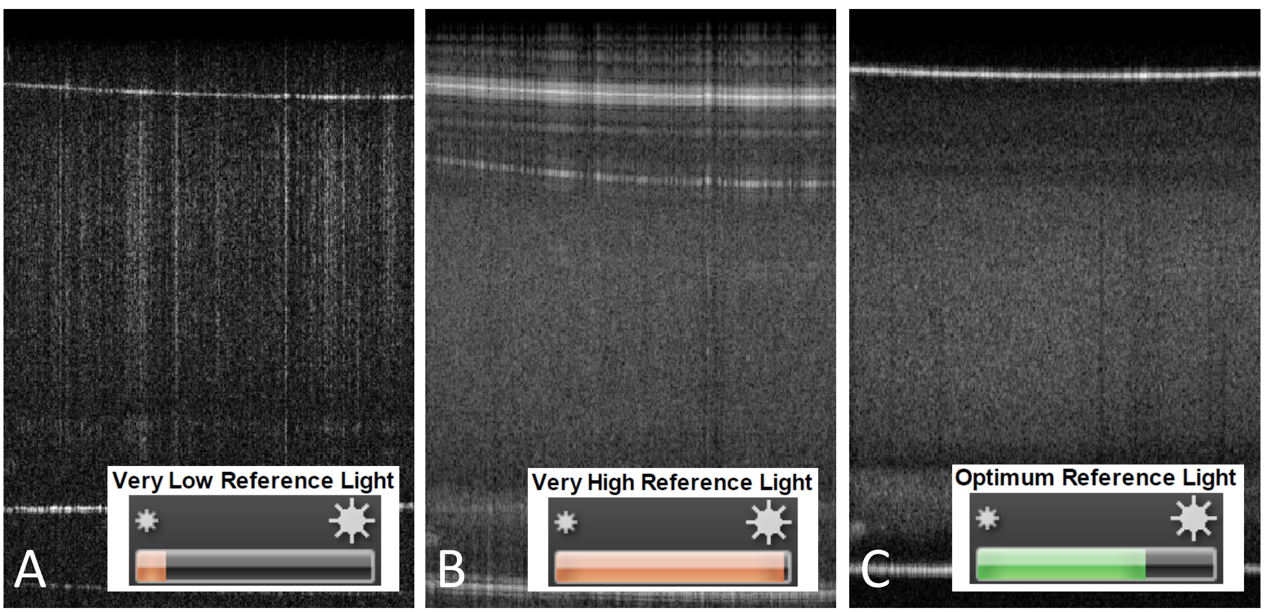

Figure 47 OCT images acquired with low (A), high (B) and good (C) reference intensity setting

With low reference intensity (see picture Figure 47A), the image becomes very noisy and auto-interference is strong compared to the signal intended (frequent issue when doing thickness measurement of reflecting films). High reference intensity (see picture Figure 47B), causes saturation and loss of information.

5.3. Auto-Interference

The fundamental principle of SD-OCT is a frequency analysis of an interference signal entering the spectrometer. In the usual case this interference signal is created by photons returned from the sample interfering with photons returned from the reference arm.

In case a sample has at least one highly reflecting surface, the reflex off this surface can interfere with other photons returned from the sample. The OCT engine cannot distinguish between interference created in respect to the reference arm and interference created within the sample. Figure 48 shows the B-scan of a sample (laminated foils).

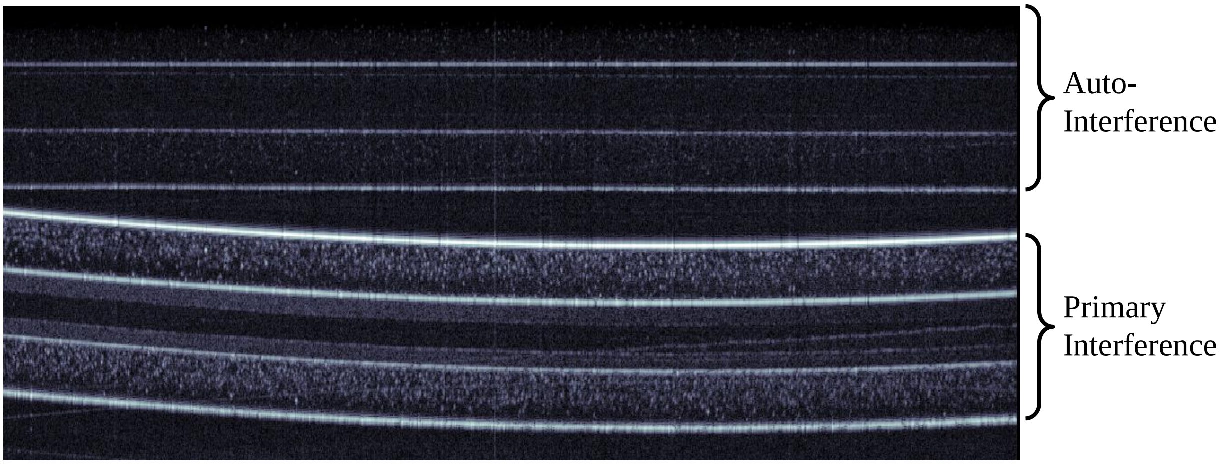

Figure 48 Auto-interference from a highly reflective sample in a B-scan

When blocking the reference arm – by turning the reference arm intensity knob counter-clockwise - the signal caused by auto-interference remains in the B-scan, while the primary interference signal disappears. This is shown in Figure 49.

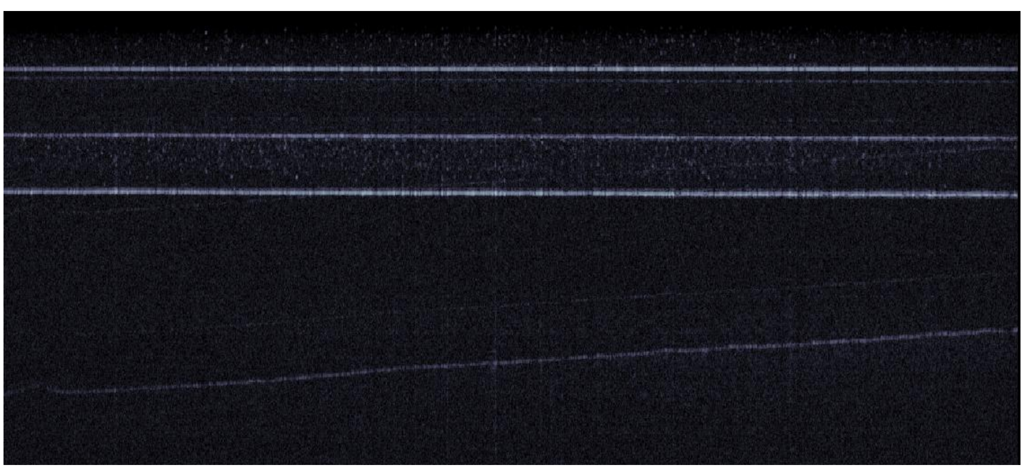

Figure 49 Auto-interference with the reference arm of the imaging probe deactivated

For thickness measurement of foils or related features, the auto-interference can be a wanted feature. For avoiding this effect, proper index matching (see Figure 46) or tilting of the sample is suggested.

5.4. Multiple Scattering

When imaging highly scattering material, a large portion of the photons returned to the detection system have been scattered multiple times from travelling into the sample until exiting. Since OCT visualizes relative travelled path lengths of photons, signals from multiple scattered photons are shown deeper in the image than physically present.

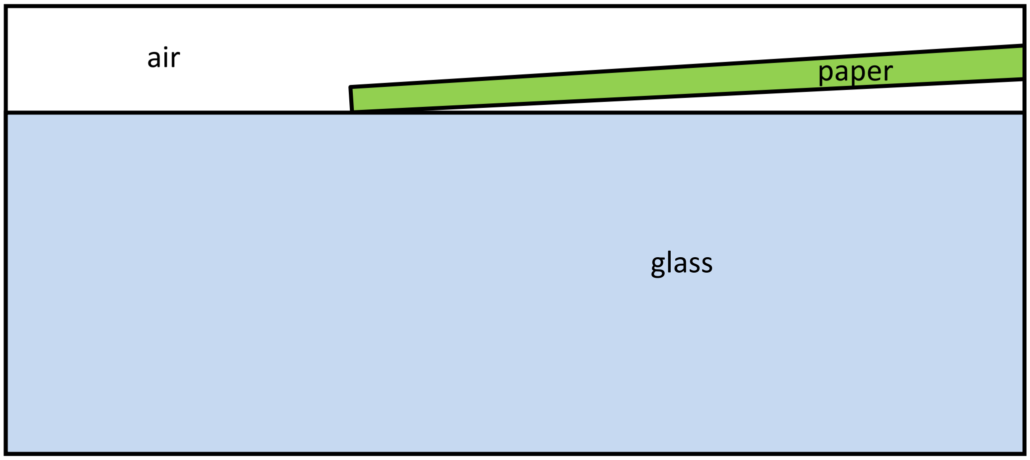

Figure 50 Schematic of a setup to show the influence of multiple scattering

Multiple scattering is intense in paper. For illustration of this artifact, a setup as depicted in Figure 50 is imaged. Here, a piece of paper is placed over a glass substrate.

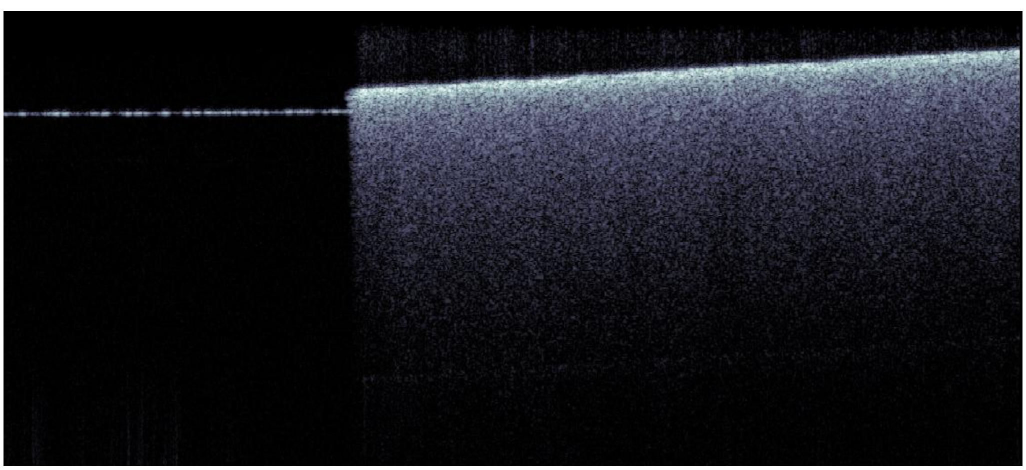

Figure 51 OCT image showing multiple scattering

In the OCT image (see Figure 51), one can clearly see that the paper appears to be very thick. This apparent thickness is induced by the relatively long travel of photons that are scattered multiple times before finding their way back into the detecting aperture.

5.5. Phase Wrapping and Fringe Washout

The A-scan data created by the SD-OCT system is produced from spectral information of an optical interference. Depending on the system setting, a certain integration time is applied for acquisition of each A-scan. Certain movement of the sample or parts of it can well be detected by comparing the phase information of adjacent A-scans. This Doppler Imaging mode is provided by the SD-OCT Software (please refer to the SD-OCT Software Manual for details). Sample movements of more than ¼ of the detected wavelength λ (from A-scan to A-scan) lead to misleading results. The maximum detectable speed (in direction of the A-scan axis) is

$$v_{\max} = f \cdot \frac{\lambda}{4}$$

For an A-scan rate of f = 92 kHz at 1.3µm, the maximum detectable speed v (in the direction of the A-scan axis) is 30mm/s. When the direction of the movement occurs at an angle with respect to the A-scan axis, larger speeds can be imaged.

For larger movements within the integration time of the detector, a complete washout of the interference will appear.

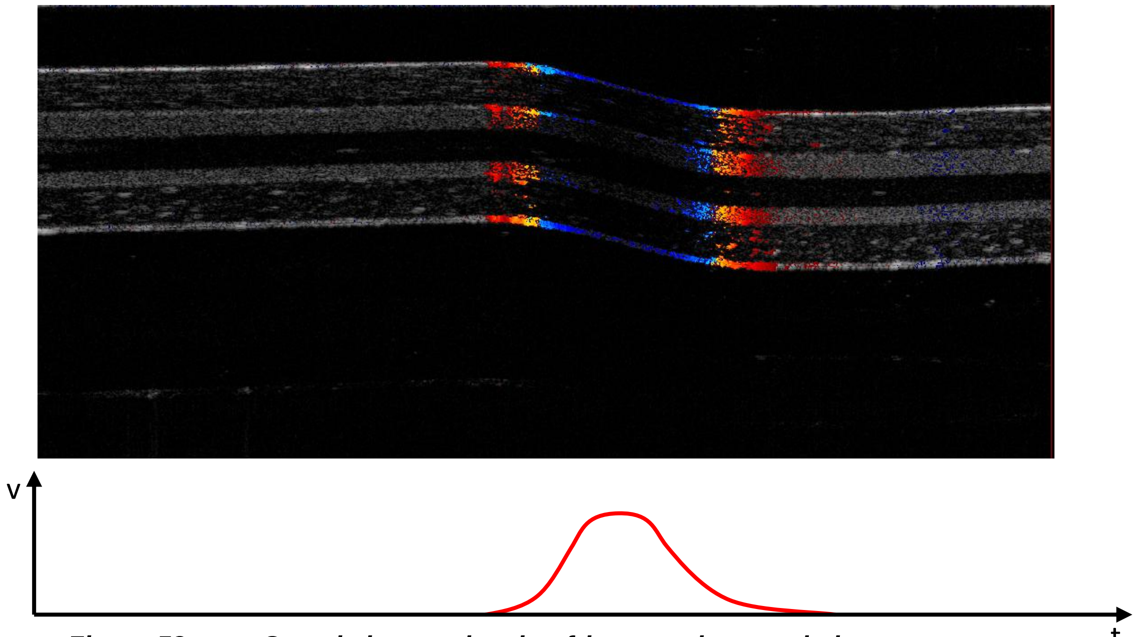

Figure 52 Sample image showing fringe washout and phase wrapping

To illustrate these effects, a sample has been moved quickly while slowly acquiring a B-scan. Figure 52 shows the result. The intensity data is shown in black and white, while the Doppler information is displayed red to blue. When the movement starts, the Doppler information is displayed red which means that the sample moves down. Now at increasing speed, the Doppler information turns blue. This means that the phases of the signal have wrapped and an inverse speed is shown. In the middle of the movement where the speed is at its maximum almost no OCT data is displayed (fringe washout).

5.6. Flipped Image

Without the introduction of additional techniques not provided by the standard SD-OCT system, there is no distinguishing between photons that traveled a distance Δd shorter or longer from the beam splitter to the sample compared to the reference arm length. When adjusting a too short reference length, the image appears flipped.

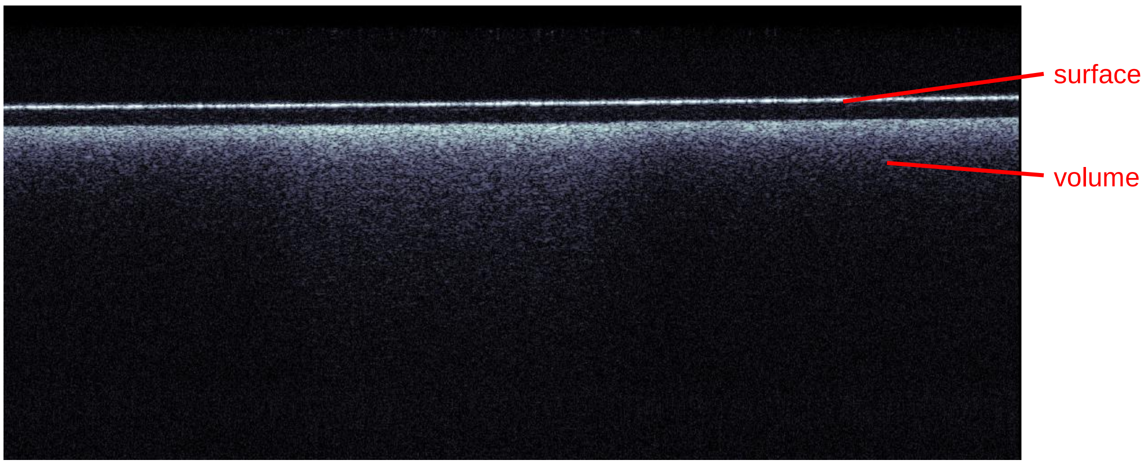

Figure 53 Correct reference length adjustment for imaging of an IR card

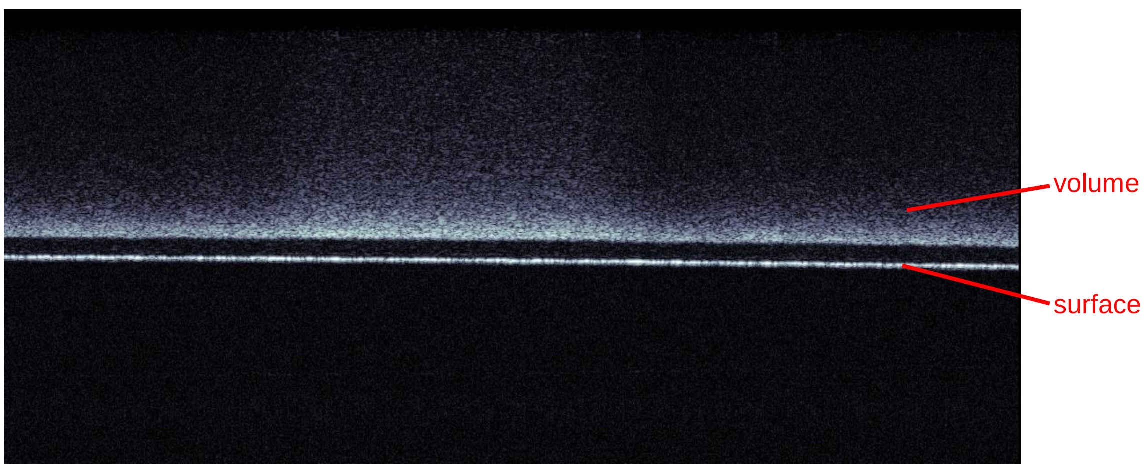

Figure 54 Incorrect reference length adjustment showing a flipped image

Figure 53 and Figure 54 show correct and incorrect adjustment of the reference length when imaging the IR viewing card provided with the system.

5.7. Shadowing

Since the SD-OCT imaging uses light for detection of depth information, one can only see information from regions in the sample, where photons are transmitted to and allowed back into the sampling aperture. Reflections, strong scattering and absorption lead to shadows in the depth distribution of the data acquired.

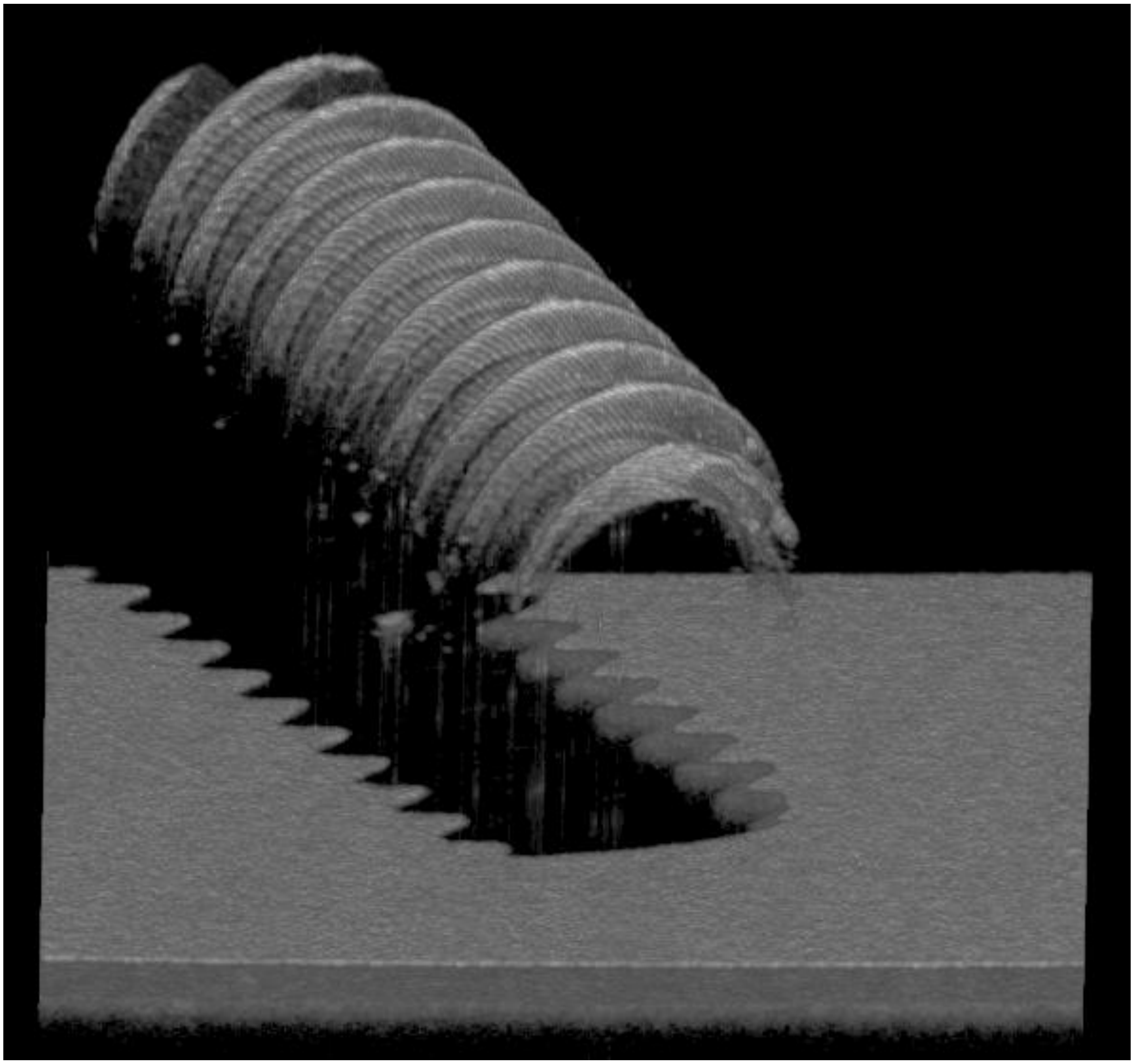

***Figure 55** Rendered volume of a screw on top of an IR viewing card displaying the shadowing effect*

5.8. Image distortion by Refractive Media

OCT images display path length differences in between reference arm length and sample arm length (distance from the beam splitter to the scattering or reflecting object). These path lengths are optical path lengths, calculated from the physical path length multiplied by the group refractive index.

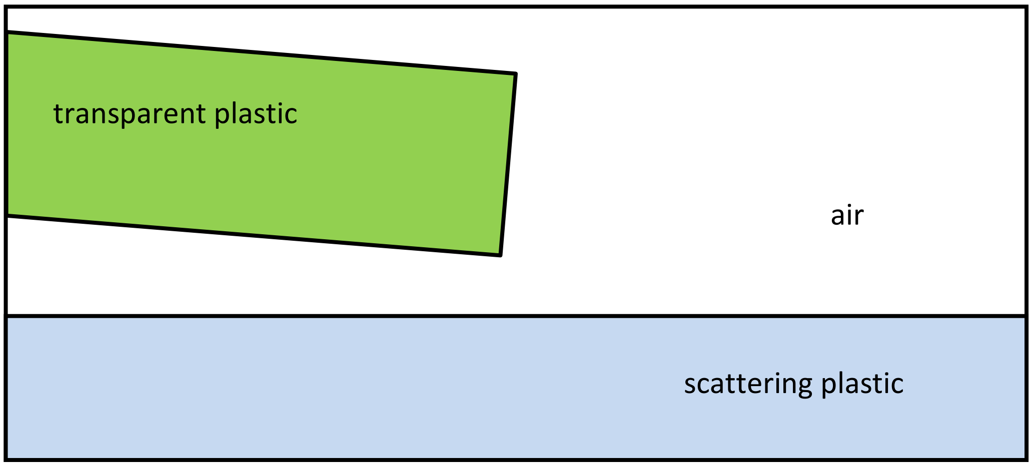

Figure 56 Schematic of a setup to show distortions from refractive media

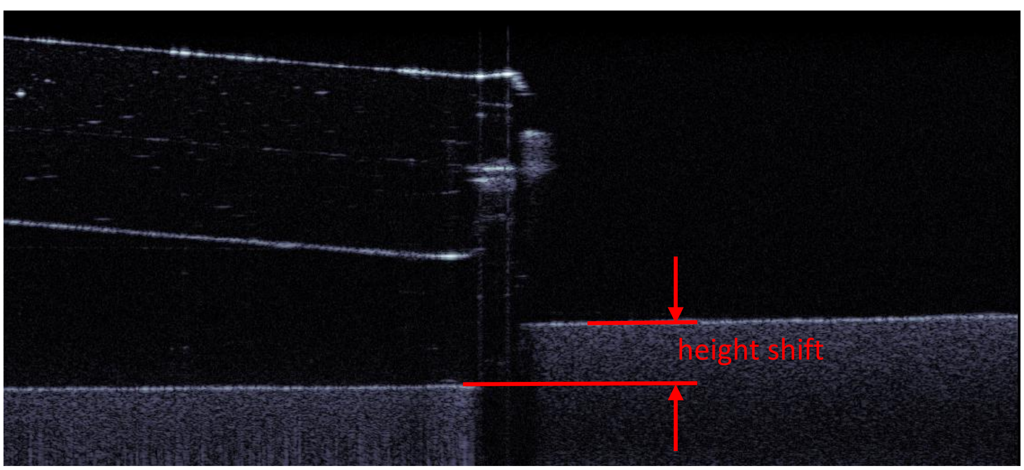

Figure 57 Height shift of OCT imaging through refractive media

5.8.1. The group refraction index

The principle of optical coherence tomography is the detection of optical path length differences between the two arms of an interferometer. The optical paths within these arms are defined by the mechanical path lengths and the refractive indices of the materials.

When talking about the refractive index of an optical material most of the time it refers to the phase velocity index. As the name indicates this is a factor for the velocity of the phase when travelling through the material in relation to the vacuum speed of light. The standard abbreviation of the Phase refractive index is n.

The group velocity of a wave is the velocity with which the overall shape of the wave's amplitudes — known as the modulation or envelope of the wave — propagates through space. This velocity usually is different from the speed of the phases of the single wavelengths. This velocity is calculated by using the group refractive index n_g of a material.

The relation of these two values is: $n_g = n - \lambda_0 \dfrac{dn}{d\lambda_0}$

In OCT systems the group refractive index defines the optical path lengths.
In the table below some materials and their phase refractive indices n_p as well as their group refractive indices n_g are given.

Material	λ = 830nm		λ = 930nm		λ = 1310nm	
	n_p	n_g	n_p	n_g	n_p	n_g
Water 24° C	1,319	1,333	1,318	1,332	1,312	1,334
Water 37,6° C	1,325	1,342	1,323	1,341	1,316	1,339
Quarz	1,453	1,466	1,451	1,464	1,447	1,462
BK7	1,510	1,526	1,509	1,523	1,504	1,519
LAKN22	1,642	1,662	1,640	1,658	1,634	1,651
SF11	1,763	1,806	1,759	1,794	1,749	1,773
SF57	1,822	1,871	1,817	1,857	1,806	1,832

In vacuum the values for n_p as well as for n_g are 1 for all wavelengths. The same applies for air.

5.8.2. Measurement Depth in OCT Systems

The spectral resolution of a frequency domain OCT system defines its possible measurement depth. This depth is the maximum detectable optical path length difference limited by the Nyquist criteria. In real materials the measurement depth of OCT systems as well as the axial resolution is reduced. The reduction of the resolution depends on the material properties between the two measured interface signals used. The reduction of the imaging depth is a result of the materials in the sample image as visualized in the graphic below:

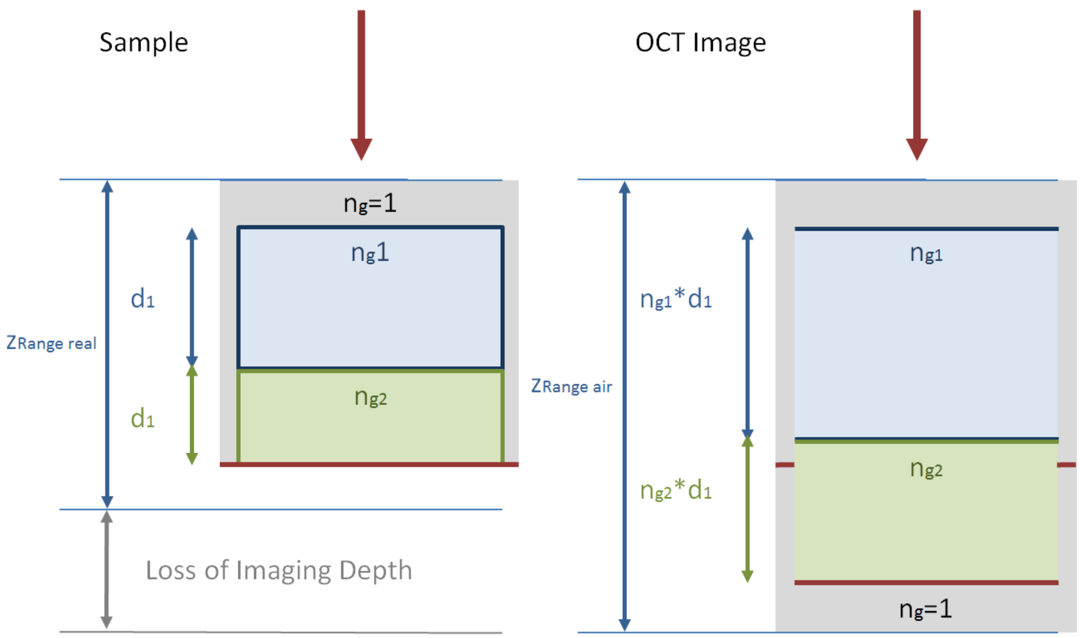

Figure 58 Measurement depth with refractive media

In the image the incoming beam from above is scanned over a structure made of two different materials named one (d_1, n_{g1}) and two (d_2, n_{g2}) stacked on a flat surface (red line). The imaging range is displayed as a light grey area. Vertical structures are barely visible.

The materials are displayed in the OCT image with an axial dimension corresponding to the optical path lengths.

In most cases the sample is not well known. The measurement depth in air (vacuum) is known and the optical path lengths of the materials are obtained – only with the knowledge of the material properties it is possible to determine the real physical thickness.

The loss of imaging depth depends on the thickness and the group refractive indices of the materials displayed within the image. It is calculated as follows:

$$loss = \sum_i (n_{gi} - 1) d_i$$

5.8.3. Distortions in the Image

In complex structures distortions occur in the OCT image which require a close look to be understood.

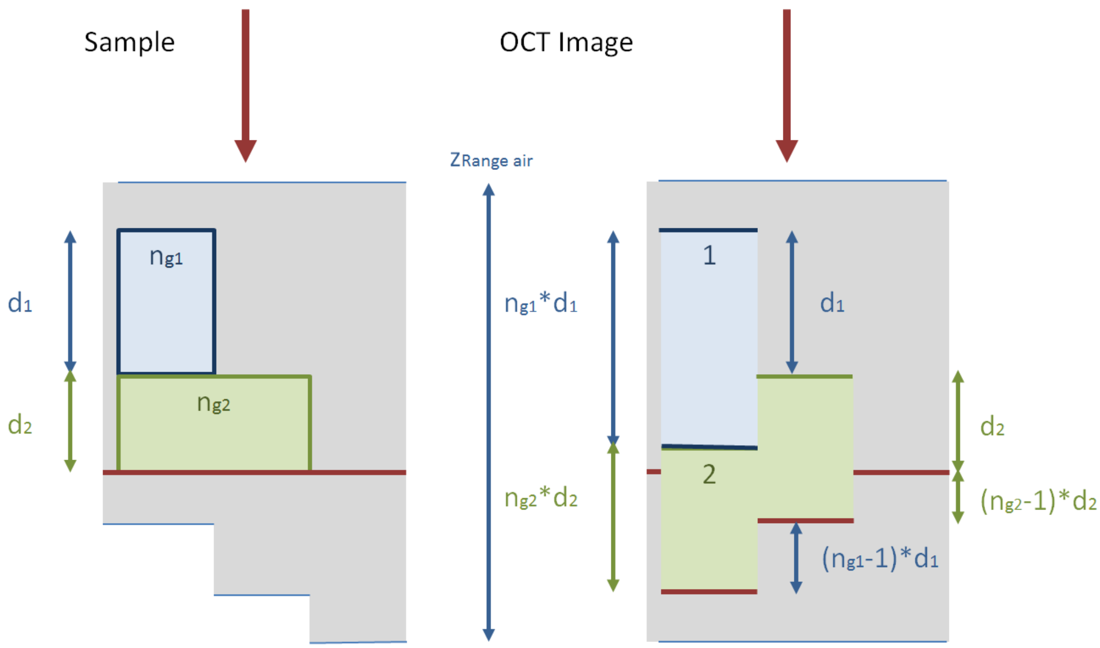

Figure 59 Different materials in one measurement

The loss of imaging depth depends on the amount of material through which the beam passes. As a result the measured depth in the sample changes throughout the scan.

In set up from Figure 55 one can determine the properties of the materials assuming the underlying surface to be flat and horizontal in the image. In the OCT image on the right the physical thicknesses d_i, optical path lengths $n_{gi}d_i$ as well as the resulting shifts of underlying structures $(n_{gi}-1)d_i$ can be determined directly.

The real imaging areas are displayed in the graphic for real sample dimensions on the left.
When the physical structure becomes more complex the resulting OCT image becomes more difficult to interpret.

Especially when the surface is not horizontal or curved, effects like shadowing, diffraction on interfaces and possible multiple measured structures may occur in addition to the changes in optical path length.

As an example a material with chamfer is analyzed:

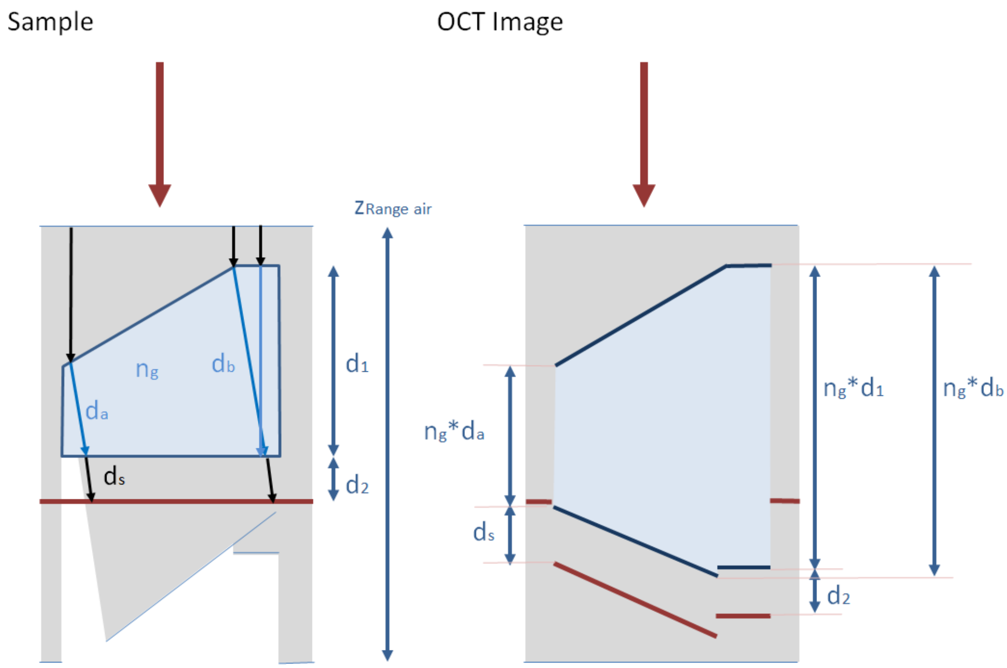

Figure 60 Complex structure in image

The block shows “standard” behavior on the right side where the surface is perpendicular to the incoming beam.

In the chamfered area there is diffraction and the beam travels under an angle through the block. The real angled physical path is enlarged a little (d_a and d_b), and d_s is not in-line with d_a.
These paths are displayed strictly vertical in the OCT image showing the expected optical path lengths $n_{gi}d_i$. The beam is displayed without rotation.

This difference between the real diffracted optical path and the displayed OCT image makes it difficult to perform an inverse ray tracing because all the diffractive interfaces need to be determined in 3D. Even this determination needs to be undertaken step after step since the first interface affects the OCT image of the second interface and so on.

The most challenging part is the light grey area in the sample marking the imaged field. In the left edge of the chamfered block there is an area which is not reached by OCT light and therefore cannot be visualized at all. On the other hand there are structures that are measured twice because of the two different optical paths leading to these structures.

In very complex structures these effects become more and more difficult to handle – Just assume spherical or curved interfaces, bubbles, inhomogeneous materials, possible imaging aberrations in the sample probe etc.

Part 6. Troubleshooting

Symptom	Possible Cause	Solution
System Does Not Start	No power is supplied to the unit	Connect the power supply
	Power cord is broken	Change power cord
	Other reason	Call Thorlabs[1]
System Does Not Make Measurements	PC crashed	Restart PC
	Poor connection of USB cable	Check USB connection
	Optical path length not matched	Adjust optical path length
	Beam is blocked	Inspect fiber tip with CL-200 fiber microscope and clean fiber tip
	Other reason	Call Thorlabs[1]
No Signal in Image	Fiber not connected	Connect fiber patch cable
	Fiber tip is dirty	Inspect fiber tip with CL-200 fiber microscope and clean fiber tip
	Scanning probe not connected	Connect scanning probe
	Focus is out of imaging area	Adjust reference length, readjust focus
	Reference intensity too high or too low	Adjust reference intensity knob
	Other reason	Call Thorlabs[1]
Bad Image Quality	Mirror image shown	Observe the OCT image while adjusting the distance of the probe to the sample
	Distance to the sample is too short	When decreasing the distance, the image needs to move towards the top of the OCT image
	Reference intensity too high or too low	Adjust reference intensity knob
	Other reason	Call Thorlabs[1]
Flipped Image	Reference length set incorrectly	Adjust reference length

[1] Please refer to Part 12 for Thorlabs contact information.

6.1. Changing the Input Fuses

If for some reason you need to replace an open fuse in the base unit, 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 base unit as shown in Figure 22 on page 25. Remove the existing fuse and install the appropriate replacement fuse for the base unit. Use only IS 2A 250VAC Type T 5x20mm style fuses (IEC 60127-2/III, low breaking capacity, slow blow).
- Slide the fuse cover closed.

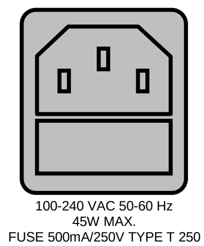

Figure 61 Fuse cover on base unit rear panel

Part 7. Certifications and Compliance

Konformitätserklärung
Declaration of Conformity
Declaration de Conformité

Thorlabs GmbH
Hans-Böckler-Str. 6
D-85221 Dachau
Germany

erklärt in alleiniger Verantwortung, dass das Produkt:
declares under its own responsibility that the product:
déclare sous notre seule responsabilité que le produit:

TELESTO II

mit den Anforderungen der Normen
fulfills the requirements of the standards
satisfait aux exigences des normes

2006/95/EC	Low Voltage Directive
2004/108/EC	Electromagnetic Compatibility Directive
DIN EN 61010-1: 2001	Safety of Test and Measurement Equipment
DIN EN 61326-1: 2006	EMC of Test and Measurement Equipment
DIN EN 61000-3-2	Harmonic Current Emission
DIN EN 61000-3-3	Voltage Fluctuations and Flicker
DIN EN 61000-4-2	Electrostatic Discharge Immunity
DIN EN 61000-4-3	Radiated RF Electromagnetic Field Immunity
DIN EN 61000-4-4	Electrical Fast Transient / Burst Immunity
DIN EN 61000-4-5	Power Line Surge Immunity
DIN EN 61000-4-6	Conducted RF Immunity
DIN EN 61000-4-11	Voltage Dips, Short Interruptions and Voltage Variations Immunity
DIN EN 60825-1	Sicherheit von Lasereinrichtungen - Teil 1: Klassifizierung von Anlagen und Anforderungen (IEC 60825-1:2007)

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

Dachau, 25.09.2013

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 8. Warranty

8.1. Lasers and Imaging Systems

Thorlabs offers a one year warranty on all lasers and imaging systems, with the exceptions of laser diodes.

8.2. 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.

8.3. 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 9. Specifications

Optical Performance Specifications – TELESTO II	
Optical	
Central Wavelength	1.3 µm
Axial Scan Rate	up to 76 kHz
Maximum Imaging Depth	3.5 mm
Axial Resolution Air/Water	5.5/4.2 µm
General	
Supply Voltage for base unit*	100 V – 240 V / AC
Maximum Power Consumption	150 W
Weight base unit	12 kg
Weight Probe	1.5 kg
Storage/Operating Temperature	10 °C to 35 °C
Dimensions of Probe Stand (L x W x H)	206 mm x 305 mm x 248 mm
Dimensions of base unit (L x W x H)	420 mm x 320 mm x 149 mm
Dimensions of Imaging Module (L x W x H)	60 mm x 85 mm x 187.8 mm

*base unit has universal AC input

Part 10. Mechanical Drawings

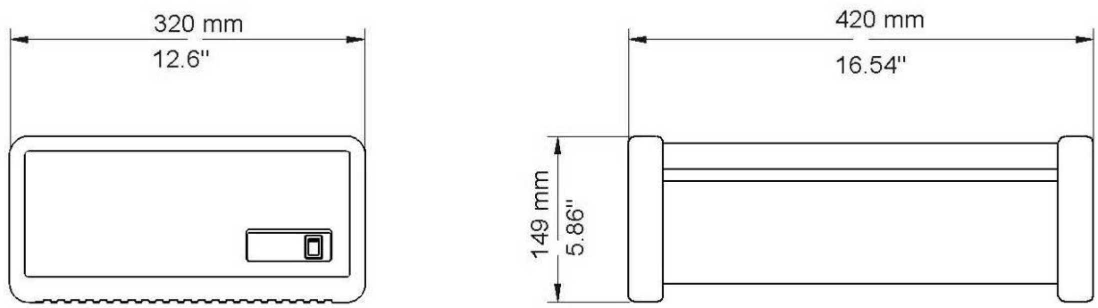

Figure 62 base unit dimensions

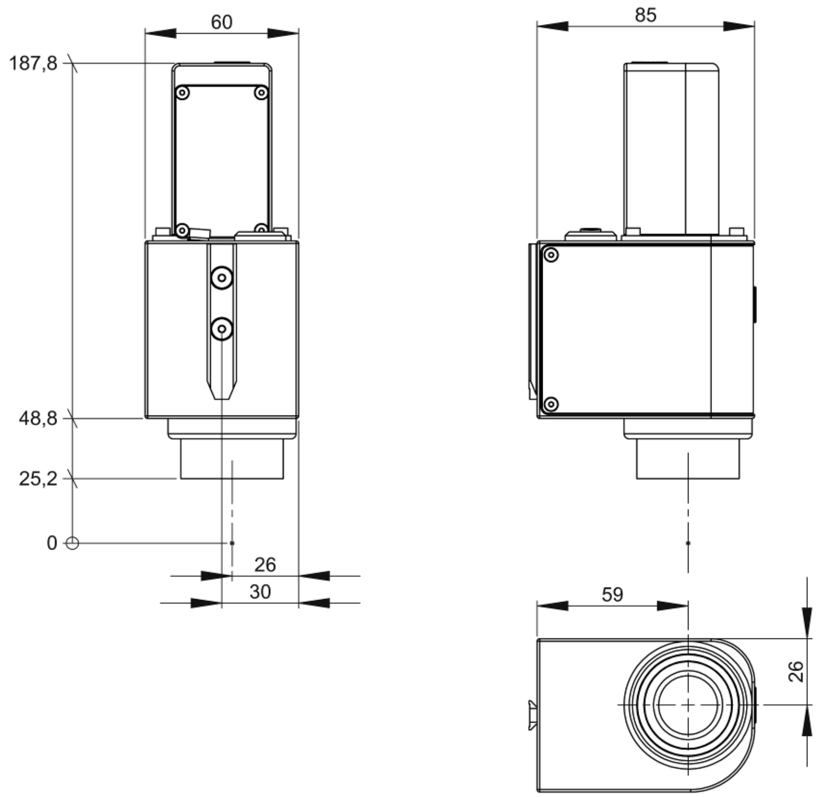

Figure 63 Imaging probe dimensions

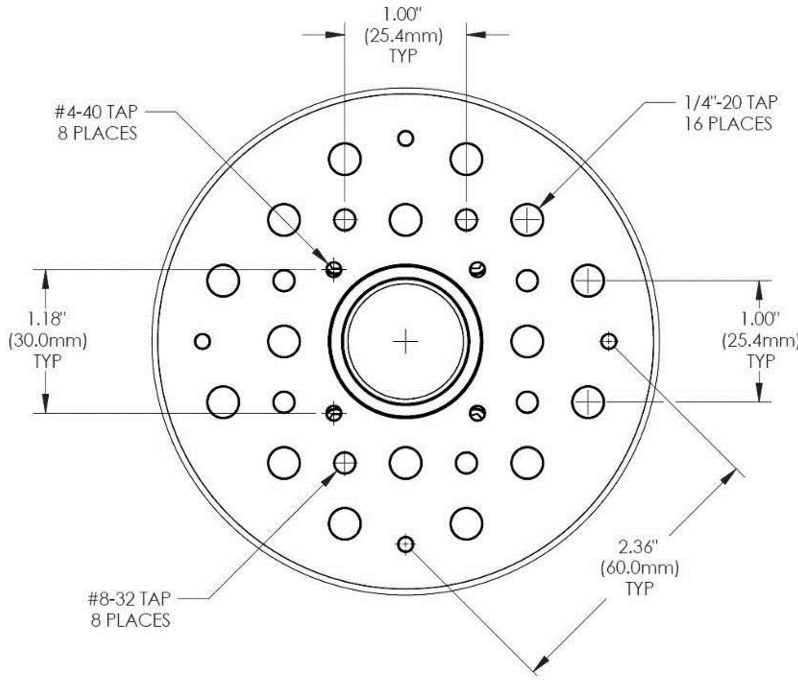

Figure 64 Dimension of the rotation stage underneath the sample plate

Part 11. 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 13, 2005
- Marked correspondingly with the crossed out "wheelie bin" logo (see right)
- 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.

11.1. 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.

11.2. Ecological Background

It is well known that WEEE pollutes the environment by releasing toxic products 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 life products will thereby avoid negative impacts on the environment.

Part 12. 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.

USA, Canada, and South America
Thorlabs, Inc.
sales@thorlabs.com
techsupport@thorlabs.com

Europe
Thorlabs GmbH
europe@thorlabs.com

France
Thorlabs SAS
sales.fr@thorlabs.com

Japan
Thorlabs Japan, Inc.
sales@thorlabs.jp

UK and Ireland
Thorlabs Ltd.
sales.uk@thorlabs.com
techsupport.uk@thorlabs.com

Scandinavia
Thorlabs Sweden AB
scandinavia@thorlabs.com

Brazil
Thorlabs Vendas de Fotônicos Ltda.
brasil@thorlabs.com

China
Thorlabs China
chinasales@thorlabs.com

Thorlabs GmbH
Hans-Boeckler-Str. 6
Dachau/Munich 85221
Germany

Phone: +49 (0) 8131-5956-0 ♦ Fax: +49 (0) 8131-5956-99
www.thorlabs.com