# TERASCAN 1550
# TERABEAM 1550

Manual

Manual: M-079 Version 03


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**(January 2019 Subject to change without notice)**

**Dear Customer,**

Welcome to the Toptica community!

We have designed this product to be easy to use and reliable so that you can focus on your work. If you have questions or need advice on how to integrate it into your setup, please contact us immediately so we can walk you through the process. We will provide you with quick and competent help through our service staff and product managers.

You can contact us in the following ways:

- Internet: service.toptica.com. In our support section you can find a list of frequently asked questions and a service contact form
- Email: service@toptica.com
- Phone: +49-89-85837-150.

Our customers in the USA and Canada may contact Toptica Photonics Inc.:

- Phone: +1-585-657-6663

Our customers in Japan may contact Toptica Photonics K.K.:

- Phone: +81-42-306-9906

Please have your product -ID and serial number ready when contacting us so we can quickly retrieve all relevant information.

As we are constantly improving our products, we greatly value all customer feedback. We encourage you to tell us what you like about our products as well as any suggestions for improvement.

Best regards,

Harald Ellmann
Director Service
Toptica Photonics AG

# Contents

# 1 Introduction

## 1.1 Technology

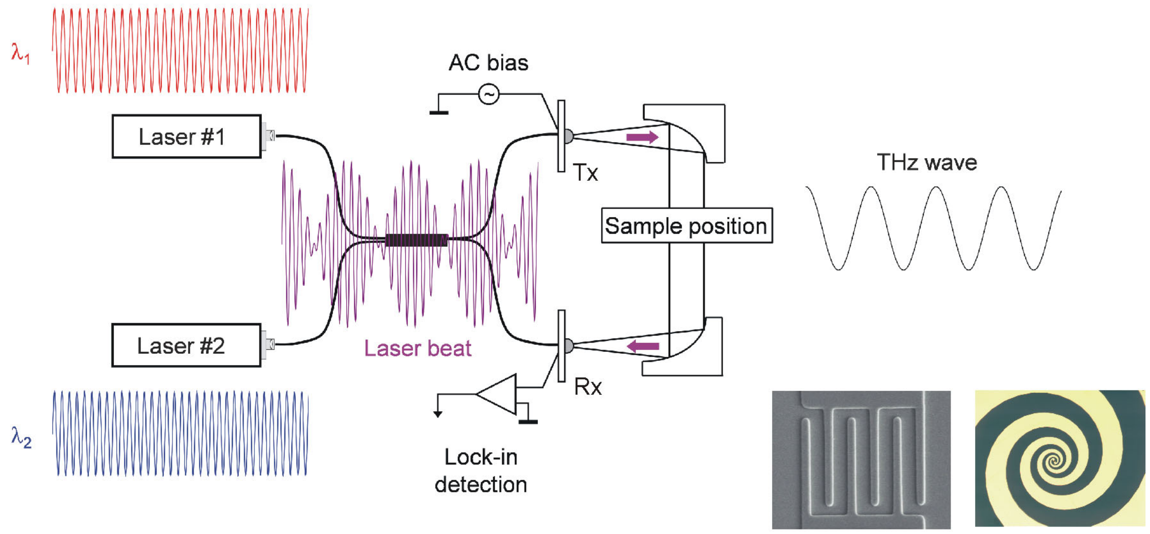



**Figure 1** Left: cw terahertz generation by optical heterodyning
Tx: Terahertz transmitter, Rx: Terahertz receiver
Bottom Right: Microscope images of an interdigitated photomixer[1] with log-spiral antenna

Continuous-wave (cw) terahertz radiation is obtained by optical heterodyning in high-bandwidth photoconductors: the output of two cw lasers converts into terahertz radiation, exactly at the difference frequency of the lasers.

The core component is the “photomixer,” a microscopic metal-semiconductor-metal structure. Near-infrared laser light irradiates this structure at two adjacent frequencies (Figure 1), creating charge carriers in the semiconductor. Applying a bias voltage to the metal electrodes then generates a photocurrent that oscillates at the beat frequency. An antenna structure surrounding the photomixer translates the oscillating photocurrent into the terahertz wave.

State-of-the-art photomixers are based on either GaAs or InGaAs/InP and require laser wavelengths below the semiconductor bandgap (i.e., around 0.8 µm or 1.5 mm, respectively). Both wavelength regimes have their own merit. Systems with GaAs photomixers provide high bandwidths, owing to the wide continuous tuning range of 780 nm lasers. Systems with InGaAs emitters, on the other hand, offer a record-level dynamic range, and take advantage of mature yet inexpensive 1.5 µm telecom components. TOPTICA´s TERASCAN 1550 combines 1.5 µm laser technology and innovative InGaAs photomixers.

The photomixer modules come equipped with a Silicon lens, an electric connector and SM/PM fiber pigtail. The all-fiber design enables an easy and flexible integration into any terahertz assembly.

On the laser side, TOPTICA´s terahertz systems make use of distributed feedback (DFB) laser technology. DFB lasers at 1.5 µm unite high output power, a narrow linewidth and mode-hop-free tuning ranges up to 600 GHz per diode. A grating structure within the active area of the semiconductor restricts the laser emission to a single longitudinal mode, and thermal tuning of the grating pitch changes the wavelength in a well-controlled and reproducible way.

Since the difference frequency of two DFB lasers can be controlled with single-megahertz precision, cw terahertz techniques lend themselves particularly to high-resolution spectroscopy, e.g., trace gas detection at low pressure.

1. T. Göbel, PhD thesis, University of Darmstadt, Germany (2010).

### 1.1.1 InGaAs Emitters

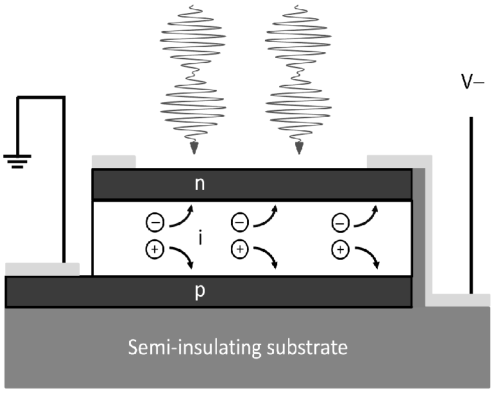



**Figure 2** Cross-section of a p-i-n photodiode emitter

InGaAs-based terahertz emitters comprise ultrafast p-i-n photodiodes, with an intrinsic layer embedded between p-doped and n-doped semiconductor layers (Figure 2). The laser light is coupled into the intrinsic layer either through one of the cover layers, or from the side, employing a waveguide geometry. In the latter design – incorporated in Toptica´s InGaAs emitter modules –, the extended absorption length leads to highly-efficient terahertz generation.

InGaAs has a semiconductor bandgap of 1.68 µm and telecom lasers at 1.5 µm are thus a perfect match. When the frequency is set to 100 GHz, Toptica´s InGaAs emitters achieve a terahertz output of approx. 65 µW, and the dynamic range of the terahertz power exceeds 90 dB.

### 1.1.2 Coherent Detection

In a coherent detection scheme, a second photomixer serves as terahertz **receiver**. Both the terahertz wave and the original laser beat illuminate the receiver. The incoming terahertz wave generates a voltage in the antenna while the laser beat modulates the conductivity of the photomixer. The resulting photocurrent is proportional to the amplitude (not the power !) of the terahertz electric field. It further depends on the phase difference between the terahertz wave and the optical beat. Spectroscopic measurements commonly take advantage of both amplitude and phase data.

Coherent detection offers the advantage of a very high efficiency, and can attain a dynamic range greater than 90 dB.

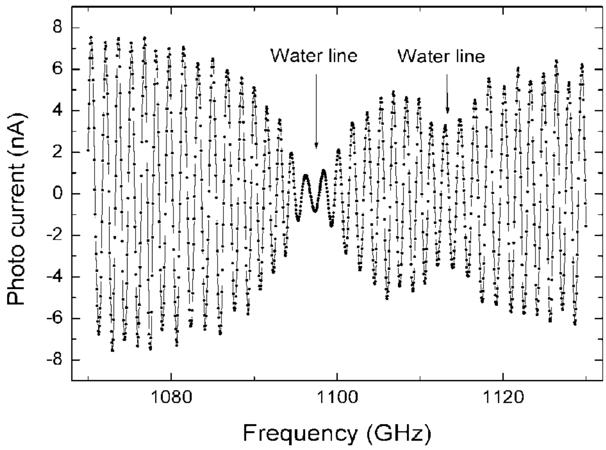



**Figure 3** Frequency step-scan across two water vapor absorption lines
The step size is 50 MHz. The fringe spacing of ~ 1.6 GHz corresponds to a path length difference $\Delta L$ of ~ 20 cm. Note the variation of the fringe period at the line center[2].

Mathematically, the relation between the photocurrent $I_R$ in the receiver, the incident terahertz electric field amplitude $E_{THz}$, and the phase difference $\Delta\phi$ between the terahertz wave and the optical beat can be expressed as[3]

$$I_R \propto E_{THz} \cos(\Delta\phi) = E_{THz} \cos(2\pi \, \nu \, \Delta L / c).$$

Here, $\nu$ is the terahertz frequency, $c$ is the speed of light, and $\Delta L$ is the deviation from zero path difference at the receiver, i.e. the difference between the length of the receiver arm, and the length of the emitter arm including the terahertz path.

Note that extracting amplitude and phase information requires a variation of $\Delta\phi$, and thus a modulation either of the optical path length, or of the terahertz frequency. In TOPTICA´s Phase Modulation Extension (section 1.3.4), fiber stretchers provide a fast and accurate means of changing the optical beam path (and thus, $\Delta L$). On the other hand, the terahertz phase can equally be varied by scanning the frequency $\nu$ in small steps. The effect is similar to scanning an interference pattern in frequency (Figure 3). Here,

$$\Delta\nu = c / \Delta L$$

is the spacing between adjacent fringe maxima. Using both maxima and minima, the *effective frequency resolution* for the amplitude becomes $c/(2\,\Delta L)$.

2. A. Deninger, *State-of-the-art in terahertz continuous wave photomixer systems*, In: D. Saeedkia (Edt.), Handbook of Terahertz Technology, Woodhead Publishing Series in Electronic and Optical Materials (2013).
3. A. Roggenbuck et al., *Coherent broadband continuous-wave terahertz spectroscopy on solid-state samples*; New J. Phys. **12** (2010) 43017.

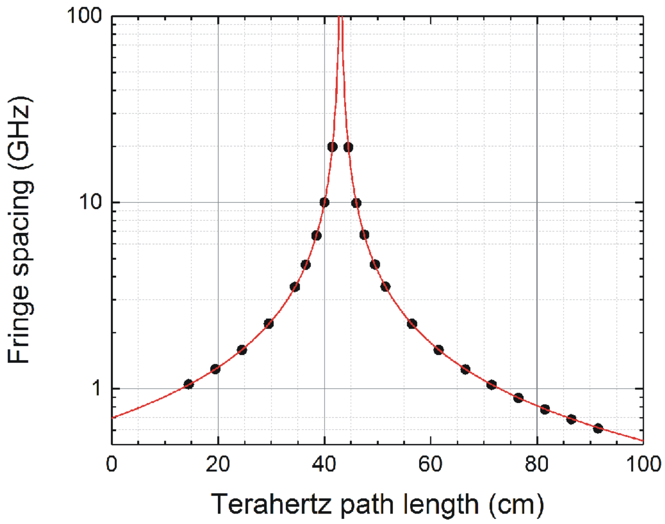



**Figure 4** Fringe spacing as a function of the terahertz path length, measured with a TERASCAN 1550. Dots: measurement, solid line: simulation for a geometric (resp. optical) length of 30 cm (43 cm) in front of the receiver

Figure 4 depicts the fringe spacing $\Delta\nu$ as a function of the terahertz path length. An "infinite" spacing, equivalent to $\Delta L$ = 0, is obtained for a terahertz path length of 43 cm. This is a consequence of the fact that in the utilized setup, the fiber pigtail of the receiver is approx. 30 cm longer than that of the emitter. Taking the refractive index of glass (~ 1.4) into account, this amounts to an extra optical path of 43 cm, and accordingly, an equally long terahertz path yields a length difference of zero at the receiver.

In order to obtain a fringe spacing between 2 GHz and 3 GHz – a practical value for most applications –, the terahertz path length should either be in the range of 28 - 33 cm, or 53 - 58 cm (note that production tolerances can lead to slightly different values in individual systems).

Please refer to section 10.10 for a detailed mathematical description of the "fringe-scanning" technique and the steps required to retrieve amplitude and phase information.

## 1.2 Signal Processing

The terahertz signal – the photocurrent in the receiver – resides in the pico- to nanoampere range. Recovering this faint signal requires lock-in detection: The terahertz beam is periodically chopped and the readout circuit “looks” at the signal modulation at the chopping frequency. The faster the chopping, the more efficient the detection becomes. An elegant way to achieve kHz-rate chopping is to **modulate the bias voltage** of the terahertz transmitter.

In all of TOPTICA’S TERASCAN/TERABEAM systems, the DLC smart unit acts as digital lock-in amplifier for the terahertz signal. The FPGA-based module feeds an AC bias to the transmitter and de-modulates the receiver photocurrent. In addition, the DLC smart tunes the terahertz frequency by precisely adjusting the temperatures of the two DFB lasers.

### 1.2.1 Digital Lock-In Amplifier

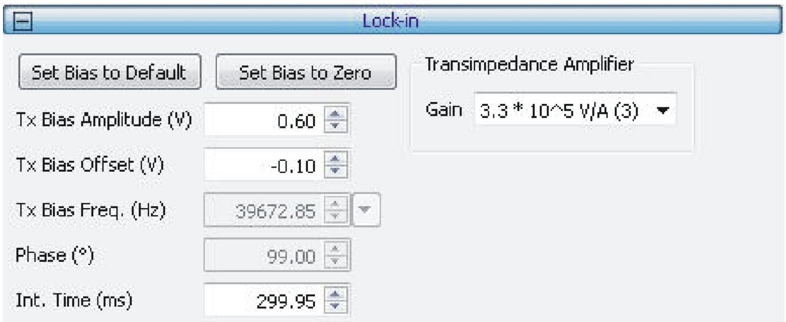



**Figure 5** Typical lock-in settings in the TOPAS TeraScan Control software

**AC and DC Bias Voltages**

The DLC smart is capable of generating both DC and AC voltages, labeled **Tx Bias Offset** and **Tx Bias Amplitude**, respectively. The user can adjust both parameters with the help of the TOPAS TeraScan Control software (see Figure 5 and section 8).

A **DC voltage** is mainly used to test the function of a photomixer: When the photomixer is illuminated and a DC voltage is applied, a DC photocurrent is generated. A correct value of this DC photocurrent - as documented in section 05 of the Production and Quality Control Datasheet - indicates that all optical and electric connections are correct, and that the photomixer itself is intact.

An **AC bias** chops the terahertz signal, as required for lock-in detection.

The bias voltage applied to the transmitter is the sum of the DC and AC contributions:

$U_{\text{Bias, Tx}}(t)$ = (Tx Offset) + (Tx Amplitude) $*$ cos[2$\pi$ $*$ (Tx Frequency) $*$ $t$]

| | |
|---|---|
| **NOTE !** | InGaAs photomixers require a negative bias offset combined with an AC amplitude. Representative settings are shown in Figure 5. |

**Bias Frequency**
The DLC smart is based on a Field-Programmable Gate Array (FPGA) with an internal clock rate of 130 MHz. Lock-in signal processing works best if the chopping frequency $f_{lockin}$ is a multiple of a $2^n$ divider of the clock rate $f_{clock}$,

$$f_{lockin} = k \times f_{clock}/2^n,$$

with $n$ and $k$ being integer numbers.

The bias voltage and lock-in frequency settings of each system produced are documented in section 05 of the respective Production and Quality Control Datasheet. In the example of Figure 5, $f_{lockin} = 39.673$ kHz $= 5 \times f_{clock}/2^{14}$.

**Integration Time**
The output filter of the lock-in amplifier is a resettable digital integrator that is synchronized with the terahertz frequency control. The integrator thus re-starts as soon as the system is tuned to a new terahertz frequency. This is a substantial advantage in comparison to a conventional analog RC low-pass filter because the analog filter requires a waiting time of several time constants. The integration times of the DLC smart are thus roughly three times larger at the same overall measurement speed.

To minimize statistical errors, the TOPAS TeraScan Control software adjusts the integration time to an exact multiple of the modulation period. For instance, at a bias frequency of 39.67 kHz, a user-selected integration time of 3 ms is changed to 3.02 ms (= $120/f_{lockin}$).

The DLC smart supports integration times between ~ 0.5 ms and 16.5 s. Long integration times result in a lower noise level (see section 1.2.3), which comes at a cost in measurement speed.

## 1.2.2 Real-Time Data Analysis

When the terahertz frequency is scanned, the raw signal - the photocurrent measured in the receiver - exhibits an oscillating pattern (see section 1.1.2 and Figure 3). The envelope of the fringe pattern yields the terahertz spectrum.

TOPTICA'S TOPAS TeraScan Control software offers the possibility to compute the envelope photocurrent in real time. This feature is dubbed "Online Analysis" and can be activated or deactivated (e.g., to save processor resources) at leisure. If activated, the underlying algorithm compares the photocurrent values $I(\nu)$ of a user-selected range of frequencies $\nu$. The number $N$ of frequency steps used for this comparison is selected via the input field **# of Points Compared**. If $N$ photocurrent values on either side of a specific data point $\nu_m$ are smaller (larger) than the photocurrent $I(\nu_m)$, then $I(\nu_m)$ is identified as a fringe maximum (minimum).

This algorithm works reliably, as long as
- the frequency steps are chosen sufficiently small so that the extrema of the fringe pattern are resolved unambiguously - a good choice is a step size that is 10 to 15 times smaller than the fringe "halfwave" (the distance between a fringe minimum and a maximum),
- the value of **# of Points Compared** equals (at least roughly) the number of data points of the fringe halfwave.

For example, at a fringe spacing $\Delta\nu = 2$ GHz, the step size should be approximately

$$\Delta\nu/2/15 \sim 65 \text{ MHz},$$

and accordingly, the value of **# of Points Compared** should be set to ~ 15.

### 1.2.3 Noise Measurements and Dynamic Range

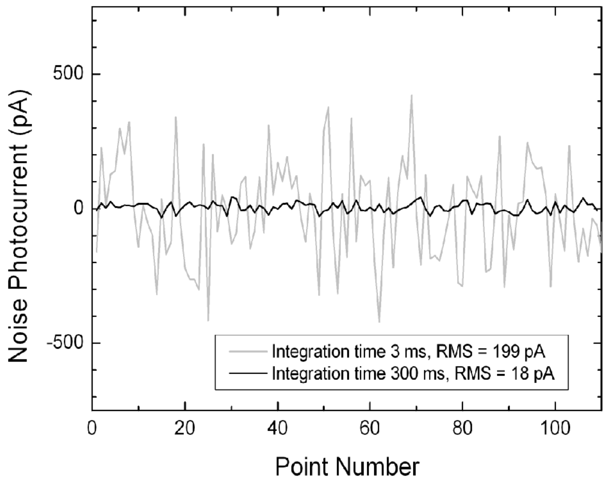



**Figure 6** Noise photocurrent at integration times of 300 ms (black trace) and 3 ms (grey trace)

Noise characteristics are of paramount importance in any spectroscopic measurement. In a cw terahertz setup with coherent signal detection, the photocurrent noise in the receiver photomixer depends on

- The intrinsic properties of the photomixer,
- The optical power on the receiver (higher laser power yields a stronger signal, but also more noise),
- The time constant of the lock-in integration, see Figure 6.

Specifically, the noise photocurrent in the receiver, $I_{noise}$, scales inversely proportional to the square root of the integration time:

$$I_{noise} \propto 1/(\text{integration time})^{1/2}.$$

This noise level is easily determined by setting the Tx Amplitude to zero, and recording a number of data points (e.g. 100 data points): The resulting RMS value is a measure of $I_{noise}$. Once the noise properties are known, the dynamic range of the terahertz power is computed via

$$\text{Dynamic range}(\nu) = 20 \times \log(I_{signal}(\nu) \,/\, I_{noise}) \;,$$

where $I_{signal}(\nu)$ is the signal photocurrent at a given frequency $\nu$ (see Figure 7).

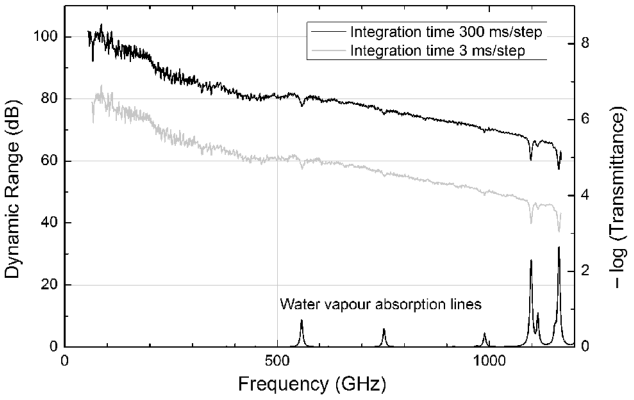



**Figure 7** Dynamic range of a TERASCAN 1550 system with InGaAs antennas at integration times of 300 ms (black trace) and 3 ms (grey trace). The dips are absorption lines of water vapor. They match with the literature values as shown on the bottom (transmittance on a log scale, right axis).

As evident from Figure 6 and Figure 7, an increase of the lock-in integration time by a factor of 100 decreases the noise floor by a factor of 10 and thus improves the dynamic range by 20 dB.

## 1.3 Product Packages

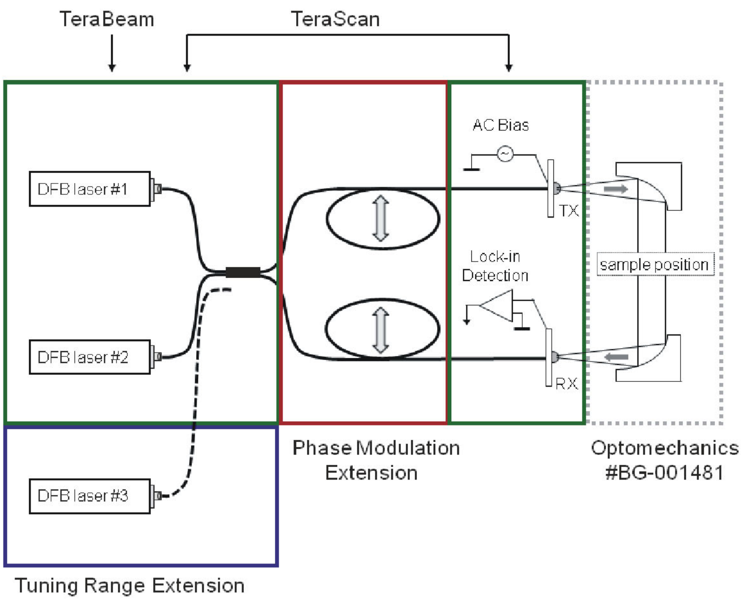



**Figure 8** TERASCAN systems with additional options

TOPTICA´S TERASCAN 1550 represents a complete platform for frequency-domain terahertz spectroscopy. The system combines tunable distributed feedback (DFB) lasers, digital control electronics and advanced InGaAs photomixer technology.

A set of modular packages (see Figure 8) extends the cw terahertz product portfolio: The TERABEAM 1550, a sub-system of the TERASCAN 1550, comprises two DFB diode lasers with fiber-optic beam combination and digital driver electronics. The Tuning Range Extension uses a third DFB laser to push the usable terahertz bandwidth out to almost 3 THz. The Phase Modulation Extension features two fiber stretchers for fast and accurate scanning of the terahertz phase. Different sets of optomechanics complement the list of accessories. Sections 1.3.1 - 1.3.5 describe the contents of the individual product packages in detail.

The packages can be combined and upgraded depending on the requirements of the experiment.

### 1.3.1 TERABEAM 1550

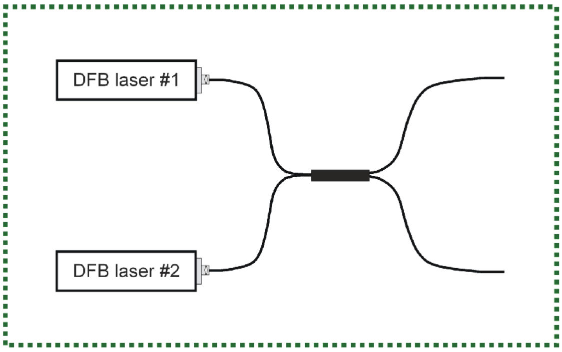



**Figure 9** TERABEAM 1550 schematic. For package contents please see Figure 18

**Specifications:**
- Available wavelengths: 1533 nm and 1538 nm, other wavelengths upon request
- Laser power per 2-color fiber output: 25 .. 30 mW
- Difference frequency tuning up to 1200 GHz
- Frequency accuracy < 2 GHz
- Minimum frequency step size < 10 MHz
- Tuning speed up to 100 GHz/s
- Computerized frequency tuning via Ethernet

**Package Contents:**
- 2 DFB pro BFY THz laser heads with integrated laser diodes and optical isolators
- SM/PM fiber combiner
- Control electronics: DLC smart rack with Ethernet interface
- USB flash drive with TOPAS TeraScan Control software (Graphical User Interface and command set) and USB drivers

**Cables and connectors:**
- Mains cable
- 2 connector cables for temperature control
- 2 connector cables for current control
- Ethernet patchcord
- Cables for photomixer connection (1 x BNC - SMB, 1 x BNC - SMA)

Each TERABEAM 1550 system comprises two butterfly-packaged DFB lasers with integrated optical isolators and fiber-optic beam combination. The TERABEAM 1550 matches the excitation wavelengths of InGaAs terahertz emitters.

TOPTICA carefully selects the laser diodes, paying close attention to their mode-hop-free tuning range, and records precise tuning curves (wavelength vs. temperature), which are stored in a lookup table. The DLC smart addresses the thermoelectric coolers of both DFB diodes in order to tune to a desired terahertz frequency. The minimum step size is on the 1 MHz level, which corresponds to a temperature change of only 40 µK per laser.

### 1.3.2 TERASCAN 1550

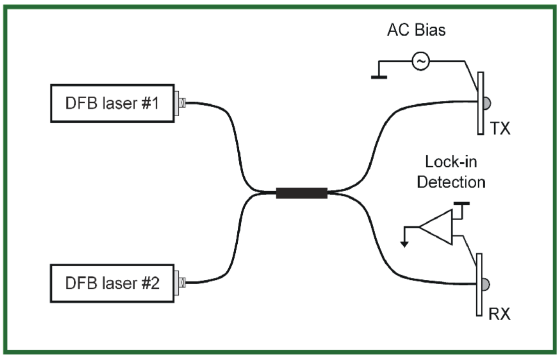



**Figure 10** TERASCAN 1550 schematic. For package contents please see Figure 19

**Specifications:**
- Frequency-domain terahertz spectroscopy platform
- Comprises TERABEAM 1550 laser system with DLC smart electronics and two fiber-coupled InGaAs photomixers
- Terahertz output: Up to 65 µW
- Dynamic range of terahertz power: Up to 90 dB
- Frequency accuracy < 2 GHz
- Minimum frequency step size < 10 MHz
- Computerized frequency tuning via Ethernet

**Package Contents:**
- TERABEAM 1550 with DLC smart electronics + 2 InGaAs photomixers
- 1 PDA-S transimpedance amplifier
- 2 fiber mating sleeves
- 1 SMA-BNC connector cable for photomixer connection
- 1 SMB-BNC connector cable for photomixer connection
- 1 BNC breakout box
- 1 BNC - BNC adaptor (female - female)

The TERASCAN 1550 is a complete platform for frequency-domain terahertz spectroscopy. Setting new benchmarks in terms of terahertz power and dynamic range, the system lends itself both as a starter package for cw-terahertz research, and as a base unit for OEM integrators.

The TERASCAN 1550 features TOPTICA's DLC smart control electronics, and an intuitive software interface. For users who prefer to control the system with their own software programs, TOPTICA offers a command reference as well as an open-source "programming example".

### 1.3.3 Tuning Range Extension

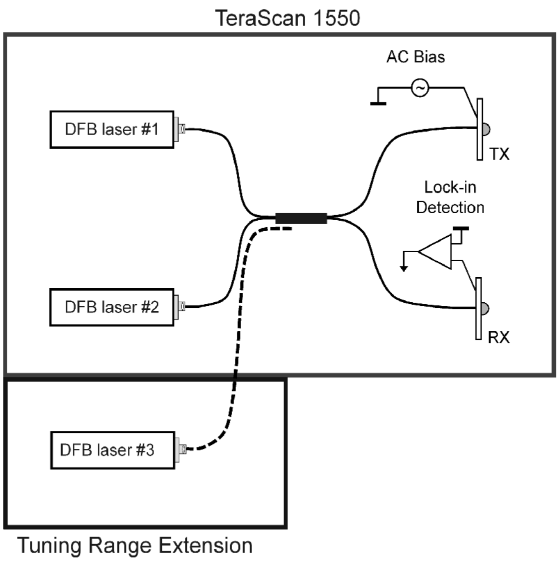



**Figure 11** TERASCAN 1550 with Tuning Range Extension

**Specifications:**
- 3rd DFB pro BFY THz laser head for access to higher frequencies
- Extends tuning range to 2.0 THz (two combinations of lasers) or even up to 2.75 THz (three combinations of lasers)

**Package Contents:**
- Additional DFB pro BFY THz laser head with built-in laser diode and optical isolator
- Additional frequency calibration file(s) for the laser combination(s) used
- Reel cleaner for optical fibers

Whilst one DFB laser at 1.5 µm offers a continuous tuning range of approximately 600 GHz, a combination of three lasers covers the entire frequency range from DC to 2.0 THz, or - using a more elaborate set of combinations - even up to 2.7 THz[4]. With two lasers operating at a time, the exchange is simple and does not affect the terahertz alignment.

The Tuning Range Extension thus provides access to a frequency range that used to be beyond reach with frequency-domain spectrometers. The frequency accuracy achieved with TOPTICA'S DLC smart controller is so high that spectra obtained with different subsets of lasers can easily be "stitched together".

The Tuning Range Extension is available for TERASCAN 1550 and TERABEAM 1550 systems.

4. A. Deninger et al., 2.75 THz tuning with a triple-DFB laser system at 1550 nm and InGaAs photomixers; J Infrared Milli. Terahz. Waves **36** (2015) 269.

## 1.3.4 Phase Modulation Extension

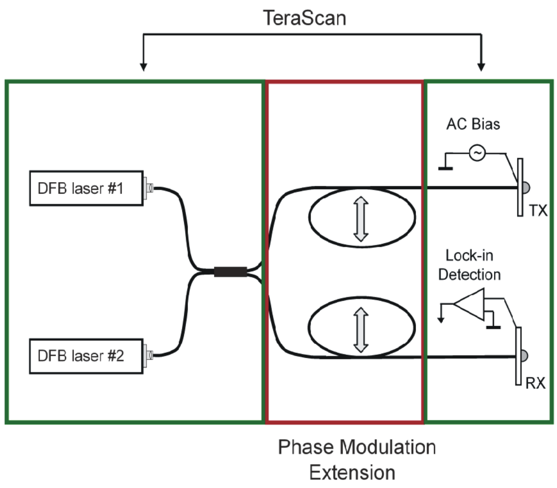



**Figure 12** Phase Modulation Extension

**Specifications:**

- Twin fiber stretcher with piezo actuators and high-voltage amplifier
- Path length modulation up to 3 mm @ 1 kHz
- Polarization-maintaining, single-mode fibers
- Enhanced thermal stability due to dual-fiber concept

**Package Contents:**

- Two fiber stretchers with piezo actuators: 60 m of SM/PM fiber
- High-voltage amplifier
- 1 branched high-voltage cable with LEMO connectors
- 1 SMB-BNC connector cable
- 1 SMA-BNC connector cable
- 1 External fiber combiner (if necessary for fiber stretcher connection)

The Phase Modulation Extension is a “resolution booster” for cw-terahertz experiments. Powerful piezo actuators scan the length of two long (~ 60 m) optical fibers - one in the transmitter path, one in the receiver path. This results in a fast and accurate modulation of the terahertz phase. Both amplitude and phase of the terahertz signal can then be retrieved with a resolution on the single-MHz level. In other words, the spectral resolution no longer depends on the phase fringes (see Figure 3); rather, the fiber stretchers enable a direct measurement of the *envelope* photocurrent.

This Extension lends itself particularly to applications that require ultimate frequency resolution (e.g. in trace-gas sensing), or for continuous measurements at a fixed frequency (e.g. terahertz imaging).

The twin-fiber concept not only doubles the modulation amplitude, but also increases the thermal stability of the setup.

### 1.3.5 Optomechanics

TOPTICA offers four different sets of optomechanics, designed for the most common beam-path configurations. For transmission-mode experiments, three rail-based assemblies produce a collimated terahertz beam (#BG-002653, compact 2-mirror setup, and #BG-001481, finely adjustable 2-mirror setup), or an additional focus (#BG-001784, 4-mirror setup). For applications that require a reflection geometry, a compact module (#OE-000888) generates a focus at the location of the sample.

**Specifications:**

- #BG-002653: Compact rail system with 2 off-axis parabolic mirrors, for transmission-mode experiments with collimated beam.
- #BG-001481: Finely adjustable rail system with 2 off-axis parabolic mirrors, for transmission-mode experiments with collimated beam.
- #BG-001784: Finely adjustable rail system with 4 off-axis parabolic mirrors, for transmission-mode experiments with focussed or collimated beam. Focus size approx. 2 mm.
- #OE-000888: Compact reflection head with 4 off-axis parabolic mirrors. Focus size approx. 2.5 mm.

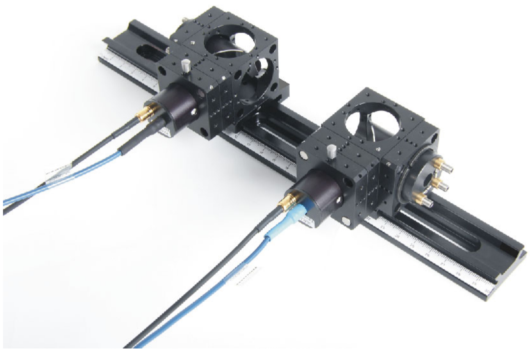


**Figure 13** Optomechanics #BG-002653 (shown with photomixers)

**Package Contents #BG-002653**

- 2 off-axis parabolic mirrors, diameter 1", focal length 2"
- 2 photomixer mounts (not adjustable)
- 1 optical rail, 25 cm length

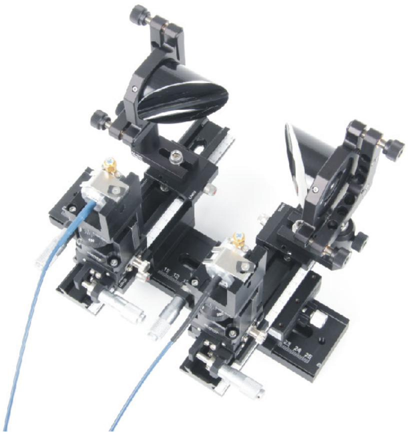


**Figure 14** Optomechanics #BG-001481 (shown with photomixers)

**Package Contents #BG-001481**

- 2 off-axis parabolic mirrors, diameter 2", focal length 3",
- 2 kinematic mirror mounts,
- 2 xyz stages and mounts for photomixers,
- Manual delay stage,
- Assembly mounted on optical rails.

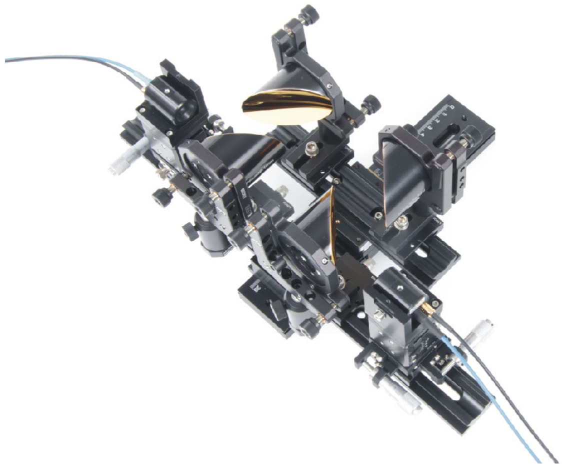


**Figure 15** Optomechanics #BG-001784 (shown with photomixers)

**Package Contents #BG-001784**

- 4 off-axis parabolic mirrors, diameter 2", focal length 3" (collimating mirrors) and 2" (focussing mirrors),
- 4 kinematic mirror mounts,
- 2 xyz stages and mounts for photomixers,
- Manual delay stage,
- Assembly mounted on optical rails.

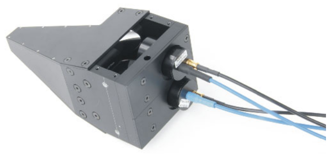


**Figure 16** Optomechanics #OE-000888 (shown with photomixers)

**Package Contents #OE-000888**

- Reflection head with 4 off-axis parabolic mirrors, diameter 1", focal length 2" (collimating mirrors) and 4" (focussing mirrors).

## 1.4 Key Features of TOPTICA's cw TERASCAN 1550 Systems

- Terahertz generation via optical heterodyning
- Tunable DFB diode lasers with microprocessor-based frequency control
- Optional Tuning Range Extension
- Optional phase modulation with fiber stretchers
- InGaAs-based photomixers
- Difference frequency tuning range up to 2.7 THz (with Tuning Range Extension)
- Terahertz power up to 65 μW
- Dynamic range of terahertz power > 90 dB (@ 100 GHz)
- Frequency resolution < 10 MHz

# 2 Safety Instructions and Warnings

Before using the TERASCAN 1550/TERABEAM 1550 System please read and follow the Safety Instructions and Warnings given in this manual.

The TERASCAN 1550/TERABEAM 1550 Systems are manufactured according to the Laser Safety Standard EN 60825-1:2014 and comply with US laws 21 CFR §1040.10 and §1040.11.

**The following safety terms are used in this manual:**

The **DANGER !** heading in this manual explains danger that could result in personal injury or death.
The **CAUTION !** heading in this manual explains hazards that could damage the instrument.
In addition, a **NOTE !** heading provides information to the user that may be beneficial in the use of the instrument.

**DANGER !**
**CAUTION !** Before operating the TERASCAN 1550/TERABEAM 1550 System please read this manual carefully to prevent injury to persons and damage to the connected photomixers. The following safety instructions must be followed at all times.

**DANGER !**
**CAUTION !** **Possibility of electrical shock !** Wherever this symbol is attached, the possibility of an electrical shock may appear. Use only equipment and accessories supplied by TOPTICA.

**Caution !** Wherever this symbol is attached read and understand the manual before operating the device. The manual must be consulted in order to find out the nature of the potential HAZARDS and any actions which have to be taken to avoid them.

**DANGER !**
**CAUTION !** The protective housing of the DFB pro BFY THz laser head must not be opened. There are no user serviceable parts inside.

**DANGER !** The Laser Driver Electronics and the Laser Heads are equipped with LEDs which indicate laser emission. (Please refer to sections 6.1 and 6.2 in this manual and to the respective laser head manual for detailed information). One has to be aware of laser emission when at least one of these LEDs lights up.

**DANGER !** **Laser light is emitted from the fibers when the photoconductive antennas are optically disconnected**. Never disconnect/connect any fibers while laser emission is switched on ! Do not look into any fiber connector ports or fiber facets. At the fiber connector ports a **divergent** laser beam is emitted (maximum power: 40 mW at each fiber output port, Class 1 laser product).

**DANGER !** Do not position the equipment so that it is difficult to operate the disconnecting device.

**DANGER !** Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous radiation exposure.

**DANGER !** If the equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.

**DANGER !** For safe operation and for proper grounding please use the supplied mains cable only. Improper or missing grounding can lead to serious injury.

**DANGER !** The electrical units should not be operated in a hazardous environment.

**DANGER !** Do not look into the laser beam under conditions which exceed the limits for class 1 specified by the United States Food and Drug Administration, Department of Health and Human Services, Center for Devices and Radiological Health, 21 CFR 1040.10 and 2 CFR 1040.11.

**DANGER !** The TOPTICA laser head DFB pro BFY THz is designed for operation with TOPTICA´S control electronics as described in this manual. When operated with TOPTICA´S control electronics, the system fully complies with all requirements for laser safety and safety regulations for electrical equipment. Choosing to use the TOPTICA laser head DFB pro BFY THz with control electronics not provided by TOPTICA, it remains in your duty and responsibility to ensure that the system fulfils all safety requirements.

**CAUTION !** While handling the photomixers we recommend to wear a high-impedance grounding strap around the wrist.

## 2.1 Safety Labels on the DFB pro BFY THz Laser Head

### 2.1.1 Protective Housing

The DFB pro BFY THz Laser Head has a protective housing which is fixed by screws. This protective housing must not be opened. There are no user-serviceable parts inside.

| | |
|---|---|
| **NOTE !** | The protective housing of the DFB pro BFY THz Laser Head is sealed by a label. Do not open the protective housing as this voids warranty. |

### 2.1.2 Laser Beam

The DFB pro BFY THz Laser Head contains a laser diode and emits invisible continuous laser radiation. The output beam is divergent, as it is emitted from an optical fiber. The maximum power of a DFB pro BFY THz is 40 mW directly at the fiber output port. The laser is thus classified as a Class 1 laser product.

| | |
|---|---|
| **DANGER !** | From each fiber output port the laser emits invisible continuous laser radiation of up to 40 mW power (Class 1 laser product). |

The following label is affixed to the housing of the DFB pro BFY THz Laser Head according to EN 60825-1:2014:


| | |
|---|---|
| Size: | 52 mm x 26 mm |
| Color: | Yellow/black |
| Location: | At the side of the protective housing |

### 2.1.3 Laser Beam Output

During operation, the laser beam is emitted from the FC/APC connector of the installed fiber, or from the fiber output port on the front panel of the housing. (For location of the laser beam output please refer to section 10.9).

| | |
|---|---|
| **DANGER !** | From each fiber output port the laser emits invisible continuous laser radiation of up to 40 mW power (Class 1 laser product). |

The following labels are affixed on the DFB pro BFY THz Laser Head front panel according to EN 60825-1:2014:


Size: 27 mm x 19.5 mm
Color: Yellow/black
Location: Besides FC/APC fiber connector

Size: 25 mm x 19.5 mm
Color: Yellow/black
Location: At the front panel of the protective housing

### 2.1.4 CFR Compliance

Compliance with US laws 21 CFR §1040.10 and §1040.11 is declared by the following label:

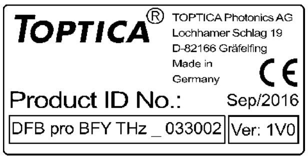
COMPLIES WITH
21 CFR 1040.10 & 1040.11
EXCEPT FOR DEVIATIONS
PURSUANT TO LASER NOTICE
No. 50, dated June 24, 2007

Size: 38 mm x 19 mm
Color: Silver/black
Location: Outside of protective housing

## 2.2 Identification of Manufacturer

### 2.2.1 DFB pro BFY THz Laser Head

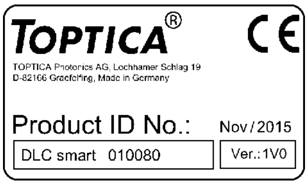
Manufacturer (name and address), Production Date, Product ID number and compliance with CE standards are noted on the identification label.




Size: 38 mm x 19 mm
Color: Silver/black
Location: On the side of the DFB pro BFY THz protective housing

### 2.2.2 DLC smart

Manufacturer (name and address), Production Date, Product ID number and compliance with CE standards are noted on the identification label:




Size: 60 mm x 34 mm
Color: Silver/black
Location: On the side of the DLC smart housing

## 2.3 Safety Features of the DLC smart Control Electronics

### 2.3.1 External Interlock

The DLC smart features an interlock connector located at the rear panel (see Figure 23). If the interlock circuit is opened, the lasers are switched OFF.

| | |
|---|---|
| **NOTE !** | To switch ON the laser emission again, please close the external interlock circuit and click the **Laser Emission On/Off** button in the **Main Window** of the TOPAS TeraScan Control software or press the ON button at the DLC smart front panel. |

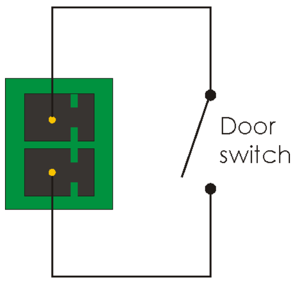



**Figure 17** Interlock connector

To install an external interlock circuit, please remove the wire in the supplied interlock plug (Phoenix Contact FK-MC 0.5/2-ST-2.5) and connect the interlock circuit.

# 3 Installation

## 3.1 Inspection after Delivery

The TERASCAN 1550/TERABEAM 1550 Systems (typical package contents shown in the following sections) are packed in a carton designed for maximum protection during shipment. If the outside of the shipping carton is damaged, notify your shipping department immediately. The shipping agent may wish to inform the carrier at this point.

If the shipping carton is undamaged externally, the parts of the TERASCAN 1550/TERABEAM 1550 System should be removed from the carton. If any damage is evident visually, please contact TOPTICA AG and your shipping agent. It is recommended to save the carton for future storage or transportation.

### 3.1.1 TeraBeam 1550

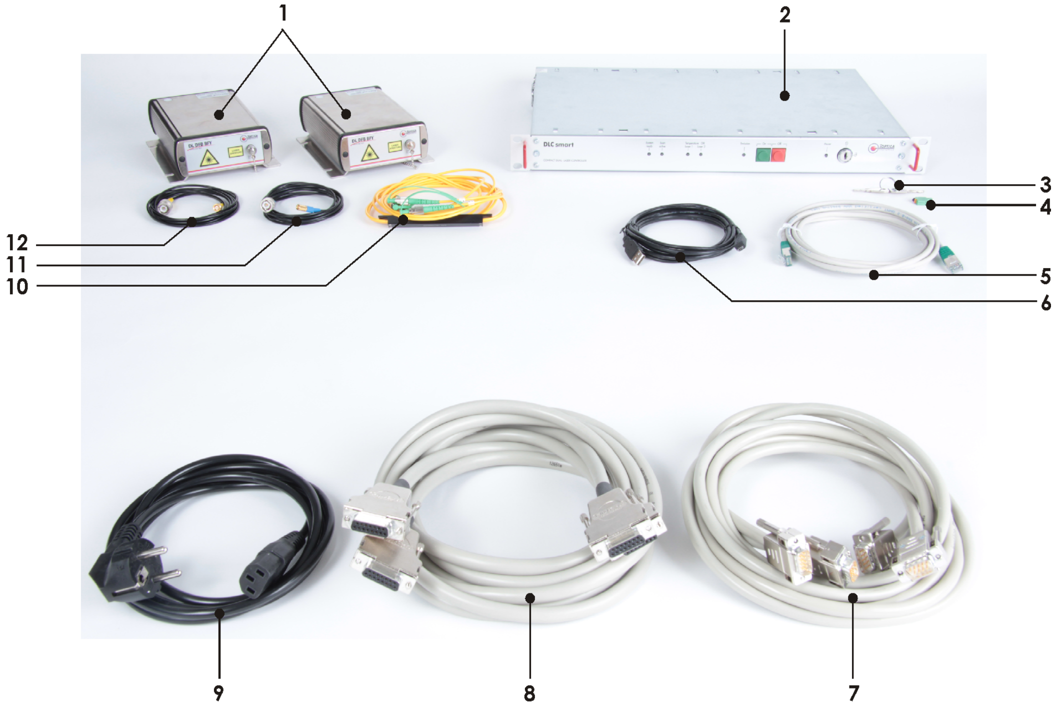



**Figure 18** TeraBeam 1550 package contents

1. TeraBeam laser system with 2 DFB pro BFY THz laser heads
2. DLC smart control electronics
3. Keys for key switch
4. Interlock plug
5. Ethernet patchcord
6. USB connector cable
7. 2 cables for current control connection
8. 2 cables for temperature control connection
9. Mains cable
10. SM/PM fiber combiner
11. SMB-BNC cable for photomixer connection
12. SMA-BNC cable for photomixer connection

Not shown: USB flash drive with TOPAS TeraScan Control software and USB drivers, TeraScan 1550/ TeraBeam 1550 System manual.

### 3.1.2 TERASCAN 1550

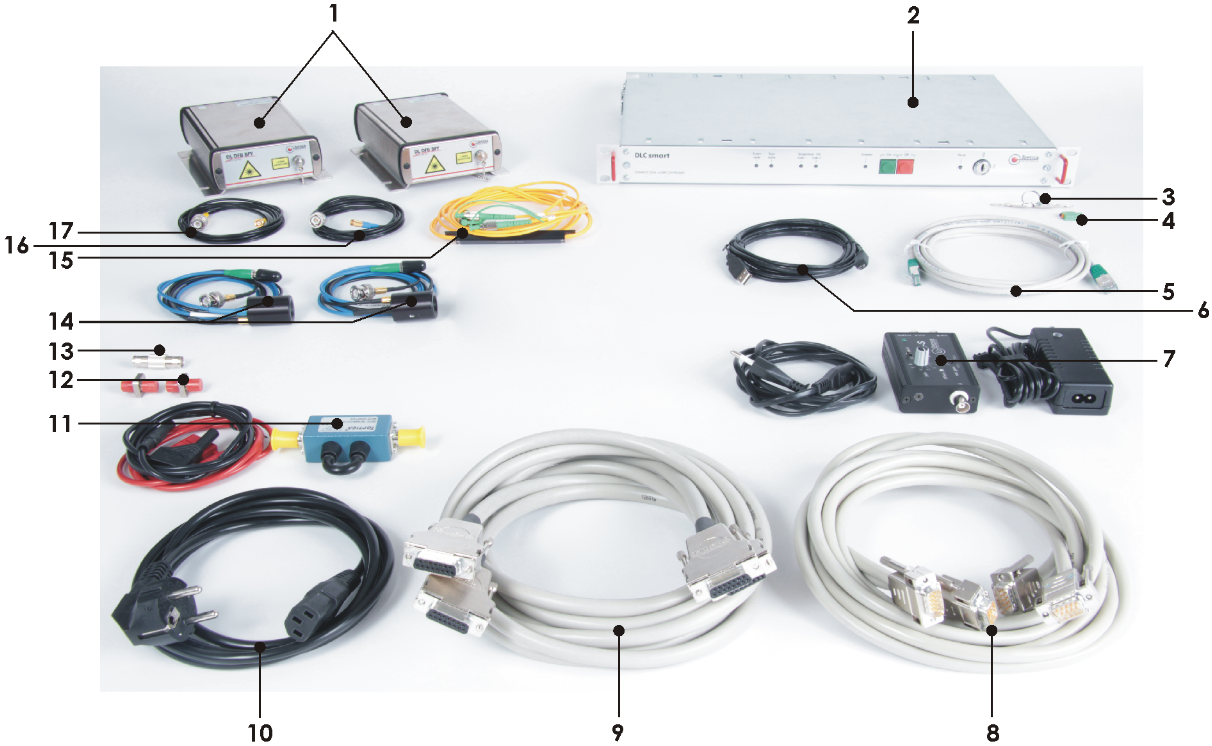



**Figure 19** TERASCAN 1550 package contents

1. TERABEAM laser system with 2 DFB pro BFY THz laser heads
2. DLC smart control electronics
3. Keys for key switch
4. Interlock plug
5. Ethernet patchcord
6. USB connector cable
7. 1 PDA-S transimpedance amplifier with power supply and mains cable
8. 2 cables for current control connection
9. 2 cables for temperature control connection
10. Mains cable
11. BNC breakout box with connector cables
12. 2 fiber mating sleeves
13. BNC - BNC adaptor (female - female)
14. 2 InGaAs photomixers
15. SM/PM fiber combiner
16. BNC - SMB cable for photomixer connection
17. BNC - SMA cable for photomixer connection

Not shown: USB flash drive with TOPAS TeraScan Control software and USB drivers, TERASCAN 1550/ TERABEAM 1550 System manual.

## 3.2 Environmental Requirements

- The TERASCAN 1550/TERABEAM 1550 Systems are designed for indoor usage, at altitudes below 2000 m.
- The DFB pro BFY THz Laser Heads can be installed in any position (e.g. horizontally or vertically). The main dimensions of the Laser Heads are noted in section 10.9.
- No particular precautions for heat sinking are required.
- It is recommended to fix the DFB pro BFY THz Laser Heads supply cables e.g. to an optical table.
- Always tighten the screws at the supply cable connectors.
- The DLC smart control electronics must always be kept in a horizontal position. Do not cover the venting grilles of the DLC smart.
- Make sure that the laser heads as well as the electronics are ruggedly fixed.
- Environmental conditions: +15 °C .. +30 °C, rel. humidity < 90 %, non-condensing.
- Never use the unit near water, for example near a wash basin, a sink or other damp environment.

# 4 DFB Lasers

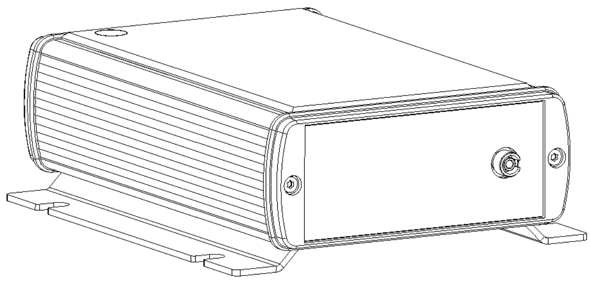


**Figure 20** DFB pro BFY THz laser head

## 4.1 Operator Controls DFB pro BFY THz Laser Head

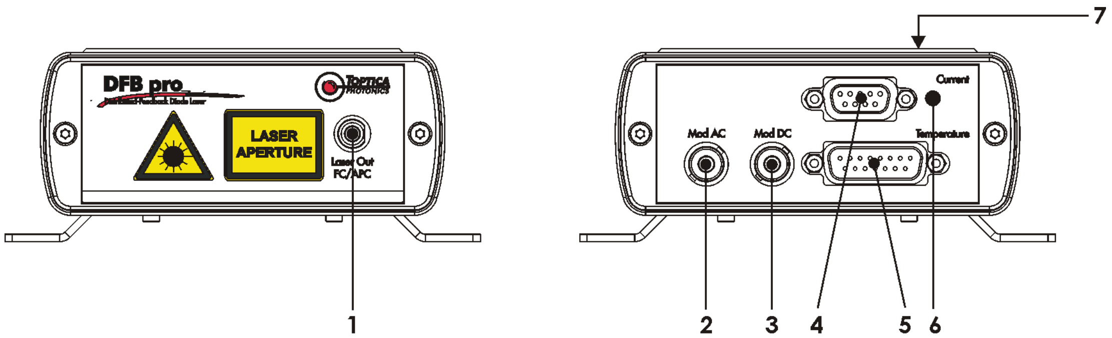



**Figure 21** DFB pro BFY THz front and rear panel

**1** FC/APC Fiber Connector

**2** Mod AC BNC Connector

**3** Mod DC BNC Connector

**4** CC D-Sub 9 Connector

**5** TC D-Sub 15 Connector

**6** Laser Radiation Emission Warning LED

**7** Laser Radiation Emission Warning LED on Top of the Protective Housing



Status: 22.1.19

## 4.2 Description of Operator Controls

| | |
|---|---|
| **1 FC/APC Fiber Connector** | FC/APC port for fiber connection. |
| **2 Mod AC**<br>• BNC-connector | not used. |
| **3 Mod DC**<br>• BNC-connector | not used. |
| **4 CC Connector**<br>• D-Sub 9-connector | D-Sub 9-connector for the current controller of the laser driver electronics. |
| **5 TC Connector**<br>• D-Sub 15-connector | D-Sub 15-connector for the temperature controller of the laser driver electronics. |
| **6 Laser Radiation Emission Warning LED** | The white LED lights up when the laser diode is emitting laser light.<br>**DANGER !** When the white Laser Radiation Emission Warning LED lights up, one has to be aware of laser emission. |
| **7 Laser Radiation Emission Warning LED on Top of Protective Housing** | The white LED lights up when the laser diode is emitting laser light.<br>**DANGER !** When the white Laser Radiation Emission Warning LED lights up, one has to be aware of laser emission. |

# 5 Photomixers

| | |
|---|---|
| **CAUTION !** | **While handling the photomixers we recommend to wear a high-impedance grounding strap around the wrist**. |

| | |
|---|---|
| **CAUTION !** | For ESD protection, connect and disconnect the photomixers electrically only when the seed lasers are switched ON. |

| | |
|---|---|
| **CAUTION !** | When handling the photomixers, it is necessary to protect them from any inadvertent electrical short-circuits and to avoid contact with current-carrying parts. The photomixers are particularly sensitive to voltage peaks. These might considerably affect the service life of the photomixers, even if a disturbance is not immediately noticeable. |

| | |
|---|---|
| **CAUTION !** | Take precautions not to destroy the fibers. Avoid sharp bends and do not drop heavy items on the fiber. |

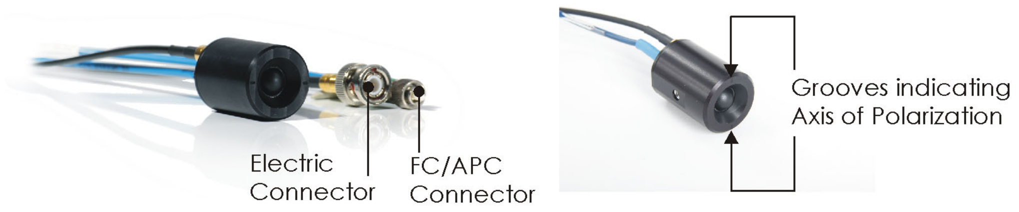



**Figure 22** InGaAs (right side) photomixer with SM/PM fiber pigtail. Right: The grooves indicate the axis of polarization.

The TERASCAN 1550 systems feature a set of fiber-pigtailed photomixers. The transmitter is based on a high-speed InGaAs photodiode and the receiver is an InGaAs photomixer, both with bow-tie antennas. This antenna geometry results in a linear polarization of the terahertz beam. Two grooves on the front side of the antenna module indicate the axis of polarization (see Figure 22).

The terahertz radiation is coupled to free space via a hyperhemispherical silicon lens. The lens serves to suppress back-reflections and pre-collimates the output beam. The residual beam divergence is:

12° FWHM @ 200 GHz
15° FWHM @ 500 .. 1000 GHz

# 6 DLC smart

## 6.1 Operator Controls

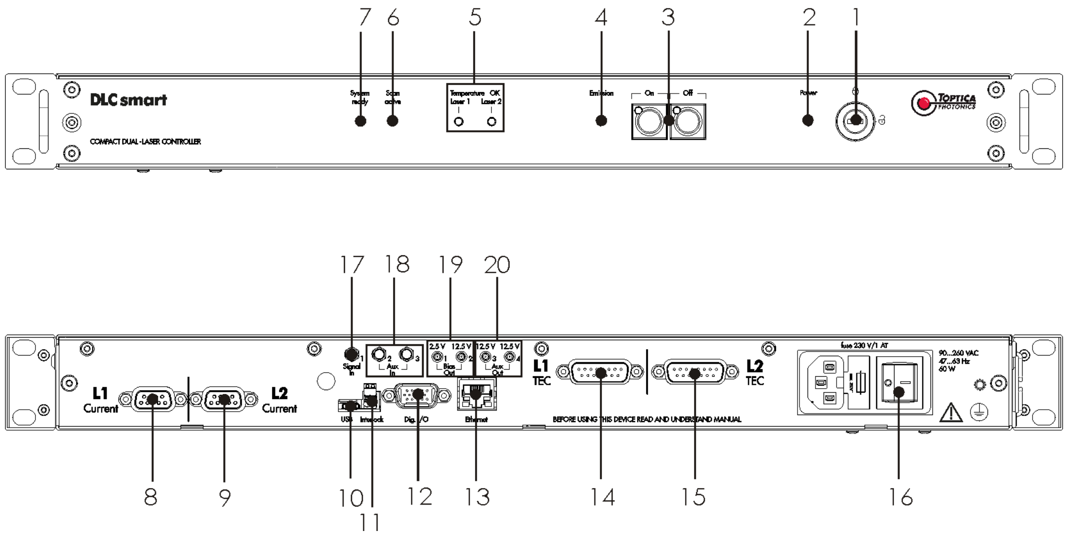



**Figure 23** Front and rear panel of DLC smart

- **1** Key Switch
- **2** Power LED
- **3** On/Off Button
- **4** Laser Radiation Emission Warning LED
- **5** Temperature OK LEDs for Laser 1 and 2
- **6** Scan active LED
- **7** System ready LED
- **8** Current Connector for Laser #1
- **9** Current Connector for Laser #2
- **10** USB Connector
- **11** Interlock Connector
- **12** Digital I/O Connector
- **13** Ethernet Connector
- **14** TEC Connector for Laser #1
- **15** TEC Connector for Laser #2
- **16** Mains Switch and Mains Connector
- **17** Signal In 1 SMA Connector
- **18** Aux in SMA Connectors
- **19** Bias Out SMB Connectors
- **20** Aux Out SMB Connectors

## 6.2 Description of Operator Controls

| | |
|---|---|
| **1 Key Switch** | Locks or unlocks the DLC smart.<br>Laser emission is only possible if the Key Switch is unlocked, i.e. in horizontal position. |
| **2 Power LED** | **OFF:** Mains switch OFF.<br>**Dimly lit:** Mains switch ON, CPU still booting.<br>**Flashing:** Booting finished, Key Switch in “locked” position.<br>**Brightly lit:** Booting finished, Key Switch in “unlocked” position. |
| **3 ON/OFF Button** | Pushing the ON Button activates the laser emission. Pushing the OFF button disables laser emission. |
| **4 Laser Radiation Emission Warning LED** | The white LED lights up when laser emission is switched on.<br><br>**DANGER !** When the white Laser Radiation Emission Warning LED lights up, one has to be aware of laser emission. |
| **5 Temperature OK LEDs Laser #1 and #2** | The Temperature OK LEDs indicate the status of the temperature controllers.<br><br>**Green:** Target temperature reached. The LED turns green when the terahertz frequency differs from the target frequency by less than 500 MHz.<br>**Yellow:** Target temperature not reached.<br>**OFF:** Temperature controller of the respective laser is switched OFF.<br>**Red:** An error has occurred at the respective temperature controller. Please check cable connections and restart the DLC smart. |
| **6 Scan active LED** | The green LED lights up while a fast scan (see section 8.7.1.3) is running. |
| **7 System ready LED** | The System ready LED indicates whether the firmware is running properly.<br><br>**Green, flashing:** Everything OK.<br>**Yellow, flashing:** Indicates a system warning, most likely a missing cable connection. Check all cable connections and restart the DLC smart.<br>**Red, flashing:** Indicates a hardware error. Restart the DLC smart. If the problem persists, contact TOPTICA Photonics AG. |
| **8 Current Connectors Laser #1:**<br>• Sub-D9-connector | Socket for the current connector cable for Laser #1. |
| **9 Current Connectors Laser #2:**<br>• Sub-D9-connector | Socket for the current connector cable for Laser #2. |
| **10 USB Connector** | USB interface for computer control. For installation of the USB driver, please refer to section 10.5. |
| **11 Interlock Connector**<br>• Phoenix-connector | Connector for setting up an external interlock circuit.<br>Connector Type: Phoenix Contact FK-MC 0.5/2-ST-2.5 |
| **12 Digital I/O Connector**<br>• Sub-D15 HD-connector | Configurable input/output connector. Not used in the TERASCAN 1550/ TERABEAM 1550 Systems. |

| | |
|---|---|
| **13 Ethernet Connector** | Ethernet interface for computer control. |
| **14 TEC connector Laser #1**<br>• Sub-D15-connector | Socket for the TEC connector cable for Laser #1. |
| **15 TEC connector Laser #2**<br>• Sub-D15-connector | Socket for the TEC connector cable for Laser #2. |
| **16 Mains Switch and Connector** | Socket for mains cable and ON/OFF switch for mains supply. The connector block also contains a cartridge with two fuses. For exchanging the fuses, please refer to section 10.4. |
| **17 Signal In 1**<br>• SMA-connector | Input connector for the pre-amplified signal of the receiver (Rx) photo-mixer. |
| **18 Aux In**<br>• SMA-connectors | Auxiliary input connectors.<br>**Aux In 3** Only used in systems with Phase Modulation Extension. Serves as input port for the monitor signal (1:100 Mon. Out) of the high-voltage amplifier.<br>**Aux In 2** Not used in the TERASCAN 1550/TERABEAM 1550 Systems. |
| **19 Bias Out**<br>• SMB-connectors | Output connector for the bias voltage of the transmitter (Tx) photomixer.<br><br>**NOTE !** **InGaAs** photomixers must be connected to output Bias Out 1 (max. ± 2.5 V). |
| **20 Aux Out**<br>• SMB-connectors | **Aux Out 3** Only used in systems with Phase Modulation Extension. Serves as output port of the piezo driver signal. Connect to the input port of the high-voltage amplifier.<br>**Aux Out 4** Not used in the TERASCAN 1550/TERABEAM 1550 Systems. |

# 7 Operation

This section describes the installation and operation of "standard" TeraScan 1550 and TeraBeam 1550 systems consisting of two DFB lasers, a fiber combiner and two terahertz antennas.

Specific instructions about systems with Tuning Range Extension, Phase Modulation Extension or Optomechanics are given in section 9.

| | |
|---|---|
| **NOTE !** | For package contents of your individual TeraScan 1550 or TeraBeam 1550 system, please refer to section 3. |

## 7.1 Basic Procedures

### 7.1.1 Cleaning and Handling of a Fiber

| | |
|---|---|
| **DANGER !**<br>**CAUTION !** | Never clean the fiber when the laser emission is switched ON ! |

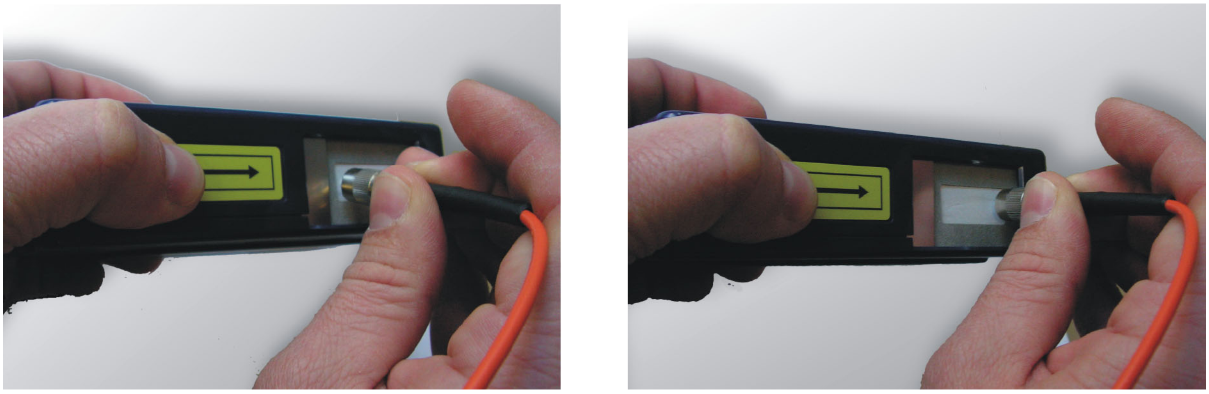


**Figure 24** Cleaning the fiber:
Hold the fiber as shown on the left side and move it twice across the cleaning surface as shown on the right side.

Before connecting an optical fiber, its facet should be cleaned with a commercially available 'reel cleaner' or a similar device that incorporates a dry woven polyester cloth as cleaning medium (see Figure 24).

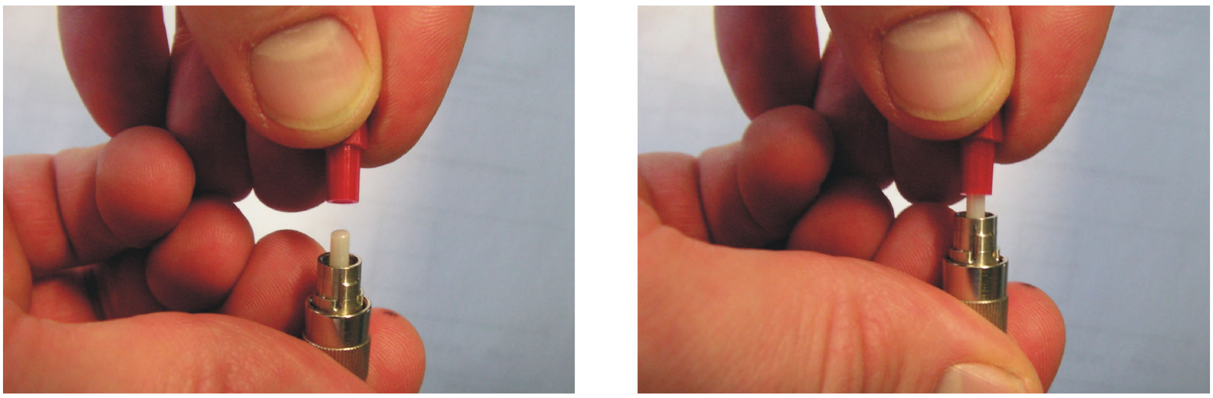


**Figure 25** Protection of the external fiber during installation

Carefully place the cap on the fiber end as shown in Figure 25 to protect it when not in use.

# 7.2 TERASCAN 1550 and TERABEAM 1550 System Installation

## 7.2.1 Computer Control and Basic Connections

**1.** Install the TOPAS TeraScan Control software on the control computer by following the steps described in section 8.3.

**2.** Connect lasers #1 and #2 to the corresponding outputs for temperature and current control on the rear panel of the DLC smart.

| | |
|---|---|
| **NOTE !** | Lasers #1 and #2 are separate units. **They are identified by their serial numbers, as listed in section 02 of the Production and Quality Control Datasheet of your system. The correct connections are shown in section 04 of the same datasheet**. |

| | |
|---|---|
| **NOTE !** | In systems with Tuning Range Extension, select the laser heads of the frequency range you wish to work at. For each frequency range, the serial numbers of the corresponding lasers are shown in section 04 of the Production and Quality Control Datasheet. |

**3.** Set-up an interlock circuit (please refer to section 2.3.1) or use the interlock plug provided.

**4.** Connect the DLC smart to mains.

**5.** Connect the DLC smart to your network, or directly to your PC via the Ethernet connector on the rear panel of the DLC smart and the supplied Ethernet patchcord. For details on the Ethernet connection please refer to section 8.1.

| | |
|---|---|
| **CAUTION !** | Do not control the system via the USB interface, as this does not support all of the software functions. Use USB for IP address configuration only (see **> DLC smart > Device Configuration > Network** in section 8.6.2). |

**6.** Switch the DLC smart ON at the mains switch on the rear panel. Wait about 45 s until the booting procedure is completed. As soon as the system is ready, an acoustic signal is emitted, and the System ready LED on the DLC smart front panel flashes green.

**7**. Turn the key switch on the DLC smart front panel to "unlocked", i.e. in horizontal position.

**8.** Start the TOPAS TeraScan Control software.

**9.** Establish a connection between the control computer and the DLC smart as described in section 8.4, steps 1 - 6.

### 7.2.2 Connecting the Photomixers

**1.** Connect the PDA-S transimpedance amplifier to mains via the power supply and the mains cable.

**2.** Clean the fiber ends of both photomixers, and of the fiber combiner, e.g. with a Reel Cleaner (please refer to section 7.1.1).
Connect the fibers of the photomixer modules, as documented in the sketch of Optical Connections (see section 07 of the Production and Quality Control Datasheet).

**3.** Switch ON lasers #1 and #2 using either the **Laser Emission On/Off** button in the **Main Window** of the TOPAS TeraScan Control software or the ON button at the front panel of the DLC smart.

| | |
|---|---|
| **CAUTION !** | Photomixers are ESD-sensitive devices. **We recommend wearing a high-impedance grounding strap around the wrist when handling photomixers.** Take care not to touch the inner conductor of the connector cable. |

| | |
|---|---|
| **CAUTION !** | Connect and disconnect the photomixers electrically only when both seed lasers are switched ON. |

| | |
|---|---|
| **CAUTION !** | Take precautions not to destroy the optical fibers. Avoid sharp bends and do not drop heavy items on the fiber. Avoid dust and scratches on the fiber facets. |

**4.** Check that **Tx Bias Amplitude (V)** and **Tx Bias Offset (V)** are set to zero. Click **Set Bias to Zero** if any of the voltages differs from zero.

**5.** Make sure that your hand, as well as the photomixer housing and the connector cable are grounded.
- Wear a grounding strap around your wrist.
- Put the photomixer housing on a grounded surface, e.g. an electrically grounded breadboard.

**6.** Connect the transmitter (Tx) photomixer to the BNC breakout box, using the BNC connector cable attached to the photomixer module. Make sure that the U-shaped link of the BNC breakout box is inserted.

**7.** Plug in the provided SMB-to-BNC cable at the rear panel of the DLC smart (see Note below). Fasten the BNC connector of the cable at the second port of the BNC breakout box.

| | |
|---|---|
| **NOTE !** | **InGaAs** photomixers must be connected to output Bias Out 1 (max. ± 2.5 V). |

**8.** Connect the receiver (Rx) photomixer to the input connector (label: in) of the PDA-S, using the BNC connector cable attached to the photomixer module.

**9.** Connect the output of the PDA-S amplifier (label: out A) to the Signal In 1 SMA-connector on the rear panel of the DLC smart, using the SMA-to-BNC connector cable.

**10.** Check that the gain setting at the PDA-S amplifier switch and the **Gain** value in the **Lock-in** folder of the TOPAS TeraScan Control software are identical. Settings are documented in section 06 of the Production and Quality Control Datasheet.

**11.** Set the bias voltage to the default values using the button **Set Bias to Default** in the **Lock-in** folder of the TOPAS TeraScan Control software.

**12.** Click **Sampling** to start the data acquisition. You should observe a non-zero photocurrent.

**13.** To switch OFF the system, please refer to section 7.4.

| | |
|---|---|
| **NOTE !** | The optical beam path between Tx photomixer and Rx photomixer must be closed ! A convenient setup to test the functionality of the system is a face-to-face configuration of the photomixers.<br>Take care to avoid ground loops between the two photomixers. There must not be a direct, electrically conductive connection between the transmitter and the receiver. |

## 7.3 Regular Power-Up

**1.** Make sure that the bias voltage line to the transmitter (Tx) photomixer is interrupted, e.g. by removing the U-shaped link of the BNC breakout box.

**2.** Switch the DLC smart ON at the mains switch on the rear panel. Wait about 45 s until the booting procedure is completed. As soon as the system is ready, an acoustic signal is emitted, and the System ready LED on the DLC smart front panel flashes green.

**3.** Start the control computer and run the TOPAS TeraScan Control software.

**4.** Establish a connection between the control computer and the DLC smart as described in section 8.4, steps 1 - 6.

**5.** Check that **Tx Bias Amplitude (V)** and **Tx Bias Offset (V)** are set to zero. Click **Set Bias to Zero** if any of the voltages differs from zero.

**6.** Switch ON lasers #1 and #2 using either the **Laser Emission On/Off** button in the **Main Window** of the TOPAS TeraScan Control software or the ON button at the front panel of the DLC smart.

| | |
|---|---|
| **CAUTION !** | Connect and disconnect the photomixers electrically only when both seed lasers are switched ON. |

**7.** Connect the PDA-S power supply to mains.

**8.** Close the bias voltage line to the transmitter (Tx) photomixer, e.g. by inserting the U-shaped link of the BNC breakout box.

**9.** Set the bias voltage to the default values using the button **Set Bias to Default** in the **Lock-in** folder of the TOPAS TeraScan Control software.

**10.** Click **Sampling** to activate the data acquisition

## 7.4 Regular Power-Down

1. Set **Tx Bias Offset** and **Tx Bias Amplitude** to zero using the button **Set Bias to Zero** in the **Lock-in** folder of the TOPAS TeraScan Control software.

2. Remove the U-shaped link of the BNC breakout box to interrupt the bias voltage line to the transmitter (Tx) photomixer.

3. Disconnect the PDA-S power supply from mains.

4. Switch lasers #1 and #2 OFF by pressing the OFF button at the front panel of the DLC smart or via the **Laser Emission On/Off** button in the **Main Window** of the TOPAS TeraScan Control software.

5. Close the connection to the DLC smart. Shut down the TOPAS TeraScan Control software.

6. Switch the DLC smart OFF at the mains switch at the rear panel.

# 8 TOPAS TeraScan Control Software and Computer Control

Frequency control of the two diode lasers, bias modulation of the terahertz transmitter and readout of the receiver photocurrent are accomplished by the DLC smart. The DLC smart itself is controlled by a standard PC (Windows 7/8/10). The TOPAS TeraScan Control software with Graphical User Interface is supplied as part of the delivery. The software enables the user to set all relevant parameters and record terahertz spectra.

## 8.1 Ethernet Connection

The Ethernet interface provides a fast and flexible way of controlling the TERABEAM/TERASCAN. To do so, the DLC smart must be connected either to a local area network (LAN) or directly to a PC, e.g. with a cross-link cable. Further, the DLC smart and the PC need to have IP addresses of the same subnet. Upon delivery the laser is configured to retrieve its IP address automatically via DHCP.

**Telnet Server / Scheme Console**

A Telnet server on standard port 1998 provides access to the command console. This is the connection intended for automated remote control via Ethernet. On this console, you can use the complete set of control commands as listed in the Command Reference document which can be displayed by selecting **Help > Command Reference** in the TOPAS TeraScan Control software.

For manual control, you can use any standard telnet client. A good choice for a third-party telnet client is PuTTY[5]. You can also try entering

```
telnet://xxx.xxx.xxx.xxx 1998
```

into the address bar of your web browser to let Windows choose its favorite telnet client. The telnet command also belongs to every standard Linux distribution.

For system control within your own software framework, please follow these steps:

1. Open a TCP/IP connection to the laser's IP address, port 1998.
2. Set the socket option TCP_NODELAY[6].
3. The laser then sends a welcome text which is completed by a prompt consisting of the two characters “> “ (“larger than” and space) at the beginning of a new line.
4. Send your commands and complete every instruction with a linefeed character (ASCII code 10 decimal, 0x0A hexadecimal).
5. The reply of the system is once again completed by the prompt.
6. When finished, close the TCP/IP connection or send `(quit)`.

The DLC smart accepts up to three telnet connections at the same time.

5. PuTTY is a free Telnet and SSH client for Windows and UNIX platforms. It can be downloaded free of charge from the official site http://www.chiark.greenend.org.uk/~sgtatham/putty/.
6. This is not mandatory but usually helps speeding up the communication, since typically many very short telegrams are exchanged between PC and laser.

**Identification Server**

In order to determine the IP address of your system, e.g. in case of an automatic address assignment via DHCP, the firmware provides an UDP-based identification service on port 60010.

If you want to program a software search to find a particular laser system within the LAN, proceed as follows:

1. On port 60010, broadcast a short string like “laserfinder” to the entire LAN (address 255.255.255.255) or to the broadcast address of you network adapter (e.g. 192.168.1.255).

2. Listen for an answer on the same port. The laser will reply with an UDP message providing information about its serial number and its firmware version. The IP address of the laser is comprised in the header of the UDP packet.

If no message is received within one second, no laser is available. If more than one laser is connected to the LAN, this procedure returns a list of all lasers.

| | |
|---|---|
| **NOTE !** | **Users of PuTTY:** When connecting via Ethernet, simply start PuTTY and enter the IP address of your system. Set the port number to 1998.<br>When using the USB interface, start PuTTY and, rather than providing the IP address, enter the number of the COM-port to which the system is connected. |

## 8.2 USB Connection

The DLC smart features an additional USB interface (see Figure 23). The USB link is selected in the **DLC smart** menu of the software (see section 8.6.2). The correct baudrate for USB control is 115200. Using the USB interface requires the installation of a USB driver. For installation of the USB driver, please refer to section 10.5.

| | |
|---|---|
| **CAUTION !** | Do not control the system via the USB interface, as this does not support all of the software functions. Use USB for IP address configuration only (see **> DLC smart > Device Configuration > Network** in section 8.6.2). |

| | |
|---|---|
| **NOTE !** | In order to address the system via USB, a specific driver needs to be installed. Please refer to section 10.5 for instructions |

## 8.3 Software Installation

### 8.3.1 System Requirements

System requirements for installation of the TOPAS TeraScan Control software with Graphical User Interface (GUI):

- Windows 7/8/10 operating system
- Min. 1-GHz-Processor
- Min. 1 GB RAM
- Min. 100 MB memory available on hard-disk
- Recommended screen resolution: 1920x1200
- Depending on the Windows setup, it might be necessary to log in with administrator rights

### 8.3.2 Installation of the TOPAS TeraScan Control Software

Copy the folder "TOPAS_TeraScanControl-x.x.x" from the supplied USB flash drive to the harddisk of the control PC, e.g. to "Program Files". Please ensure that you have access rights to read, write and create files in this folder.

## 8.4 Quickstart for System Operation with TOPAS TeraScan Control

**1.** Connect the DLC smart to your network via the Ethernet port, or directly to your PC via the USB interface or a cross-link network cable (see section 8.1).

**2.** Start the DLC smart (mains switch on rear panel to position “ON”, key switch to position “unlocked”).

**3.** Select the harddisk folder of your PC to which you have copied the control software of the DLC smart. Start the software by clicking on **TOPAS_TeraScanControl.exe**. A window with the Graphical User Interface opens.

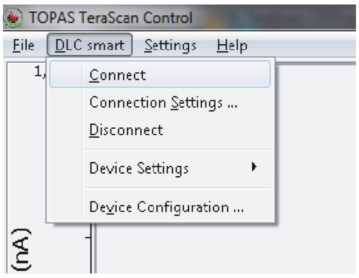



**Figure 26** TOPAS TeraScan Control – DLC smart menu

**4.** Select **DLC smart > Connection Settings** (see Figure 26).

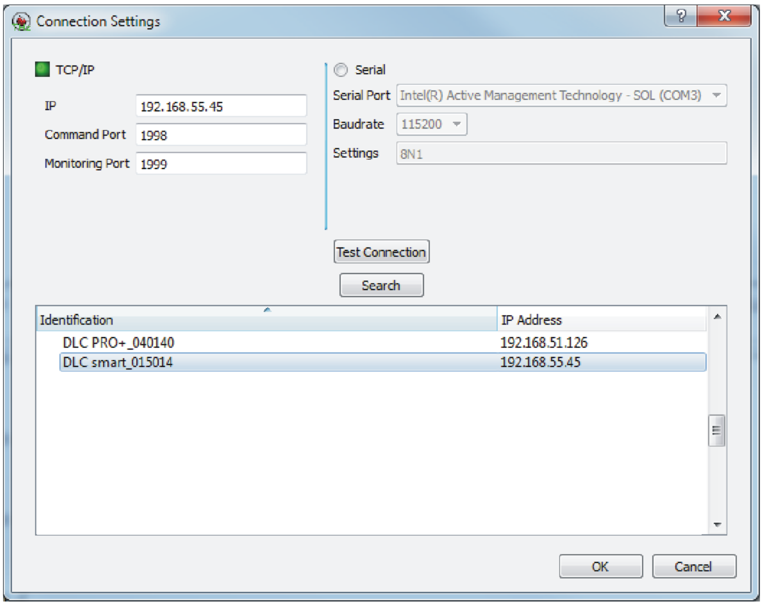



**Figure 27** Connection Settings window

**5.** In the **Connection Settings** window, select **TCP/IP** for control via Ethernet, or **Serial** for control via USB (see Figure 27). If several systems are displayed in the **Identification** field, e.g., as part of a larger network, first select the system that you wish to control.
You can then verify whether the connection works properly by clicking **Test Connection.** Click **OK** to save the settings and close the window.

| | |
|---|---|
| **NOTE !** | For a detailed description of the connection properties, please refer to section 8.1 of this Manual. |

**6.** Select **DLC smart > Connect** to establish a connection to the device.

| | |
|---|---|
| **NOTE !** | Make sure the photomixers are optically connected as described in section 7.2.2 and that the PDA-S transimpedance amplifier is plugged in. |

**7.** Click **Laser Emission On/Off** in the **Main Window** (see Figure 36).

**8.** Close the bias voltage line to the transmitter (Tx) photomixer, by inserting the U-shaped link of the BNC breakout box.

**9.** Click **Set Bias to Default** in the **Lock-in** folder (see Figure 40).

**10.** The system can now be operated using the TOPAS TeraScan Control software.

### 8.4.1 Recording a Frequency Scan

The following description assumes that the optical beam path between Tx photomixer and Rx photomixer is closed. You can, e.g., use an optomechanical setup with two mirrors (#BG-002653 or #BG-001481, see section 9.4).

| | |
|---|---|
| **NOTE !** | Take care to avoid ground loops between the two photomixers. There must not be a direct, electrically conductive connection between the transmitter and the receiver. |

**1.** Follow steps 1 - 9 as described above (section 8.4).

**2.** Set the terahertz frequency to a moderately large value, e.g. 500 GHz. Click **Sampling** to start the data acquisition. You should observe a non-zero photocurrent. Wait until the photocurrent signal becomes reasonably stable..

**3.** Set the **Step** size to a small value, e.g. 30 MHz.

**4.** Set the **Integration Time** in the **Lock-in** folder to approx. 80 ms.

**5.** Click **Scan Up** and wait until the oscillating photocurrent signal has completed a few fringes (= phase maxima and minima), then click **Scan Up** again to stop the scan. The fringes should have a – more or less – sinusoidal shape. If this is not the case, try improving the alignment of the terahertz beam path first.

**6.** Determine the approximate fringe spacing, then set the **Step** size to a value that is approx. 30 times smaller than the fringe spacing.

**7.** Set the value of **# of Points Compared** in the **General** settings folder to 15.

**8.** Set the terahertz frequency to a low value, e.g. 150 GHz. Confirm by clicking Enter and wait until the lasers are tuned to the new frequency.

**9.** Define the scan boundaries: Set **Min** to 150 GHz and **Max** to 1120 GHz.

**10.** Set the scan mode to **Fast** and the **Integration Time** to 3 ms.

**11.** Click **Clear Data** to clear the display.

**12.** Start the scan by clicking **Scan Up**.

You should observe fringes with decreasing amplitude in the lower graph of the Main Window, and the *envelope* of the fringes in the upper graph. The envelope trace should show the strong water vapor signature at 1097 GHz. Depending on the length of the terahertz beam path, you may also be able to see weaker water lines at 752 GHz and 988 GHz.

## 8.5 Overview of the TOPAS TeraScan Control Software

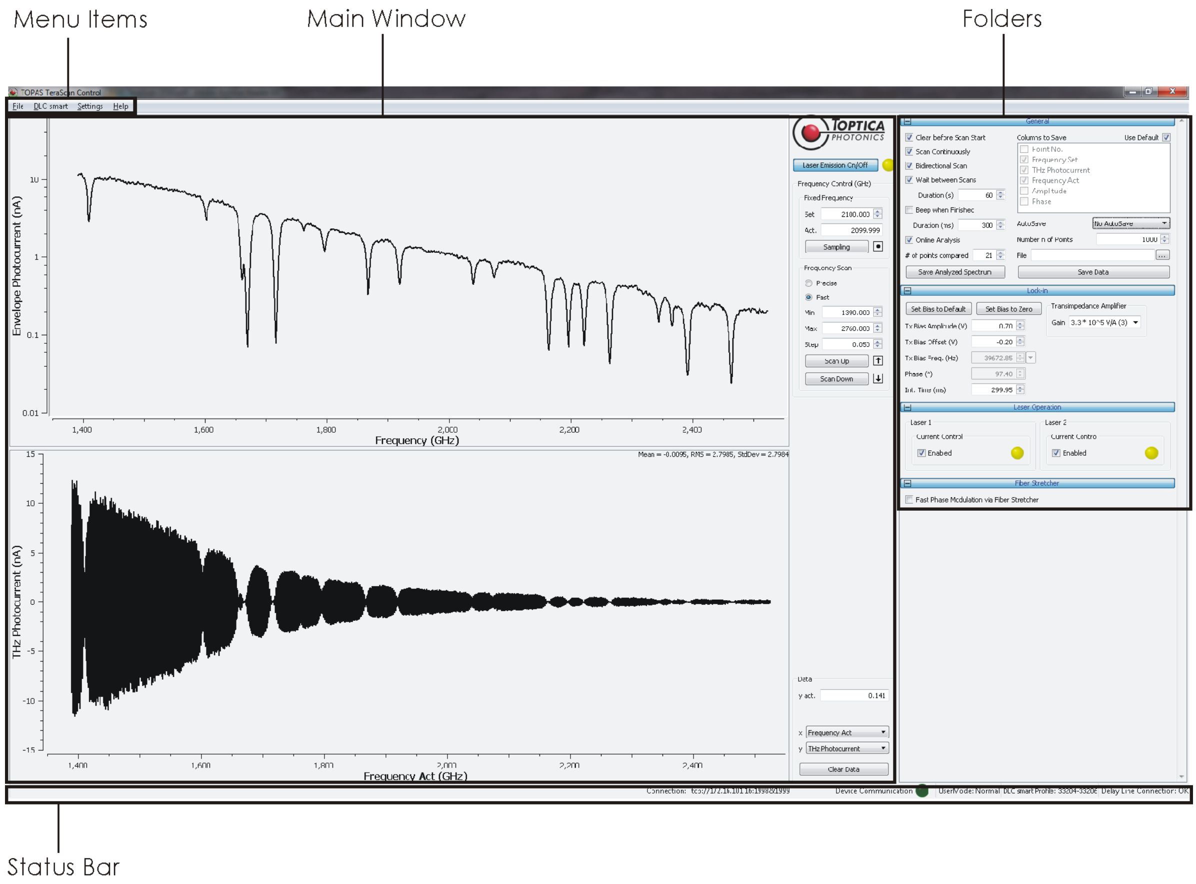



**Figure 28** Graphical User Interface of the TOPAS TeraScan Control software

## 8.6 Menu Items

### 8.6.1 File Menu

**Close** Closes the TOPAS TeraScan Control software.

### 8.6.2 DLC smart Menu

In this menu, you can configure the connection settings between your control PC and the DLC smart. You can establish or close a connection, and upload firmware files to the microprocessor built into the DLC smart.

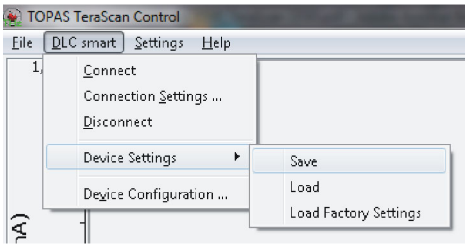



**Figure 29** DLC smart menu

**> DLC smart > Connect** Establishes a connection to the device selected in the Connection Settings window.

**> DLC smart > Connection Settings** Opens a new window where the Connection Settings can be configured (see Figure 30).

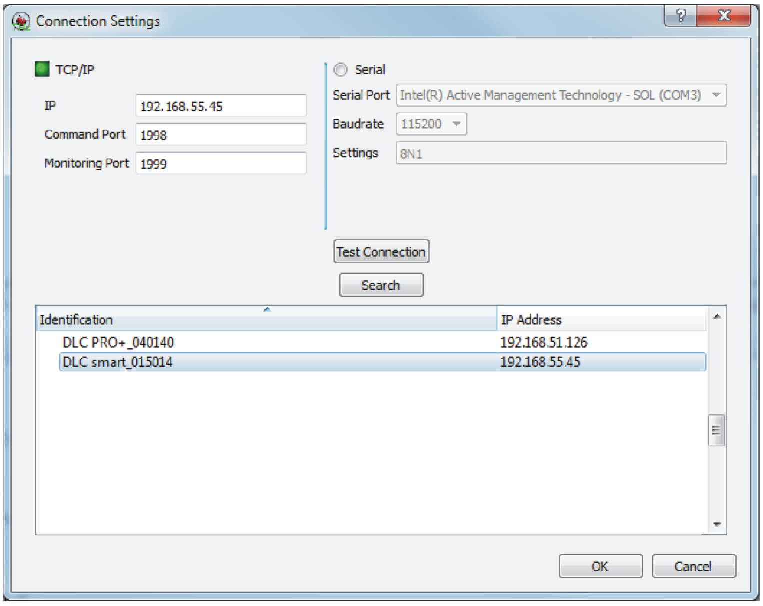



**Figure 30** Connection Settings Window

The display area of the Connection Settings Window lists all devices connected to the local network via TCP/IP. After selecting a device, relevant connection parameters (**IP address**, **Command Port** and **Monitoring Port**) are displayed in the respective fields.

| | |
|---|---|
| **TCP/IP** | When selected, all devices within the network connected via Ethernet are listed in the display area. After selecting a device, its connection properties are shown in the respective fields. |
| **Serial** | Enables device control via the USB interface. Use the pull-down menu to select the Serial Port. The correct Baudrate setting is 115200. |

**NOTE !** Do not control the system via the USB interface, as this does not support all of the software functions. Use USB for IP address configuration only (see **> DLC smart > Device Configuration > Network** below).

| | |
|---|---|
| **Test Connection** | Establishes a test connection to the selected device and then closes it. If the connection test was successful, a pop-up window displays details on the selected device and, in case of a TCP/IP connection, the DLC smart emits an acoustic signal. If the connection test fails, an error message is shown. |

**NOTE !** This function is only available for system control via TCP/IP.

| | |
|---|---|
| **Search** | Searches for devices in the network, connected via TCP/IP. The search results are displayed in the area below. |
| **OK** | Saves the settings and closes the window. To establish a connection with these settings, select **Menu > Connect**. |
| **Cancel** | Discards changes and closes the window. |

| | |
|---|---|
| **> DLC smart > Disconnect** | Closes the connection to the device. |
| **> DLC smart > Device Settings** | Opens a pull-down menu to store and retrieve parameter settings of the DLC smart. |
| **Save** | Stores the currently adjusted parameters in the start-up configuration of the DLC smart. |
| **Load** | Loads previously saved parameters and updates the settings in the DLC smart. |
| **Load Factory Settings** | Retrieves the default parameter settings as stored during system production at TOPTICA. |

**> DLC smart > Device Configuration > User Level**

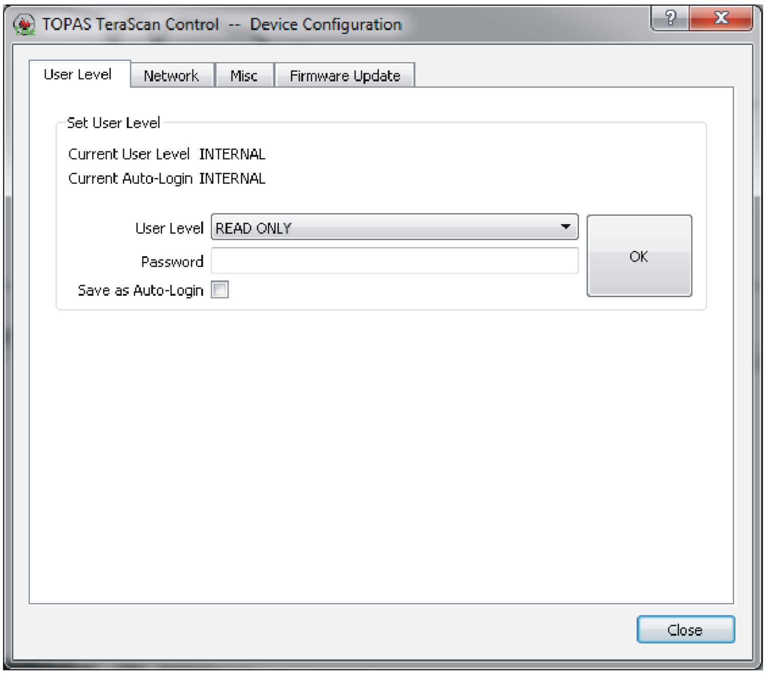



**Figure 31** Device Configuration Window, User level tab

Some parameters and commands are user level-restricted, either because they are not required for regular operation, or because they can adversely affect the system performance. The following user levels are implemented:

| | |
|---|---|
| 4 - READ ONLY | lowest priority level |
| 3 - USER | normal operation |
| 2 - MAINTENANCE | maintenance level |
| 1 - SERVICE | service level |
| 0 - INTERNAL | for Toptica internal use only |

**CAUTION ! Do not change any user level settings.**

| | |
|---|---|
| **User Level** | Pull-down menu to select the user level. |
| **Password** | Input field for entering passwords. |
| **Save as Auto-Login** | When checked, the presently active user level is saved for Auto-Login. |
| **OK** | Confirms the present settings. |
| **Close** | Closes the window. |

**> DLC smart > Device Configuration > Network**

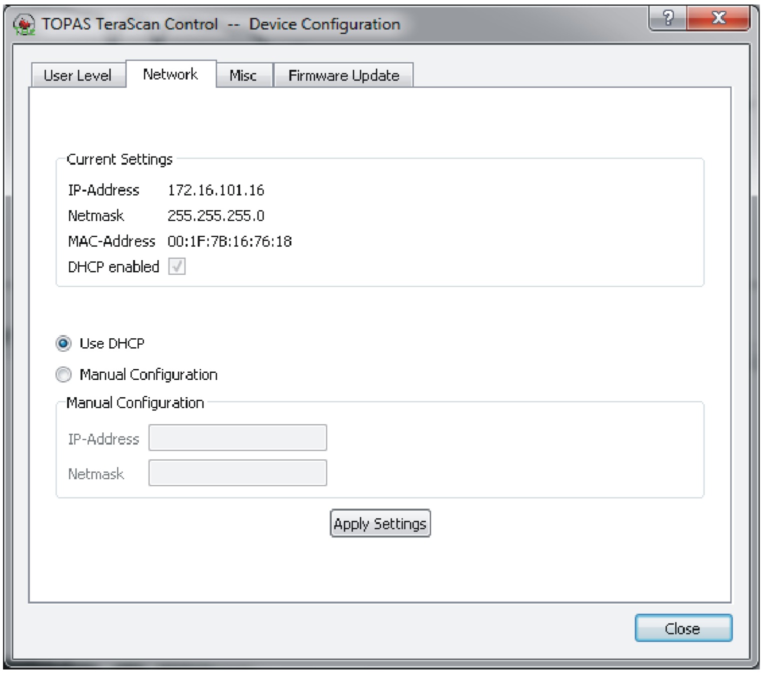



**Figure 32** Device Configuration Window, Network tab

| | |
|---|---|
| **NOTE !** | Changing the network settings works best if you are connected via USB. Please refer to the description in section 10.6. |

**Current Settings** — Display of the current network settings.

**IP-Address** — Shows the current IP address of the connected device.

**Netmask** — Shows the current subnet mask of the connected device.

**MAC-Address** — Shows the hardware/MAC address of the network adapter of the connected device.

**DHCP enabled** — Indicates whether the device is configured for automatic IP address retrieval by a DHCP server.

**Use DHCP** — Changes the network adapter configuration to automatic setup by a DHCP server. After selecting this option, the IP address and netmask will not yet have changed. The new network adapter configuration will take effect upon the next adapter restart.

**Manual Configuration** — Changes the network adapter configuration to a static IP configuration. Both the desired IP address and netmask have to be provided in the **IP address** and **Netmask** field, respectively. After entering the values, the IP address and netmask will not yet have changed. The new network adapter settings will take effect upon the next adapter restart.

**IP-Address** Input field for manual configuration of the IP address. The desired IP address must be provided as IPv4 address in the format "xxx.xxx.xxx.xxx", e.g. "192.168.54.82".

**Netmask** Input field for manual configuration of the subnet mask. The netmask must be provided as IPv4 address in the format "xxx.xxx.xxx.xxx", e.g. "255.255.248.0".

**Apply Settings** Restarts the network adapter, making use of the current network configuration. Please note that your current TCP/IP connections might be lost if you click this button and confirm the following dialog window with Yes. Select Menu > Connect to reconnect to the system.

**CAUTION !** Use this button only if the system is connected via USB. Clicking **Apply Settings** and confirming with **Yes** while the DLC smart is connected via TCP/IP will cause an undefined start of the network adapter.

**Close** Closes the window.

**NOTE !** Some IP-Address combinations may cause problems with the software. One working combination of addresses is:
**DLC smart IP-Address**: 192.168.54.82
**PC IP-Address**: 192.168.54.83
**Both subnet masks**: 255.255.248.0

**> DLC smart > Device Configuration > Misc**

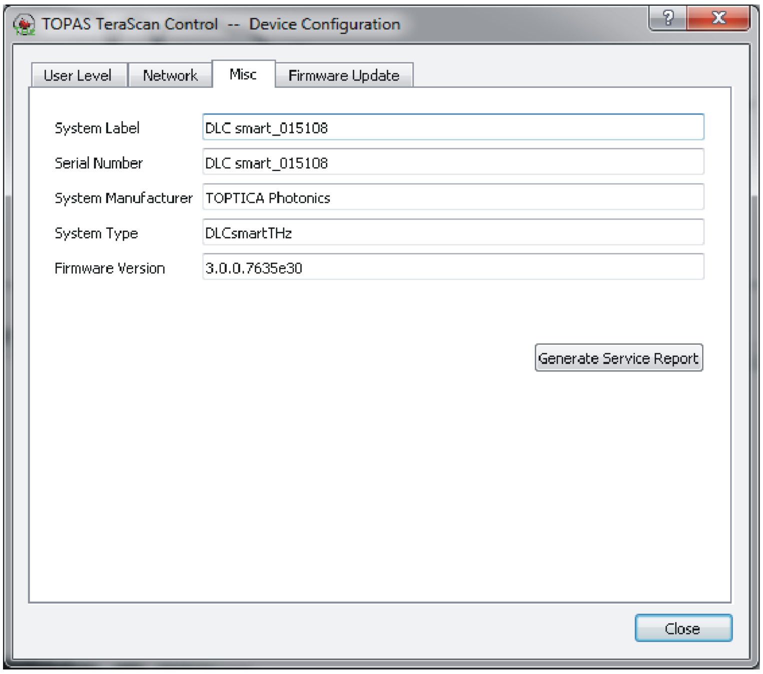



**Figure 33** Device Configuration Window, Misc tab

**System Label** Input field for entering an individual name for the currently connected device.

**Serial Number** Displays the serial number of the currently connected device.

**System Manufacturer** Displays the manufacturer of the TeraScan 1550/TeraBeam 1550 system.

**System Type** Displays the type of the currently connected device.

**Firmware Version** Displays the currently installed firmware version.

**Generate Service Report** Generates a binary file (*.bin) that can be emailed to Toptica to trace down possible sources of error in service cases. A window appears and indicates that the service report is generated. Click **Cancel** to stop the process.

| | |
|---|---|
| **NOTE !** | Do not change any settings within the TOPAS TeraScan Control software or at the DLC smart front panel while the Service Report is being generated. |

**Close** Closes the window and stores the settings.

**> DLC smart > Device Configuration > Firmware Update**

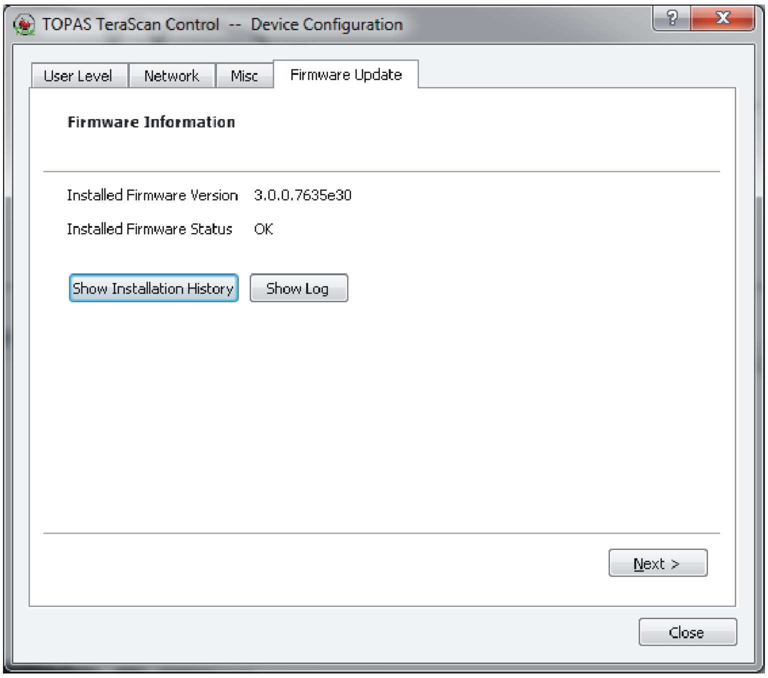



**Figure 34** Device Configuration Window, Firmware Update tab

| | |
|---|---|
| **Firmware Information** | Displays information about the currently installed firmware version and its status. |
| **Show Installation History** | Displays the history of the installed firmware versions. |
| **Show Log** | Displays a log file of the firmware installer. |
| **Next >** | Opens the Archives window, where firmware files can be added and selected for installation. |

Please refer to section 10.7 for step-by-step instructions for a firmware update.

### 8.6.3 Settings Menu

**Show Control Folders**

When activated, additional folders (General, Lock-in and others according to the system configuration) are displayed on the right hand side of the main window.

**SuperUser Mode**

The SuperUser mode allows for changing system-specific settings. This mode is only used during system assembly and protected by a password.

### 8.6.4 Help Menu

**Command Reference**

Opens a pdf file with a description of all relevant software commands, for users who wish to control their TERASCAN 1550/ TERABEAM 1550 system with their own software framework.

**Version Numbers**

Displays information about the version of the currently installed TOPAS TeraScan Control software.

**Legal Info DLC smart**

This product incorporates certain third party software. The license and copyright information associated with this software is available after clicking **Legal Info DLC smart**.

**About**

Displays information about the TOPAS software in general and shows TOPTICA´s contact address.

## 8.7 Features of the TOPAS TeraScan Control Software

The TOPAS TeraScan Control software permits two ways of operation. A **Fixed Frequency** mode is available for system alignment, or for continuous measurements at a single terahertz frequency, e.g. for terahertz imaging. The **Frequency Scan** mode, on the other hand, varies the terahertz frequency over a user-defined range in adjustable steps.

When the TOPAS TeraScan Control software is started, the connection between the external PC and the DLC smart must be established as described in section 8.1. The default settings are loaded from an initialization file into the control software. The terahertz frequency, for example, is set to a default value, approximately at the center of the scan range.

### 8.7.1 Main Window

#### 8.7.1.1 Data Display

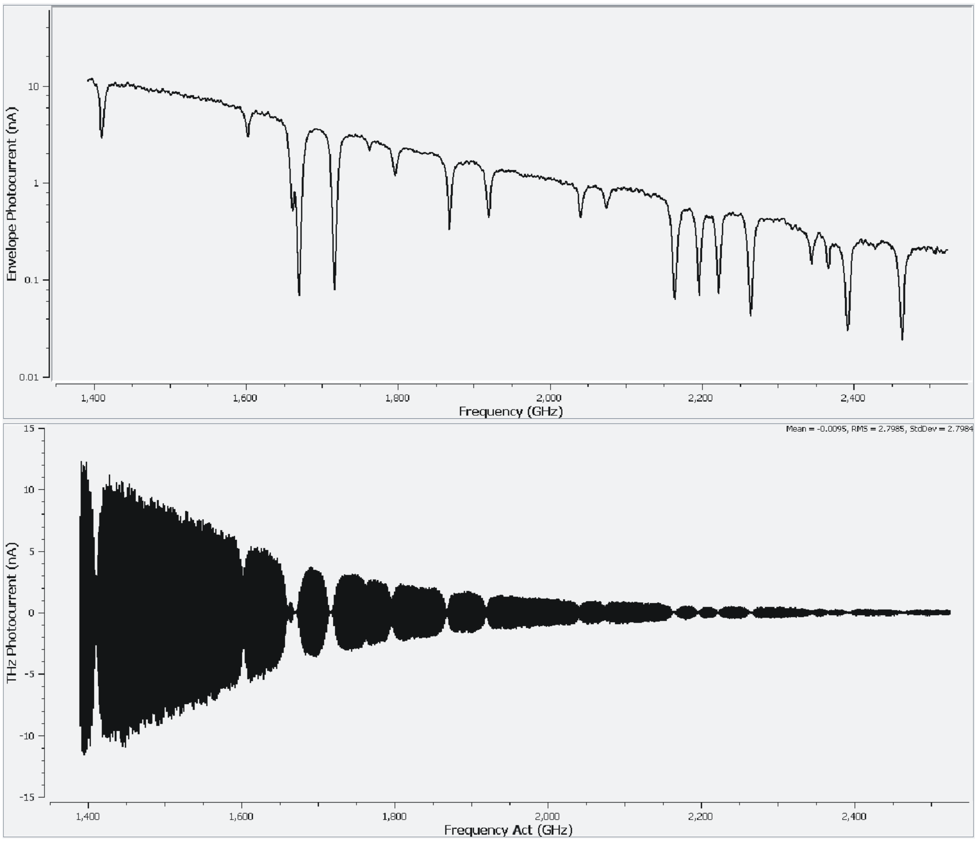



**Figure 35** Data Display in the Main Window

The measured photocurrent is displayed in the window on the bottom left. In **Fixed Frequency** mode, the abscissa is a time axis (label: Point No.). When **Frequency Scan** is selected, the abscissa is automatically changed to a frequency scale in units of GHz.

When the terahertz frequency is scanned, the photocurrent follows an oscillating pattern (please refer to section 1.1.2). The envelope of this oscillation yields the terahertz spectrum. This envelope can be displayed in the window on the top left, as shown in Figure 28.

| | |
|---|---|
| **NOTE !** | A right-click in one of the data display windows opens a "Plot Settings" menu, where the scale and appearance of the graph can be changed. |

### 8.7.1.2 Laser Control

| | |
|---|---|
| **NOTE !** | Laser emission can be switched ON/OFF either directly at the DLC smart front panel (please refer to section 6.1) or via the **Laser Emission On/Off** button in the **Main Window** of the TOPAS TeraScan Control software. |


**Figure 36** Laser Control section in the Main Window

| | |
|---|---|
| **NOTE !** | The lasers can be enabled/disabled separately by the checkboxes in the **Laser Operation** folder (see Figure 41). By default, both lasers are enabled. |

**Laser Emission On/Off** — Switches both lasers ON and OFF.

**Indicator** — Displays the status of the lasers.
**Yellow:** Lasers are switched ON
**OFF:** Lasers are inactive.

### 8.7.1.3 Frequency Control

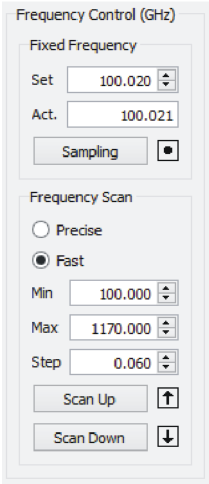



**Figure 37** Frequency Control section in the Main Window

**Fixed Frequency**

**Set**

Sets the terahertz frequency to the desired value, in units of GHz. The frequency can be changed in three different ways:

**(a)** By typing a new number and confirming by Enter,
**(b)** By using the arrow keys on the right hand side of the input field,
**(c)** By using the arrow keys of the keyboard of the control computer.

In options (b) and (c), the arrow keys change the digit left of the cursor position.

**Act.**

Displays the actual terahertz frequency in units of GHz as calculated from the measured, instantaneous laser temperatures. The displayed value shows the reaction of the system to frequency changes initiated by the software.

| | |
|---|---|
| **NOTE !** | When the terahertz frequency is set to a new value, the system should be given ample time to tune the laser temperatures. Wait until the difference between **Set** and **Act.** frequencies amounts to no more than ~ 100 MHz before starting a new measurement. |

**Sampling**

Starts a terahertz measurement in Fixed Frequency mode. Clicking the button again stops the measurement.

**Indicator**

Status of a fixed-frequency measurement:
**Green:** Measurement ongoing.
**OFF:** Measurement stopped, or frequency scan in progress.

**Frequency Scan**

The TOPAS TeraScan Control software supports two scanning modes. When **Precise** is selected, each data point is transferred individually from the DLC smart to the external PC. This mode is used e.g., in systems with fiber stretcher, and is the most straightforward scanning mode for system control via software commands rather than the Graphical User Interface (see section 8.6.4 for information about the Command Reference pdf document).

| | |
|---|---|
| **NOTE !** | The measurement speed of the **Precise** scanning mode is limited by the communication speed between DLC smart and external PC. The maximum data transfer rate is about 15 Hz. |

By contrast, the **Fast** scan option has been designed to quickly acquire a terahertz spectrum. When this option is selected, 1000 data points are temporarily stored in the DLC smart, and transferred in "chunks" to the external PC. This scan mode is recommended in particular for lock-in integration times of 1 .. 10 ms.

**Min, Max and Step** These parameters define the properties of a frequency scan. All of these values have units of GHz. **Min** and **Max** define the lower and upper border, respectively, while **Step** refers to the size of an individual frequency step.

**Scan Up** Starts a scan in the direction of increasing terahertz frequencies. Clicking the button again stops the scan.

**Scan Down** Starts a scan with decreasing frequencies. Clicking the button again stops the scan.

| | |
|---|---|
| **NOTE !** | A scan always starts from the momentary terahertz frequency. In order to avoid large, inaccurate frequency steps, the start frequency must be between **Min** and **Max**. Otherwise, a warning prompt is displayed in the status bar. |

#### 8.7.1.4 Data Display Options

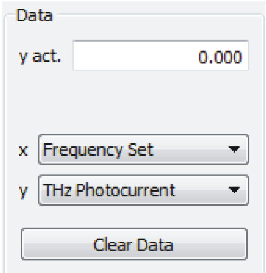



**Figure 38** Data Display options section in the Main Window

**y act.** Numeric value of the data point momentarily displayed in the lower window (usually photocurrent in units of nA).

**x and y** Option to manually change the display on the abscissa/ordinate.

- **Point No.** Measurement point number.
- **Frequency Set** Terahertz frequency in units of GHz, set by the TOPAS TeraScan Control software.
- **THz Photocurrent** Measured photocurrent of the terahertz receiver, in units of nA.
- **Frequency Act** Terahertz frequency in units of GHz, as calculated from the measured, instantaneous laser temperatures.

**Clear Data** Deletes the data displayed in both diagrams and in the memory.

### 8.7.2 General Settings Folder

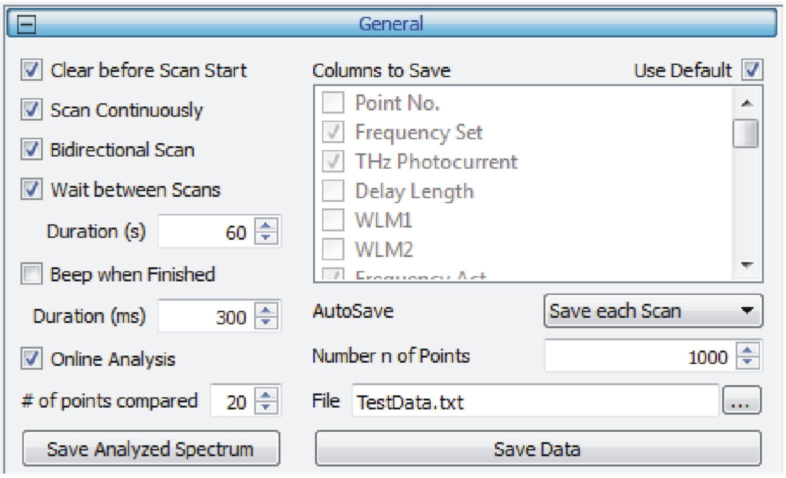



**Figure 39** General Settings folder

This folder allows the user to define general settings in the TOPAS TeraScan Control software.

**Clear before Scan Start** — When this checkbox is activated, the display in the two windows of the **Main Window** is cleared as soon as a new scan is started, i.e. once **Scan Up** or **Scan Down** is clicked.

**Scan Continuously** — When activated, the terahertz frequency is scanned continuously between **Min** and **Max**; otherwise, a scan is performed only once.

**Bidirectional Scan** — When activated, a continuous scan acquires terahertz data both while scanning up and scanning down.
Otherwise, a continuous scan is repeated in one direction only, as defined by either **Scan Up** or **Scan Down**.

> **NOTE !** The checkboxes **Wait between Scans** and **Bidirectional Scan** are only effective when the checkbox **Scan Continuously** is activated.

> **NOTE !** **Bidirectional scans** increase the frequency repeatability of the TeraBeam 1550/ TeraScan 1550 systems. This is relevant in particular for **Fast** scans. Even if only "up"-scan data are used for evaluation, it is recommended to always proceed with a "down"-scan, rather than jumping back to the initial frequency.

**Wait between Scans** — Introduces a delay between subsequent scans.

**Duration (s)** — Duration of the delay between subsequent scans, in seconds.

**Beep when Finished** — When activated, an acoustic signal is generated upon completion of a scan.

**Duration (ms)** — Duration of the acoustic signal in milliseconds.

**Online Analysis** — When activated, the software performs a real-time analysis of the photocurrent data during a scan. The envelope of the photocurrent fringes is displayed on a logarithmic scale in the top left window of the **Main Window**. The display is updated as the scan progresses.

**# of points compared** Specifies the number of points used for the envelope computation in the online analysis (see section 1.2.2)

| | |
|---|---|
| **NOTE !** | The value used for **# of points compared** should equal the number of frequency steps between a fringe maximum and minimum. |

**Save Analyzed Spectrum** Saves the data of the envelope spectrum as displayed in the top left window of the **Main Window**. After clicking the button, a Save-as window opens, where path and file name can be selected. Data are saved in ASCII format, as *.txt file with a header line. Frequency and photocurrent values are separated by a tabulator, one data point per line.

**Columns to Save** Manual selection of the raw data columns that are written in the .txt file, when **Save Data** in the **Main Window** is clicked. The respective checkboxes are only accessible when **Use Default** is not activated.

| | |
|---|---|
| **Point No.** | Measurement point number |
| **Frequency Set** | Terahertz frequency in units of GHz, set by the TOPAS TeraScan Control software |
| **THz Photocurrent** | Measured photocurrent of the terahertz receiver, in units of nA. |
| **Frequency Act** | Terahertz frequency in units of GHz, as calculated from the measured, instantaneous laser temperatures |

**Use Default** Automatically selects the raw data columns that are written in the .txt file, when **Save Data** in the **Main Window** is clicked.

**AutoSave** Option to automatically save photocurrent raw data. The settings selected under **Columns to Save** are applied here. The pull-down menu offers three choices:

| | |
|---|---|
| **No AutoSave** | No automatic saving; all data must be saved manually. |
| **Save n Points** | All data are saved to the same file, which is updated after a pre-selected number (n) of data points is acquired, either in frequency scanning or in sampling mode. |
| **Save each Scan** | Each completed scan is saved into a separate data file. |

**Number n of Points** Number of data points to be acquired prior to being saved (option **Save n Points**).

**File** Allows the user to select the file name for the **AutoSave** > **Save each Scan** option. The file name extension needs to be specified at the end of the filename (e.g., .txt or .dat). Data files automatically receive a numeric extension _0001, _0002, etc.

| | |
|---|---|
| **NOTE !** | When the option **Save each Scan** is selected, the checkbox **Clear before Scan Start** should be activated too, so that each saved file contains only one scan. |

**Save Data** Saves the data displayed in the lower diagram. After clicking the button, a Save-as window opens where path and file name can be selected to save the data as an ASCII file.
The file extension needs to be specified at the end of the filename (e.g., .txt or .dat). The file contains a header line; values are separated by a tabulator.

| | |
|---|---|
| **NOTE !** | By default, the data columns **Frequency Set**, **THz Photocurrent** and **Frequency Act** are saved. These settings can be changed in the **General Settings** folder, see section 8.7.2. |

## 8.7.3 Lock-In Folder

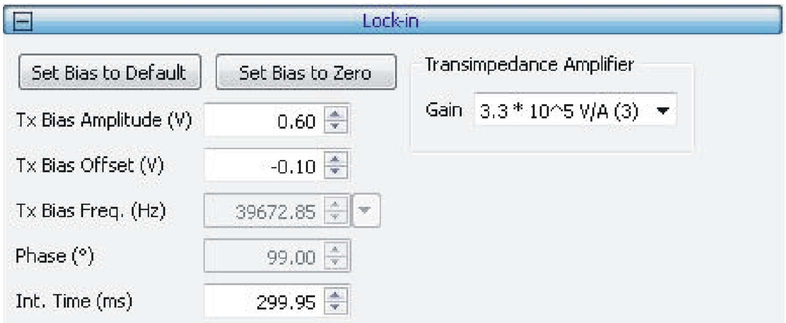



**Figure 40** Lock-in folder

This folder configures the lock-in amplifier within the DLC smart. The **Tx Bias** settings define the bias voltage applied to the terahertz transmitter.

For a correct display of the photocurrent detected in the terahertz receiver, the **Transimpedance Amplifier Gain** has to match the gain switch setting of the photocurrent amplifier PDA-S.

**Set Bias to Default** Sets Values for **Tx Bias Amplitude (V)** and **Tx Bias Offset (V)** to default values recommended for system operation. The bias voltage is available at the SMB-connectors labeled Bias Out 1 or 2 at the DLC smart rear panel.

**Set Bias to Zero** Sets Values for **Tx Bias Amplitude (V)** and **Tx Bias Offset (V)** to zero.

**NOTE !** Default Values for **Tx Bias Amplitude** ($U_{AMP}$) and **Tx Bias Offset** ($U_{offset}$) are configured during system production, and are documented in section 05 of the Production and Quality Control Datasheet, item “Recommended bias for terahertz generation”.

**Tx Bias Amplitude (V)** AC modulation amplitude applied to the transmitter photomixer. The signal is sinusoidal and symmetric with respect to the adjusted **Tx Bias Offset**. The output is available at the SMB-connectors labeled Bias Out 1 or 2 at the DLC smart rear panel.

**Tx Bias Offset (V)** DC output applied to the transmitter photomixer. The signal is available at the SMB-connectors labeled Bias Out 1 or 2 at the DLC smart rear panel.

**CAUTION !** **InGaAs** photomixers have to be connected to output Bias Out 1 (max. ± 2.5 V) and require typical bias settings of Tx Bias Offset = - 0.1 V and Tx Bias Amplitude = 0.6 V.

**Tx Bias Freq. (Hz)** Modulation frequency of the Tx Bias Amplitude. The value is preset by TOPTICA.

**NOTE !** The time-dependent bias voltage applied to the transmitter is defined by **Tx Bias Offset**, **Tx Bias Amplitude** and **Tx Bias Frequency**:
$U_{Bias}$, Tx($t$) = (Tx Bias Offset) + (Tx Bias Amplitude) x cos[2π x (Tx Bias Frequency) x $t$]

**Phase (°)**
Reference phase for the lock-in detection, in degrees. The easiest way to adjust the lock-in phase is to vary the value until the terahertz photocurrent equals zero, and then adding or subtracting 90 degrees (only possible in the "SuperUser" level of the software).

**NOTE !** **Tx Bias Frequency** and lock-in **Phase** are pre-selected, matching the modulation properties of the respective photomixers.

**Int. Time (ms)**
Lock-in integration time per measurement, in milliseconds (range: ~ 0.5 ms .. 16.5 s). The value is changed by typing a new number and confirming by Enter, or by using the arrow keys.

**NOTE !** To achieve the lowest possible noise performance, the lock-in time constant is always set to an integer multiple of the inverse modulation frequency (please refer to section 1.2.1. In the example of Figure 40, the software has changed the pre-selected value of 3 ms to 3.02 ms (= 120/$f_{lockin}$).

**Transimpedance Amplifier Gain**
Gain setting of the PDA-S transimpedance amplifier. This value must equal the switch position of the PDA-S module. Correct settings are documented in section 06 of the Production and Quality Control Datasheet.

## 8.7.4 Laser Operation Folder

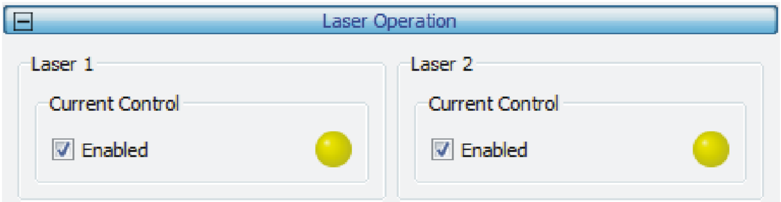



**Figure 41** Laser Operation folder

This folder allows separate control of each individual laser.

**Current Control Enabled**
These boxes control the operation of each laser head individually. Laser emission is only possible if the **Current Control Enabled** checkbox of the respective laser is activated.

**Indicator**
Displays the status of the respective laser.
**Yellow:** Lasers are switched ON.
**OFF:** Lasers are switched OFF.

**NOTE !** Laser emission is only possible if the global **Laser Emission On/Off** button in the **Main Window** is ON, and the respective laser is activated at its individual **Current Control Enabled** checkbox.
To only switch ON one laser, make sure the corresponding box is checked and the other box is unchecked. Then start laser emission via the **Laser Emission On/Off** button.

### 8.7.5 Fiber Stretcher Folder

This folder is available in systems that feature the Phase Modulation Extension. The terahertz phase is varied with the help of two fiber stretchers – one in the transmitter path, one in the receiver path –, both of which are wound around piezo actuators.

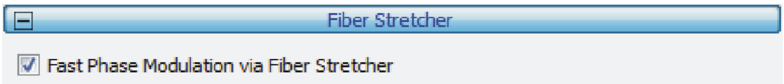



**Figure 42** Fiber Stretcher folder

**Fast Phase Modulation via Fiber Stretcher** When the box is checked, the fiber stretchers are activated.

| | |
|---|---|
| **NOTE !** | To activate this checkbox, the scanning mode has to be set to **Precise**. |

When **Fast Phase Modulation via Fiber Stretcher** is activated, the top graph in the Data Display shows the terahertz photocurrent as a function of the stretcher voltage (Delay Monitor Voltage = 1/100 of piezo voltage). The bottom graph shows the envelope photocurrent, i.e. the amplitude spectrum of the terahertz electric field.

**Please note:**

- The transmitter bias voltage is still chopped, but at a slower frequency as compared to a standard scan (i.e., without fiber stretchers).
- Activating the Phase Modulation option changes the default settings of "**Columns to Save**". When activated, the terahertz frequency, amplitude and phase are saved once "Save Data" is pressed.
- All internal parameters of the fiber stretcher are set automatically and are only accessible in the "SuperUser" level of the software.

# 9 System Extensions

## 9.1 Tuning Range Extension

Systems with Tuning Range Extension feature a third DFB pro BFY THz laser head (see section 1.3.3). The combination of different laser pairs provides access to different frequency ranges.

Typical frequency ranges are:

**Tuning Range Extension 2.0**
0 - 1.2 THz with lasers #1 and #2;
1.0 - 2.2 THz with lasers #2 and #3.

**Tuning Range Extension 2.7**
0 - 1.2 THz with lasers #1 and #2;
1.0 - 2.2 THz with lasers #2 and #3;
1.6 - 2.7 THz with lasers #1 and #3.

The DLC smart automatically recognizes the laser heads connected, and adjusts the operating parameters and software settings accordingly. In order to change the frequency range, proceed as follows:

1. Shut down the system as described in section 7.4 (The PDA-S may remain connected.)

2. Select the laser heads of the new frequency range you wish to work at. The serial numbers of the corresponding lasers are shown in section 04 of the Production and Quality Control Datasheet. Optical and electric connections are also documented in section 04 of the same Datasheet.

3. Connect the selected lasers to the corresponding outputs for temperature and current control on the rear panel of the DLC smart.

4. Connect the SM/PM fiber combiner to the selected laser heads.

5. Continue with the Power Up procedure described in section 7.3.

## 9.2 Phase Modulation Extension

For an introduction to the Phase Modulation Extension, please refer to section 1.3.4.

The fiber stretchers of the Phase Modulation Extension are placed between the seed lasers and the photomixers.

### 9.2.1 Basic Connections

| | |
|---|---|
| **NOTE !** | Details of the electric and optical connections are provided in section 07 of the Production and Quality Control Datasheet. |

| | |
|---|---|
| **NOTE !** | Please follow the installation instructions for standard TERABEAM 1550/TERASCAN 1550 systems as outlined in section 7.2. Additional installation steps for the Phase Modulation Extension are provided below. |

**Electric Connections**

1. Connect the LEMO input connector of the branched high-voltage cable to the Output port at the front panel of the high-voltage amplifier.

2. Connect the two LEMO output connectors of the branched high-voltage cable to the respective ports at the front panel of the fiber stretcher box.

3. Connect the provided SMB - BNC connector cable to the Aux Out 3-connector at the DLC smart rear panel, as specified in section 07 of the Production and Quality Control Datasheet.
   Connect the BNC plug to the Input port of the high-voltage amplifier.

4. Connect the provided SMA-BNC connector cable to the Aux In 3-connector at the DLC smart rear panel, as specified in section 07 of the Production and Quality Control Datasheet.
   Connect the BNC plug to the 1:100 Monitor output of the high-voltage amplifier.

**Optical Connections**

1. **Make sure that both seed lasers are switched OFF**.
   Connect the outputs of the fiber combiner to the two input fiber ports on the fiber stretcher box as specified in section 07 of the Production and Quality Control Datasheet.

2. Connect the fibers of the Tx and Rx photomixers to the two fiber ports on the fiber stretcher box as specified in section 07 of the Production and Quality Control Datasheet.

### 9.2.2 Power-Up

This section and the following one describe the regular start-up and shut-down procedures of TeraBeam 1550/TeraScan 1550 systems with Phase Modulation Extension.

**1.** Make sure that the bias voltage line to the transmitter (Tx) photomixer is interrupted, e.g. by removing the U-shaped link of the BNC breakout box.

**2.** Switch the DLC smart ON at the mains switch on the rear panel. Wait about 45 s until the booting procedure is completed. As soon as the system is ready, an acoustic signal is emitted, and the System ready LED on the DLC smart front panel flashes green.

**3.** Start the control computer and run the TOPAS TeraScan Control software.

**4.** Establish a connection between the control computer and the DLC smart as described in section 8.4.

**5.** Switch ON lasers #1 and #2 using either the **Laser Emission On/Off** button in the **Main Window** of the TOPAS TeraScan Control software or the ON button at the front panel of the DLC smart.

| | |
|---|---|
| **CAUTION !** | Connect and disconnect the photomixers electrically only when both seed lasers are switched ON. |

**6.** Connect the PDA-S power supply to mains.

**7.** Close the bias voltage line to the transmitter (Tx) photomixer, e.g. by inserting the U-shaped link of the BNC breakout box.

**8.** Switch the high-voltage amplifier ON using the ON switch at the front panel of the high-voltage amplifier.

**9.** Activate the **Fast phase modulation via fiber stretcher** checkbox in the TOPAS TeraScan Control software in the **Fiber Stretcher** folder (see Figure 42).

| | |
|---|---|
| **NOTE !** | To activate this checkbox, the scanning mode has to be set to **Precise**. |

**10.** Adjust the **Tx Bias Offset** and **Tx Bias Amplitude** settings in the **Lock-in** folder of the TOPAS TeraScan Control software to the $U_{offset}$ and $U_{amp}$ values as noted in section 05 of the Production and Quality Control Datasheet, item “Recommended bias for THz generation with activated Stretcher”.

**11.** Click **Sampling** in the **Main Window** to activate data acquisition.

### 9.2.3 Power-Down

1. Set **Tx Bias Offset** and **Tx Bias Amplitude** to zero using the button **Set Bias to Zero** in the **Lock-in** folder of the TOPAS TeraScan Control software.

2. Switch the high-voltage amplifier OFF using the switch at the front panel of the high-voltage amplifier.

3. Disconnect the PDA-S power supply from mains.

4. Remove the U-shaped link of the BNC breakout box to interrupt the bias voltage line to the transmitter (Tx) photomixer.

5. Switch lasers #1 and #2 OFF by pressing the OFF button at the front panel of the DLC smart or via the **Laser Emission On/Off** button in the **Main Window** of the TOPAS TeraScan Control software.

6. Close the connection to the DLC smart. Shut down the TOPAS TeraScan Control software.

7. Switch the DLC smart OFF at the mains switch at the rear panel.

## 9.3 Compact Rail System (#BG-002653)

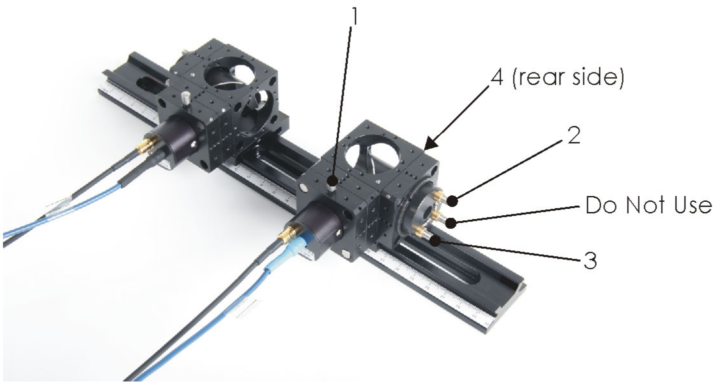



**Figure 43** Compact terahertz optomechanics with two parabolic mirrors (TOPTICA article code #BG-002653)

Function of the screws:

(1) Locking screw for fixing the photomixers
(2) Vertical and
(3) Horizontal tip/tilt alignment of the mirrors,
(4) Locking screw for the optical cage

### 9.3.1 Terahertz Beam Alignment

| | |
|---|---|
| **NOTE !** | In systems without Phase Modulation Extension, the terahertz photocurrent can be optimized either at a positive or at a negative maximum. This choice has no impact on the quality of the alignment.<br>It is recommended to check from time to time whether the terahertz amplitude is still at a positive (or negative) maximum. Use the terahertz frequency to change the phase.<br>Readjust the phase if required. |

| | |
|---|---|
| **NOTE !** | In systems that include the Phase Modulation Extension, the value to be observed is the amplitude of the fit curve (upper graph in the **Data Display** in the **Main Window**. |

**1. Preparation**

**1.1** Place the photomixers in their mounts, so that the rear side of the photomixer housing is approx. 6 cm away from the center of the mirror. When correctly positioned, the full length of the flattened part of the cylindrical housing just about protrudes out of the mount (see Figure 44 and NOTE ! below).
Make sure that the angular orientation of both photomixers is the same, i.e. the polarization is either vertical or horizontal. The polarization axis is indicated by two small grooves on the front side of the housing (see Figure 22). Fix the photomixers with the locking screws (1).

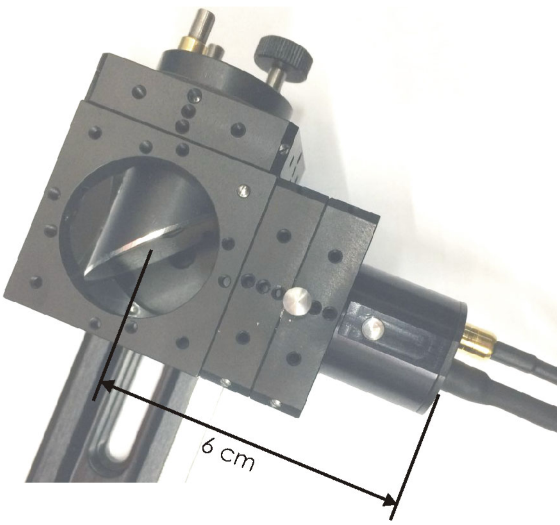



**Figure 44** Positioning the photomixers

**1.2** Start the system as described in section 7.3 (configuration without Phase Modulation Extension) or section 9.2.2 (configuration with Phase Modulation Extension). Set the **Int. Time** (ms) in the **Lock-in** folder of the TOPAS TeraScan Control software to approx. 80 ms, and the value **Fixed Frequency - Set** in the **Main Window** to 500 GHz.

**1.3** Click **Set Bias to Default** in the **Lock-in** folder of the TOPAS TeraScan Control software.

**1.4** Click **Sampling** to start the data acquisition. You should then see a non-zero terahertz signal (i.e., photocurrent).

**1.5** Change the terahertz frequency until the signal reaches a positive or negative maximum. Fix the cage with locking screw (4).

**2. Mirror Alignment**

**2.1** Adjust the tip/tilt screws (2, 3) of each mirror separately.

**2.2** Next, “walk” the beam:
Change the “tip” screw of mirror 1. Now, the signal should now decline a bit, as the position has already been optimized. Try to compensate the signal loss by adjusting the “tip” screw of mirror 2. Repeat the previous step a couple of times, until you see a trend to either higher or lower signal values. If the signal increases, continue. If not, try the opposite direction.

**2.3** Repeat the same procedure with the “tilt” screws of both mirrors.

| | |
|---|---|
| **NOTE !** | Figure 44 shows the correct position of the photomixers. However, the initial alignment becomes easier if the photomixer modules are pushed further in, so that the thread is approx. half-covered. Once the alignment is optimized for frequencies up to 500 GHz, pull the antennas further out and optimize the alignment at 1000 GHz. |

## 9.4 Two-Mirror Optomechanics (#BG-001481)

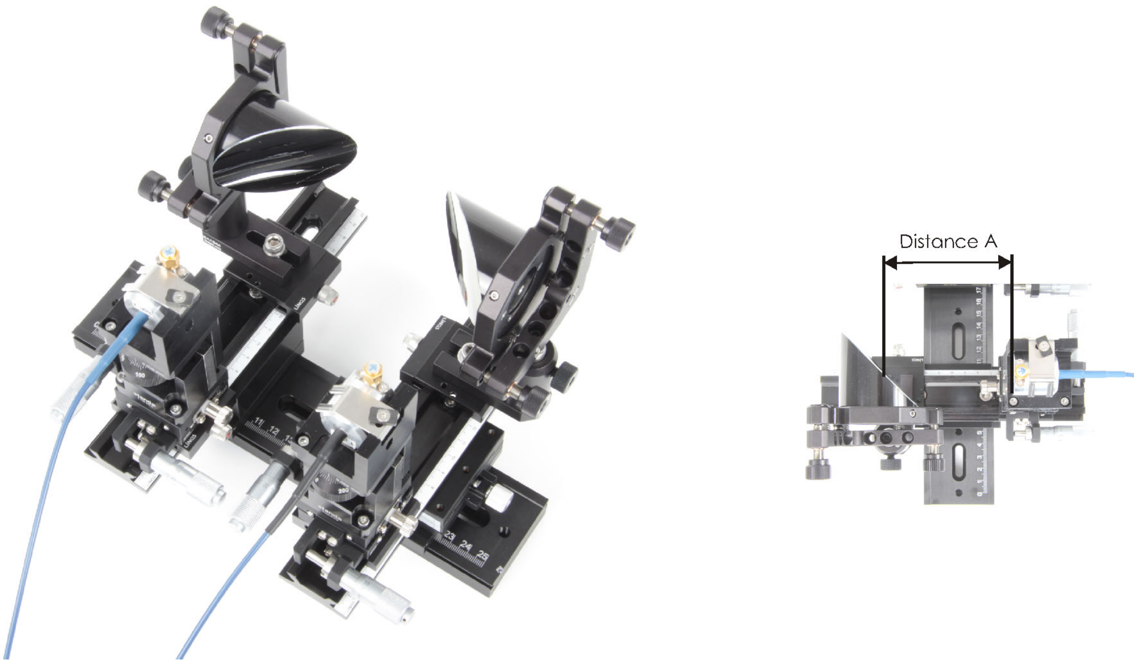



**Figure 45** Terahertz optomechanics with two parabolic mirrors (TOPTICA article code #BG-001481, left). For **InGaAs** photomixers, TOPTICA uses mirrors with 3” focal length for beam collimation. The distance A is then ~ 5.5 cm.

The optomechanical assembly #BG-001481 consists of two 3-axis stages (one for each photomixer), 2 off-axis parabolic mirrors to collimate and re-focus the terahertz beam, kinematic mirror mounts and a manual delay stage. The entire setup is mounted on rails, with two shorter rails – carrying one photomixer mount and one mirror mount each – residing on a longer system rail (see Figure 45).

The user can easily change the length of the collimated beam path by moving the slides that carry the short rails. When the system is correctly aligned, such a length shift should only have a minimal impact on the terahertz amplitude.

### 9.4.1 Photomixer and Mirror Mounts

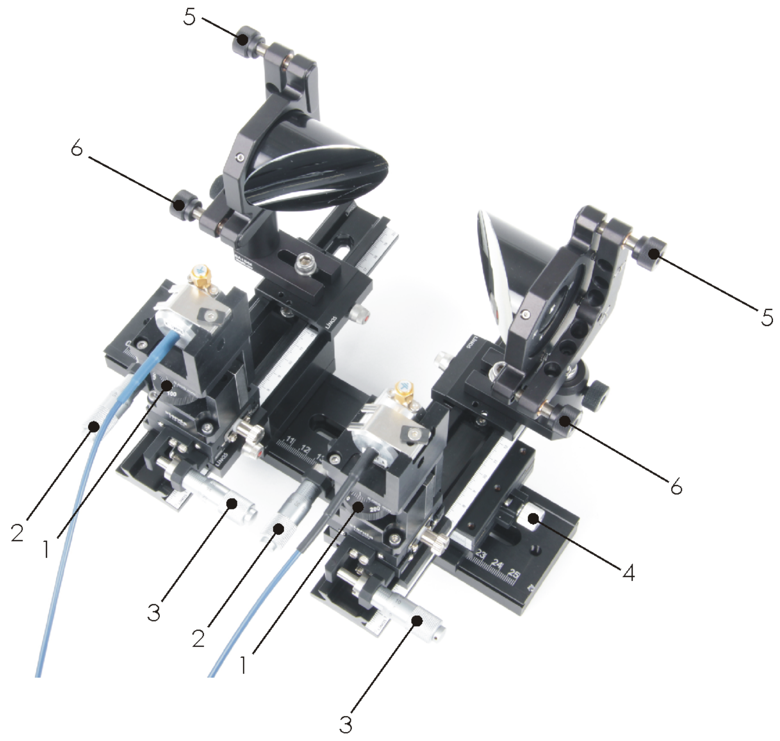



**Figure 46** Adjustment screws of photomixer and mirror mounts

Each photomixer mount features three orthogonal translation stages. Their functions are (from top to bottom, as viewed from the side):

(1) Vertical alignment
(2) Focus alignment
(3) Horizontal alignment

In addition, a manual delay stage (4) adjusts the distance between the two short rails. This stage does not change the beam alignment, but serves to vary the terahertz phase. When turning the screw continuously in one direction, you will observe a periodic oscillation of the terahertz amplitude (please refer to section 1.1.2; the movement of this delay stage corresponds to a change of $\Delta L$).

Each mirror mount features two screws, for vertical (5) and horizontal (6) tip/tilt alignment, respectively.

## 9.4.2 Terahertz Beam Alignment

| | |
|---|---|
| **NOTE !** | In systems without Phase Modulation Extension, the terahertz photocurrent can be optimized either at a positive or at a negative maximum. This choice has no impact on the quality of the alignment.<br>It is recommended to check from time to time whether the terahertz amplitude is still at a positive (or negative) maximum. Use the manual delay stage (item 4 in Figure 46) to change the phase. Readjust the phase if required. |

| | |
|---|---|
| **NOTE !** | In systems that include the Phase Modulation Extension, the value to be observed is the amplitude of the fit curve (upper graph in the **Data Display** in the **Main Window**. |

**1. Preparation**

**1.1** Make sure that the photomixers are securely fixed on their mounts. Take care that the angular orientation of both photomixers is the same, i.e. the polarization is either vertical or horizontal. The polarization axis is indicated by two small grooves on the front side of the housing (see Figure 22).

**1.2** Adjust the vertical alignment screws (1) so that both photomixers have the same height. Use a ruler and/or bubble level to check the alignment. The center of the photomixer should be level with the center of the parabolic mirrors.

**1.3** Measure the distance between the center of the mirror, and the front facet of the photomixers (Distance A in Figure 45). Adjust the distance to **~ 55 mm for InGaAs photomixers**.

**1.4** Start the system as described in section 7.3 (configuration without Phase Modulation Extension) or section 9.2.2 (configuration with Phase Modulation Extension). Set the **Int. Time (ms)** in the **Lock-in** folder of the TOPAS TeraScan Control software to approx. 80 ms, and the value **Fixed Frequency - Set** in the **Main Window** to 500 GHz. Click **Sampling**.

**1.5** Click **Set Bias to Default** in the **Lock-in** folder of the TOPAS TeraScan Control software.

**1.6** Click **Sampling** to start the data acquisition. You should then see a non-zero terahertz signal (i.e., photocurrent).

**1.7** Move the manual delay stage (4) until the signal reaches a positive or negative maximum.

If there is no signal at all, then start at a lower frequency (e.g., 100 GHz or 200 GHz). At lower frequencies, both, terahertz power and detection efficiency are higher and therefore the signal is stronger. Also, the larger wavelength facilitates the alignment.

The goal of the following steps is, to adjust the amplitude so that it matches, as closely as possible, the value (Rx Signal) specified in section 05 of the Production and Quality Control Datasheet.

### 2. Photomixer Position

**2.1** Use the vertical-alignment screw (1) to shift the first photomixer up and down. Try to increase the signal. If the signal level rises – good. If not, try the opposite direction.

**2.2** Repeat with the second photomixer.

**2.3** If no further improvement is possible, try moving both mixers up or down in parallel.

**2.4** Repeat these steps using the horizontal-alignment screws (3) of both photomixers.

### 3. Mirror Alignment

**3.1** Adjust the tip/tilt screws (5, 6) of each mirror separately.

**3.2** Next, "walk" the beam:
Change the "tip" screw of mirror 1. Now, the signal should now decline a bit, as the position has already been optimized. Try to compensate the signal loss by adjusting the "tip" screw of mirror 2. Repeat the previous step a couple of times, until you see a trend to either higher or lower signal values. If the signal increases, continue. If not, try the opposite direction.

**3.3** Repeat the same procedure with the "tilt" screws of both mirrors.

### 4. Focus Alignment

Turning the focus-alignment screw (2) has two effects:

(a) It changes the focal distance between mirror and photomixer,
(b) It alters the length of the terahertz beam path and, consequently, the terahertz phase.

Don't be surprised that (b) has a great impact on the terahertz signal. In fact, the screws (2) have the same effect as the "large" delay stage (4)!

**4.1** Continue turning the screw (2) of the first photomixer in one direction and observe the amplitude of the signal oscillation.

**4.2** You will finally see an effect of the focus position, i.e. the amplitudes become smaller or larger. Try maximizing the amplitude of the oscillations.

**4.3** Repeat with the second photomixer.

### 5. Iteration

**5.1** Repeat steps 2 - 4.

**5.2** If you started at a low frequency, set the system to a higher frequency (e.g. 800 GHz) and repeat the alignment.

## 9.5 Four-Mirror Optomechanics (#BG-001784)

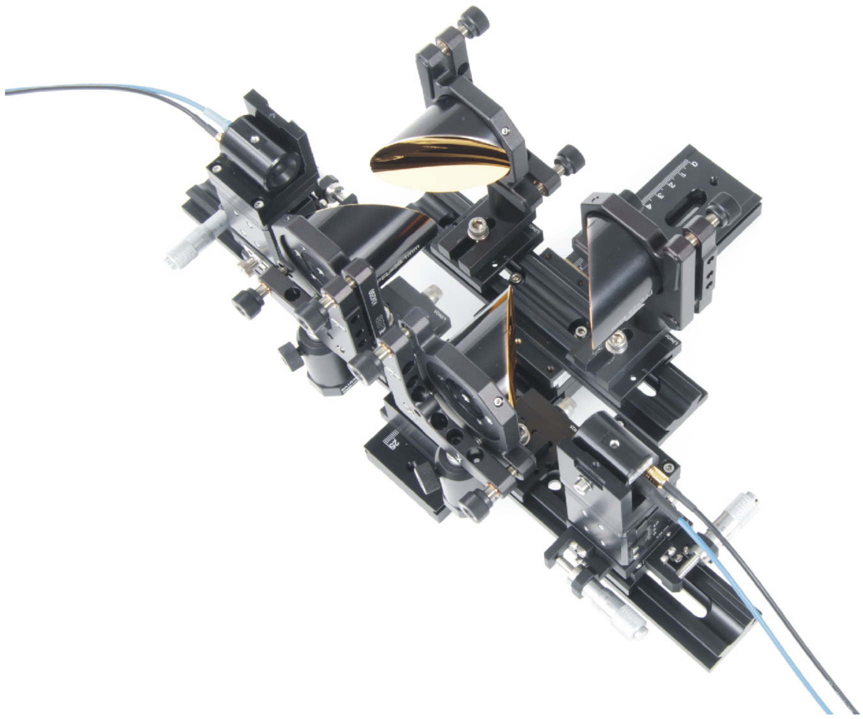


**Figure 47** Terahertz optomechanics with four parabolic mirrors (TOPTICA article code #BG-001784)

The optomechanical assembly consists of two 3-axis stages (one for each photomixer), 4 off-axis parabolic mirrors to collimate and re-focus the terahertz beam, kinematic mirror mounts and a manual delay stage. The entire setup is mounted on rails (see Figure 47).

The user can easily change the length of the collimated beam path by moving the slide that carries the two mirrors. When the system is correctly aligned, such a length shift should only have a minimal impact on the terahertz amplitude.

| | |
|---|---|
| **NOTE !** | For alignment of the four-mirror optomechanics, please refer to section 9.4.2 and follow the procedure accordingly.<br>Before starting with the alignment, adjust the position and height of all of the mirrors, as well as the photomixer mounts, as accurately as possible with the help of a ruler and bubble level. |

# 10 Appendix

## 10.1 Abbreviations

| | |
|---|---|
| THz | Terahertz |
| cw | Continuous wave |
| Tx | Transmitter |
| Rx | Receiver |
| InGaAs | Indium gallium arsenide |
| DFB Lasers | Distributed feedback laser |
| DFB pro BFY THz | Product name of TOPTICA's DFB laser based on butterfly (BFY) packaged diodes |
| DLC smart | Product name of TOPTICA's laser controller |

## 10.2 TERASCAN 1550 Specifications

| **System Components and Performance** | **TERASCAN 1550** |
|---|---|
| Key advantages | High terahertz power, compact laser unit |
| Lasers | TERABEAM 1550 (2x DFB pro BFY THz) |
| Laser wavelengths (typ.) | 1533 nm + 1538 nm |
| Laser power | 25 .. 30 mW<br>(per two-color fiber output) |
| Difference frequency tuning range | 1.2 THz |
| Tuning range extensions | Up to 2.0 THz or 2.7 THz (with addition of 3rd laser) |
| Tuning speed | Up to 100 GHz / sec |
| Frequency accuracy | < 2 GHz absolute |
| Minimum frequency step size | < 10 MHz |
| Frequency stability per laser * | Typ. 20 MHz RMS, 100 MHz p-p @ 5 hrs |
| Terahertz emitter | #EK-000724, high-bandwidth InGaAs photodiode |
| Terahertz receiver | #EK-000725, InGaAs photomixer |
| Antenna type | Bow-tie |
| Terahertz polarization | Linear |
| Beam divergence<br>(See section 10.2.1) | 12° FWHM @ 200 GHz<br>15° FWHM @ 500 .. 1000 GHz |
| Emitter and receiver package | Cylindrical, ∅ 25 mm<br>Integrated Si lens and SM/PM fiber pigtail |
| Emitter and receiver bandwidth | Approx. 3 THz |
| Terahertz power (typ.) | 65 µW @ 100 GHz<br>5 µW @ 500 GHz |
| Terahertz dynamic range<br>(300 ms integration time) | 90 dB @ 100 GHz<br>70 dB @ 500 GHz |
| Recommended operating conditions | Laser power 30 mW,<br>Typ. bias settings: -0.1 V DC, +/- 0.6 V AC |
| Lock-in amplifier | Integrated in DLC smart |
| Lock-in integration time | 0.5 ms .. 16.5 s |
| Transimpedance amplifier | PDA-S, included |
| Control unit | DLC smart |
| Software | TOPAS TeraScan Control software with GUI + Remote command interface |
| Terahertz optomechanics | Optionally available |
| Phase modulation | Optional, with fiber stretchers<br>(Phase Modulation Extension) |

| **General and Environmental Specifications** | **TERASCAN 1550** |
|---|---|
| Computer interface | Ethernet |
| DC input requirements | 110 – 240 V~, 50/60 Hz |
| Power consumption | 90 W max. |
| Warm-up time | approx. 30 min. after cold start |
| Environmental requirements | Indoors, altitude < 2000 m<br>Always keep electronics in horizontal position. |
| Temperature range | Operating: 15 - 30 °C, non condensing<br>Storage: 0 - 40 °C, non condensing<br>Transport: -10 - 40 °C, non condensing |
| Laser head size + weight | Two laser heads, each with dimensions 60 x 120 x 165 mm, 1 kg |
| DLC smart size + weight | 480 x 290 x 50 mm, 4 kg |
| Laser diode warranty | 5000 hrs or 2 years<br>(whatever comes first) |

* Under constant environmental conditions

### 10.2.1 Beam Divergence

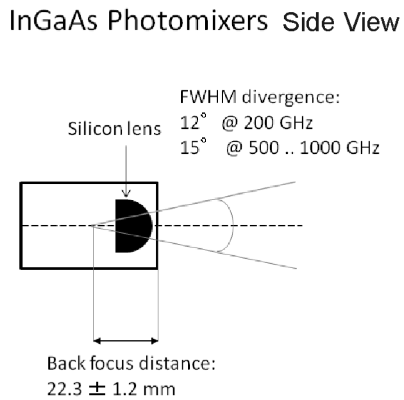



**Figure 48** Beam divergence properties of InGaAs photomixers

## 10.3 DC Photocurrent Measurements

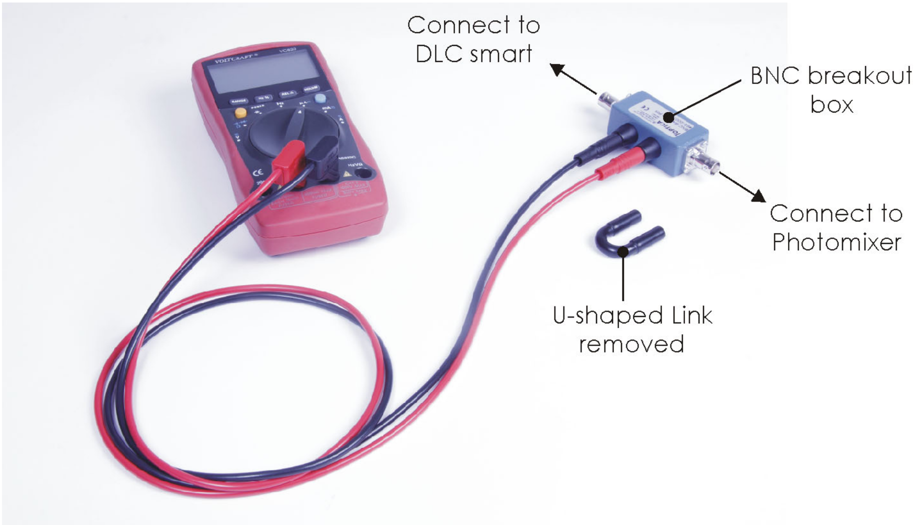



**Figure 49** BNC Breakout Box connected for photocurrent measurement

A straightforward way of testing the basic functionality of a photomixer is a measurement of the photocurrent under an applied DC bias. A BNC Breakout Box for photocurrent measurements is supplied with each TeraScan 1550 system.

The BNC Breakout Box (see Figure 49) features two female BNC connector ports and is thus conveniently inserted between the SMB-BNC connector cable (plugged to the Bias Out-connector of the DLC smart) and the photomixer under test. Inside the box, the inner conductor is fed to two banana jacks, which are either bridged by a removable, U-shaped link, or connected to an amperemeter with the help of the supplied probe leads.

DC photocurrent values of both transmitter and receiver photomixer are documented in section 05 of the Production and Quality Control Datasheet.

| | |
|---|---|
| **CAUTION !** | Photomixers are ESD-sensitive devices. **We recommend wearing a high-impedance grounding strap around the wrist when handling photomixers**. Take care not to touch the inner conductor of the connector cable. |

**Test procedure:**

**1.** Make sure that the photomixer under test is optically connected to the seed lasers, but disconnected electrically.

**2.** Start the TOPAS TeraScan Control software.

**3.** Switch ON the lasers.

| | |
|---|---|
| **CAUTION !** | Connect and disconnect the photomixers electrically only when both seed lasers are switched ON. |

**4.** Connect an SMB-BNC connector cable to one of the Bias Out-connectors on the rear panel of the DLC smart (see NOTE ! below), and to one side of the BNC Breakout Box.

| | |
|---|---|
| **NOTE !** | To test an **InGaAs transmitter/receiver** of the TERASCAN 1550 system use the Bias Out 1-connector labeled 2.5 V. |

**5.** Remove the U-shaped link from the BNC Breakout Box. Plug the supplied probe leads in and connect them to an amperemeter. Switch on the amperemeter and select the working range (µA or mA).

**6.** Connect the photomixer that you wish to test (i.e. TX or RX) to the other side of the BNC Breakout Box.

**7.** Adjust the **Tx Bias Offset** setting in the **Lock-in** folder of the TOPAS TeraScan Control software to the $U_{offset}$ value as noted in section 05 of the Production and Quality Control Datasheet, item “Recommended bias for terahertz generation”. Compare the amperemeter reading with the documented photocurrent value.

| | |
|---|---|
| **CAUTION !** | The Bias Voltages must not exceed the Values for $U_{offset}$ specified in section 05 of the Production and Quality Control Datasheet, item DC photocurrent @ $U_{offset}$ .<br>Applying bias voltages to the receiver should only be done very carefully for testing purposes. |

**8.** When finished, set **Tx Bias Offset** to zero.

## 10.4 Fuse Replacement

| | |
|---|---|
| **DANGER !** | Before exchanging a fuse, make sure to disconnect the DLC smart from the mains supply ! |

The connector block on the rear side of the DLC smart contains a cartridge with two fuses (see Figure 50).

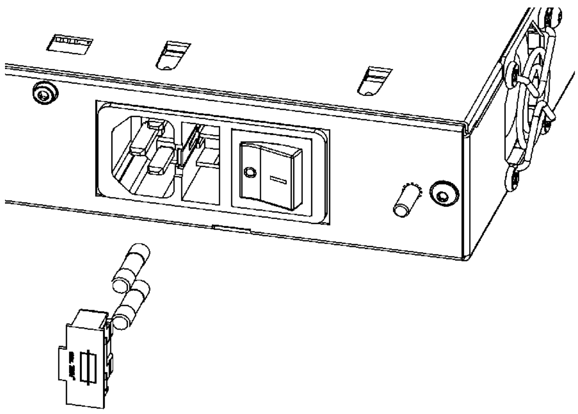


**Figure 50** Fuses in the DLC smart connector block

To replace the fuses, pull out the fuse cartridge as shown in Figure 50. Use only fuses made for 250 V, 1 A T (slow blow), size 5 x 20 mm.

| | |
|---|---|
| **NOTE !** | Both fuses are actively in use. Consequently, both fuses have to be checked ! |

## 10.5 USB Driver Installation

| | |
|---|---|
| **NOTE !** | Do not control the system via the USB interface, as this does not support all of the software functions. Use USB for IP address configuration only (see **> DLC smart > Device Configuration > Network** in section 8.6.2). |

In order to address the system via USB, a specific driver needs to be installed. With the shipment of the TeraScan 1550/TeraBeam 1550 system, Toptica provides a USB flash drive that contains the USB driver files and the TOPAS TeraScan Control PC-GUI.

| | | |
|---|---|---|
| USB driver files: | **dlcsmart-usb-serial.inf** | (Setup Information) |
| | **dlcsmart-usb-serial.cat** | (Security Catalog) |

**Prerequisites:**

- Administrator privileges for the control computer.
- The two USB driver files need to be copied to the computer.

**Installation instructions:**

**1**. Make sure that the DLC smart is switched on but not connected to the control computer via USB.

**2**. On the computer, browse to the directory that contains the DLC smart USB driver files, right-click **dlcsmart-usb-serial.inf** (Setup Information), and click **Install**.

**3**. For operating systems **up to Windows 7**: When the security warning is displayed, select the option to install the driver.
**Windows 8**: When the confirmation dialog window is displayed, select the option to install the driver.

The USB driver is installed.

**4**. Connect the control computer to the USB connector on the DLC smart rear panel (please refer to section 6.1). Wait until the new hardware is detected.

**5**. Start the TOPAS TeraScan Control PC-GUI and configure it for operation via USB connection as described in section 8.2.

## 10.6 Assigning a Static IP Address

Upon delivery, the DLC smart electronics is configured to retrieve its IP address automatically via DHCP. If the system is not part of a network, but directly connected to a control computer, then a fixed IP address needs to be assigned.

The IP addresses of the DLC smart and the control computer must differ only in the last two digits, and both devices have to use the same subnet mask.

| | |
|---|---|
| **NOTE !** | Some IP-Address combinations may cause problems with the software. One working combination of addresses is:<br>**DLC smart IP-Address**: 192.168.54.82<br>**PC IP-Address**: 192.168.54.83<br>**Both subnet masks**: 255.255.248.0 |

To assign a fixed IP address to the DLC smart, proceed as follows:

**1.** Make sure that the USB driver is installed (please refer to section 10.5). Connect the system via USB.

**2.** In the DLC smart menu of the TOPAS TeraScan Control software, select **Device Configuration > Network** and check **Manual Configuration**.

**3.** Enter the new IP address and netmask (see example above). Click **Apply Settings**.

**4.** Select **Device Configuration > Disconnect**, then restart the DLC smart.

**5.** Connect the Ethernet cable.

**6.** Assign a fixed IP address to your control computer. To do so, navigate to
Control Panel > Network and Internet > Network Connections > LAN-Connection > Properties > Local Area Connection Properties.
Select Internet Protocol Version 4 (TCP/IPv4) and click Properties in the list. The window Internet Protocol Version 4 (TCP/IPc4) Properties appears to enter the new IP address and netmask (see example above).

**In order to change back to a dynamic IP address,**

**1.** In the DLC smart menu of the TOPAS TeraScan Control software, select **Device Configuration > Network** and check **Use DHCP**.

**2.** Click **Apply Settings**.

**3.** Disconnect the ethernet cable and reboot the DLC smart. Then, connect the DLC smart to your network.

**4.** Change the settings of the control computer back to automatic address retrieval.

## 10.7 Firmware Update

The software for firmware updates is provided by TOPTICA as an ASCII file containing BASE64-encoded binary data. The file extension is .fw, e.g. "DLC smart-archive x.x.x.fw".

**1.** Switch ON the DLC smart at the mains switch on the rear panel and wait for the boot procedure to finish (please refer to section 7.3).

**2.** Make sure that both photomixers are electrically disconnected.

**3.** Start the TOPAS TeraScan Control software. Establish a connection to the DLC smart (please refer to section 8.4). In the software, select **DLC smart > Device Configuration > Firmware Update**.

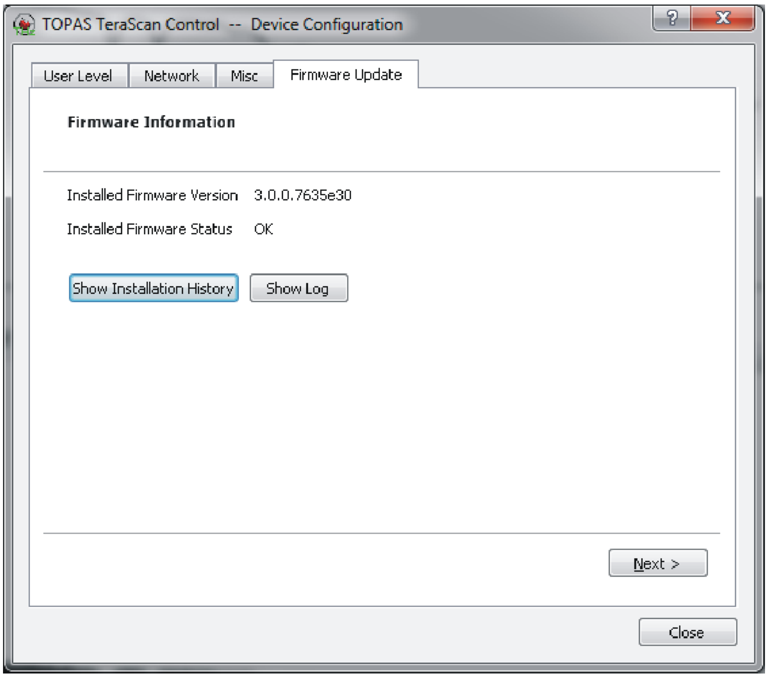



**Figure 51** TOPAS TeraScan Control Firmware Update window

**4.** Click **Next** to open the Upload Firmware Archives window.

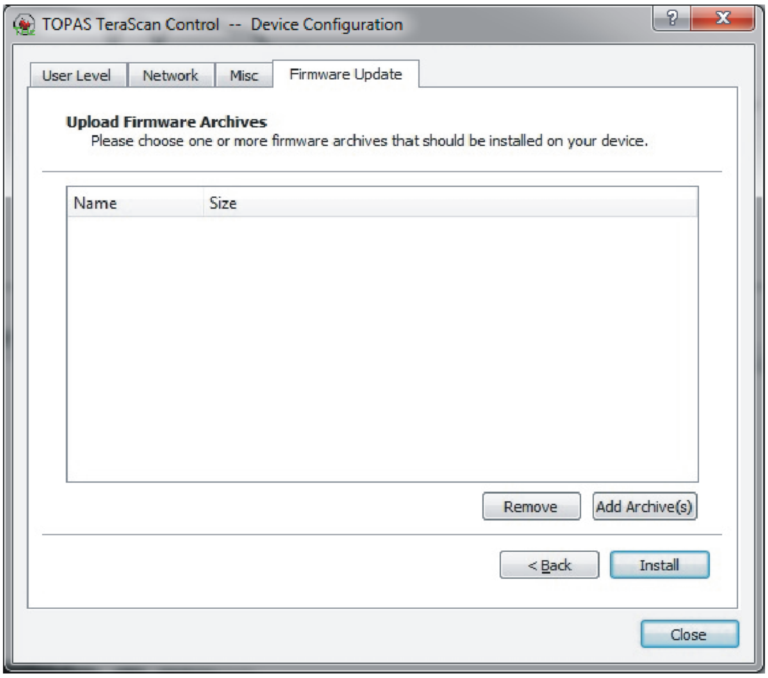



**Figure 52** Upload Firmware Archives window of the TOPAS TeraScan Control

**5.** Click **Add Archive(s)** and select the new firmware file in the browser window. The firmware update file is added to the list in the Upload Firmware Archives window.

**6.** Click **Install** to start the firmware upload.

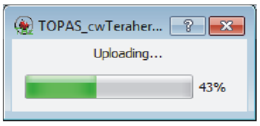



**Figure 53** TOPAS TeraScan Control window during firmware update

A window appears, stating that the firmware update is in progress (see Figure 53). Once finished, a new window appears, confirming that the firmware file has been transferred successfully. You are prompted to restart the DLC smart. Confirm with **OK**.

**7** Switch the DLC smart OFF and then ON again at the mains switch at the rear panel. The restart initiates an update of the FPGAs of both the temperature and current controllers.
During the update process, the Scan active LED on the DLC smart front panel flashes yellow.
Once the update is completed, the four LEDs Scan active, Temperature OK Laser 1 and 2, and System ready turn green.
The update process takes approx. three minutes.

**8.** Restart the DLC smart once again to make the changes take effect.

**9.** Establish a new connection to the DLC smart (please refer to section 8.4). Now the DLC smart operates with the new firmware.

## 10.8 Troubleshooting

| Problem | Cause | Solution |
|---|---|---|
| No communication with DLC smart. | Ethernet connection missing. | Check ethernet connector cable. If applicable: check the status of the network (see section 8.1). |
| | DLC smart switched OFF. | Check if DLC smart is switched ON. |
| No laser light. | Cable connections not properly installed. | Check cable connections. |
| | External interlock circuit open. | Close external interlock circuit (see section 2.3.1). |
| | Key switch on DLC smart in wrong position. | Set key switch to position unlocked. |
| | **Laser Emission On/Off** in the **Main Window** of the TOPAS TeraScan Control software not clicked. | Click **Laser Emission On/Off** to switch on laser emission. |
| | Emission for the particular laser not enabled. | Check corresponding box in the **Laser Operation** folder. |
| Low fiber output power. | Fiber facet dirty or damaged. | Clean fiber facet, e.g. using a Reel Cleaner (see section 7.1.1). Inspect under a microscope if possible. Contact service@toptica.com for assistance. |
| | Laser diode defective. | Contact service@toptica.com. |
| No terahertz signal. | No bias voltage or DC voltage applied. | Check AC bias voltage of transmitter, e.g. using an oscilloscope. |
| | Incorrect optical or electric connection. | Check fiber-to-fiber connections of photomixers. Verify that the orientation of the fiber keys matches on both sides of the mating sleeve. |
| | | Apply DC bias offset to transmitter, check DC photocurrent using the BNC Breakout Box and an in-line amperemeter (see section 10.3). |
| | | If transmitter displays correct photocurrent, apply DC bias to receiver and repeat measurement. |
| | | If photocurrent is zero, check laser power and electric connections of photomixer. |
| | PDA-S not plugged in. | Check power supply of PDA-S. |

| | | |
|---|---|---|
| Photomixers show correct DC photocurrent, but no/ low terahertz signal at receiver. | Incorrect beam alignment of terahertz beam. | Adjust terahertz beam (position of photomixers, orientation of mirrors etc). |
| | Phase offset between optical beat and terahertz wave at receiver. | Vary terahertz path length or frequency. |
| Terahertz fringes look distorted. | Incorrect beam alignment. | Adjust terahertz beam. Pay particular attention to the focus distance. |
| Terahertz fringes show offset different from zero. | Ground loops. | Fix photomixers in a way that they are not in direct electric contact with one another. |
| Communication between TOPAS TeraScan Control software and the device and reaction times are unusually slow. | Some IP-Address combinations have caused problems with the software. | The System is working with the combination:<br>DLC smart IP-Address: 192.168.54.82<br>PC IP-Address: 192.168.54.83 PC<br>Both subnet masks: 255.255.248.0 |

## 10.9 DFB pro BFY THz Laser Head Main Dimensions

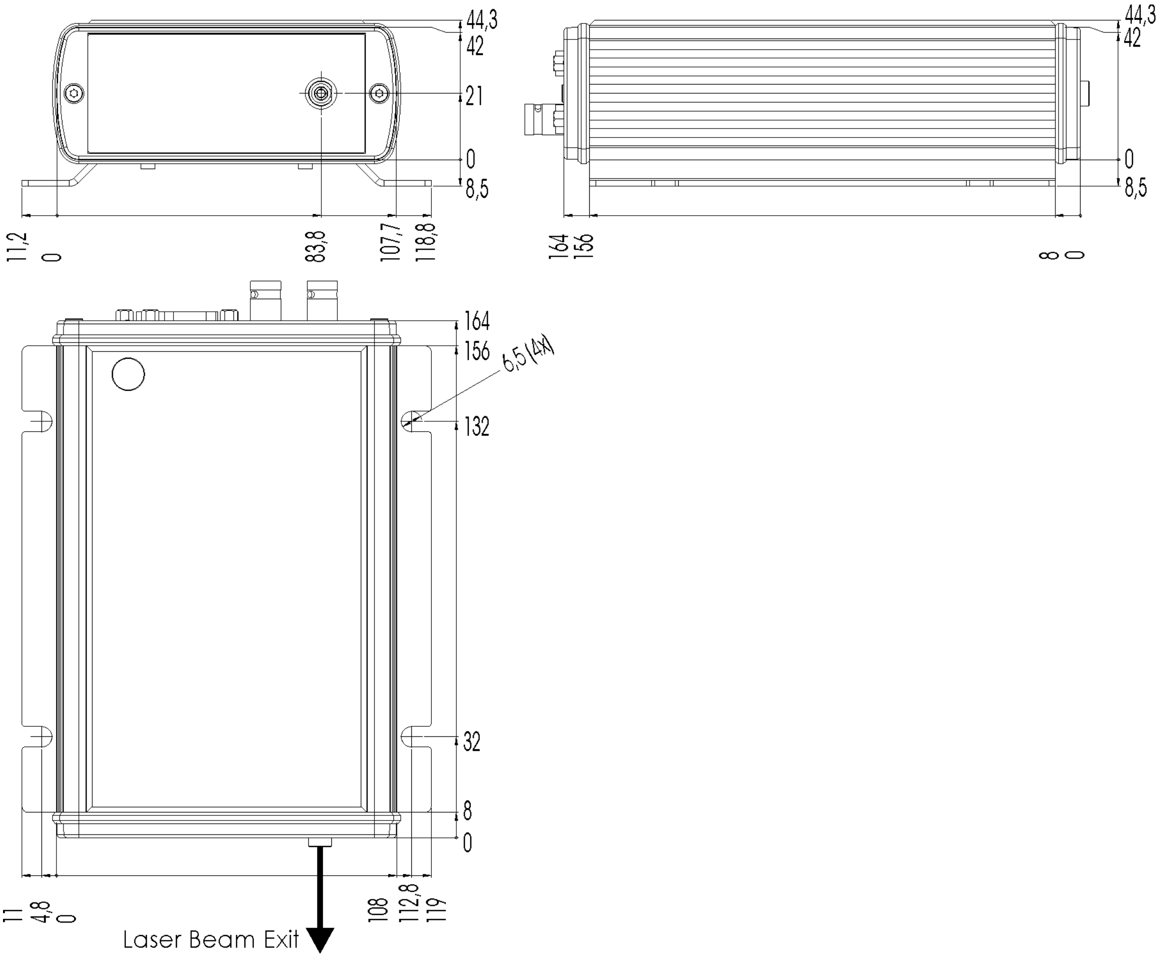



**Figure 54** Main dimensions of DFB pro BFY THz laser head

## 10.10 Data Analysis: Frequency Scan with Fixed Path Length

The photocurrent in the terahertz receiver is given by

$$I_{\mathrm{ph}} \propto E_{\mathrm{THz}} \cos\varphi = E_{\mathrm{THz}} \cos(2\pi L\nu/c)$$

where $E_{THz}$ is the amplitude of the terahertz electric field, $L$ is the deviation from zero path difference at the receiver, i.e. the difference between the length of the receiver arm, and the length of the emitter arm including the terahertz path, ν is the terahertz frequency and c the speed of light in vacuum.

In the method described here, $L$ is fixed and only ν is varied ("scanned"). Neglecting any dispersive effects of the path length (i.e. $L(\nu) = L$ = const), the frequency dependence of $I_{ph}(\nu)$ can be expressed

$$I_{\mathrm{ph}}(\nu) = E_{\mathrm{THz}}(\nu) \cos(2\pi L\nu/c)$$

The receiver photocurrent thus oscillates as a function of the terahertz frequency ν, with a period $\Delta\nu=c/L$.

For a reliable analysis, $\Delta\nu=c/L$ should, on one hand, be significantly larger than the uncertainty of the frequency $\delta\nu \sim 10$ MHz. On the other hand, $\Delta\nu/2$ determines the effective frequency resolution and should thus be smaller than the frequency scale of a feature of interest, e.g. a spectral line. The value of $L$ can be chosen by tailoring the lengths of the optical fibers connecting the transmitter and receiver, and by varying the free-space terahertz beam path. For many applications, a suitable value is $L \approx 30$ cm and thus $\Delta\nu = c/L \approx 1$ GHz. This fulfills the requirement $\Delta\nu >> \delta\nu$, yet keeping $\Delta\nu$ significantly smaller than the linewidth of typical solid-state samples.

The amplitude values of the photocurrent $I_{ph}$ are easily determined from the envelope of $I_{ph}(\nu)$, either by a cosine fit around local maxima and minima, or simply by identifying the extrema of the photocurrent oscillations. The phase can equally be determined either by a cosine fit, or by analyzing the positions of the extrema and/or zero crossings of the photocurrent $I_{ph}(\nu)$.

### 10.10.1 Amplitude

We assign a counting index $m$ = 0, 1, 2, ... to the extrema of the photocurrent $I_{ph}(\nu)$, with even values of $m$ corresponding to maxima and odd values corresponding to minima of $I_{ph}(\nu)$. Further, we denote the frequency and photocurrent in the $m$-th extremum by $\nu_m$ and $I_m$, respectively. As indicated above, the extrema $I_m$ may be determined - if appropriate, after smoothing of the raw data - by a search algorithm that either just identifies local maxima and minima or fits low-order polynomials around the maxima and minima. We recommend to combine the information contained in a given maximum and the adjacent minimum, in order to eliminate possible offsets in the photocurrent:

$$\hat{I}_m(\hat{\nu}_m) = |I_m - I_{m+1}|/2, \quad \hat{\nu}_m = (\nu_m + \nu_{m+1})/2$$

Thus, one obtains one data point $(\hat{I}_m, \hat{\nu}_m)$ per interval $\Delta\nu/2$, at an interpolated frequency $\hat{\nu}_m$. This confirms the above statement that $\Delta\nu/2$ is the effective frequency resolution of this measurement technique.

The photocurrent amplitude $\hat{I}(\nu)$ can be linearly interpolated to arbitrary frequencies ν, using the two adjacent data points:

$$\hat{I}(\nu) = \frac{\hat{\nu}_{m+1} \quad \nu}{\hat{\nu}_{m+1} - \hat{\nu}_m}\hat{I}_m + \frac{\nu \quad \hat{\nu}_m}{\hat{\nu}_{m+1} - \hat{\nu}_m}\hat{I}_{m+1} \quad \text{with} \quad \hat{\nu}_m \leq \nu < \hat{\nu}_{m+1}$$

The transmittance through a sample, at any frequency ν, is computed by comparing the photocurrent amplitude $\hat{I}_{\mathrm{sam}}$ of the sample to the amplitude $\hat{I}_{\mathrm{ref}}$ of a reference measurement without the sample:

$$T(\nu) = \left(\frac{\hat{I}_{\mathrm{sam}}(\nu)}{\hat{I}_{\mathrm{ref}}(\nu)}\right)^2$$

with $\hat{I}_{\mathrm{sam}}(\nu)$ and $\hat{I}_{\mathrm{ref}}(\nu)$ interpolated to the same frequency ν.

### 10.10.2 Phase

In addition to the terahertz amplitude, the phase φ, too, can be determined from the raw data. To do so, one can either use cosine fitting of $I_{ph}(\nu)$ at the frequency ν of interest. Or, alternatively, one can simply analyze the positions (in frequency) of the extrema and/or zero crossings of $I_{ph}$. The cosine fit requires more computing power and might be affected by the frequency dependence of $E_{THz}(\nu)$, whereas the zero crossings are independent of $E_{THz}(\nu)$.

Analog to the amplitude analysis, we regard the extrema of the photocurrent, to which we once again assign the counting index *m*. One can approximate (for $E_{THz}(\nu)$ ~ const)

$$\varphi(\nu_m) = 2\pi L(\nu_m)\nu_m/c = m\pi$$

Like the amplitude, the phase can be linearly interpolated to arbitrary frequencies:

$$\varphi(\nu) = \frac{\nu_{m+1} - \nu}{\nu_{m+1} - \nu_m}\varphi_m + \frac{\nu - \nu_m}{\nu_{m+1} - \nu_m}\varphi_{m+1} \quad \text{with} \quad \nu_m \leq \nu < \nu_{m+1}$$

However, in contrast to the amplitude, the correct order *m* of the extremum must be used. In the ideal case, when the data acquisition is started at ν = 0 and all extrema are identified unambiguously, the extrema can simply be counted.

Commonly though, no reliable terahertz data are available below 50 to 100 GHz - due to both the working range of the photomixers, and parasitic interference effects (standing waves) prevalent at low frequencies. However, a broadband measurement allows for extrapolating φ(ν) for ν → 0, resolving the ambiguity in *m*. To do so, one exploits the fact that *L*(ν) usually exhibits very low dispersion, i.e. one assumes *L*(ν) = *L*= const.

Then, one obtains an estimate for *L* from two extrema (e.g. with a spacing of $m_1 - m_2 \sim 10 .. 100$):

$$L = \frac{c}{2}\frac{m_1 - m_2}{\nu_{m_1} - \nu_{m_2}}$$

The order *m* follows from

$$m \approx 2L\nu_m/c$$

by rounding to the nearest integer value (even integer for a maximum, odd integer for a minimum).

The phase shift $\Delta\varphi$ introduced by the sample corresponds to the difference of the phase values of sample and reference measurement, $\varphi_{sam}$ and $\varphi_{ref}$:

$$\Delta\varphi(\nu) = \varphi_{\rm sam}(\nu) - \varphi_{\rm ref}(\nu)$$

Similarly, the change of the optical path length, introduced by the sample, is given by

$$\Delta L(\nu) = L_{\rm sam}(\nu) - L_{\rm ref}(\nu) = \frac{\Delta\varphi}{2\pi}\frac{c}{\nu}$$

Neglecting interference effects within the sample (i.e. multiple reflections between the sample's surfaces), and assuming that the thickness *d* of the sample is known, the refractive index *n* of the sample is then calculated from

$$(n-1)d \approx \Delta L$$

Interpolation errors can be minimized by using extrema of different orders. Let $m_{sam}$ denote the order of a photocurrent extremum of the sample measurement, and $m_{ref}$ the order of a photocurrent extremum of the reference measurement. Ideally, the extrema should be selected so that the frequencies of sample and reference measurement, $\nu_{sam}$ and $\nu_{ref}$, are close to each other, i.e. $\nu_{\rm sam,\mathit{m}_{sam}} \approx \nu_{\rm ref,\mathit{m}_{ref}}$.

Then, using the frequencies $\nu_{ref}$ at extrema $m_{ref}$ and $m_{sam}$,

$$\nu_{\rm ref,\mathit{m}_{ref}} = m_{\rm ref}\frac{c}{2L} = (m_{\rm sam} + (m_{\rm ref} - m_{\rm sam}))\frac{c}{2L} = \nu_{\rm ref,\mathit{m}_{sam}} + (m_{\rm ref} - m_{\rm sam})\frac{c}{2L}$$

which can be rearranged:

$$\nu_{\rm ref,\mathit{m}_{sam}} = \nu_{\rm ref,\mathit{m}_{ref}} + (m_{\rm sam} - m_{\rm ref})\frac{c}{2L}$$

Subtracting the frequency $\nu_{\rm sam,\mathit{m}_{sam}}$ of the sample measurement on both sides, multiplying with $L/\nu_{\rm sam,\mathit{m}_{sam}}$ and using Eq. (4)[7] yields a final expression for the refractive index *n*:

$$(n-1)d = \frac{\nu_{\rm ref.\mathit{m}_{ref}} - \nu_{\rm sam,\mathit{m}_{sam}}}{\nu_{\rm sam,\mathit{m}_{sam}}} \cdot L + (m_{\rm sam} - m_{\rm ref}) \cdot \frac{c}{2\nu_{\rm sam,\mathit{m}_{sam}}}$$

7. A. Roggenbuck, H. Schmitz, A. Deninger, I. Cámara Mayorga, J. Hemberger, R. Güsten, M. Grüninger: Coherent broadband continuous-wave terahertz spectroscopy on solid-state samples; New J. Phys. 12 (2010) 43017-43029.

## 10.11 Declaration of CE Conformity

**Konformitätserklärung**

**Declaration of Conformity / Declaration de Conformitè**

| QM-Formular: | F-173 | Stand Formular: | 15.12.2016 | Version Formular: | 10 | Seite: | 1 von 1 |
|---|---|---|---|---|---|---|---|

| | |
|---|---|
| Wir / *We / Nous* | **TOPTICA Photonics AG** |
| Anschrift / *Address / Adresse* | **Lochhamer Schlag 19**<br>**82166 Graefelfing**<br>**Germany** |

erklären in alleiniger Verantwortung, daß das Produkt / *declare under our sole responsibility, that the product / declarons sous notre seule responsibilité, que le produit*

| | |
|---|---|
| Bezeichnung / *Name / Nom* | **TeraBeam 1550, TeraScan 1550** |
| Artikelnr. / *Article No. / No. d'Article* | **TeraBeam 1550, TeraScan 1550** |
| Beschreibung / *Description / Description* | **Platforms for frequency-domain terahertz spectroscopy.**<br>**TeraBeam 1550: Laser system with digital control unit;**<br>**TeraScan 1550: TeraBeam 1550 system with InGaAs antennas** |

mit den grundlegenden Anforderungen der Richtlinien / *fulfills the requirements of the standard and regulations of the directives / satisfait aux exigences des normes et directives*

**2014/30/EU (Elektromagnetische Verträglichkeit), 2014/35/EU (Niederspannungsrichtlinie)**
**2011/65/EU (RoHS-Richtlinie)**

übereinstimmt und damit den Bestimmungen entspricht. / *and therefore corresponds to the regulations of the directive. / et, ainsi, correspond au règlements de la directive.*

Angewendete harmonisierte Normen / *Applied harmonized standards: / Normes harmonisées appliquées*:

| | |
|---|---|
| **DIN EN 61326-1** | VDE 0843-20-1:2013-07 Elektrische Mess-, Steuer-, Regel- und Laborgeräte - EMV-Anforderungen - Teil 1: Allgemeine Anforderungen (IEC 61326-1:2012); Deutsche Fassung EN 61326-1:2013<br>*Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 1: General requirements (IEC 61326-1:2012); German version EN 61326-1:2013* |
| **DIN EN 61010-1** | Sicherheitsbestimmungen für elektrische Mess-, Steuer-, Regel- und Laborgeräte - Teil 1: Allgemeine Anforderungen (IEC 61010-1:2010 + Cor. :2011); Deutsche Fassung EN 61010-1:2010<br>*Safety requirements for electrical equipment for measurement, control and laboratory use - Part 1: General requirements (IEC 61010-1:2010 + Cor. :2011); German version EN 61010-1:2010* |
| **DIN EN 60825-1** | Sicherheit von Lasereinrichtungen - Teil 1: Klassifizierung von Anlagen und Anforderungen (IEC 60825-1:2014); Deutsche Fassung EN 60825-1:2014<br>*Safety of laser products - Part 1: Equipment classification and requirements (IEC 60825-1:2014); German version EN 60825-1:2014* |
| **DIN EN 50581** | Technische Dokumentation zur Beurteilung von Elektro- und Elektronikgeräten hinsichtlich der Beschränkung gefährlicher Stoffe; Deutsche Fassung EN 50581:2012<br>*Technical documentation for the assessment of electrical and electronic products with respect to the restriction of hazardous substances; German version EN 50581:2012* |

Durch nicht von uns autorisierte Änderungen am Produkt verliert diese Erklärung ihre Gültigkeit. / *Non authorized changes at the product result in the invalidity of this declaration. / Changements au produit, qui ne sont pas autorisées par nous, ont pour conséquence l'invalidité de cette declaration.*

| | |
|---|---|
| Gräfelfing, den 21.04.2017 | Dr. Thomas Weber<br>Vorstand |
| Ort und Datum der Ausstellung<br>*Place and Date of Issue*<br>Lieu et date d'établissement | Name und Unterschrift des Befugten<br>*Name and Signature of authorized person*<br>Nom et signature de la personne autorisée |

Electromagnetic noise emissions of the system meet the requirements according to class B, with an interference immunity factor for operation in industrial applications.

## 10.12 License and Copyright Information associated with Third Party Software

This product incorporates third-party software. The license and copyright information associated with this software is available via the command **general:legal-info** or by clicking on **Legal Info DLC smart** in the Help menu of the TOPAS TeraScan Control Software (please refer to section 8.6.4).

This product contains software which, according to GNU General Public License Versions 2 and 3, is subject to disclosure. TOPTICA Photonics AG offers on request an entire copy of the corresponding machine-readable source code at cost price.

This product further contains software covered by the GNU Lesser General Public License. Upon request, TOPTICA Photonics AG offers to grant the rights resulting from this license.

Please address your request to TOPTICA Photonics AG, Head of Development, Lochhamer Schlag 19, 82166 Graefelfing, Germany.

| **Open-Source Software Incorporated in the TOPAS TeraScan Control Software** | | |
|---|---|---|
| **Name** | **Copyright** | **License** |
| busybox | Copyright (c) 1989, 1991 Free Software Foundation, Inc. | GPL-2.0-only |
| bzip2 | Copyright (c) 1996-2007 Julian R Seward. | bzip2-1.0.5 |
| dhcp | Copyright (c) 2004-2010 by Internet Systems Consortium, Inc. ("ISC")<br>Copyright (c) 1995-2003 by Internet Software Consortium | ISC |
| eventlog | | BSD-3-Clause |
| fbgrab | Copyright (c) 1989, 1991 Free Software Foundation, Inc. | GPL-2.0-only |
| gdbserver | Copyright (c) 1989, 1991 Free Software Foundation, Inc. | GPL-2.0-only |
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| kernel-header | | GPL-2.0-only |
| kmod | Copyright (c) 1989, 1991 Free Software Foundation, Inc. | GPL-2.0-only |
| libffi | Copyright (c) 1996-2012 Anthony Green, Red Hat, Inc and others. | MIT |
| libusb | Copyright (c) 1991, 1999 Free Software Foundation, Inc. | LGPL-2.1-or-later |
| linux | | GPL-2.0-only |
| mtd-utils | Copyright (c) 1989, 1991 Free Software Foundation, Inc. | GPL-2.0-only |
| ncurses | Copyright (c) 1998-2004,2006 Free Software Foundation, Inc. | NCURSES |
| openssh | | OPENSSH |
| openssl | Copyright (c) 1998-2011 The OpenSSL Project. All rights reserved.<br>Copyright (c) 1995-1998 Eric Young (eay@cryptsoft.com)<br>All rights reserved. | OpenSSL |
| proftpd | Copyright (c) 1989, 1991 Free Software Foundation, Inc. | GPL-2.0-only |

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| strace | Copyright (c) 1991, 1992 Paul Kranenburg <pk@cs.few.eur.nl><br>Copyright (c) 1993 Branko Lankester <branko@hacktic.nl><br>Copyright (c) 1993 Ulrich Pegelow <pegelow@moorea.uni-muenster.de><br>Copyright (c) 1995, 1996 Michael Elizabeth Chastain <mec@duracef.shout.net><br>Copyright (c) 1993, 1994, 1995, 1996 Rick Sladkey <jrs@world.std.com><br>Copyright (c) 1998-2001 Wichert Akkerman <wak-kerma@deephackmode.org><br>All rights reserved. | BSD-3-Clause |
| syslog-ng | Copyright (c) 1989, 1991 Free Software Foundation, Inc. | GPL-2.0-only |
| u-boot | Wolfgang Denk et al. | GPL-2.0-only |
| udey | Copyright (c) 1989, 1991 Free Software Foundation, Inc. | GPL-2.0-only |
| usbutils | Copyright (c) 1989, 1991 Free Software Foundation, Inc. | GPL-2.0-only |
| util-linux | Copyright (c) 1989, 1991 Free Software Foundation, Inc. | GPL-2.0-only |
| zip30 | Copyright (c) 1990-2007 Info-ZIP. All rights reserved. | Info-ZIP |

## 10.13 EU Legislation for Electrical and Electronic Equipment (EEE)

Companies selling electrical and electronic goods in the European Union must conform to the EU legislation for electrical and electronic equipment (EEE), which includes the Waste Electrical and Electronic Equipment Directive (WEEE). Assigned duties affect product design of the equipment, disposal of used appliances as well as organizational responsibilities, i.e. product registration.

There are different requirements for household WEEE and that which is sold business to business (B2B). All equipment TOPTICA Photonics AG handles is classed as B2B. TOPTICA is registered at the Competent Authority (Stiftung Elektro-Altgeräte Register EAR) under No. DE70442884.

At end-of life return your product back to TOPTICA. TOPTICA will dispose used equipment in such a manner as to meet all relevant local, country and EU requirements and guideline.

To return products please mark them clearly with “intended for disposal”. Contact TOPTICA prior to shipping and send them to the following address:

TOPTICA Photonics AG
Lochhamer Schlag 19

D-82166 Graefelfing

# 11 Guarantee and Service

On the following page you will find the **Guarantee Registration Form** in which the warranty conditions are defined. Please complete in the Guarantee Registration Form immediately after you receive your device and return it to TOPTICA Photonics AG by mail or fax.

As a first step toward obtaining technical support, please contact your local distributor or visit the support pages on our web site: http://www.toptica.com/support/.

In case you wish to return a product for diagnosis and/or repair, please contact us prior to sending it so we can issue a **Return Material Authorization** (RMA) number for you.

You can contact us in the following ways:

- Internet: service.toptica.com. In our support section you can find a list of frequently asked questions and a service contact form.
- Email: service@toptica.com
- Phone: +49-89-85837-150

Our customers in the USA and Canada may contact TOPTICA Photonics Inc.:

- Phone: +1-585-657-6663

Our customers in Japan may contact TOPTICA Photonics K.K.:

- Phone: +81-42-306-9906

# Guarantee Registration Form

| QM form: F-015 | Status of form: 13.10.2015 | Version of form: 02 | Page: 1 of 1 |
|---|---|---|---|

return to

**TOPTICA Photonics AG**
**Customer Service**
**Lochhamer Schlag 19**
**D- 82166 Graefelfing/Munich**
**Germany**

FAX: +49 89 85837-200

sender:

______________________________
______________________________
______________________________
______________________________
______________________________

## Guarantee Conditions

The products of TOPTICA Photonics AG are produced with the greatest possible care using high-quality components and are checked in detail before being delivered. Therefore, as the manufacturer, TOPTICA Photonics AG gives a guarantee of durability according to the following terms:

1. **TOPTICA Photonics AG guarantees the buyer that there will be no defects in the product based on defective material or processing, for a period of 12 months from first delivery (guarantee period).** Natural wear and tear as well as defects resulting from improper use or use contrary to the specifications, from failure to observe operating instructions, from insufficient maintenance and care or from modifications, interventions or attempted repairs that are neither carried out nor authorized by TOPTICA Photonics AG, are not covered by the guarantee.
2. **Unless expressively stated in the order acknowledgement or the invoice semiconductor light emitting devices like laser diodes, tapered amplifier chips, Terahertz transmitters and receivers etc. whether sold as single parts or integrated in systems are not covered by the guarantee.**
3. If a defect covered by the guarantee arises during the guarantee period, TOPTICA Photonics AG shall rectify such defect within a reasonable period at its own discretion by repairing or replacing the product or the defective part.
4. The guarantee period shall commence upon delivery of the product by TOPTICA Photonics AG or by a third party that obtained the product directly from TOPTICA Photonics AG for the purpose of selling it to the buyer.
   The claim under the guarantee shall be excluded if the defect is not notified to TOPTICA Photonics AG in writing immediately after having been discovered, and no later than one month after expiry of the guarantee period.
   For the purpose of rectifying a defect covered by the guarantee, the product or the relevant part shall be sent to TOPTICA Photonics AG at the expense and risk of the buyer. The product shall be returned at the expense and risk of TOPTICA Photonics AG.
5. No claims may be derived from this guarantee other than claims for rectification of the defects falling within the scope hereof, in accordance with the present terms. In particular, the buyer is not entitled under this guarantee to claim damages or a reduction in price from TOPTICA Photonics AG, or to rescind the contract. Potential, more far-reaching claims of the buyer against its seller shall not be affected by this guarantee.
6. **Important!: The obligation of TOPTICA Photonics AG under this guarantee is subject to the condition that the buyer gives his/her express consent to them by sending the signed duplicate of this form to TOPTICA Photonics AG immediately after delivery, also truthfully indicating the model number, the serial number and the date on which the product was delivered.**
7. The buyer may not assign claims under this guarantee to third parties without the prior written consent of TOPTICA Photonics AG.
8. This guarantee is governed by substantive German law to the exclusion of the provisions of the UN-Convention on Contracts for the International Sale of Goods (CISG). The Regional Court [Landgericht] Munich I shall be the court of exclusive international, local and subject-matter jurisdiction for legal disputes arising under or in connection with this guarantee.

I request the above mentioned guarantee for the purchased products and herewith consent to the above mentioned Guarantee Conditions:

| | | | |
|---|---|---|---|
| Model No.: | ____________________ | Date: | ____________________ |
| Serial No.: | ____________________ | Signature: | ____________________ |
| Date of Delivery: | ____________________ | Name/Title: | ____________________ |

To be completed by the buyer and returned to TOPTICA Photonics AG by mail or fax (+49 - 89 – 85837 – 200).