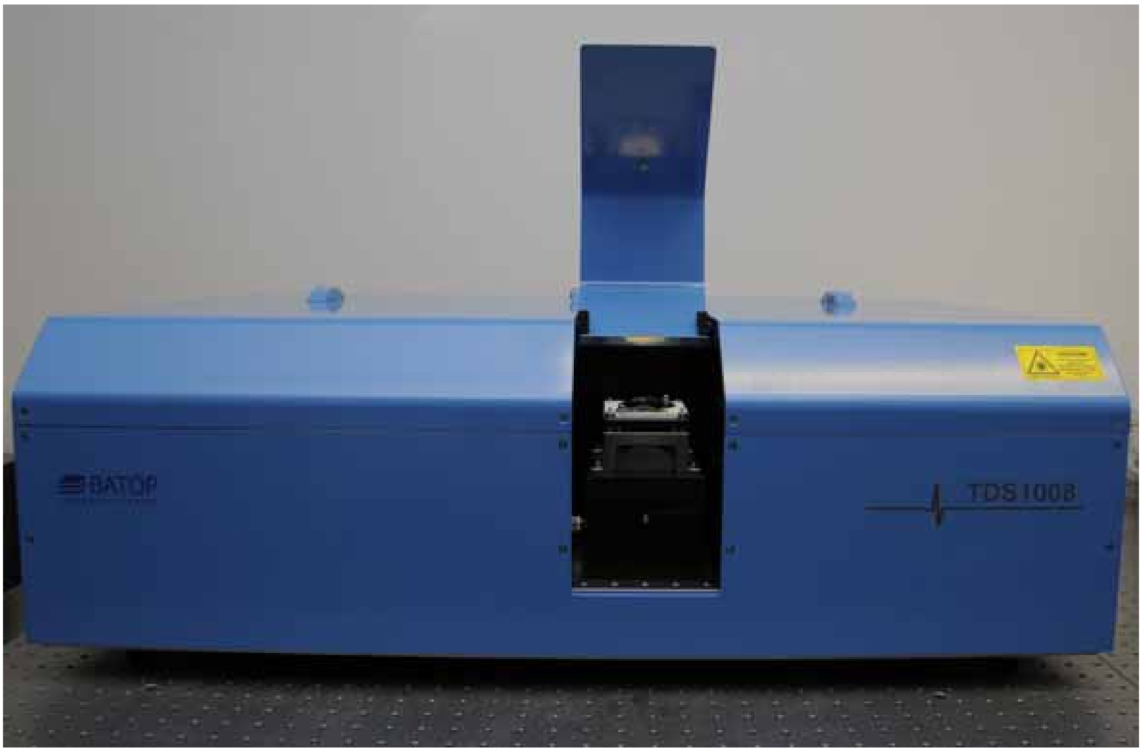
Manual for TDS 10XX system



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0. Safety instructions and warnings

Every TDS system uses a short pulse laser in order to drive the terahertz emitter and detector antennas. Before continuing to read this manual you should read the manual of the laser manufacturer first, in order to operate the laser and the system safely.

Because of the high laser power, the invisible nature of the radiation and the short pulse duration the inside of the enclosure of the TDS system has to be categorized as a class 4 laser product. Any reflected laser light may cause serious injury to your eyes. Therefore, if you need to open the enclosure while the laser is switched on, always put on safety goggles first (e.g. in case of aligning the optical path). Make sure that the safety goggles match the laser wavelength and the peak power in order to protect your eyes sufficiently. It is also recommended to avoid blocking the laser beam with your hand or any other part of your body as this may result in local damage to your skin and additional light scattering.

An LED on the laser controller indicates whether the laser is switched on or off. If you do not need the laser to be on while you are working inside the TDS enclosure, we recommend switching off the laser and turning the main power key switch on the controller into the off position, avoiding that the laser can be switched on accidentally.

If your TDS system is equipped with external fiber-coupled antennas please always turn off the laser before disconnecting the optical fiber of an antenna from the fiber port. Subsequently, you may hook up the optical fiber of another antenna. If you choose to not connect any fiber-coupled antennas please use the metal caps provided in order to close the fiber ports correctly. If the fiber ports are left open you have to wear your safety goggles every time the laser is switched on even if the enclosure has been closed.

In case you purchased a terahertz system without enclosure you always need to wear safety goggles when the laser is turned on. Additionally, everyone entering the room where the system is operating in needs to be aware whether the laser is on or off in order to ensure that the person puts on safety goggles upon entering the lab.

Please remember that any disregard of the safety measurements poses a serious risk of injury, especially to your eyes.

1. Installation and start-up

Before you can start the software and operate the TDS system you need to connect the computer to the hardware. If you purchased a TDS system with enclosure, use the USB-cables supplied to establish a connection between the computer, the data acquisition system and the linear stage(s). Turn on the TDS system using the power switch on the backside of the enclosure. Subsequently, you should be able to find the data acquisition system (NI-USB) and the linear stage(s) in the device manager. The latter will be present on one of the COM-ports as described in the T3DS software manual. If you have chosen the fast scan option as well there is an additional USB-port on the back side of the spectrometer which can be used to establish a connection between the computer and the voice coil. If the voice coil is working properly you will find a second active COM-port.

Figure 1: Backside panel of a TDS system with power supply, nitrogen purge and the voice coil USB-connector which enables the fast scan option in the T3DS software.

If you have purchased a fiber-coupled setup please connect the antennas to the corresponding BNC adapters and fiber ports and arrange the antennas in the desired configuration (transmission or reflection). In case you also bought the xy-stage for imaging purposes, please connect the x-stage to the Mini-Din port and the y-stage to the x-stage in a daisy-chain configuration (please see Zaber manual). Green LEDs on the stages will indicate that they have been connected correctly and the power supply works (avoid using the manual knob; stage movement would be indicated by the orange LED). However, please note that they can only be used by the T3DS software if they have been connected before the software was started.

If you did not purchase the full TDS system including the enclosure please see the manual for the T3DS software. There you will find the description on how to connect the computer to the data acquisition system and the linear stages. Also, you can connect your optical fibers directly to the collimators as well as the BNC cables to the data acquisition system.

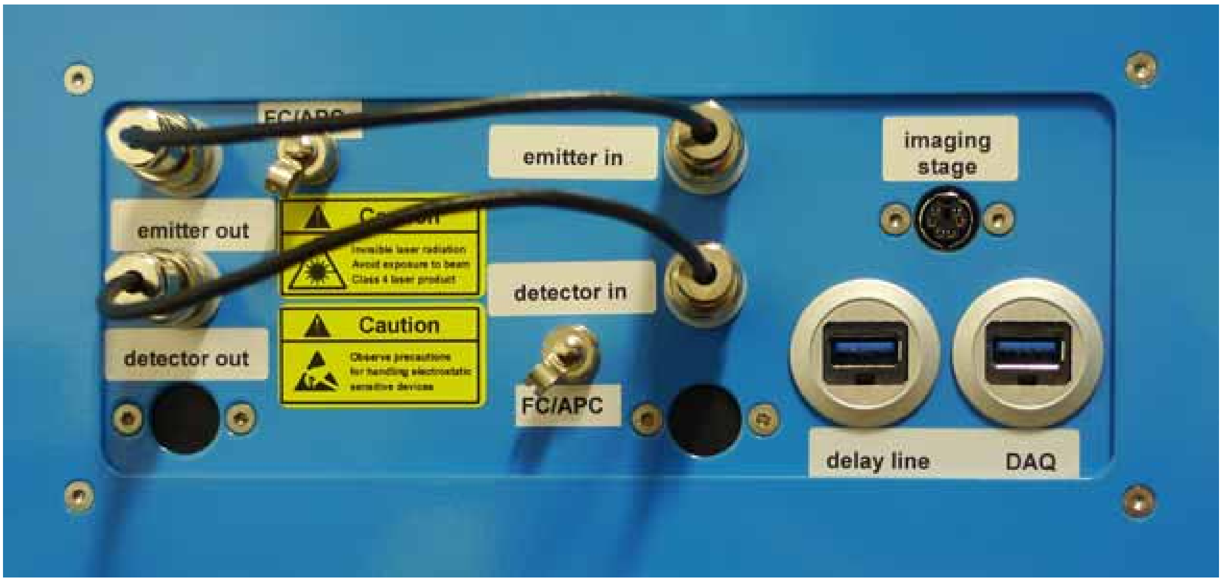

Figure 2: Panel on the right hand side of a TDS system with ports for electrical and optical connection of internal / external antennas, the imaging stage, the delay line and the data acquisition system (DAQ).

Since the data acquisition system can only handle one emitter and one detector antenna at a time, please make sure to connect either both free space antennas or both fiber-coupled antennas. In the former case use the two short BNC cables and connect the “emitter in” / “detector in” port to the corresponding “emitter out” / “detector out” port. As a result, the internal free space antennas are connected directly to the data acquisition system (which also provides the voltage to the emitter antenna). If you choose to use the fiber-coupled antennas please connect the emitter antenna to the “emitter out” port, the detector antenna to the “detector in” port and the optical fibers to the corresponding FC/APC ports.

Once everything is set you can turn on the laser as well. We recommended that you wait for about 15 minutes after switching on all the hardware in order to ensure that the data acquisition system and the laser have warmed up and are ready to go.

Please be aware that in case you are using a Toptica FemtoFErb 1560 laser, there is a shutter supplied by BATOP GmbH which is installed right next to the collimator where the beam exits the optical fiber attached to the laser. The shutter is required because the first laser pulses have an increased power level that may otherwise damage the terahertz antennas. Once the shutter is connected to the power supply and the SMA cable is connected to the trigger output of the laser, the shutter will open when the laser is switched on (with a designated delay of a few ms). You will hear a clicking noise when the shutter moves upward into the hold position and as it falls back when the laser is turned off again.

Before starting a measurement always make sure that the voltage applied to the emitter antenna is safe (please see the antenna specifications).

2. Alignment and signal optimization

If you put your system in operation for the first time or there is some deterioration in the signal strength you may need to adjust the optical and terahertz beam path in order to obtain the signal-to-noise ratio and bandwidth according to the specifications. As this requires the enclosure to be opened please put on your safety goggles beforehand. In order to open the lid of your spectrometer you have to loosen the screws on the frontal lid. Inside the spectrometer you will find the laser, the linear stage, the data acquisition system and the optical elements necessary to divide the laser beam into two beams (one for the detector and one for the emitter antenna). If you purchased a voice coil for fast measurements you will find additional optical parts and a box that contains the electronics to drive the voice coil.

2.1 Optimize for low antenna resistance

For all antennas with a BNC connector the first step is to connect the antenna to a multimeter and measure the resistance. At first, this should be done with the laser being in the off state. Upon switching the laser on the resistance of the antenna drops. If the alignment of the optical path is ok the resistance will match the specifications of the antenna (e.g. in case of an antenna for 1560 nm the resistance may drop to roughly 50 % of the dark resistance). For the internal free space antennas use the “emitter in” or “detector out” port to connect your multimeter to the corresponding antenna.

If there is only little change in the resistance you may use the last mirror before the free space antenna or change the orientation of the free space antenna itself to dial in on a low resistance. You will find that little changes in the orientation will have a large effect on the resistance, so be careful. For fiber-coupled antennas you can adjust the orientation of the collimator in addition to the last mirror before the collimator.

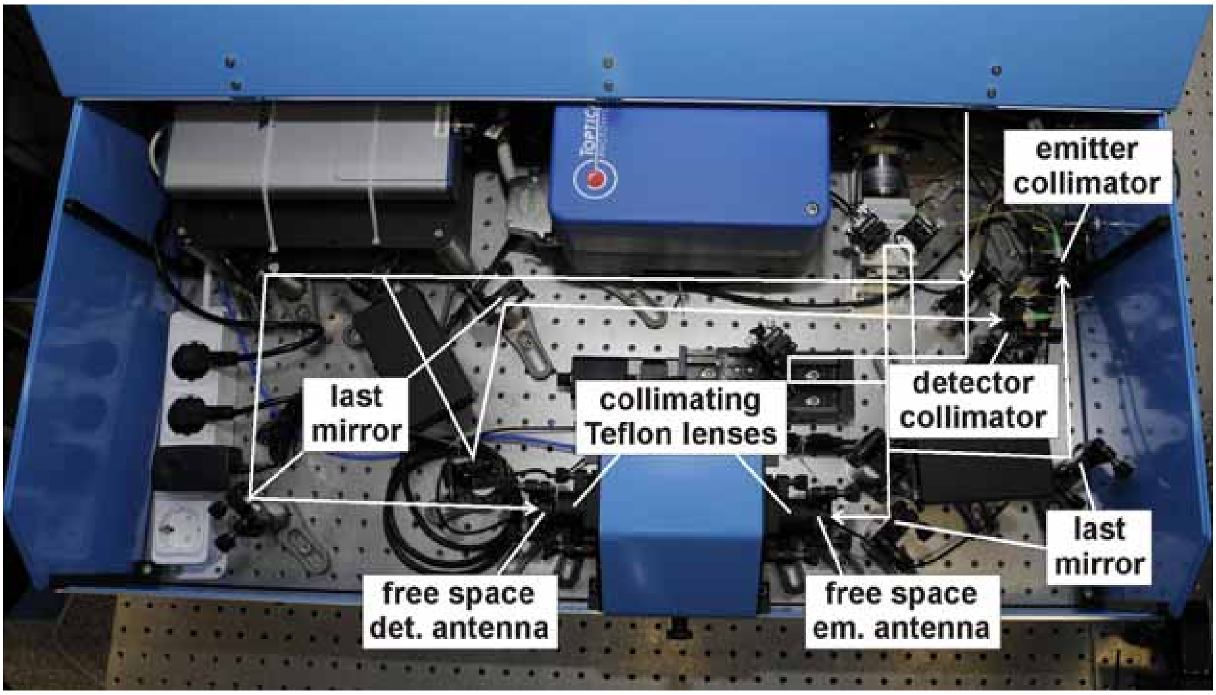

Figure 3: Inside of a spectrometer with free space antennas and collimators for fiber-coupled antennas. Please use the last mirrors as well as the mounts with the free space antennas and collimators to optimize the antenna resistance for the free space / fiber-coupled antennas.

Once you have found a setup with reasonable changes in the antenna resistance (similar to the antenna specifications) you can go on and start looking for a terahertz signal using the T3DS software. Make sure that you first reconnect all the antennas to the corresponding BNC ports.

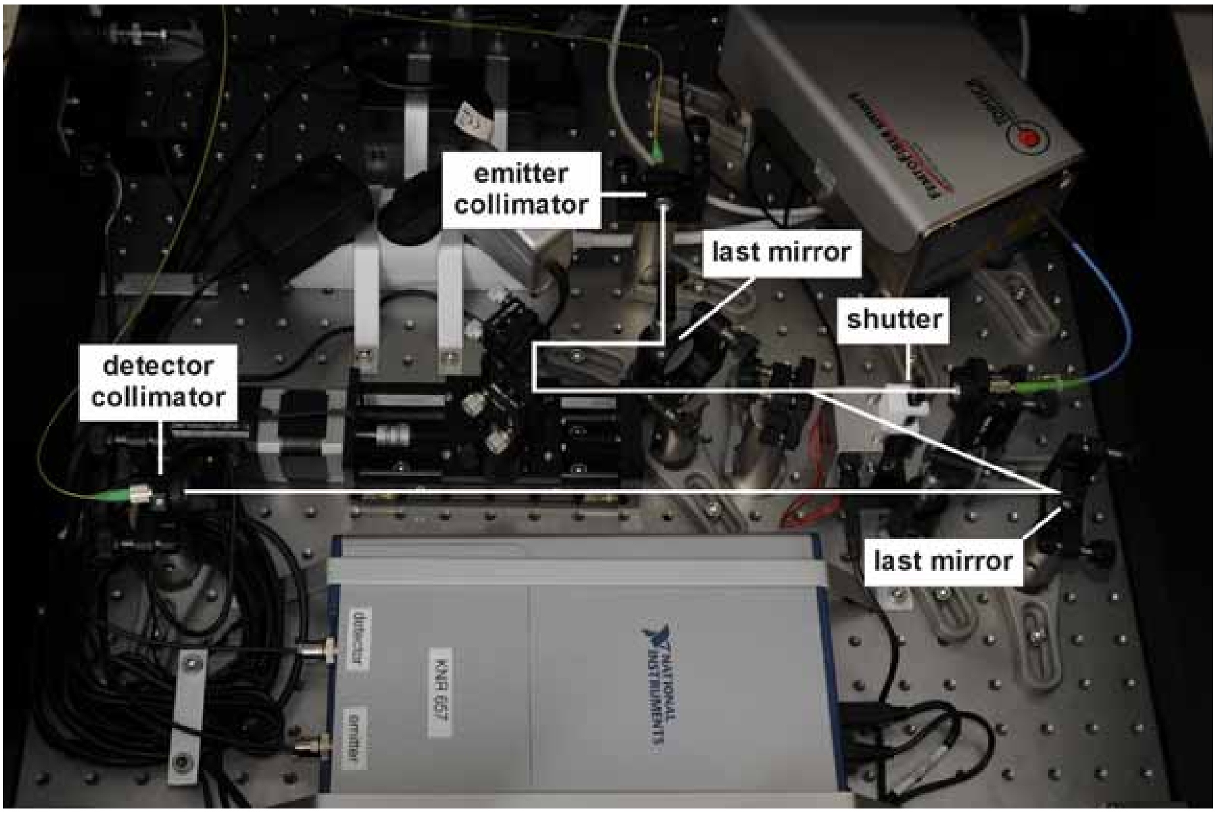

Figure 4: Inside of a fiber-coupled spectrometer. Please use the collimators and last mirrors before the collimators for optimizing the light coupling into the optical fibers.

Before considering changing the light intensity by rotating the neutral density filters always see the antenna specifications and contact us in order to avoid any damage to the antennas.

2.2 Optimizing the signal strength

After you have made sure that the antennas are illuminated correctly you can go on looking for the terahertz signal. First off start the T3DS software and conduct a slow scan using a broad interval (say from 50 – 450 ps). In order to speed up the process you can use a large stepwidth (> 0.1 ps) and a short integration time (0.1 s). For a reflection setup make sure to install the reference mirror.

If you already know the peak position or the system has been tested before shipment you can skip this step because the T3DS settings file contains the interval of interest. Therefore, you may only need to do a long scan if you build the spectrometer yourself or there have been some modifications to the optical or terahertz beam.

Once you have found the peak you can make a more detailed measurement using a narrower interval (20 – 30 ps should suffice), a smaller stepwidth (0.025 – 0.2 ps, depending on the peak width you expect) and a longer integration time (0.5 s or more). Afterwards, change to the static measurement tab on the T3DS software, push the “go to max” or “go to min” button and start the static measurement.

You will find that the graph starts to fill, displaying the voltage currently measured. At first you should use the buttons “adjust phase shift” and “optimize timing”. Please note that if there is a large offset (background signal) adjusting the phase shift automatically may not work very well and you may have to do it manually (this requires the static measurement to be stopped temporarily and typing in a new value by hand). Subsequently, you can start improving the signal strength by adjusting the same mirrors (and/or collimators) that you have used to optimize the antenna resistance. However, as these optical elements will only change the illumination of the antennas, you should focus on the optical elements that change the terahertz beam path. Depending on your geometry, you have the following options:

- Free space antenna: - adjusting the Teflon lenses between emitter and detector antenna
  - changing the orientation of the reflector
- Fiber-coupled antenna: - adjusting the orientation of the emitter and detector antenna package
  - changing the orientation of the reflector

Figure 5: Sample holder for transmission measurements.

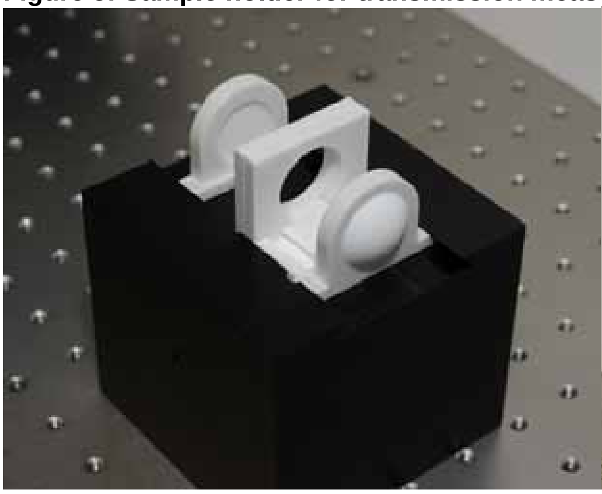

Figure 6: Sample holder for reflection measurements.

In case of fiber-coupled antennas you may also choose to change the distance between the antennas. However, if you do so you have to stop the static measurement and do a slow scan measurement in order to find the new peak position. If you use a focusing geometry changing the distance is not recommended unless you plan to use other focal lengths. Otherwise changing the distance between the antennas would result in the terahertz beam not being projected onto the detector antenna correctly.

If you use a TDS 10XX system and change the configuration in the sample compartment from transmission to reflection you have to be aware that this will result in a shift of the peak position, because of the terahertz path being roughly 45 mm longer. Hence, the peak position is shifted by about 150 ps. This value has to be added to the peak position that worked for transmission measurements. You should choose a slightly broader interval in order to compensate for some inaccuracy in the geometry. Otherwise, you may have to do another scan before you will find the new peak position.

The sample holder for reflection measurements allows you to change the orientation of the reflecting object in order to improve signal strength but please note that this may shift the peak position. Additionally, you can rotate the sample holder like for the transmission setup. In both cases, if you choose to use additional focusing Teflon lenses you have to be aware that again, this will shift the peak position (adding roughly 25 - 35 ps, depending on the focal length).

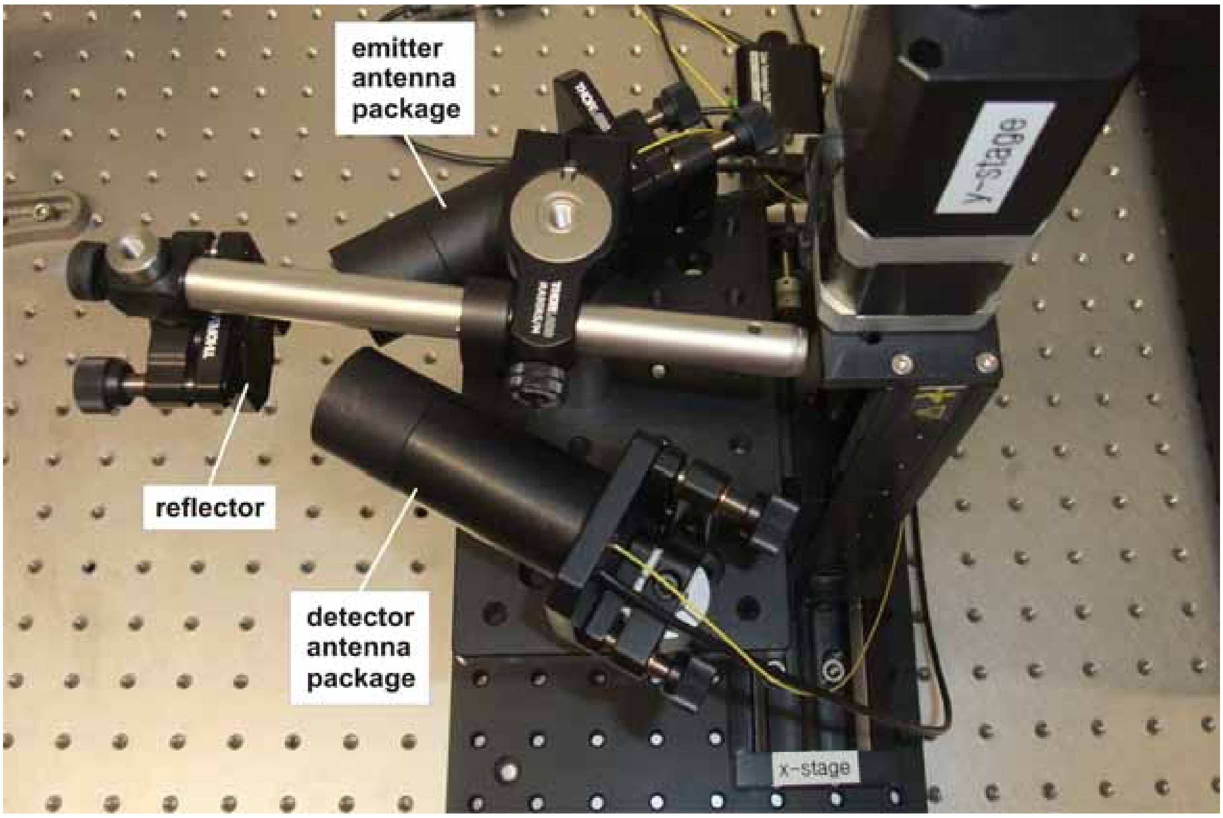

Figure 7: Fiber-coupled THz antennas in a reflection setup for imaging purposes.

If obtaining a high SNR and band width proves to be difficult with the free space antennas you may also adjust the orientation of the Teflon lenses and antennas in the reflection setup. However, this means you have to realign the setup for transmission measurements. Contrary to the fiber-coupled setup you can move the focusing Teflon lenses in line with the terahertz path to improve signal strength. Hence, the free space setup gives you more degrees of freedom to work with.

After improving the signal strength using the static measurement mode you can switch back to the slow scan tab and do another scan. You should then find an improved SNR as well as a broader frequency spectrum. If you're still not pleased with the SNR and bandwidth you have to repeat the procedure (preferably starting with the other local extremum). For more details on the measurement modes please see the T3DS software manual.

3. Conducting measurements

After you have optimized the signal strength and frequency spectrum you can now conduct your measurements. The two most commonly used measurement modes will be discussed briefly in this chapter. For a more detailed description please see the T3DS software manual.

3.1 Slow scan mode

The slow scan mode is used if you plan to investigate material properties. In this mode of operation the sample is characterized either in a transmission or reflection geometry. If you plan to investigate the material properties you need to conduct a reference measurement, consisting of a baseline and a 100 % transmission / reflection measurement. You may do a slow scan first in order to get an idea about the interval of interest as this will be fixed once you have conducted the reference measurement (see software manual). To obtain the best results turn on the nitrogen purge that comes with the internal sample compartment beforehand.

Upon starting the reference measurement you will be asked to block the THz beam path / cover the detector antenna using a metallic object. After the baseline data has been collected you have to unblock the THz beam and the reference measurement for 100 % transmission / reflection is conducted. Now that the reference data is available you can start your sample measurements. If you are working with a reflection setup please now remove the reflector and put in the designated sample.

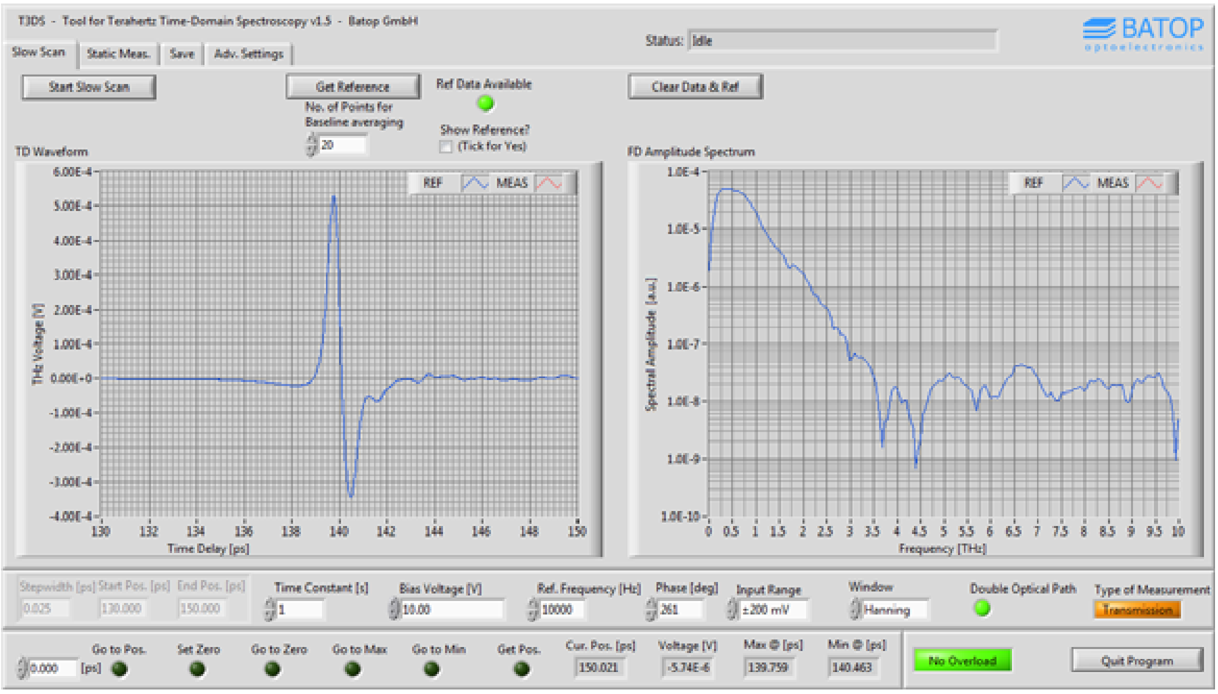

Figure 8: Result of a slow scan measurement displaying the time-domain and FFT data.

Please note that the time-domain data displayed in the T3DS software includes the subtraction of the baseline (in case there no reference data has been collected, a linear baseline is subtracted by default). While the time-domain data is always saved as raw data the frequency spectrum is saved as displayed, being Fourier-transformed from the time-domain data after baseline subtraction.

In case you decide to change the geometry from transmission to reflection or add / remove focusing Teflon lenses remember to account for the change in the length of the THz path and choose the interval of interest accordingly (see previous chapter).

3.2 Imaging mode

If you purchased the additional xy-stage and connected it to the TDS system before starting the software, the imaging tab will be activated on the T3DS front panel.

In the imaging mode you can conduct a slow scan at a number of points on a xy-plane of an object. Therefore, the object should be arranged as parallel as possible to the movement directions of the xy-stage, especially for reflection measurements. Depending on your measurement parameters the imaging measurement may take minutes (e.g. if you collect just one data point at each xy-position) or days (in case you do a full scan at each position). The program will give you a rough time estimate for the chosen set of parameters by multiplying the time for each scan with the number of points on the xy-plane that have to be measured.

In contrast to a slow scan measurement the imaging measurement automatically saves the data while being executed with the file name that has been chosen beforehand. In order to make things easier for you the data of all pixels of your image will be stored in a separate folder using the same name as the chosen file name. The file name for each pixel will include additional characters to indicate the xy-position (for more details please see the T3DS software manual).

During the measurement the image will start to fill and after each scan the time-domain data and frequency spectrum is updated on the slow scan tab. The software displays a normalized peak to peak voltage on the imaging tab with light blue corresponding to a value of one (maximum value) and black corresponding to zero. As the system collects the data pixel by pixel the colors on the image may be rescaled depending on the peak to peak voltage of the last scan.

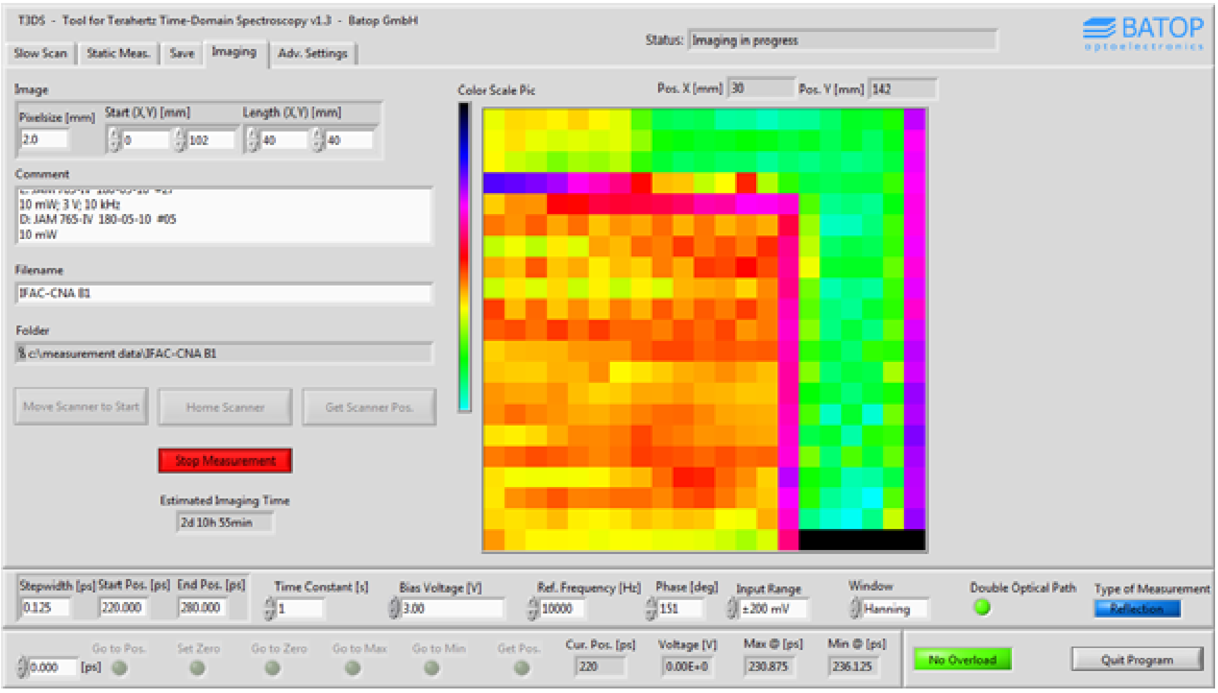

Figure 9: Data of an ongoing imaging measurement.

If you stop the imaging measurement you have to wait till the current slow scan has ended. Therefore, please choose your parameters carefully as this may take some minutes.

4. System specifications

The TDS 10XX system comes in different versions depending on the laser and optional parts like fiber-coupled antennas, linear stages for imaging or different sample holders. Please see the following table for the corresponding spectrometer specifications.

laser parameters	TDS 1008	TDS 1010	TDS 1015
laser wavelength	780 nm	1060 nm	1560 nm
laser output power	> 140 mW	> 100 mW	> 100 mW
pulse duration	< 100 fs	< 100 fs	< 100 fs
spectrometer parameters			
useful spectral range	0.05 – 3.5 THz	0.05 – 2.5 THz	0.05 – 1.2 THz
SNR @ THz maximum	≥ 65 dB	≥ 60 dB	≥ 50 dB
slow scan duration	8 min	6 min	3 min
maximum scan range[1]	500 ps		
frequency resolution	2 GHz		
THz beam diameter	22 mm (collimated) / 1-3 mm (focused)		
sample size [mm][2]	≥ 30 x 30 (collimated) / ≥ 5 x 5 (focused)		
supply voltage	100-240 V @ 60/50 Hz		
power plug	CEE 7/4 (IEC type F)		
spectrometer dimensions [cm]	90 x 60 x 30	60 x 60 x 30	60 x 60 x 30
spectrometer weight	~ 95 kg	~ 65 kg	~ 65 kg
periphery			
laser controller dimensions [cm]	32 x 24 x 14	17 x 10 x 5	11 x 10 x 4
laser controller weight	4.5 kg	0.65 kg	0.2 kg
imaging			
linear stage travel length[3]	15 cm x 15 cm		
imaging stage dimensions	35 cm x 40 cm x 20 cm		
imaging stage weight	6 kg		

[1] Other scan ranges are possible; the frequency resolution will change accordingly.
[2] Sample holders for other geometries are possible; please contact us with detailed information.
[3] Travel lengths up to 45 cm for imaging option are available; the stage dimensions and weight will change accordingly.

All TDS systems have an integrated signal generator / data acquisition unit to drive the terahertz emitter antenna and simultaneously measure the voltage of the detector antenna. The systems are equipped with a sample compartment for transmission and reflection measurements which can be purged with nitrogen. Both, free-space and fiber-coupled antennas can be used in either reflection or transmission geometry with or without focusing Teflon lenses. Additionally, an imaging unit can be purchased that enables scanning an object using the fiber-coupled antennas. It is also possible to purchase a setup with fiber-coupled antennas only, if free-space antennas are not required. Please note that the spectral range and the signal-to-noise ratio are given for the free space antenna version.

5. Contact details

If you have any further questions or remarks, please do not hesitate to contact us.

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