

Kit for building your own THz Time-Domain Spectrometer

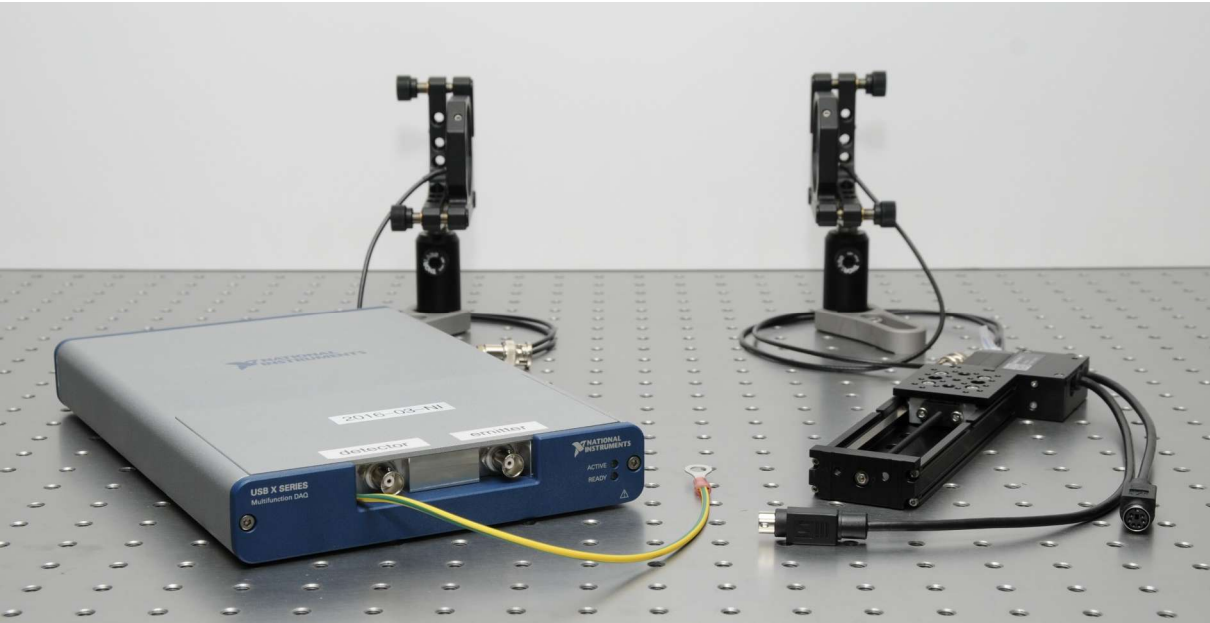


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0. Parts for the THz Kit

The kit to build your THz Time-Domain spectrometer includes the following items:

- delay line (linear stage) from Zaber Technologies to match the pulse propagation times of optical and THz beam path
- combined pulse generator and lock-in detector based on a data acquisition system from National Instruments
- set of two THz antennas (free space or fiber-coupled)
- a DVD with the T3DS software package to control the delay line and the data acquisition system plus all drivers required to run the T3DS software on a Windows 7 64 bit computer

1. Delay line

Zaber Technologies Inc. provides a number of different linear stages, rotary devices and multi-axis systems. The basic BATOP THz kit comes with a T-LSM100A model that has a travel length of 100 mm which corresponds to a maximum time delay of about 650 ps when using two mirrors on the stage to redirect the optical beam.

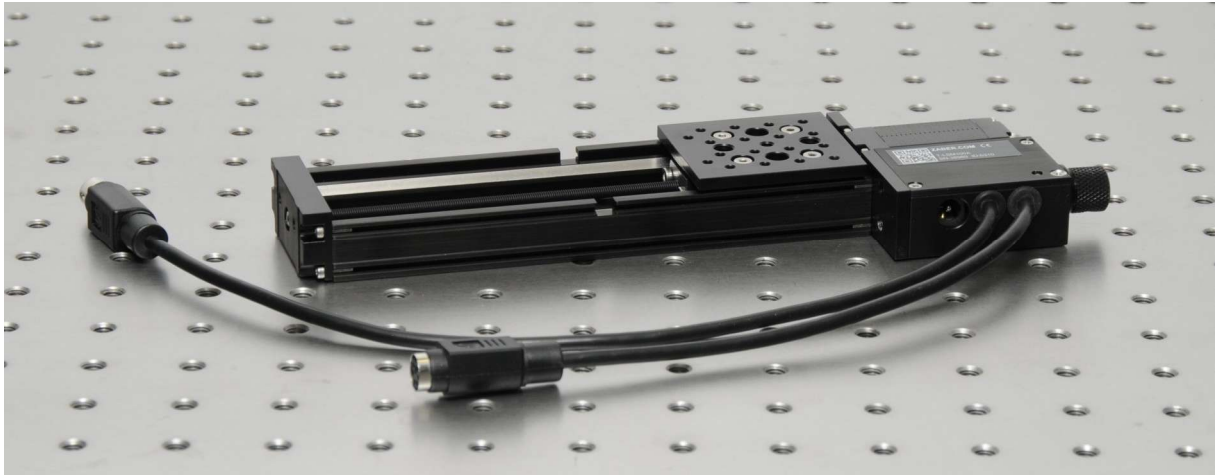


Figure 1: Zaber linear stage typically used as delay line in THz spectrometer.

The T3DS software can handle all linear stages of the T-LSR and T-LSM series as a delay line but we recommend using type A stages because of the low position error compared to type B and type D drives. However, type B and type D stages may be used to build your own imaging stage as the position error and accuracy will always be much better than the spot diameter of the focused THz beam (the latter typically being a few hundred micrometer).

In order to hook up the linear stage to your computer just use the Mini-Din to USB cable provided. Once the stage is hooked up and the power supply is plugged in you can find the stage on one of the COM-ports in the device manager. If so, the T3DS software will detect the type of stage automatically upon start-up.



Warning:

For safety reasons you must never put your hand on the stage while it is moving. The linear stage can cause serious damage to your hand and fingers. Hence, before you can change the configuration on the stage please always disconnect it from the power supply.

2. Pulse generator and lock-in detector

In order to create a THz pulse a voltage has to be applied to the emitter antenna. On the right hand side of the front panel of the data acquisition system you will find a BNC port that the emitter antenna can be hooked up to. Once the laser pulse hits the gap of the antenna free charge carriers are created and a very brief current will flow between the contacts, thus creating a THz pulse.



Figure 2: Data acquisition systems with BNC ports for emitter and detector antenna.



Caution:

The maximum voltage that the system can put out is 20 V. When using the T3DS software please make sure that the voltage applied to the emitter antenna is always within safe limits. Do not exceed the antenna specifications!

At the detector antenna the THz pulse is converted into a small voltage if the pulse coincides with the laser pulse. The linear stage moves in order to adapt the pulse propagation times, changing the length of the laser beam path for the emitter antenna (please see Chapter 5). The voltage of the detector antenna is fed back to the left BNC port on the data acquisition system.

During measurements the T3DS software will set the emitter voltage (typically a 10 kHz signal) and process the signal from the detector antenna. Using the lock-in technique the chosen frequency is filtered out. Please note that the signal-to-noise ratio is strongly affected by the integration time but it may also be limited by the stability of the laser source.

The National Instruments data acquisition system is connected directly to the computer using the USB cable provided. You can find the system in the device manager once it has been hooked up, connected to the power supply and switched on. The yellow/green wire may be used to connect the housing of the data acquisition unit to ground.

3. THz antennas

The THz kit provided by BATOP comes with either free space or fiber-coupled antennas. The free space antennas give you the best performance as all elements of the THz path can be aligned independently. The downside is that the laser beam path and the THz beam path are not independent. Hence, any alteration of the THz side requires careful planning.

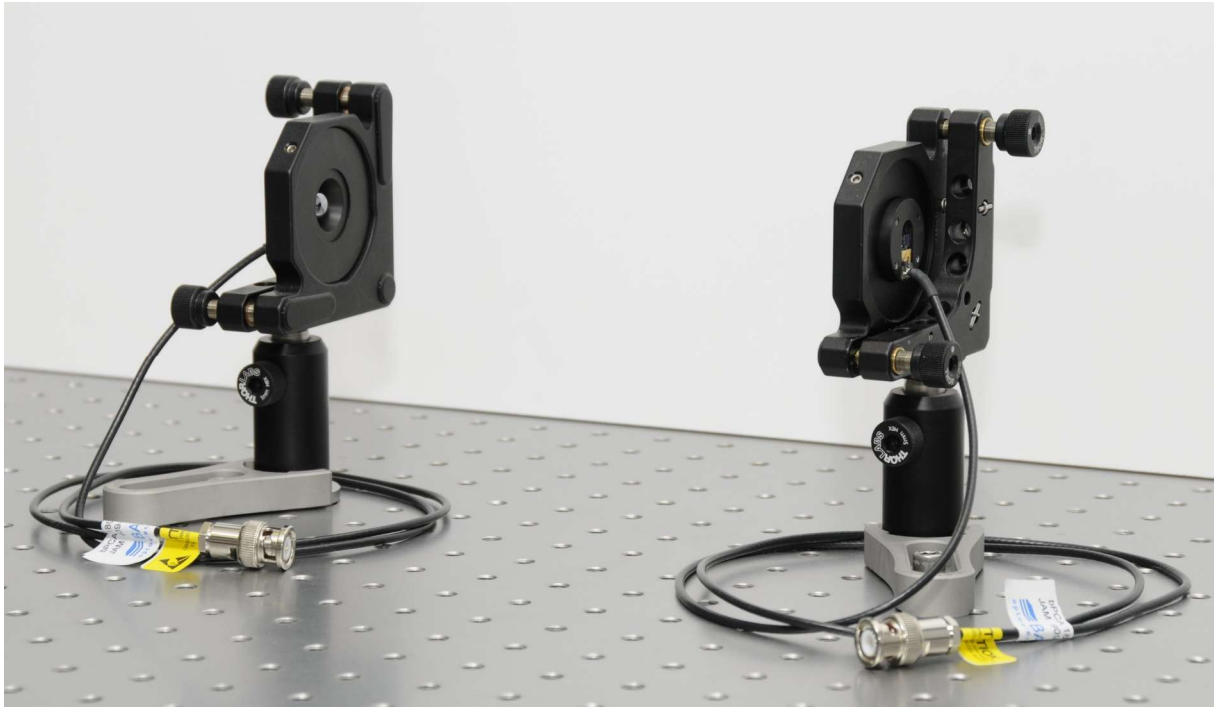


Figure 3: Set of two free space antennas setup in a transmission configuration.

In contrast, using fiber-coupled antennas gives you greater flexibility when setting up the THz beam path. You can set up the antennas independently in different configurations without the need to change the laser beam path. This makes fiber-coupled antennas an ideal choice for THz imaging.

However, there is a disadvantage compared to free space antennas. As the fiber-coupled antennas are usually mounted together with the THz lenses there are fewer degrees of freedom to optimize the THz signal. Additionally, the dispersion inside the glass fiber leads to a broadening of the laser pulse, resulting in smaller and longer THz pulse. Consequently, fiber-coupled antennas exhibit a poorer THz performance compared to free space antennas.

In order to keep the dispersion effect to a minimum we recommend using dispersion compensating fibers (at 1560 nm) or a pulse stretcher (at 1060 nm or 780 nm). Feel free to get in touch with us for more details.



Caution:

The THz antennas come with a designated maximum operating voltage and a maximum optical power. Do not exceed these limits as the antennas may otherwise be damaged permanently. Please also handle the antennas carefully as electric discharges may lead to a breakdown, creating a short circuit.

4. T3DS software package

The T3DS software allows you to record the signal of the detector antenna while the delay line changes its position in order to match the pulse propagation times of the optical and the THz beam path. The time-domain graph is updated in real time while the frequency spectrum is calculated and displayed once the measurement has been finished.

Using the software you can acquire baseline and reference data which may be used later in order to determine material properties of a chosen sample using the T3DS calculator software. The baseline and reference data will be saved together with the sample data in a single file. While the time-domain data is saved as raw data, the frequency spectra is calculated after subtracting the baseline and applying the preset window function.

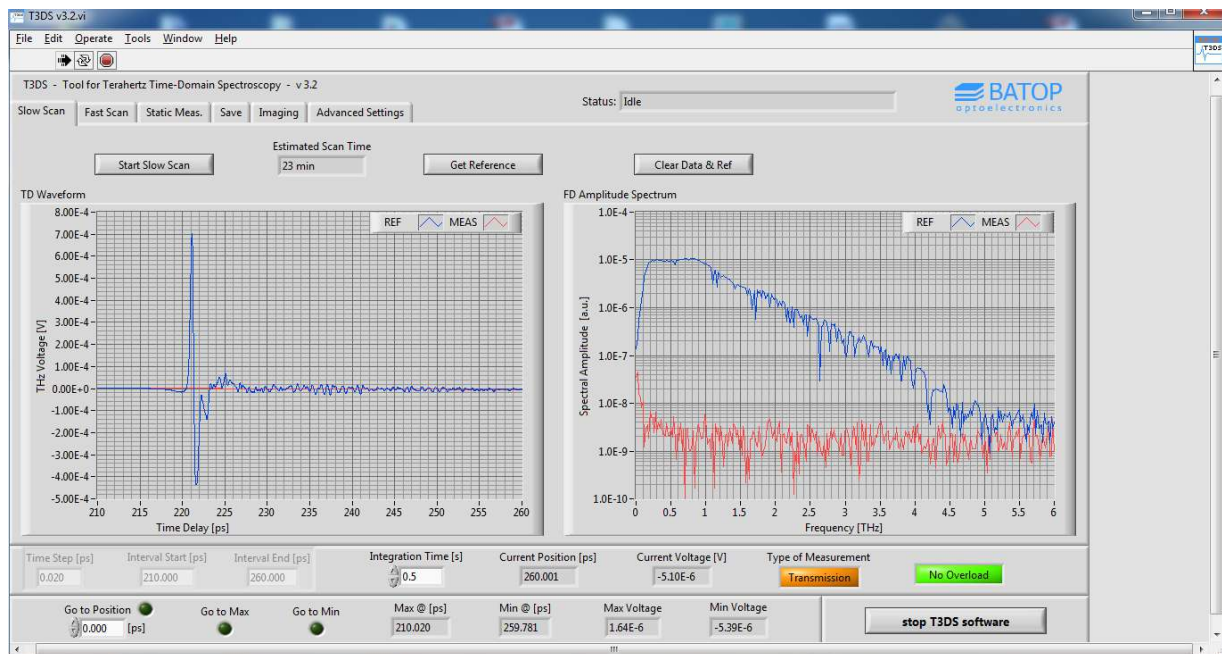


Figure 4: Front panel of the T3DS software displaying the results of a reference measurement.

When you found a first weak THz signal we suggest using the static measurement mode in order to improve the THz signal by adjusting the alignment of the optical and THz beam path. Once you are done optimizing the signal you may compare the results of a slow scan with the antenna specifications.

The T3DS software has been designed to accommodate external measurement setups. If you connect an imaging unit or a T2T setup in a daisy chain configuration to the delay line the software will automatically activate the corresponding tab on the main window upon start-up. Furthermore, the software may be used to measure a real-time THz pulse using the Fast Scan Unit. Again, this tab will be activated if the corresponding hardware has been detected upon start-up. For more details please see the manuals for the T3DS software, the Fast Scan Unit and the external measurement setups.

While the T3DS software has been designed to control the spectrometer hardware there is a separate program to calculate the material properties from the data obtained. The T3DS calculator loads the results of THz measurements and enables the user to analyze the frequency spectra in order to determine the complex refractive index. The software only requires an estimated sample thickness to get started.

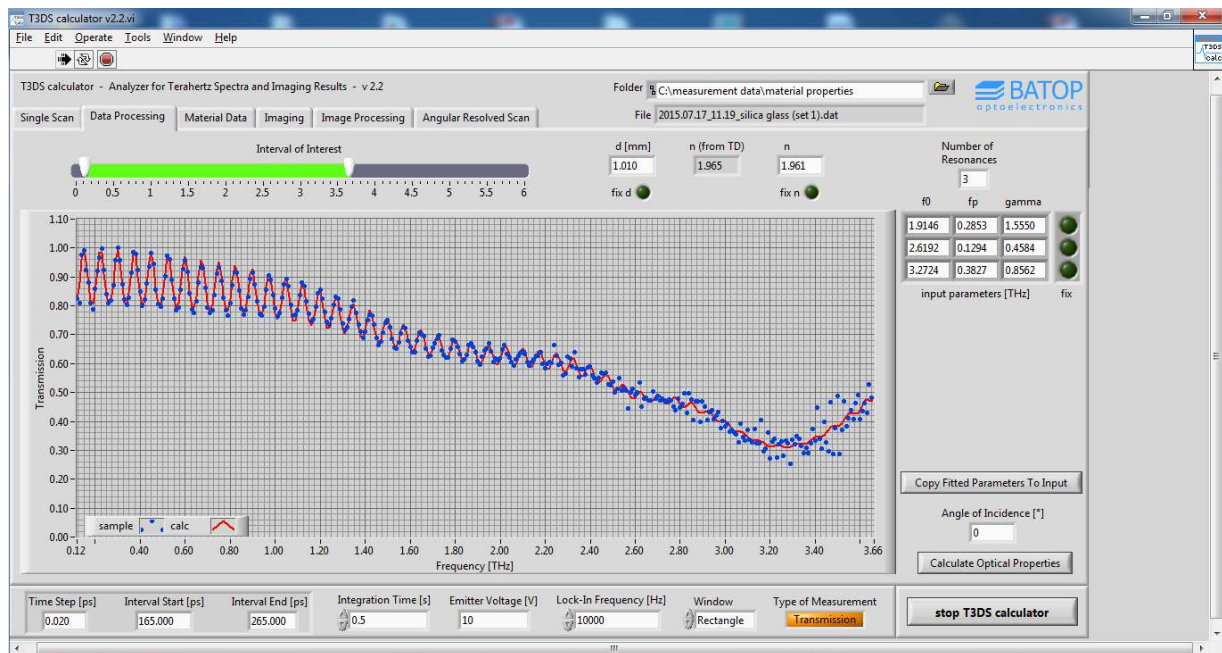


Figure 5: T3DS calculator displaying the fitted curve for a transmission measurement.

The T3DS calculator fits the sample data using a dispersion based model. After loading the data and choosing the interval of interest the user sets the number of resonances and starting points for the parameters. These values are used by the software to start with the fitting process. After the sample data has been fitted the software uses the parameters in order to calculate the real and imaginary part of the refractive index. The final data can then be saved.

Besides analyzing material properties the T3DS calculator can also be used to load the data of imaging or angular resolved measurements. The software allows the user to analyze the imaging data in detail which cannot be done during the data collection when operating the T3DS software. Additionally, the data can also be processed if the image plane was not parallel to the object plane. This is a necessary feature as the effect may otherwise complicate the interpretation of image features.

5. Basic steps to build your THz spectrometer

The THz antennas can be ordered as free space or fiber-coupled versions. Accordingly, there will be some differences in the way you build your spectrometer. However, the basic rules for setting up the optical and THz beam path are very much the same.

- Choose the configuration and placement of your antennas

Since the pulse propagation times have to add up later on it is very important to make sure that the configuration does not need to be altered. Ideally, you will plan for a focusing geometry with a focal length of about 30 mm for the THz lenses and place your antennas and collimating THz lenses accordingly. You may remove the focusing THz lenses and work with a collimated beam but by preparing the setup as described you have the possibility to add them if needed without changing the position of the antennas. This way only the time shift due to the added material has to be accounted for (typically about 25 ps for a pair of THz lenses).

- Make a first sketch of the optical path for the emitter and detector antenna

In general the optical path will start with the laser beam being fed into your setup either directly or using a collimator (depending on your laser output). In the former case we recommend using a mirror as starting point because a free space laser output will not give you the same alignment options as a fiber-coupled laser which requires a collimator by default.

The laser beam will first be split into two paths using a 50:50 beam splitter. The beam going towards the emitter antenna is to be redirected by the two mirrors on the linear stage at some point while the beam going towards the detector antenna should only be redirected by stationary mirrors. This type of setup has proven to yield a better performance than having the linear stage incorporated on the detector beam path. It was found that the stability of the illumination of the detector antenna is more important than for the emitter antenna.

- Setting up a preliminary version of your spectrometer according to your sketch

Set up the laser and the optical elements as planned and measure the length of the laser beam path for both antennas, starting at the beam splitter. Make sure to position the linear stage at around 25 mm of its travel length using the manual knob. Add the length of the THz path to the laser beam path of the emitter antenna and try to match it with the length of the laser beam path for the detector antenna.

Remember to account for the GaAs chips of the antennas (0.6 mm each), the two silicon lenses (each 7 mm thick) and the collimating / focusing THz lenses (TPX, 8 mm per lens) when calculating the THz path length. These elements add about 40 mm to the measured THz path in air. Note, that in case you need to change the laser beam path length it is usually easier to modify the part for the detector antenna (because there are not moving parts).

If you use a fiber-coupled setup it is very easy to adapt your configuration as you basically just need to reposition the collimators needed to get the laser pulse into the fibers of your antennas. For a free space setup you have to bear in mind that the THz beam and the laser beam should ideally be collinear. Hence, the last mirrors to redirect the two laser beams and the antennas have to be in one line (see Figure 7). Therefore, you are less flexible when it comes to repositioning optical elements.

If you have chosen to work with fiber-coupled antennas it is very common to have the antennas mounted in lens tubes together with the collimating THz lenses. The focusing lenses may then be attached to these lens tubes, resulting in a very compact setup with few alignment options. Because of the fixed distance between the focusing lenses (60 mm) there is a preset distance between the THz antennas. Hence, the THz path “T” for fiber-coupled antennas is typically 210 mm (in air) when setting up the antennas with the standard focusing THz lenses.

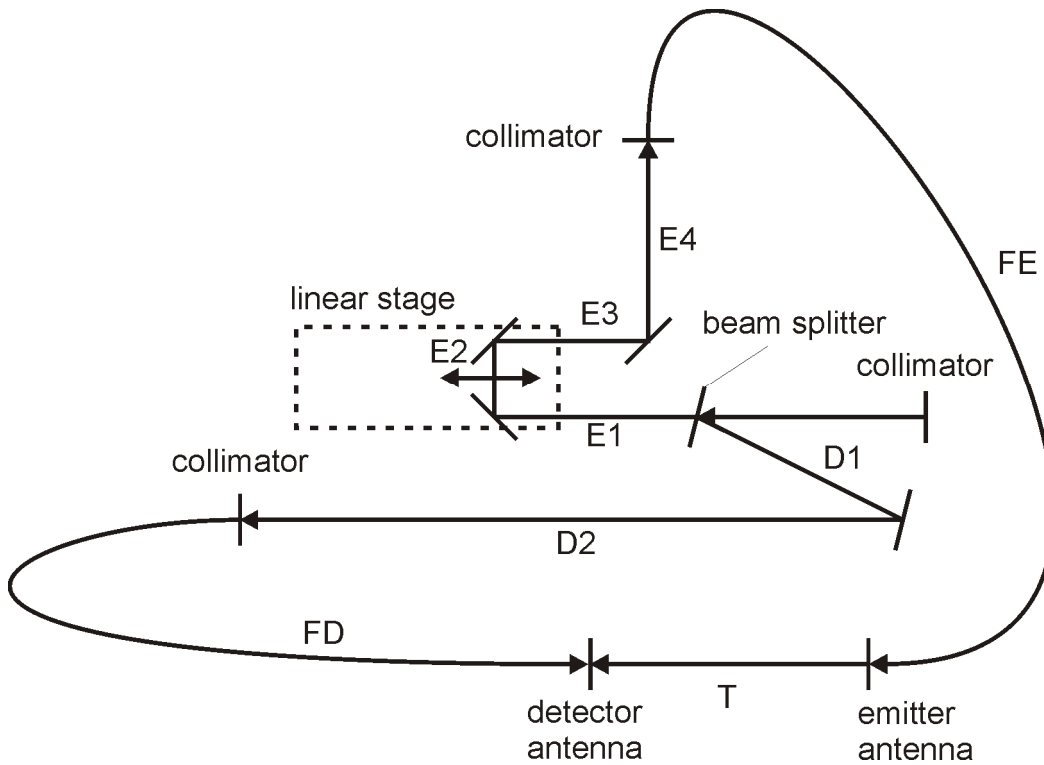


Figure 6: Exemplary setup of a THz time-domain system with fiber-coupled antennas.

According to Figure 6 the path lengths of the fiber-coupled setup have to meet the following criteria:

$$D_1 + D_2 + F_D = E_1 + E_2 + E_3 + E_4 + F_E + T ,$$

with D_i and E_j being the lengths of the free space laser beam paths, F_D and F_E being the lengths of the fibers (multiplied by 1.5 because of the refractive index of glass) and T being the length of the THz path.

The formula looks slightly different for a system with free space antennas. According to Figure 7 the path lengths now have to meet the following criteria:

$$D_1 + D_2 + D_3 = E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + T ,$$

with D_i and E_j being the lengths of the free space laser beam paths and T being the length of the THz beam path.

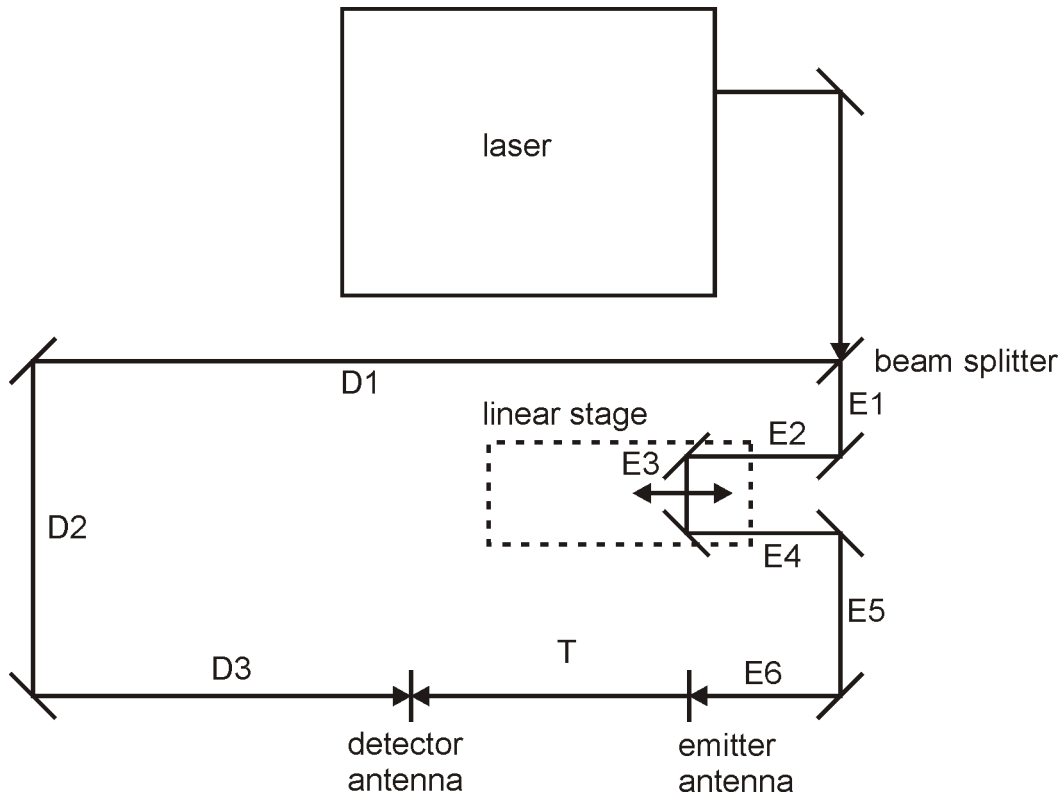


Figure 7: Exemplary setup of a THz time-domain system with free space antennas.

- Aligning your optical path

First off, take out all the optical elements but the one that is used to couple in the laser beam. It is crucial that the laser beam is as parallel as possible to the optical table and that it remains that way all throughout your spectrometer. Hence, start with the collimator / first mirror and take good care of the correct height by dialing in with an aperture that will then be used for the rest of the setup. After this step put in the beam splitter, check the height and the power level on both beams. If the powers are too high you may use a neutral density filter before the beam splitter in order to dial them down.

While adjusting the stationary mirrors is very straight forward you have to take great care with the alignment of the mirrors on the linear stage. At first you need to align the height of the incoming beam that crosses the delay line. Then, try to get the laser beam to run parallel to the movement direction of the stage. As a next step you need to attach a second aperture to the delay line (as the other one is still designated for a fixed height above the optical table). This aperture needs to be optimized vertically as well as horizontally. Once the correct height has been determined it will not be changed again.

In order to get a perfect alignment of the laser beam and the movement direction of the delay line you now have to optimize the horizontal alignment of the laser beam. In order to do so the linear stage is moved back and forth. At the home position of the stage the x-axes of the mirror before the stage is being optimized in order to get the highest power reading. In contrast, at the end position of the stage the horizontal position of the aperture has to be tuned. This is an iterative process that can take some time. If you are successful the power of the laser beam behind the aperture will change less than 5 % while the stage is moved from start to end. Please note that most of the changes occur at the first and last centimeter of the stage.

Once the beam entering the stage has been aligned correctly put the first mirror on the stage, deflect the beam by 90° and check the height of the reflected beam. Afterwards put in mirror number two, deflect the beam by 90° and check the height of the reflected beam again. Now use the standard aperture, move the stage back and forth and try to get the power reading as stable as possible. Again, this is achieved by repositioning the aperture and changing the horizontal orientation of the mirror. The goal is to have less than 10 % change in the power reading behind the aperture during stage movement (most of that close within the first / last centimeter).

In case you use free space antennas the final adjustment is about the two laser beams being directed towards the antennas. Start with the antennas and THz lenses being removed (just leave the posts on the table). Block one of the beams before it hits the last mirror and align the other beam to match the positions of the THz antennas. Once this is done block the other beam and repeat this procedure. As a result, the two beams should be almost collinear.

- Final check of the path lengths and last adjustment

Now that all optical elements have been put into place move the delay line back to the position at around 25 mm of its travel length and measure the length of the optical paths for both antennas. Add the length of the THz path to the result for the emitter antenna and compare it to the length of the optical path of the detector antenna. If the difference is within 1–2 cm you are good to go. If not we recommend repositioning mirrors on the beam path for the detector antenna and realigning the beam using the same procedure as before. In case of fiber-coupled antennas you can simply change the position of the collimators.

- Illuminating the antennas

Depending on your antennas you have to either couple the light back into the collimators or focus the laser light onto the free space antennas.

In the former case we advise you to use a single mode fiber connecting the collimator with the power meter. Ideally, the fiber is of the same type as the one attached to the antenna (same mode field diameter). You need to adjust the alignment of the collimator and the last mirror in order to optimize the coupling. We recommend beginning with a multi mode fiber in order to get a good starting point for the single mode fiber.

Once the power has been optimized with the single mode fiber, dial the power level to the recommended value using the attenuator, hook up the antenna and watch for the resistance to drop upon illumination. You may need to realign the collimator and last mirror since there is likely to be a small change in orientation compared to the adapter fiber. Aim for a low antenna resistance as it indicates a high illumination.

For free space antennas you have to first do a coarse positioning of the antennas in terms of height and xy-position. Afterwards adjust the orientation to make sure that the antenna chip is perpendicular to the incoming light (you may need an IR viewer). Next, you can put in the optical lenses to focus the laser beam. Make sure to choose the correct focal length in order to get a spot that is roughly the size of the antenna gap (6-7 μm for a 5 μm x 10 μm gap).



Caution:

When choosing the focal length and optical power make sure that the pulse fluence of the laser spot does not exceed the antenna specifications (see data sheet)!

- Looking for a THz signal

Once you are done with the optical alignment put in the collimating THz lenses (in case of free space antennas), hook up your delay line and the data acquisition system to the computer / power supply and start the T3DS software. Scan the whole range from 0 to 650 ps using a reasonable step width (compare with the data of the antennas) and a short integration time (e.g. 0.05 s). Once you have found a signal go to the maximum / minimum and proceed as described in the software and spectrometer manual to optimize the THz signal.

Once the frequency spectrum matches the specifications you have successfully set up your THz time-domain spectrometer.



Attention:

If you're using fiber-coupled antennas you'll need to take care of the dispersion that occurs inside the optical fiber. Otherwise the performance of your THz antennas may be limited by a broadened laser pulse. You may want to check with us if you have questions concerning dispersion compensation.

6. Contact details

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

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