



**Rigel 1550
Terahertz
Spectrometer**

User Manual

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System Description

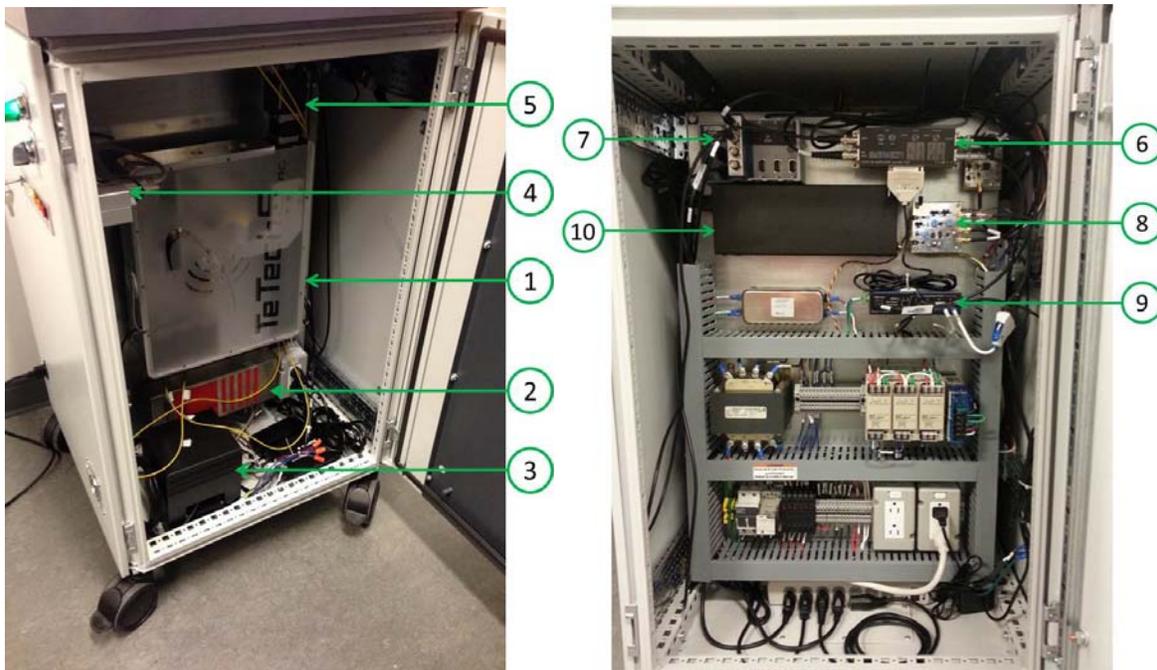
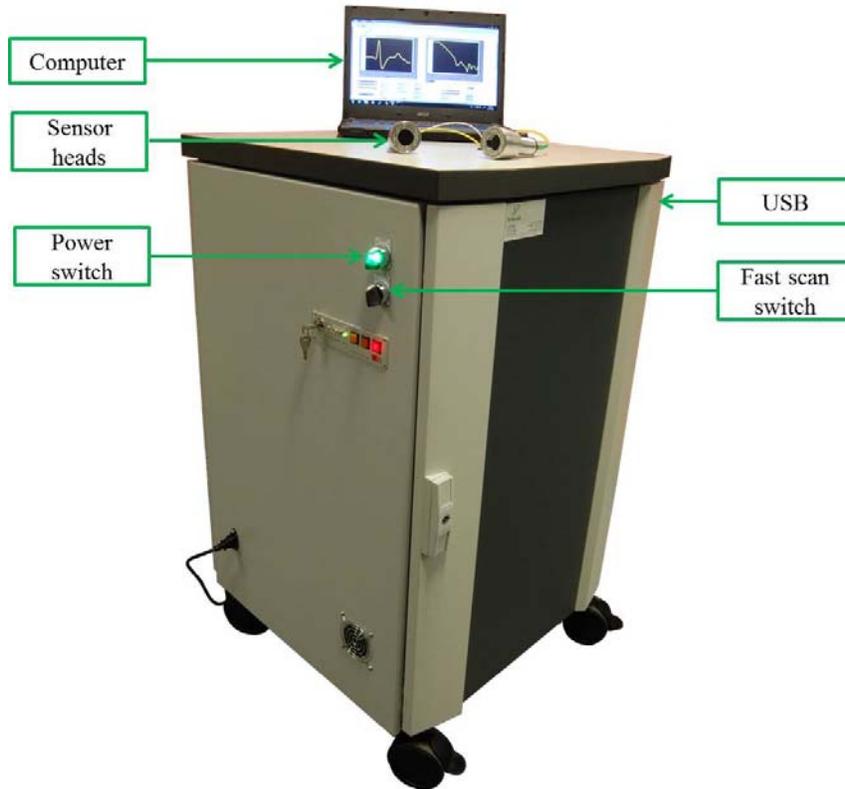
Overview

The Rigel 1550 Spectrometer is a versatile instrument operating in the terahertz range. Rigel 1550 spectrometer is a portable, modular, compact, and reconfigurable terahertz time-domain spectrometer system capable of testing solid, powder, thin film, gas, and liquid samples for material sensing and characterization applications. The fiber coupled movable transmitter and receiver heads can be mounted around the sample or process under test, for the cases where bringing the sample or process under test inside the spectrometer housing is not feasible. The terahertz transmitter and detectors are driven by a Femtosecond fiber laser at 1550 nm.

Part Names

Figure 1 shows the main components of the front and back of Rigel 1550 terahertz spectrometer.

1. Optical Delay module
2. Onefive ORIGAMI Femtosecond Laser
3. Shaker electronic controller
4. Laser driver
5. Linear stage for slow scan
6. Lock-in amplifier
7. NI DAQ for data acquisition
8. Square wave generator
9. USB Hub
10. Shaker power supply



(a)

(b)

Figure 1 Main features of Rigel 1550 Terahertz spectrometer: (a) Front panel and (b) Back panel.

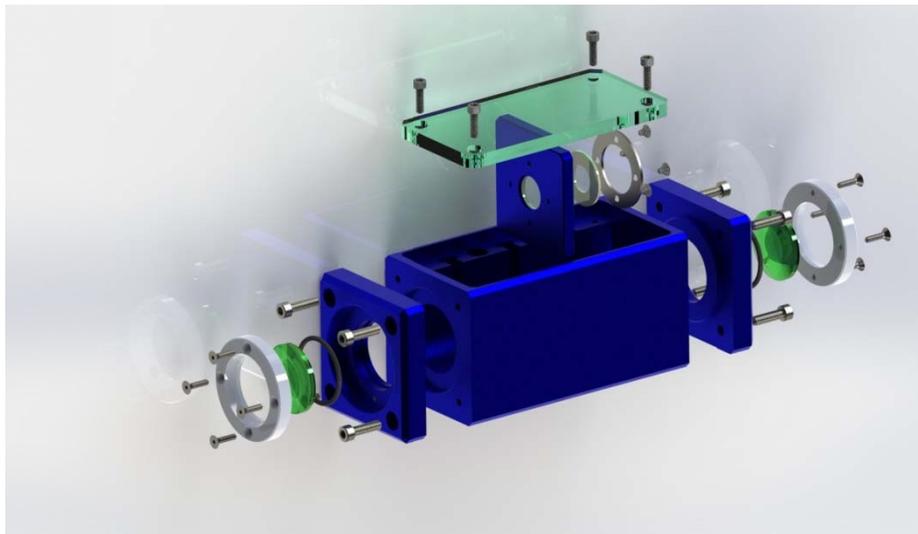
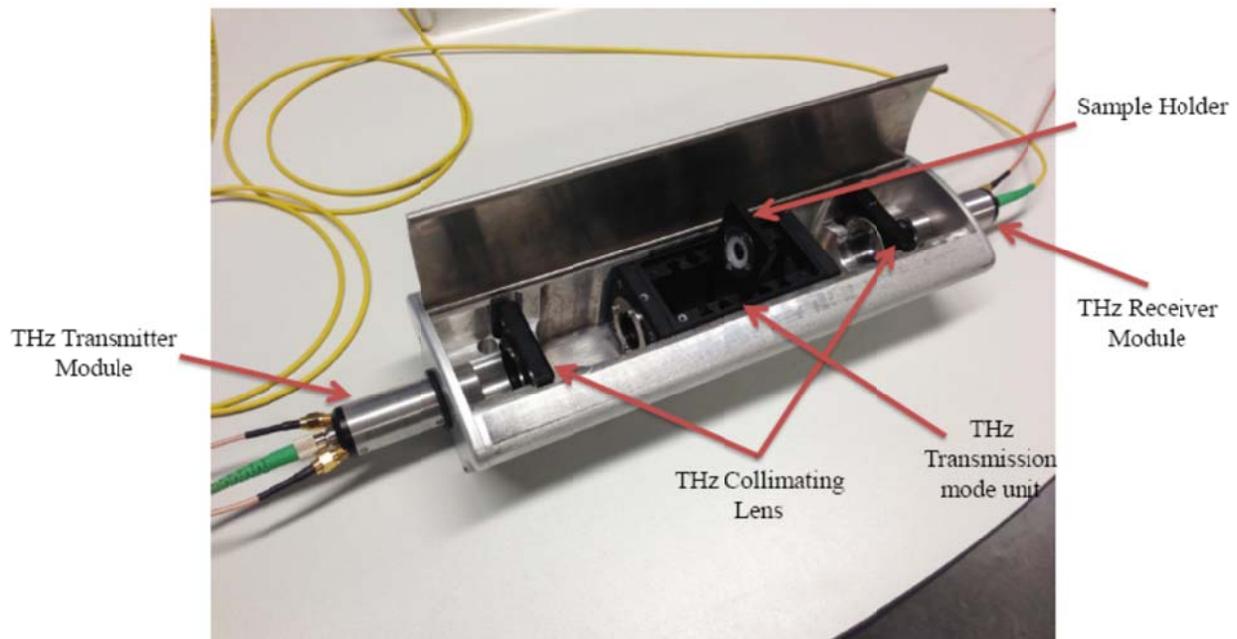
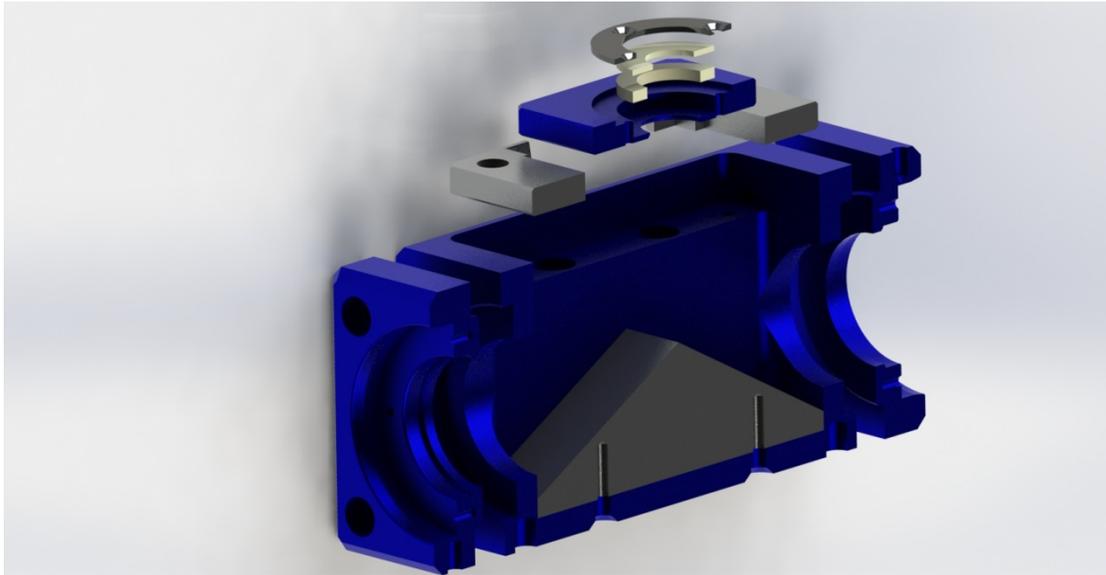
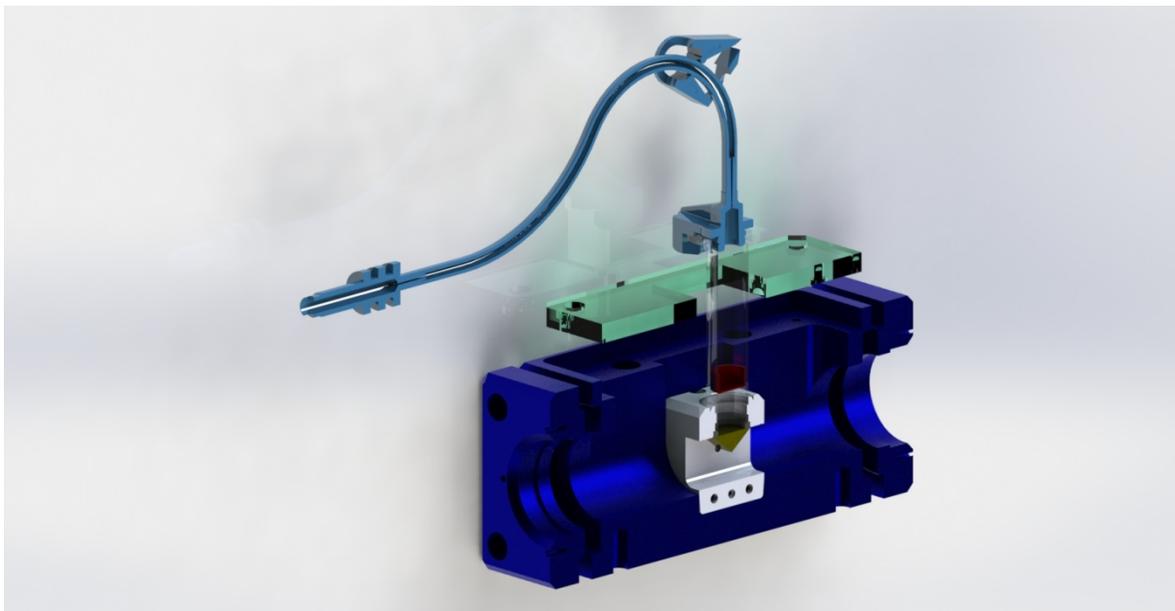


Figure 2 Rigel 1550 Spectrometer Head for Transmission-mode THz-Time domain Spectroscopy (TDS).

Rigel 1550 spectrometer has optical light delivery system that includes an optical delay box for slow and fast terahertz scan. The slow scan can be used to find the THz signal peak and scan over longer ranges, longer distance between transmitter and receiver with less noise or high signal to noise ratio. The fast scan option allows for almost real-time measurement of changes when a sample is placed in the THz transmission mode unit or the user puts in the THz transmitter and receiver modules in the path of a process outside the spectrometer head.



(a)



(b)

Figure 3 Rigel 1550 Spectrometer Head for (a) Reflection-mode and (b)ATR THz-Time domain Spectroscopy (TDS).

Operating Conditions

Electrical requirements: 100-240 V; 50-60 Hz, <5 A

Operating temperature: 15 - 35°C

Storage temperature: -15° - 65°C

Humidity: < 50%

Warm-up time: 10 minutes for laser emission

Start-up Procedure

CAUTION *Do not turn the power to the instrument on and off quickly as this may cause damage to the units and power supply*

1. Open the sample compartment spectrometer head and make sure there is no sample in sample holder and place sample holder in the center.
2. Make sure the THz Beam path between transmitter and receiver modules is free from obstructed.
3. Connect the power supply, the fiber optic cable for the Transmitter (Blue) and the other to the receiver (Red), one SMA connection labeled Tx to the Transmitter and the other SMA connection to the output from the receiver module.
4. Connect the USB from your Laptop or computer to the USB connection on side of the spectrometer cabinet for electrical components.
5. Turn the **FAST SCAN OFF** and **POWER ON** and green light comes on and the spectrometer is ready for use.

6. Turn the key for the laser to **On** position and wait till the status LED stops blinking and has stable green light. Then press **Emission** button until it turns red light.



7. Wait until Windows recognizes the instruments and initialization is complete.
8. Run the *Rigel 1550 Spectrometer Software* to do a scan and find the THz peak signal before fast scan or simply conduct a slow THz scan using the spectrometer.

Safety

Laser Safety

Rigel 1550 spectrometer transmitter and receiver are driven by Fiber-coupled femtosecond laser from Onefive. Onefive's ORIGAMI is a Class 3B laser. If user opens optical delay module, direct and mirror reflected high-peak-power, invisible light pulses can be hazardous to eyes. If fiber is disconnected or the optical delay module open, the laser power emitted by the ORIGAMI may cause retinal or corneal damage. The skin of the human body can severely be damaged when exposed to the radiation. Therefore, extreme care should be exercised during laser operation. User does not need to eye-wear during normal operation of the Rigel 1550 THz spectrometer.

Direct exposure of the eye to the invisible laser beam must be avoided.



DANGER
AVOID EYE AND SKIN EXPOSURE TO LASER RADIATION
RADIATION OF THE ORIGAMI IS INVISIBLE AND IN FIBER AND
DO NOT DISCONNECT THE TX AND RX FIBERS.

Electrical Hazards

The Rigel 1550 spectrometer contain electrical circuits, devices and components operating at high voltages. Contact with these circuits, devices and components can cause death, serious injury, or painful electrical shock. Good grounding is essential to avoid a potentially serious electric shock hazard. Application of the wrong supply voltage can create a fire hazard and potentially serious shock hazard, and could seriously damage the Rigel 1550 spectrometer system, and any attached equipment.

CAUTION Do NOT use power cords with faulty or frayed insulation.

CE compliance

The Rigel 1550 spectrometer and sensor heads have been designed to comply with the requirements of the Electromagnetic Compatibility (EMC) Directive and the Low Voltage Directive or LVD of the European Union.

Installation

How to Install Sensors heads and connect to Spectrometer

WARNING *Do not disconnect the fiber and MMCX cable from the Rx and Tx sensor heads.*

1. The Transmitter and Receiver sensor heads come disconnected from the chassis of the Spectrometer. Both the optical fiber and electrical SMA connector must be connected during installation process.
2. Connect the Tx fiber (labeled as Tx) with one end already connected to the sensor to the collimator output (labeled Tx) on the chassis after passing the fiber through the hole on the top of spectrometer. The Tx is the middle Fiber output to the right of the Rx Fiber output.
3. Connect the Rx fiber (labeled as Rx) with one end already connected to the sensor to the collimator output (labeled Rx) on the chassis after passing the fiber through the hole on the top of spectrometer.
4. Connect the MMCX to SMA connector on Transmitter sensor to SMA cable from spectrometer electrical connections label Tx. The Tx and Rx output SMA cables pass through the hole at the top of the spectrometer.
5. Connect the MMCX to SMA connector on Receiver sensor to SMA cable from spectrometer electrical connections label Rx output.

How to Restore Terahertz Signal

CAUTION *The Transmitter and Receiver can be placed around any process under test or on optical breadboard but the shortest or minimum distance between the Tx sensor lens to Rx sensor lens is 17 cm. One can increase the distance between the sensor heads up to a distance of 47 cm. Ensure the polarization of the Tx and Rx sensor is correct by lining up the markers on the end-caps of the sensors.*

1. Place the transmitter and receiver sensor heads in optical view of each other. The Tx and Rx should be on the same level vertically and horizontally. The user has the option of placing the transmitter and receiver sensor heads around process or material under test but a breadboard is also provided for mounting the Tx and Rx on post.

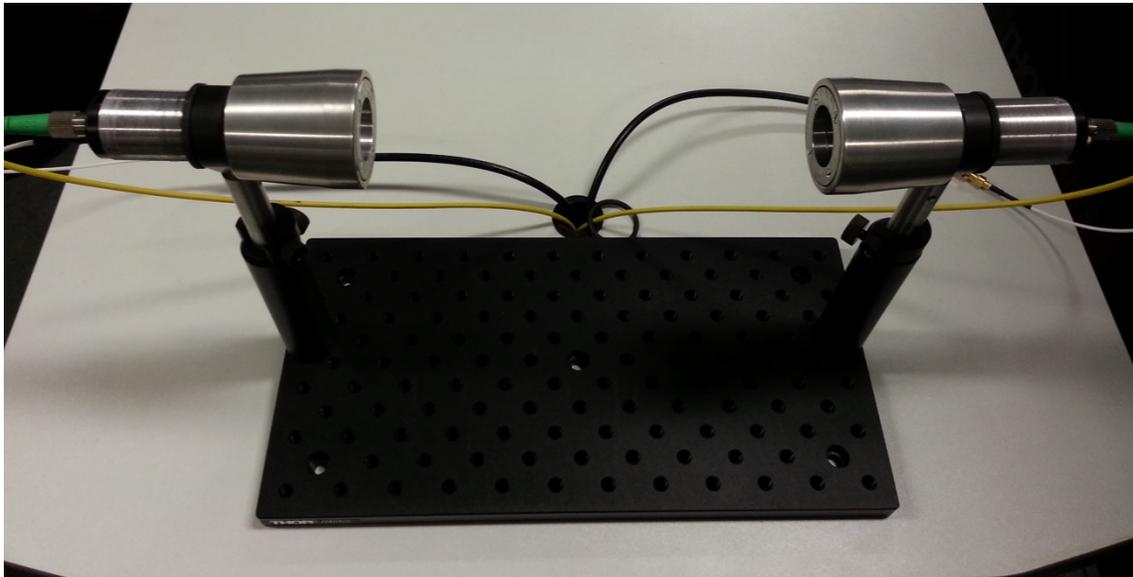


Figure 4 Rigel 1550 Terahertz Spectrometer Sensor Heads.

2. Conduct a **long THz scan** using **Rigel 1550 Software** by setting motor speed to 0.5 mm/s and scan range from 0 to 20mm. Follow the instructions on **Running Rigel 1550 Spectrometer Software** to conduct slow THz scan. If you do not find the THz peak and signal in this range change the delay in increments of 20 mm (from 20 mm to 40 mm) until you find the right delay for the THz peak.

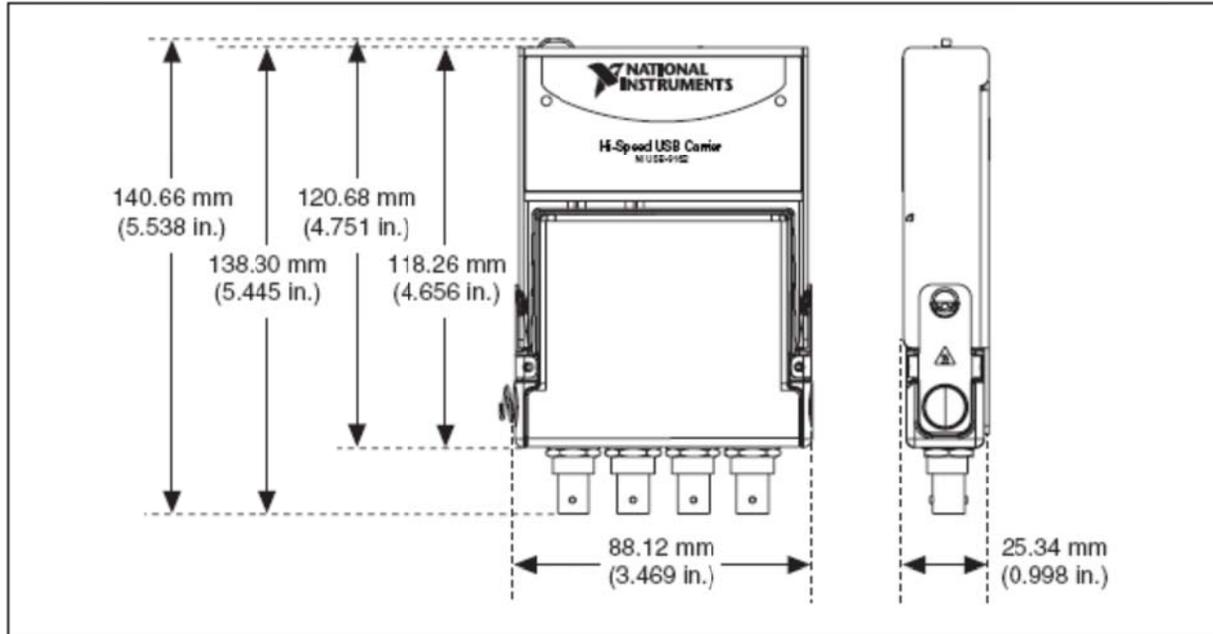
3. Once the THz signal is obtained on the time domain graph, the software automatically finds the THz peak and goes to the optical delay position for that THz peak.
4. The next step involves the maximizing the THz peak signal. In order to do that launch **Show Peak THz Signal** application that shows the signal level in *real-time* for the current delay position.
5. To improve the alignment the Tx and Rx sensor heads should be tilted along y-axis (z-axis being optical axis) one by one to maximize signal ensuring the polarization is the same. The direction of the enclosure of the Tx and Rx antenna must be changed along the plane made by the marker for the polarization and the optical axis.
6. Then change the delay, after adjustment and changing the direction of the antennas, to maximize the THz signal reading. The delay can be changed by entering the position in mm for start position and going there by clicking **GO START POSITION**. The new position should be close to the peak position.
7. Repeat process by doing Steps 6 and 7 for finer alignment and should get a value for THz signal around 6.

Data Acquisition for Fast Scan

The Rigel 1550 terahertz (THz) Spectrometer has fast scan option for conducting fast scan with setting of 1 Hz or one waveform per second. The waveform scan length is 50 ps and step size is 50 fs. By selecting the **Fast Scan** button and clicking **START SCAN** button in Rigel 1550 spectrometer software followed by turning on the **FAST SCAN switch** on the cabinet for the electronic housing one can do fast scan.

CAUTION *Before selecting the Fast Scan option make sure the lock-in setting in the Rigel 1550 Spectrometer software is set to sensitivity of High Dynamic mode and with 12 dB/Oct filter setting and time constant of 3 ms. The display range scaling should be the value of the sensitivity for example 1E-3 for 1 mV gain setting.*

For continuous real-time fast scan and data acquisition (DAQ) after doing one fast scan in main window of Rigel 1550 spectrometer software and switching on the **FAST SCAN switch** on the cabinet of the electronic housing run the **DAQ FAST Real-time** program. The **DAQ FAST Real-time** use a data acquisition of the analog THz signal from lock-in amplifier with a sampling rate of 20 kSamples/second on each channel and is used in acquiring one waveform per second and displaying the terahertz signal and spectrum. The DAQ has capability to go up to 100 kS/s per channel. The spectrometer comes with 4 slots for use of DAQ and is extendable for an array of terahertz transmitter and receiver modules. This is advantageous for industrial applications where an array of fiber-coupled terahertz transmitter and receiver sensor pairs are used to inspect an industrial process and the data is acquired in parallel. The **DAQ FAST Real-time** allows for any change in the path of the terahertz beam between transmitter and receiver such as putting a plastic or paper sample or any material to be observable in the delay of the terahertz signal, change in the amplitude of the THz signal and spectrum of the THz signal.



National Instruments DAQ that can be used by Rigel 1550 Spectrometer software

Installing Drivers for the DAQ and Rigel 1550 Spectrometer Software

For Rigel 1550 Spectrometer Application (Rigel.exe) to work properly the user has to install the **Labview Run –Time 8.5** and **NI-DAQmx Device Driver 9.3** on your computer or Laptop.

To install the Labview Run-Time 8.5:

1. Download the installation from the National Instruments (NI) website at <http://www.ni.com/downloads/>
2. Run the application and follow the instructions.

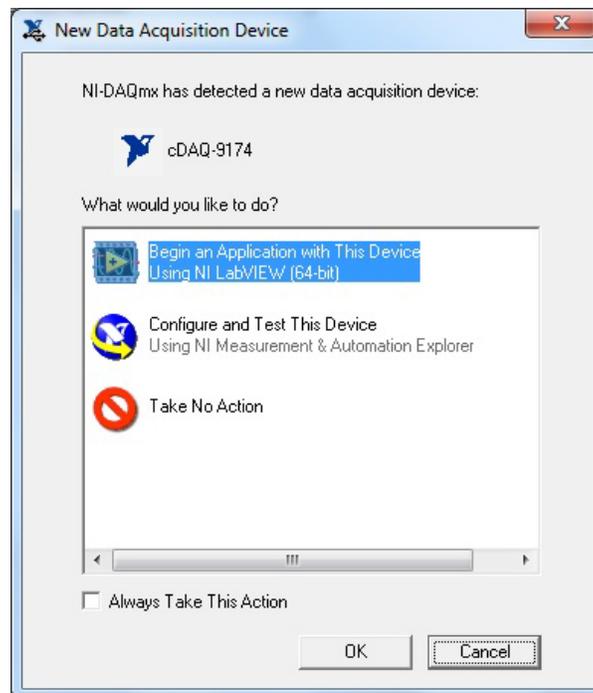
To install the NI-DAQ driver version 9.3

1. If you have other versions of the NI-DAQ on your computer, remove it and install the NI-DAQ driver by running the **NIDAQ930f2.exe** that comes with Rigel 1550 Spectrometer and Rigel 1550 Real-Time terahertz signal acquisition tool.
2. Follow the instructions for the installation of the driver for the DAQ.

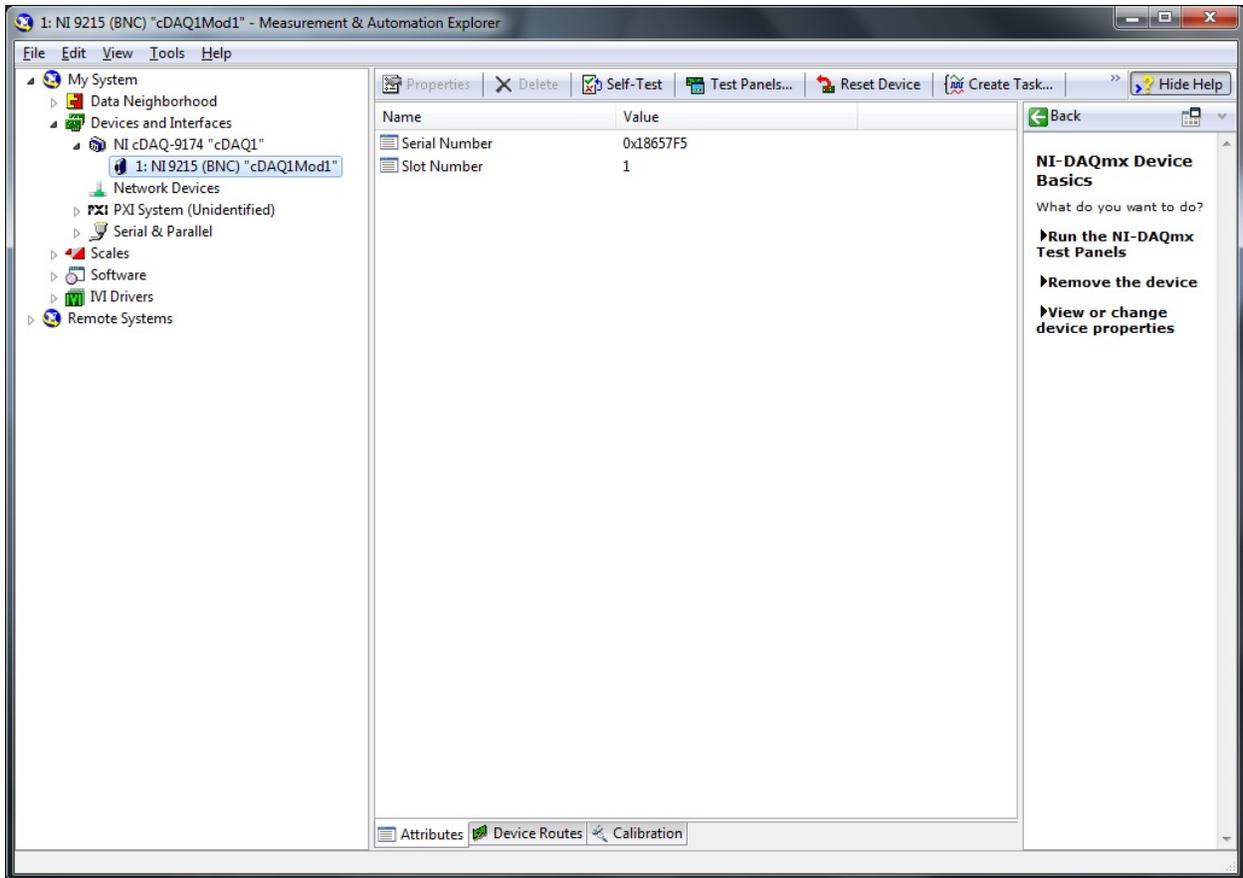
Running Rigel 1550 Spectrometer Software

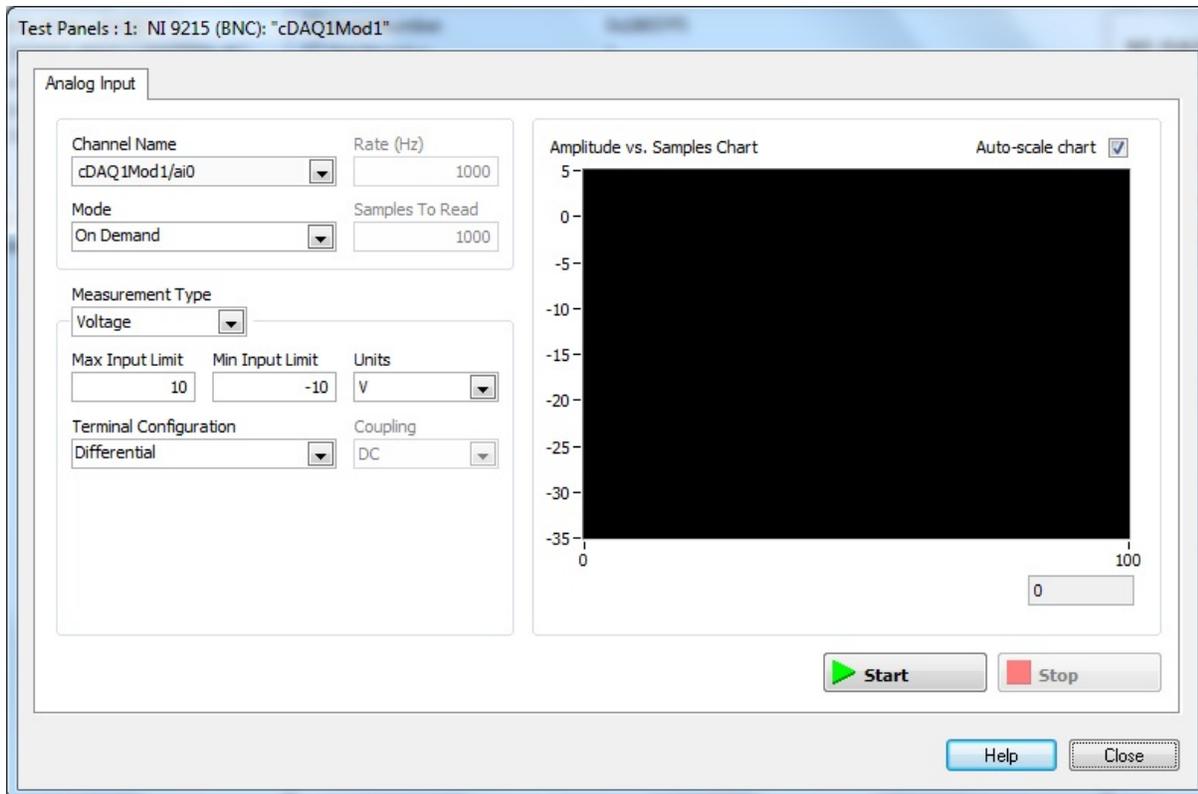
After installing the drivers, connect the USB cable to the Laptop or computer and the operating system will detect the 4 devices connected using the USB cable. The cDAQ-9174 should be detected and the NI 9125 connected to it. The other three devices are the lock-in amplifier, Linear stage for the slow scan and shaker controller for the Fast scan.

1. Before running **Rigel.exe** to launch Rigel 1550 spectrometer software make sure the DAQ is connected and run a test using Measurement & Automation Explorer (NI MAX) to make sure the DAQ is connected. Select *Configure and Test This Device* below.

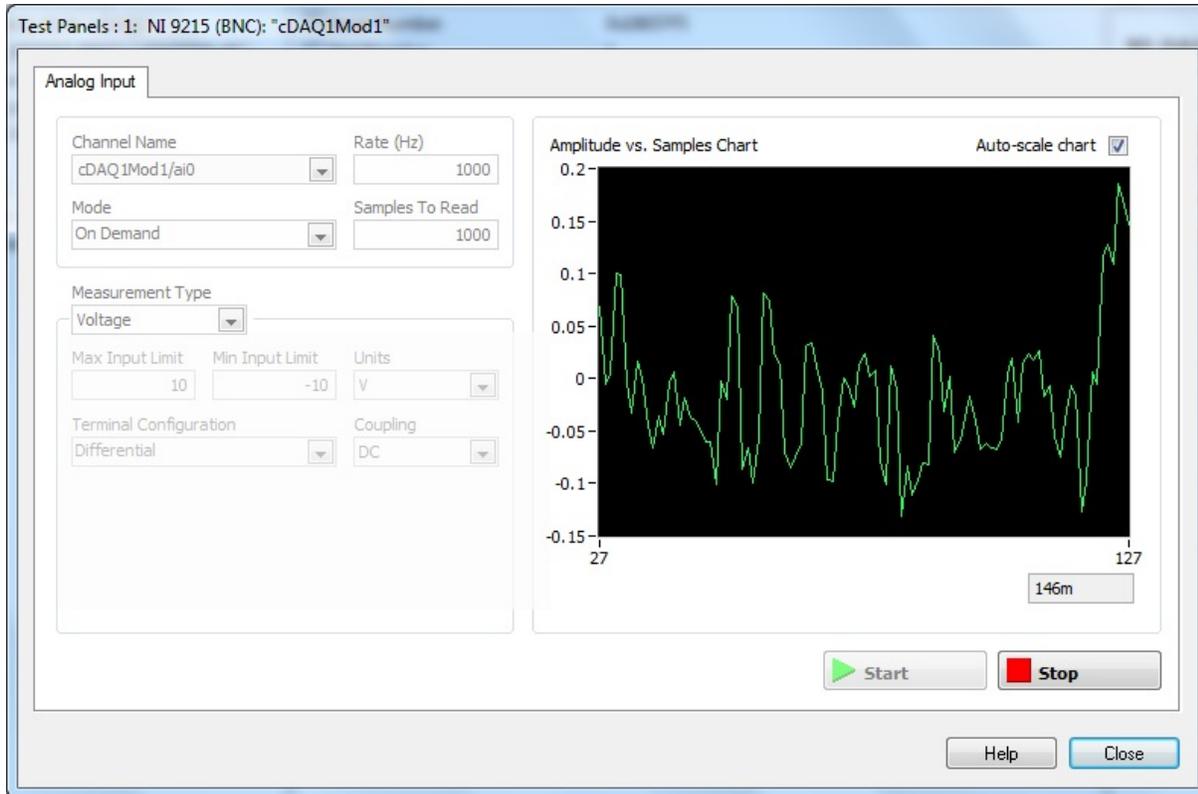


2. Right click on the NI 9125 (BNC) that is highlighted and run **Self-Test** and the program returns a message saying “The device passed the self-test”. The click on **Test Panels** at the top of the window and you should see the screen below:



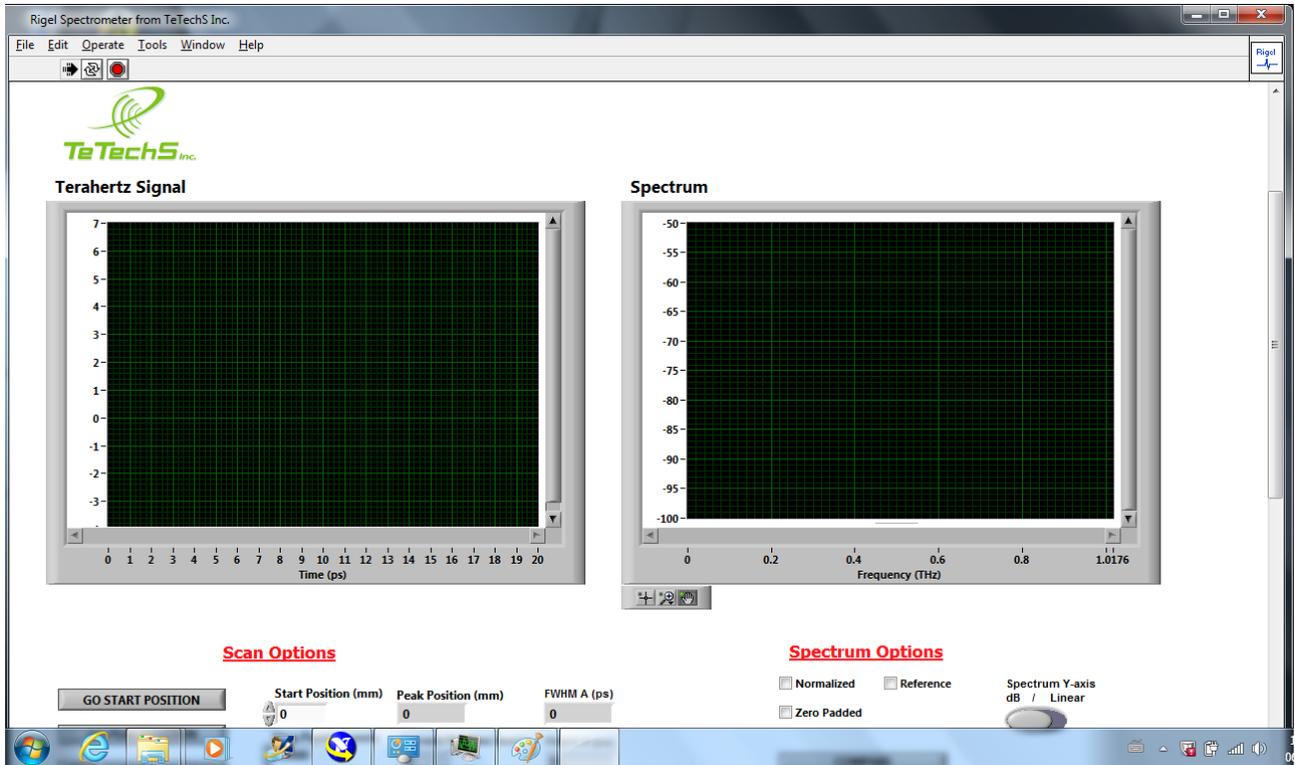


3. Click **Start** to run the DAQ and make sure there is a signal on the screen then click on **Stop** then **Close**. Now DAQ is ready to use in Rigel 1550. Note: Make sure the name of the Channel is as shown on the screen image above.

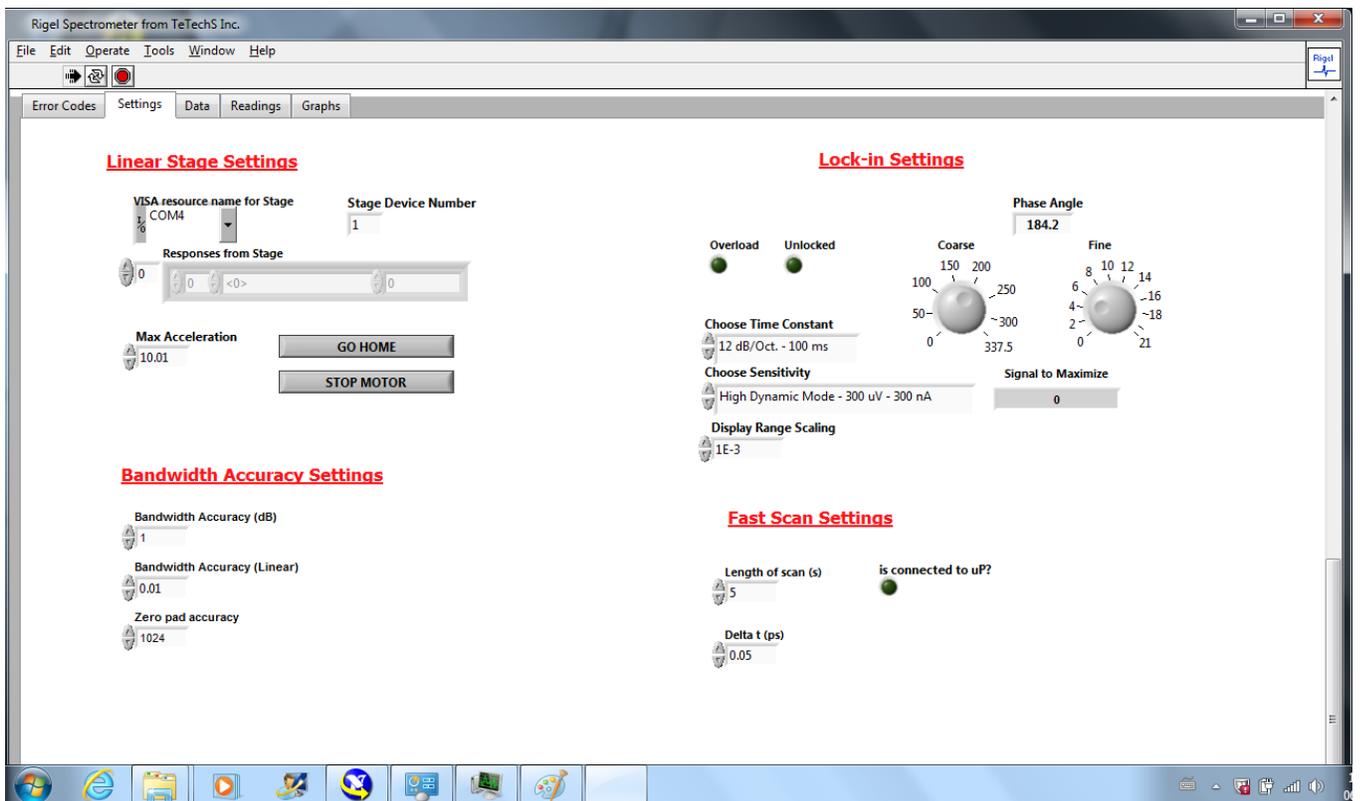


Launch Rigel

1. Run **Rigel.exe** from the Rigel 1550 Spectrometer folder.
2. Adjust the screen to fit window of your Laptop or Computer.

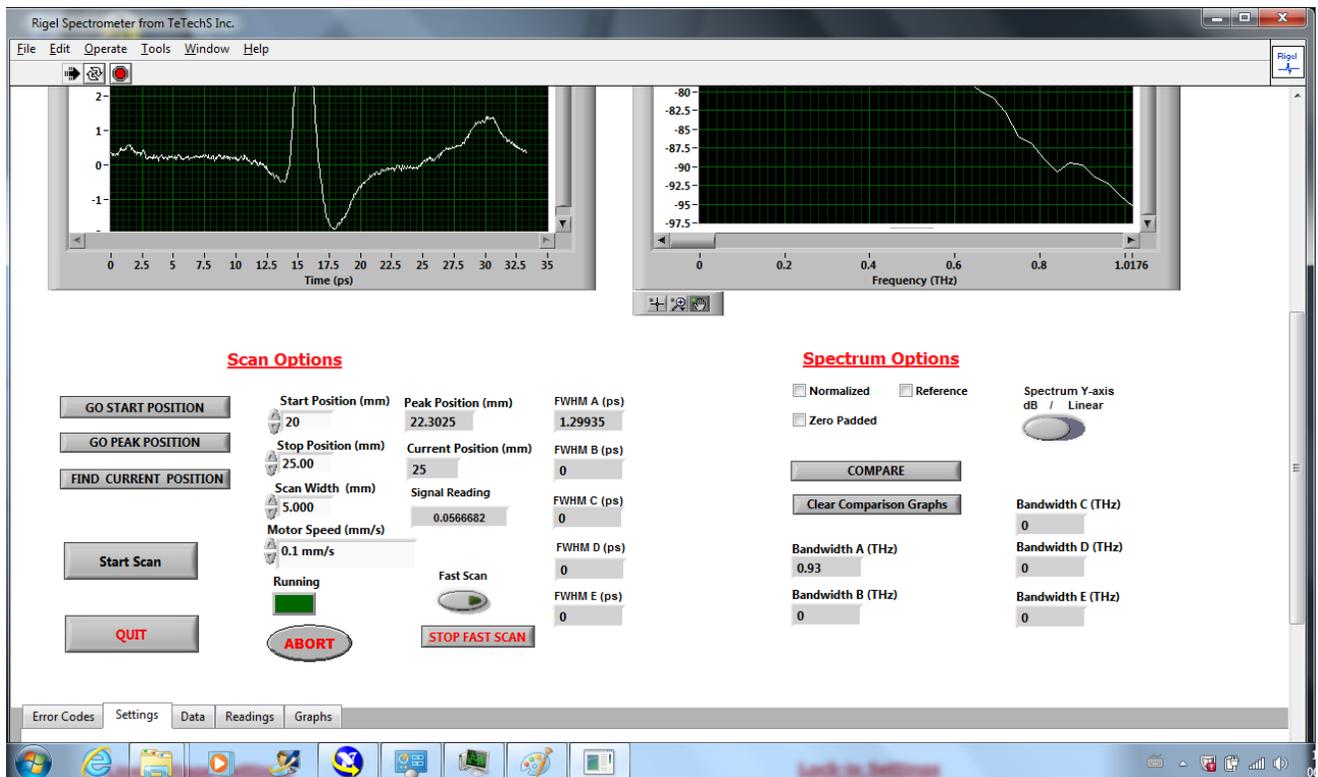


3. Scroll down to screen with Tabs and select **Settings** Tab. The **Lock-in Settings**, **Linear Stage settings** and **Fast Scan settings** are as shown below:



The setting for the lock-in **Time constant** is 100 ms and the **Sensitivity** is 300 μV . For the fast scan and other normal scans the **Delta t** or time resolution of the scan is 50 fs or 0.05 ps.

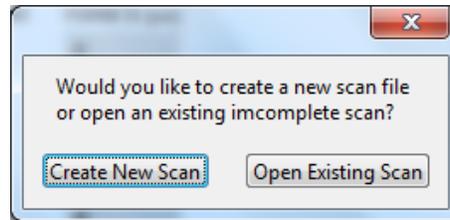
4. Click on **GO HOME**.
5. Under **Scan Options** after scrolling up enter the **Start Position** in mm, **Scan Width** in mm and **Motor speed** in mm/s for the normal scan. The Stop position is automatically calculated so it does not have to be entered.



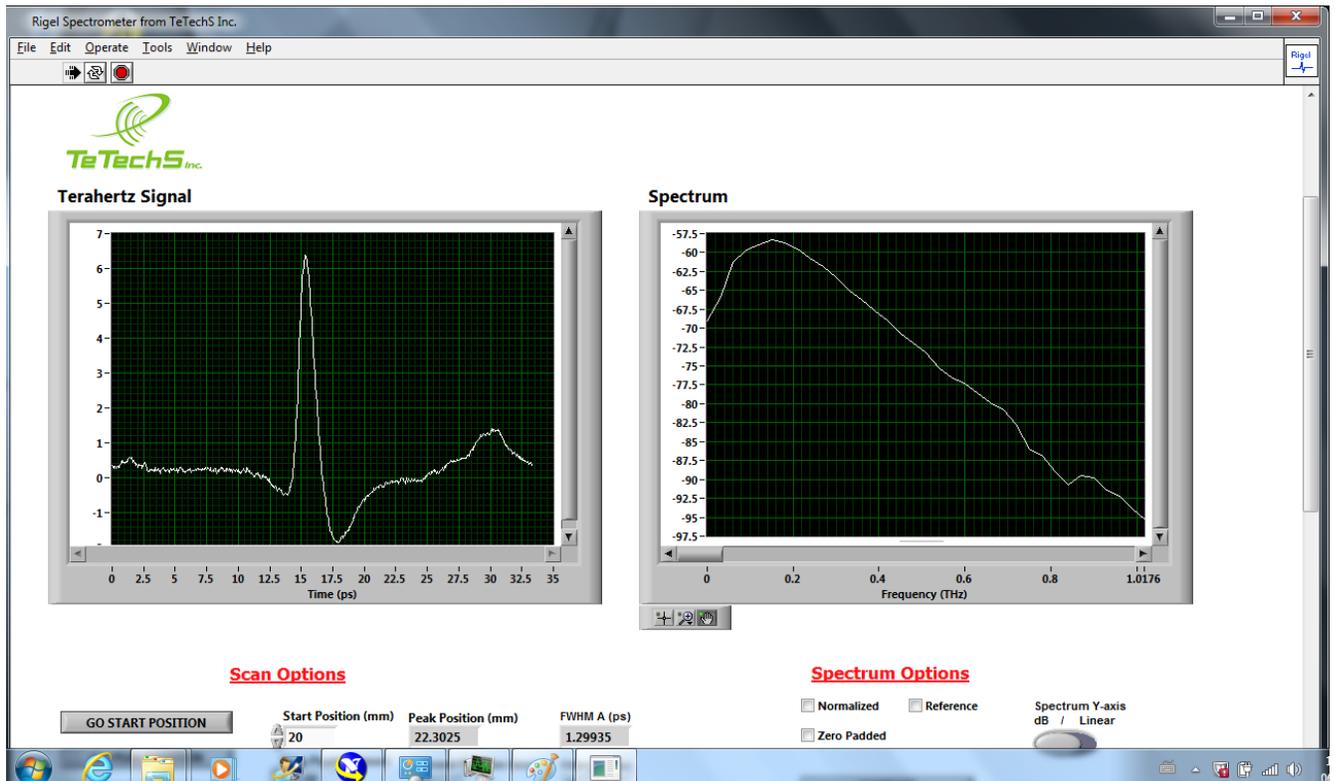
For example for the position of where the Tx and Rx are located. We do a scan for the delay starting at 20 mm and for 5 mm scan with a motor speed of 0.1 mm/s. This corresponds to a 33.3 ps scan. Rigel 1550 spectrometer returns the time domain signal, spectrum, peak position in mm, Full-width half maximum (FWHM) of the pulse, and the THz power spectrum bandwidth, which is 20 dB above the noise floor. The pulse width of our measurement in free-space for a large-aperture transmitter and 5 μm dipole as receiver is 1.3 ps and bandwidth of 0.93 THz. Rigel 1550 goes to the peak position automatically after each scan.

Note: When clicking Start Scan for the first time the Shaker controller and motor for it is turned on and comes to center position affecting delay by 5 mm. The “*is connected to uP?*” LED lights up when servo motor is on and goes to center position for fast scan (if **FAST SCAN** is turned on the servo motor for the Shaker will oscillate w.r.t. the center position).

6. Click **GO START POSITION**
7. Make sure the Emission light on the Laser is ON before doing a scan. Once the motor finishes going to the Start Position, Click **START SCAN** then click **Create New Scan**.



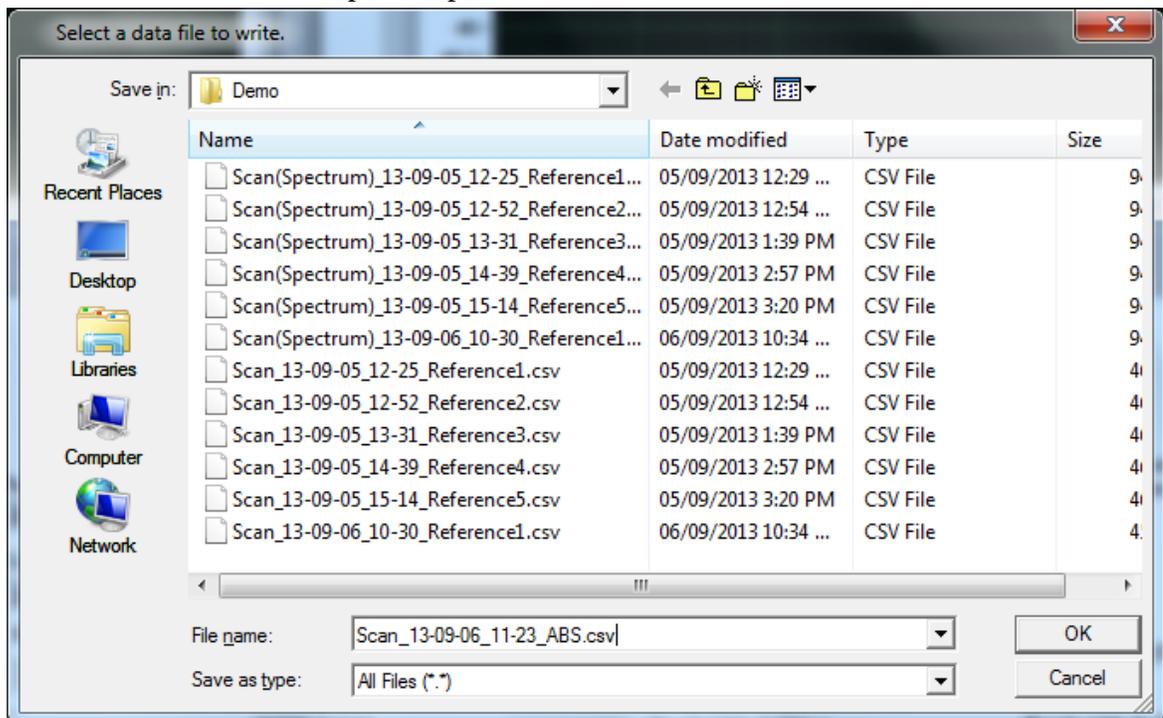
8. Enter Filename for the Time domain signal to store and Spectrum to store as .csv comma delimited files. The filename contains the data and time of scan. Once you click OK the shaker is turned on for the first time scan and then the *Running* Button will turn on green. At the end of the scan we get the signal and spectrum shown below.



9. One can do repeated measurements by putting a sample in transmission mode between the transmitter and receiver and doing the scan over the *same range* to see delay of the pulse and effect on the spectrum or changing the *start position* of the scan with the same *scan width* to measure and store the time domain signal and spectrum for post-processing and comparison. Note: The value of 6V THz signal corresponds to $6V/10V \times 300\mu V \times 1 \mu A/V$ Gain = 180 pA THz current on Rx antenna.

Comparing Spectra

After finding the delay and obtaining the THz pulse using procedure of initializing and running Rigel 1550, put the sample in between the transmitter and receiver. To compare the spectra first put sample at focus of the transmission module or if using the collimated beam between Tx and Rx, put sample in the middle.



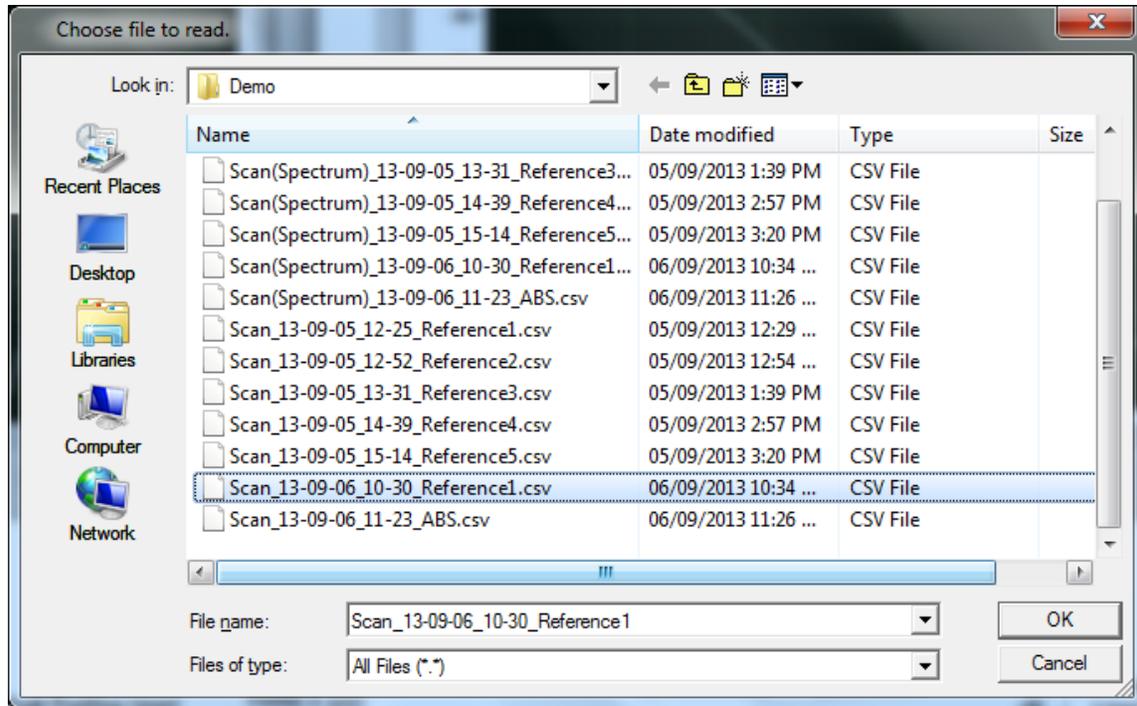
For example here we compare the scan of ABS plastic sample.

1. After putting the sample in between the terahertz sensors, conduct a scan over the same range from 20 mm to 25 mm with a speed of 0.1 mm/s. The resulting time domain signal and spectrum are shown below.

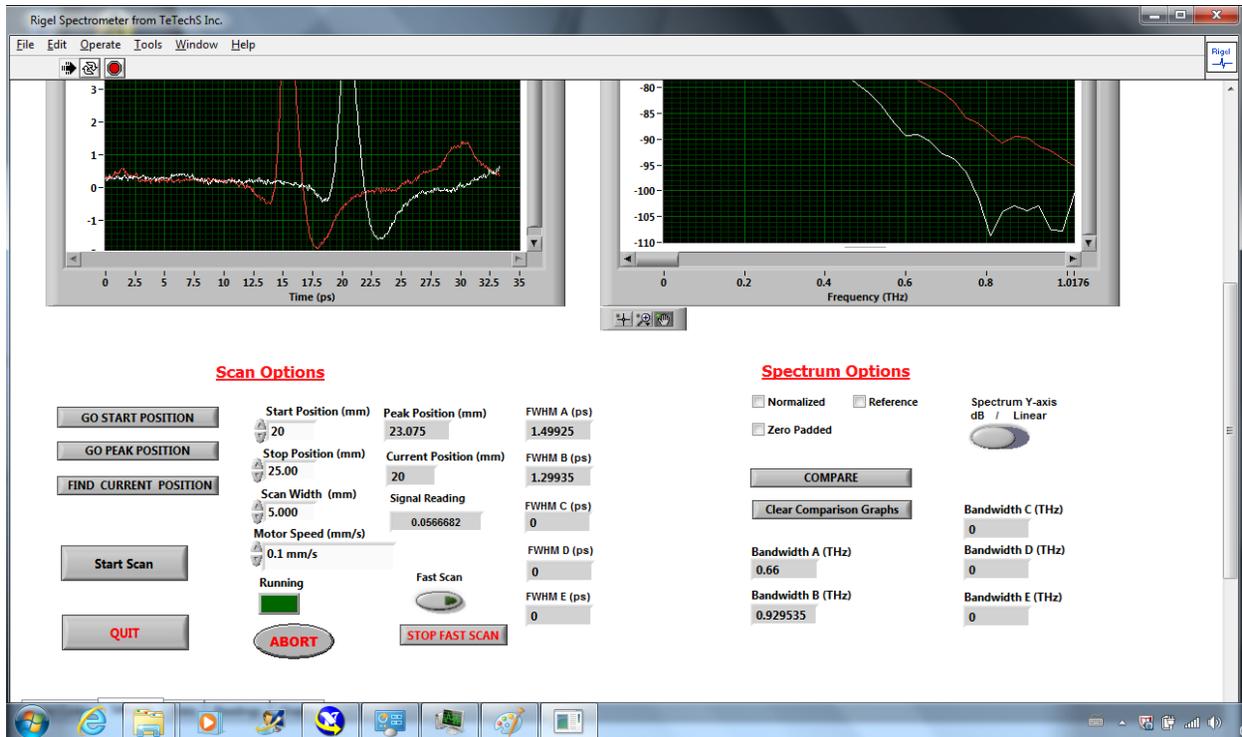


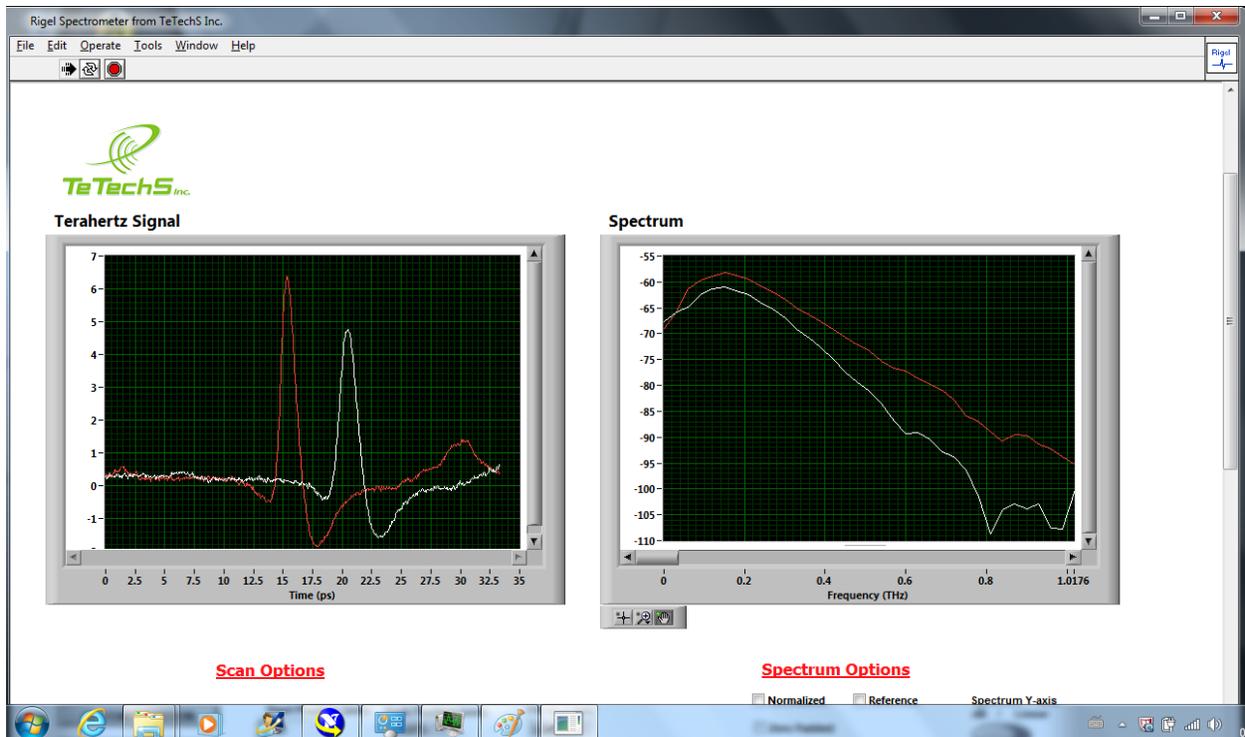
It is shown that the pulse is broader from 1.3 ps in freespace to 1.5 ps with the ABS sample and the peak position shifted to 23.08 mm. There is also attenuation due to the sample.

- To compare the spectra with other measurements or for this example the reference click on **COMPARE**. *Select the file to compare which is a time domain scan csv file. Do not load the spectrum as the only time domain signal csv file is used to compare the signal and spectrum.*



The Reference is loaded in red and the ABS sample measurement is in white shown below. The change in FWHM of pulses and 20-dB bandwidth above noise floor is shown too.





There is a clear difference in the spectrum and delay in the pulse in the time domain. *Here again the ABS sample is shown in white and the reference air measurement shown in red.* If you click **clear comparison graphs** it will clear the loaded signal and spectra to compare and shows the last scan which is in *white* line.

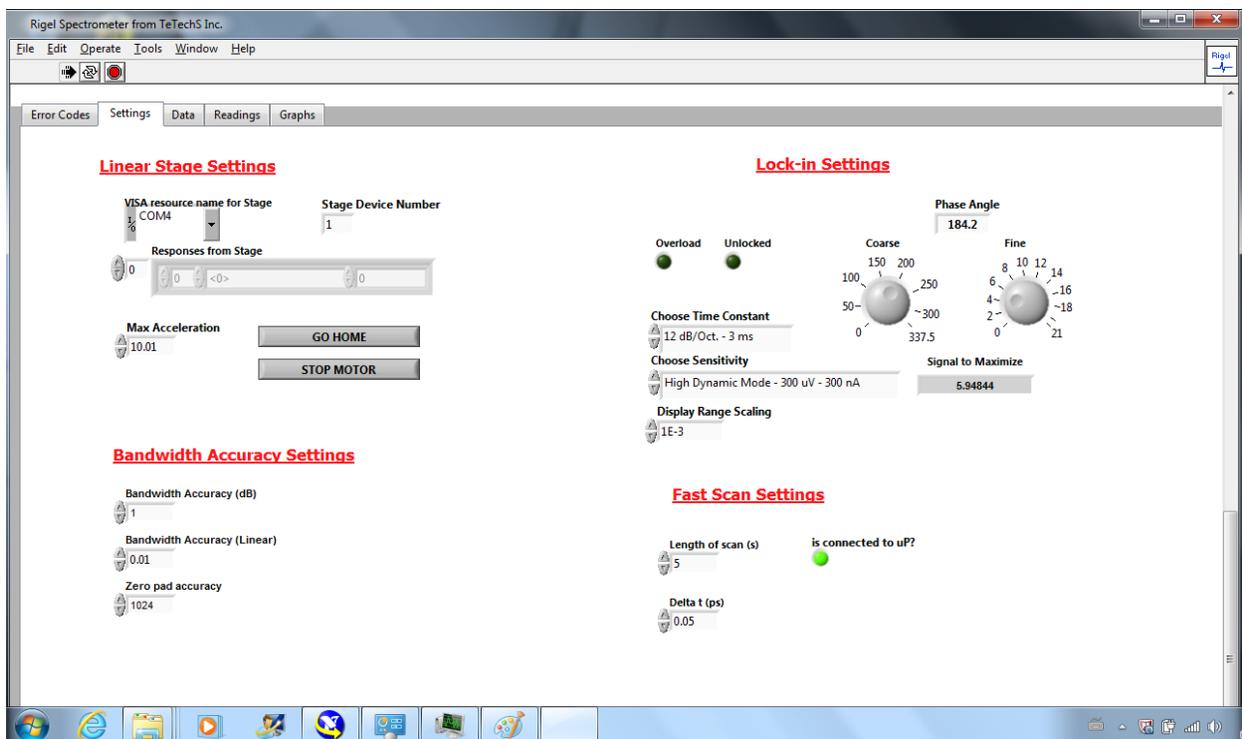
Note: For convenience one can scan the sample first and store the data and do a reference measurement in air next to show the reference in *white* line as last scan. The data for the samples are then loaded using **COMPARE** from the stored data and shown in color such as red.

Running FAST SCAN

The fast scan option uses a sine wave generator with position voltage ranging from -1.5 V to 1.5 V and frequency of 1 Hz. The Fast scan acquires a waveform every 500 ms using this setting. The sine wave generator that drives the shaker servo motor can be increased to 20 Hz.

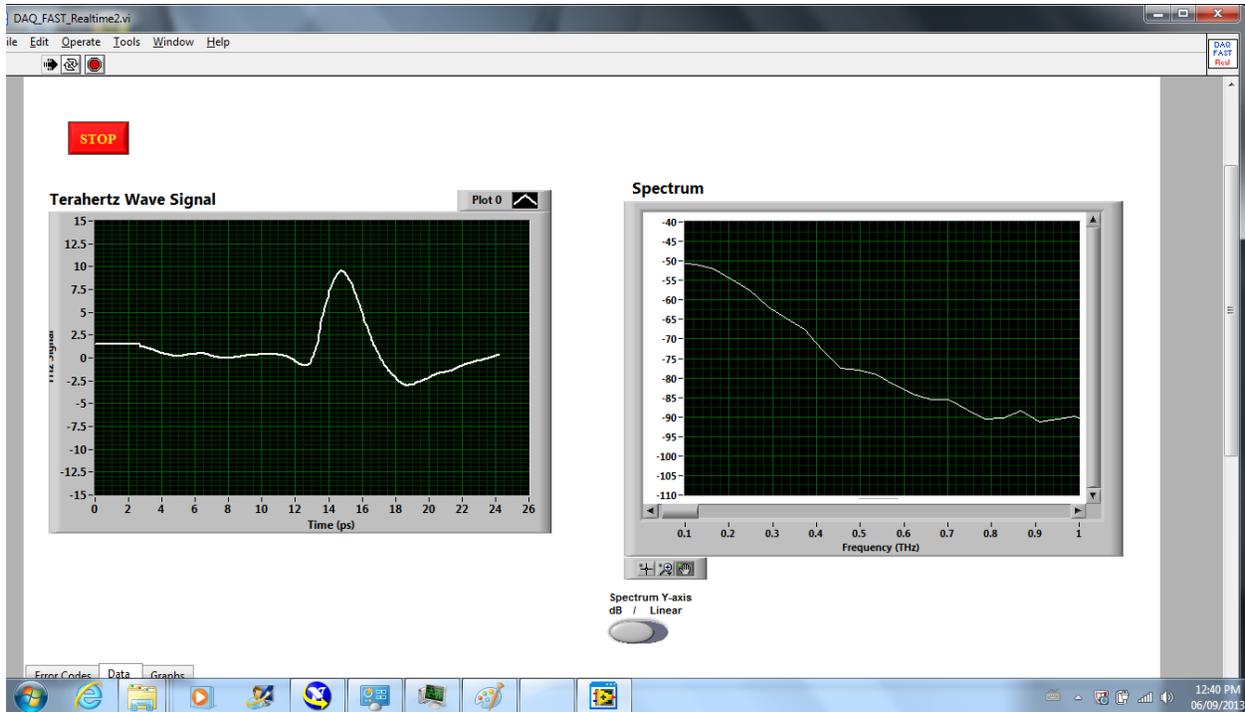
To run Fast scan mode, first load Rigel.exe for normal slow scan mode and get the signal using the Rigel 1550 spectrometer software as outlined above. Rigel 1550 spectrometer automatically goes to the peak position. Then follow the following steps:

1. Change the Time constant of the lock-in amplifier under **Lock-in settings** to 12 dB/ Oct. - 3 ms as shown below. The unlocked led light turns on if the signal is unlocked if reference is disconnected. The overload turns on if the gain is high. But the **Signal to Maximize** should show a signal between range of -10 V to 10 V with display range scaling of 1e-3. If the signal is within this range the DAQ is working and the lockin is not overloaded.

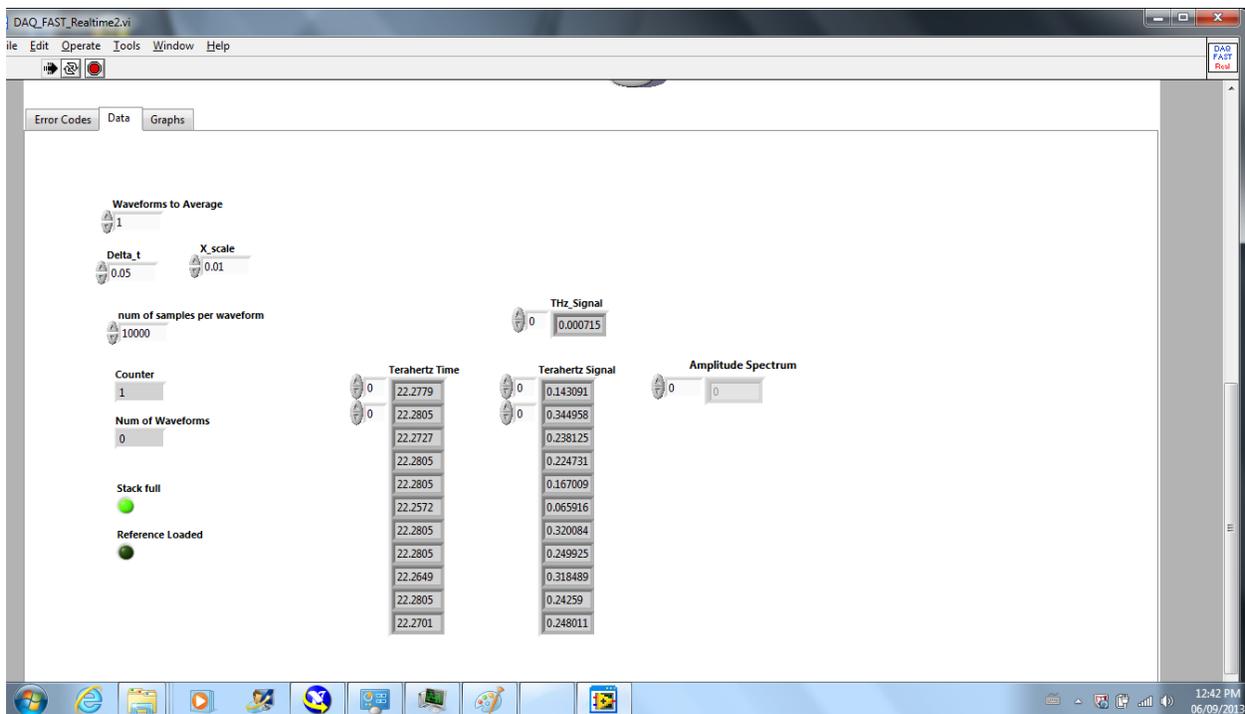


2. Turn the **FAST SCAN** manual switch at the side of spectrometer ON
3. Run **RigelRealTime.exe**

NOTE: The Main Rigel.exe application program must be running with the lock-in settings mentioned above for the real-time signal and spectrum to show in the Rigel 1550 Real-Time application.



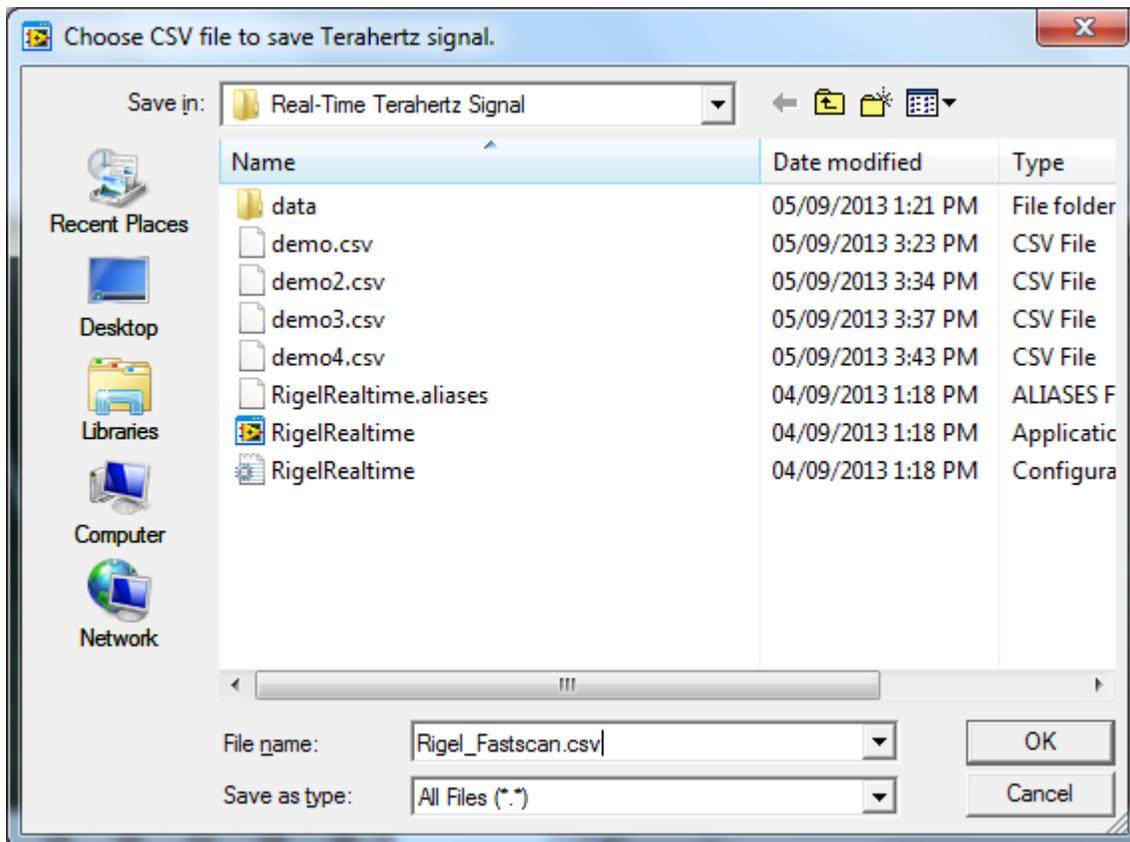
The Figure above shows the real-time signal and its spectrum after running RigelRealTime application. If a sample is placed between the transmitter and receiver, the change would be shown in real-time or in a matter of ms.



The **Data** tab shows the setting for Delta t which is 50 fs, the number of waveforms to average is set to 1 for fast scan and up to 5 to average out the noise. Since a 3 ms time constant averages out

the noise at that speed, there might not be a need to average the waveforms for this setting but if the Fast scan is increased to 20 Hz this function is used to average the waveforms say up to 11 waveforms before showing the THz signal and spectrum. The X scale is a scale for the amplitude of the THz signal and it is set to 0.01. This scale is adjusted to view the THz signal to values of between -15 to 15 for sensitivity of 300 μ V on the lock-in.

4. Click the **STOP** to stop the continuous data acquisition after doing measurements



Rigel 1550 program will ask you to save the THz signal when you clicked STOP into a CSV file.

Calculating Absorption Coefficient

1. In order to calculate absorption coefficient of a material, first place material in transmission module or in between the transmitter and receiver and conduct a scan within the same scan range that you would use for reference scan in air
2. Check the checkbox on the right that is named **Reference** and run another scan removing the material and conducting an air scan within the same range.

NOTE: Make sure the pulse for the reference is in the same scan range window as the material under test.

3. While the **Reference** checkbox is clicked, the last scan you did without a sample is the reference scan and will be used to compute the absorption coefficient by clicking **COMPARE** button.
4. Similar to the comparison of spectra, the software will ask the user to select the file name (Time domain csv file) of the material that was scanned in step 1 and show the absorption coefficient once the files is loaded in the Spectrum window.
5. To clear the graphs showing the absorption coefficient, click **Clear Comparison Graphs**.

Zero Padding Option

Before a scan, one can select **Zero Padded** checkbox to zero-pad the time domain signal with the number of zeros equal to the *Zero pad accuracy* or default setting of 1024. The user can change the zero pad accuracy or number of zeros to add to the signal for zero padding before computing the spectrum for higher resolution by changing the *Zero pad accuracy* setting under the **Bandwidth Accuracy Settings**.

Accessories

The Rigel 1550 terahertz Spectrometer comes with a transmission mode measurement module for conducting spectroscopy of power samples compressed into a 13 mm diameter pellet or to put any sample at focus of terahertz beam. The terahertz transmission-mode measurement module uses two focusing lenses to focus the collimated terahertz beam from the transmitter module unto the sample with a beam spot size of 3 mm or less. The second focusing lens collects the transmitted beam through the sample and collimates the beam that is collected by the receiver sensor module. Unlike the case of putting a sample such as a large plastic in between the transmitter and receiver without the transmission-mode measurement unit where the collimated beam interacts with the sample, using the transmission-mode measurement unit focuses the beam to a sample spot size so the beam interacts with the sample over the small region such as the case for a 13 mm diameter pellet.

The transmission-mode measurement unit also has two other positions to put the sample holder with the sample to have the sample interact with a slightly de-focused THz beam. Although the spot size at these locations is not at focus, the beam spot sizes are smaller than the case for the collimated THz beam.

Exiting and Shutdown of Spectrometer

1. Turn the Emission red button on the laser off.
2. Press **Quit** button in Rigel 1550 Terahertz Spectrometer software.
3. Unplug the USB connection to the Spectrometer
4. Turn the key on the laser to switch OFF the laser.
5. Turn the Green button for the Spectrometer **OFF**.

Contacts

TeTechS Inc.

295 Hagey Blvd., 1st Floor
Waterloo, Ontario
N2L 6R5 Canada

Toll Free: +1 (855) 574-1764

Tel: +1 (519) 584-0791

Fax: +1 (519) 513-2421

www.tetechs.com

Email: info@tetechs.com

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