SAFETY AND PREPARATION FOR USE

WARNING
Dangerous voltages, capable of causing injury or death, are present in this instrument. Use extreme caution whenever the instrument covers are removed. Do not remove the covers while the unit is plugged into a live outlet.

WARNING
This is a Class IIIb laser product. Laser light (up to 50 mW of 783nm or 855nm) is emitted from the optical ports of the PB7200 chassis during operation. Normally, a fiber is connected to the port or the safety cover is in place. If the fiber is removed and the safety cover lifted while the system is operating, the beam from the port could cause serious damage or even complete blindness to the unprotected eyes.

WARNING
Attempting to make adjustments to the instrument without first reading and understanding this manual completely could result in damage to the instrument and void the warranty.
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1 SYSTEM DESCRIPTION

The sub-millimeter (sub-mm) and Terahertz (THz) regime of the electromagnetic spectrum has historically been employed to measure the frequencies of rotational transitions in molecular gases for applications involving compounds of atmospheric importance. Recently, there has been an interest in employing THz radiation for the measurement of low energy vibrational transitions in solid materials as well. Some of the compounds of significant interest include: illicit drugs, paintings and artwork, explosives and biologically important compounds like sugars and hormones.

The EMCORE PB7200 represents the latest advancement in THz technology. It employs precisely tuned fiber coupled, butterfly packaged semiconductor DFB (distributed feed-back) lasers, advanced fiber-coupled, photo-mixing source and detector, and sophisticated digital control hardware and software to provide a fully turnkey laboratory THz spectrometer that is highly compact, versatile and economic. The system employs an extremely sensitive room temperature coherent detection technique that eliminates the need for cryogenics. Further, the highly efficient CW (constant wave) nature of the photo-mixing source puts all the THz power at the frequency of interest, yielding excellent signal-to-noise ratios (SNR) across the scan range of up to 70 dB-Hz. Unlike time-domain systems requiring complicated mode-locked lasers, the tunable semiconductor laser diodes in the PB7200 allow the system to stay at one specific THz frequency, scan across the entire bandwidth or even ‘frequency hop’ between frequencies of interest to scan specific regions of the spectrum with varying degrees of resolution.

The fiber-optically-coupled source and detector heads are mounted on a rail system and configured for transmission or reflection measurements or both simultaneously. They may also be detached from the processor unit and used with extended fiber-optic cables to provide maximum measurement flexibility in a wide range of applications. The software is intuitive and easy to use and the data is recorded as in simple comma separated file that may be imported into any analysis software.

1.1 THEORY OF OPERATION

The PB7200 employs high frequency photomixing to generate and detect THz radiation. This is achieved through combining the output of two single frequency diode lasers in a low-temperature grown Gallium Arsenide photomixer (also referred to as a Photo-Conductive Switch or PCS). An
The wavelength of one (or both) of the lasers is temperature tuned to vary the THz output frequency. For instance, as shown in Figure 1.1.1 above, if a laser at a wavelength of 782 nm is mixed with another laser at a wavelength of 783 nm, a beat frequency of 480 GHz will result (this frequency corresponds to 1 nm at these wavelengths.) The mixing product is then radiated by the antenna and partially collimated with a Silicon lens.

In many spectroscopic applications of photomixing to date, the THz output beam from the PCS is coupled to a sensitive broadband thermal detector (e.g., LHe bolometer or Golay cell), making the overall signal processing incoherent and phase insensitive. Coherent detection can be achieved at room temperature by mixing the same optical radiation from the diode lasers in a detector PCS onto which the THz signal is also incident (Figure 1.1.2).
This is referred to homodyne detection and it provides greater sensitivity and faster data acquisition than incoherent techniques. It also preserves phase information. Figure 1.1.3 illustrates how the PB7200 employs a standard 2 X 2 polarization maintaining fiber coupled optical splitter/combiner to both equally combine and split the output of each of the lasers onto the source and detector PCS.

A simple way to increase the SNR of a homodyne system is to employ a lock-in amplifier and "lock" to an amplitude or frequency modulated signal. In the PB7200 this is achieved by biasing the source PCS with a 6 kHz square wave modulated voltage (amplitude modulation). A lock-in amplifier is then employed on the detection circuit and only amplifies signals at the lock-in frequency to within
a bandwidth set by the time constant of the lock-in. More information about the theory and the operation of the lock-in amplifier may be found in the literature.

One of the challenges with building a coherent frequency domain THz spectrometer is balancing the lengths of the optical and THz paths of what is principally an interferometer with two different length arms (Figure 1.1.4). The path length difference between A and B will result in an interference pattern with frequency periodicity proportional to the delay. With a fiber-based system this may be achieved by increasing the length of the detector PCS fiber relative to the length of the source PCS fiber and thereby balance the arms of the interferometer.

Figure 1.1.4: Illustration of the optical and THz paths that make up the arms of the interferometer.

In order to effectively control the resolution required to properly record a scan, it is necessary to carefully balance the path lengths of the arms of the interferometer. The most appropriate spacing of the pattern is dependent upon the sample characteristics, the desired spectral resolution and the need for recording dispersion characteristics. For instance, Figure 1.5 illustrates a scan where the separation of the source and detector heads is chosen to result in a fringe spacing of approximately 5 GHz.
Figure 1.1.5: A single scan of laboratory air using the PB7200 portable THz spectrometer. Source-to-detector head spacing resulted in an interference pattern with a roughly 5 GHz period. Bottom trace is the noise level.

A resolution of 500 MHz is then chosen to accurately record the interference fringes. A scan from 200 GHz to 1500 GHz with 500 MHz resolution records 2600 data points. If the integration time is 1 second for each point, the scan will take roughly 45 minutes to complete. If a sixty point smoothing is performed on the data (Figure 1.1.6), the interference pattern is removed and absorptions are visible (in this case atmospheric water vapor).

Figure 1.1.6: The data from the previous scan with a 60 point smoothing function applied to remove the interference pattern and more clearly show the absorption features.
By adjusting the distance between the source and detection heads, different interference fringe frequency spacing is obtained. Figure 1.1.7 shows the same scan conditions as Figure 1.1.6, but with the path length imbalance reduced by adjusting the spacing between the THz source and detector heads.

Further adjustment of the physical separation of the source and detector heads may be performed to completely balance the optical and THz arms of the interferometer. However, in practice, perfect balance at all frequencies is impossible to achieve due to antenna and device dispersion.

1.2 PHOTOMIXER CHIRALITY

The data illustrated in the previous section was recorded with a PB7200 configured for transmission measurements. Operating the system in reflection mode will also produce an interference pattern, however, there are requirements on the chirality of the antenna structures for both transmission and reflection and this requirement changes. Photomixers are available in both clock-wise (CW), counter clock-wise (CCW) and bowtie (BOW) configurations (Figure 1.2.1).
The square spiral antennas (and log spiral antennas – not shown) produce circularly polarized THz radiation while the bowtie antennas produce linearly polarized radiation. At extremely high frequencies the polarization of the spiral antennas also becomes linearly polarized. For a system configured for recording the transmission of the THz radiation through the sample (transmission), the chirality of the source and the detector photomixing antenna must be the same. For a system configured for recording the reflection of the THz radiation from a sample, the chirality of the source and detector photomixers must flip (reflection). Figure 1.2.2 illustrates a system configured for simultaneous transmission and reflection measurements. Note the chirality of the various photomixer heads. Failure to do this will result in a 50 dB-Hz degradation to system dynamic range. Because the bowtie antennas produce linearly polarized THz radiation, there isn’t an issue with chirality and the same style photomixer may be used for transmission and reflection measurements.

**Figure 1.2.1**: The different types of photomixers and the chirality
**Figure 1.2.2:** A system configured for simultaneous reflection and transmission measurements.

The chirality or type of the photomixer is labeled on the photomixer body and can be easily determined by looking at the THz head unit. In Figure 1.2.3 the THz head on the left has a counter clockwise spiral antenna (CCW) while the head on the right is labeled and has a clockwise spiral antenna (CW). A bowtie or log spiral antenna would be similarly labeled.

**Figure 1.2.3:** The THz heads illustrating how the CCW and CW photomixers are clearly labeled.
2 SYSTEM ASSEMBLY

2.1 SETUP

The PB7200 consists of four basic components (Figure 2.1.1):

1. The control unit which houses the lasers, fiber optics and control circuitry;
2. The THz source head with an off-axis parabolic mirror;
3. The THz detector head with an off-axis parabolic mirror;
4. The rail system for phase delay adjustment.

Figure 2.1.1: PB7200 (1) with source head (2) and detector head (3) heads attached and mounted on the rail system (4)

The PB7200 arrives disassembled and needs to be assembled before operation. Please read the assembly instructions completely before attempting to assemble and operate the system. It is advisable to find a clean and clutter free bench or table to assemble the PB7200. The only tool that is required for assembly is a high quality fiber optic cleaning tool (included).
First, remove all of the items from the case and set them aside. Please pay particular attention to the cables making sure they are not pinched or kinked. It may be necessary to remove the first layer of foam from the case to find all of the components. Set the rail on the bench and position the THz optics stages next to the rail in the orientation shown (Figure 2.1.2).

![Figure 2.1.2: The THz optics and rail system laid out and ready for assembly](image)

The first thing to note is the differences between the THz source head and the THz detector head. Besides the labels, the electrical cables are different. This difference is evidenced in the connector keying. Figure 2.1.3 illustrates the differences.

![Figure 2.1.3: An end view of the source cable with a single keyed connector (left) and the detector cable with a double keyed connector (right)](image)
The electrical cables can be snapped into their respective heads (Figure 2.1.4). They should “click” into place and can be removed by gently pulling on the barrel of the connector.

![Figure 2.1.4: A picture of the electrical connector correctly inserted into the THz head.](image)

**NOTE**: Do not attempt to disconnect the electrical cable by pulling on the cable itself, but always pull on the barrel of the connector.

The next step is to insert the optical connectors into their respective heads. As with the electrical connectors the optical cable for the source and the detector are different. Unlike with the electrical connectors, however, the optical connector is not different, but the **length** of the optical patch cables are different. The optical connectors are keyed and may only be inserted one way (Figure 2.1.5)
Figure 2.1.5 illustrates how the SC/APC connector is keyed and inserted into the THz head.

Figure 2.1.6: A picture of the optical connector inserted into the THz head. Notice the depth to which the connector is seated into the bulkhead.

NOTE: The optical connector should snap into the bulkhead connector with an audible “click.” If you don’t hear the “click,” pull the connector out slightly and repeat the procedure.
**NOTE:** The *longer* fiber optic patch cord attaches to the THz *detector* head.

**NOTE:** Maintaining fiber tip cleanliness is *critical* for the proper operation of the PB7200 and the fiber tips should always be cleaned with the one-step cleaner that was included with the system before inserting them into the bulkhead connections.

**NOTE:** Do not attempt to disconnect the optical fiber by pulling on the fiber itself, but always pull on the connector body.

![Image](image-url)

**Figure 2.1.7:** The optical and electrical connections to the THz head unit

After connecting the cables to their respective THz heads, they may then be connected to the control unit *(Figure 2.1.8)*. The same procedures should be employed when connecting or disconnecting the cables from the control unit.
Figure 2.1.8: The optical and electrical connections to the control unit mirror those on the THz heads.

**NOTE:** The PB7200 control unit should always be “OFF” when the optical and electrical connections are made or broken.

After the THz heads are connected to the control box, it is necessary to assemble the rail unit. Like the THz heads, everything on the rail unit snaps or slides into place. Before assembling the rail unit however, it is best to first inspect the off-axis parabolic mirror assembly to make sure that nothing has moved during transportation. Compare the distances of the different components to those in Figures 2.1.9 and 2.1.10.

**NOTE:** Extreme care should be taken not to touch the gold surface of the off-axis parabolic mirrors in the mirror assembly and the Silicon lens on the source/detector heads.
Figure 2.1.9: A side view of the off-axis parabolic mirror assembly illustrating the distances of the separate components relative to each other.

Figure 2.1.10: A top view of the off-axis parabolic mirror assembly illustrating the distances of the separate components relative to each other.

If the optical components have moved significantly or slipped off during transportation, please restore them to the positions shown in the figures before continuing.

After inspection, the off-axis parabolic mirror mounts may be attached to the rail system so that both of the locking screws are on the side with the ruler (Figure 2.1.11). Move the heads until they
are separated by the distance indicated on the calibration sheet at the back of the user manual. This separation is typically 4 to 7 cm.

![Figure 2.1.11: The rail system with the off-axis parabolic mirror mounts in attached and at the proper separation.](image)

The stages may be locked in this position by turning the locking screws on the base of the stages. After the stages are locked in place, the heads may be attached by simply sliding the clip over the lip and allowing the magnets to seat them in position (Figure 2.1.12).

![Figure 2.1.12: Installing the THz head units to the off-axis parabolic mirror mounts.](image)
Connecting the power and USB control cable to the back panel is fairly straightforward because they are common connectors (Figure 2.1.13).

As noted on the back panel the PB7200 operates on 19 V, 3 Amp DC supply with a positive center electrode. Use the one that was shipped with the system (Figure 2.1.14).
After the cables are connected and the power is switched on (the I is depressed) it is necessary to turn the key on the top of the unit to enable laser operation (Figure 2.1.15).

When the lasers are enabled, the LED over the key switch will illuminate.
NOTE: The PB7200 contains two Class IIIb lasers. Laser light (780 or 855nm, 50mW) is emitted from the optical ports of the PB7200 chassis during operation. Do not look into the port the beam emitted could cause serious damage or even complete blindness to the unprotected eye.

NOTE: The PB7200 is battery operated! Unplugging the unit does not necessarily mean that the lasers are disabled. You must make sure the unit is powered off and the enable key is in the off position before inspecting any fibers.

2.2 THZ OPTICS ALIGNMENT

One of the greatest challenges with operating a THz spectrometer is in achieving the proper alignment between the source and the detector. The process is difficult because there are six different degrees of freedom on each off-axis parabolic mirror and a seemingly infinite number of local maxima and minima. Further, the beam is invisible and very difficult to detect with anything other than the detector to which it needs to be aligned! The only fortunate situation occurs because the source and detector photomixers are exactly the same and the relative positions of the THz optics should therefore be the same (i.e. symmetric). That is to say, one off-axis parabolic mirror should not be positioned differently, with respect to its Silicon lens, than the other off-axis parabolic mirror to its Silicon lens. We have included this section with tips and suggestions on how to align the THz optics should they become misaligned. However, obtaining the optimal alignment of a THz optical system requires experience and patience.
**NOTE:** The first, and most important, step in testing the alignment is to assemble the system as shipped and measure the detected power levels for the given frequencies that are recorded in the calibration sheet at the back of this manual. This testing is described in Section 3.4.

Typically, the off-axis parabolic mirrors will have shifted slightly and will need to be realigned. This may be achieved by manually adjusting the two knobs on each of the mirror mounts (Figure 2.2.1) while monitoring the power level (Section 3.4)

![Figure 2.2.1: The tip and tilt adjustments found on the back of the off-axis parabolic mirror mounts.](image)

As you adjust the tip and tilt settings the power will change dramatically. Unfortunately, there are an infinite number of local maximums and minimums and therefore you sometimes need to adjust through a maximum to find a higher maximum.

The suggested approach is to coarsely tune one axis and find the highest maximum and then continue onto the next axis. Continue to adjust each axis. If the power recorded in the calibration sheet is not achieved, adjust one of the axis to a new position and readjust the remaining axis to maximize the power in this position.
As previously mentioned, the system characteristic that makes this possible is that the optics should be symmetric from side to side (Figure 2.2.2 and Figure 2.2.3).

Figure 2.2.2: A side view of the rail system illustrating how the off axis parabolic mirrors are horizontal and not at significant angles to the optical axis.

Figure 2.2.3: A top view of the rail system illustrating how the off axis parabolic mirrors are aligned. Note that the left one is slightly tilted. More asymmetry than this is not typically required.

If for some reason, the off axis parabolic mirror assembly should come off during shipping, or if the mounting plate should somehow move, then it may be necessary to start the alignment process from scratch. To do this, first use the previous images to set the distance of the mounting plate from the mounting cube (Figure 2.1.9 and 2.1.10) or approximately 1 cm. Then check that the Si lens is centered and fills the off axis parabolic mirror when viewed along the THz optical axis (Figure 2.2.4)
Figure 2.2.4: Viewing down the THz optical axis to check off-axis parabolic alignment. Note that the Si lens is in the center of the off-axis parabolic mirror.

If the Si lens is not centered on the off-axis parabolic mirror, the adjust mounting plate, the rotation and the tip and tilt until it is.

Figure 2.2.5: If the mountain plate moved significantly during shipping return it to the following distance ($\sim 1$ cm) or until the Si lens is aligned as illustrated in Figure 2.2.4.
Figure 2.2.6: If the off-axis parabolic mirror has rotated, the set screw may be loosened and the mirror rotated to achieve the alignment illustrated in Figure 2.2.4.

NOTE: The THz optics alignment is not a trivial procedure and can be very time consuming.
3  2. PB7200 SOFTWARE

3.1 INSTALLATION

The PB7200 software will work on PCs operating Windows XP SP3, Vista, Windows 7 or Windows 8 only. It is unlikely that the software will run on machines other than a PC even if a Window Kernel is running.

To install the software first make sure that the computer is connected to the internet and has access to the World Wide Web. Insert the USB flash drive into the computer. If the installer does not automatically start, please navigate to the top directory on the USB flash drive. Double click on the Setup.exe file and follow the prompts. This will install the PB7200 Software to the local hard drive of the computer. This should take under 1 minute.

You may be prompted to download Microsoft .Net. These files are required to run the Visual Basic software and if they are not already installed on the computer, the installer should download them automatically from the internet. If you do not have access to the internet or have trouble downloading the .Net files, they are included on USB flash drive in a folder labeled Microsoft .Net 4.0.

After the software has been installed there will be a shortcut created on the desktop and the start menu. A link to the data directory is also created.

Figure 3.1.1: The shortcut locations for the PB7200 control software
3.2 FIRST OPERATION

Double-clicking the program shortcut will start the program. If this is the first time the spectrometer has been connected to the computer the following window may pop up and inform you that communication with the PB7200 has failed (Figure 3.2.1).

![Figure 3.2.1](image)

Figure 3.2.1: When the software is started the first time or if there is an issue with the COM port an error message will alert the user.

If this occurs, simply click on the “OK” button. This will bring up a window that will allow you to select the com port that the PB7200 is attached to (Figure 3.2.2). In this case, it is attached to COM PORT 3 but each computer may be different.

![Figure 3.2.2](image)

Figure 3.2.2: The port selection widow allows the user to connect to the PB7200

Choose the port that the PB7200 is connected to and click on “Okay.” The system will then transfer the calibration files from the spectrometer to the computer and the following window will appear (Figure 3.2.3).
Figure 3.2.3: The progress of the transfer of the calibration files to the computer

Transferring the calibration files will require about 90 seconds and will only occur the first time that the PB7200 is connected. After the calibration file has been downloaded from the PB7200 the scanning interface should appear.

Figure 3.2.4: The PB7200 GUI that greets the user after the software has been correctly installed and the calibration files are set up.

NOTE: In Windows XP, themes must be disabled in order to see the tabs. This is a bug in Windows XP, not with the PB7200 software.

3.3 USB DRIVER INSTALLATION

If the port that the PB7200 is connected to is not visible, it will be necessary to install the drivers that support the USB port. This may be accomplished by clicking on the button that states “Install Drivers (As Administrator)” (Figure 3.3.1).

Figure 3.3.1: Installing the USB drivers if the PB7200 is not showing up attached to a COM port.
This will bring up the USB driver installation interface.

![USB driver installation interface](image)

**Figure 3.3.2**: The USB driver installation window that will guide the installation of the USB drivers required for Windows to communicate with the PB7200

Simply follow the instructions presented by the installation program to install the drivers. After the drivers are installed it may be necessary to restart software and repeat Section 3.1.

### 3.4 Dwell Tab (Alignment)

Switching on the power for the PB7200 and then starting the software program will bring up the graphical user interface. This interface defaults to the scanning tab when it is started. If the system has just been assembled it is necessary to make sure that the system has been properly assembled and the optics are properly aligned. In order to do this, select the “Dwell” tab that is on the left-hand side of the interface (**Figure 3.4.1**).

![Dwell tab](image)

**Figure 3.4.1**: Selecting the Dwell or Alignment tab in the software interface.
Clicking the dwell tab brings up the dwell control with a strip chart display in the center and a power bar on the right (Figure 3.4.2). The user can enter a dwell frequency and a time constant (red box). The system will remember the last setting that was entered by the user, but will default to 200 GHz the first time the software is operated.

![Figure 3.4.2: The Dwell interface with the Frequency and Time Constant inputs.](image)

Clicking the “START” button will operate the system at the frequency and time constant entered. It will require a minute or two for the lasers to stabilize to the proper frequency. During this time the power will fluctuate (Figure 3.4.3). After the system has stabilized the chart will produce a constant and smooth line and the bar graph on the right will display the power.

![Figure 3.4.3: When the Dwell function starts, the power will fluctuate as the system stabilizes.](image)
If the system has just been assembled and/or the THz optics are being adjusted, refer to the last page of the manual for the power that should be achieved for each frequency setting and follow the process detailed in Section 2.2.

After adjustment has been performed at 200 GHz simply enter the next frequency and readjust the THz optics to maximize the power (Figure 3.4.4).

![Figure 3.4.4: Changing the Dwell frequency results in a lower power.](image)

After the THz optics have been aligned and the powers at the various frequencies match those recorded on the calibration sheet the system is ready for use.

**NOTE:** As the system frequency is increased, the optics will become more sensitive to adjustment and aligning the system to the best high frequency power generally results in higher low frequency power as well. Therefore, start the alignment at lower frequencies and then increase the frequencies.

**NOTE:** Dwell does not need to be stopped in order to change the frequency or time constant. Simply change the value and hit enter on the keyboard.

**NOTE:** If the signal is extremely noisy it may be first necessary to check the head spacing and the interference pattern spacing with a short scan before doing the alignment. The heads should be spaced the distance apart recorded in the calibration sheet shipped with the system.

The PB7200 can record data while dwelling at a single frequency. This is achieved by simply checking the radio box labeled “Record Dwell Data” (Figure 3.4.5).
Figure 3.4.5: Choosing the Record Dwell Data will record the data from that moment until Dwell is stopped or the box is unchecked.

The data will begin recording when the button is checked and will record the instantaneous frequency and power. Be warned that if this feature is turned on and forgotten it may fill the computer hard drive. Also note that the data is recorded and displayed at the rate that is set by the time constant. For instance, if 100 ms is chosen, a data point is recorded 10 times per second.

After the user is finished with the Dwell function the Stop button must be pressed in order to change to scanning.
3.5 SCANNING TAB

The scanning interface for the PB7200 has been designed to be straightforward and simple to operate. It contains the following controls (Figure 3.5.1):

![Figure 3.5.1: The scanning interface of the PB7200 software](image)

i. Start (GHz) – this is the starting frequency in GHz. The value cannot be set to a frequency lower than the system is capable of operating. If an unacceptable value is chosen the system will default to the minimum that is capable of.

ii. Stop (GHz) – this is the stop frequency in GHz. The value cannot be set to a frequency greater than the system is capable of operating. If an unacceptable value is chosen the system will default to the maximum that it is capable of.

iii. Step (MHz) – this is the resolution of the scan in MHz, not GHz. Note that the smaller this number, the more points per scan that will be taken and the scan will be longer. For most applications we suggest a 1000 MHz step size.

iv. Time Constant (mS) – the PB7200 employs lock-in detection and therefore an integration time has to be selected. The longer the integration time, the greater the system dynamic range. For most applications we suggest a 100 mSec time constant. Please note that if the computer is multitasking and being used for other simultaneous applications, the time constant will not be accurately represented. Normalization occurs based on the actual integration time and not on the setting, however.

v. Scans – the software is capable of averaging multiple scans. Selecting a value of “0” will force the system to do a single scan of increasing frequency. Any number greater than zero will result in an up in frequency and a down in frequency scan. The more scans that are averaged, the better the SNR and the dynamic range. The current scan number appears next to the control.

vi. Smooth Amount – smoothing may be applied to the data as it is being recorded. If smoothing is changed after the scan has completed, a button will appear to allow the user to resave the data with the new smoothing if desired.
vii. Notes – the notes field is for the user to enter information that they wish to have recorded with each scan.

**NOTE:** Increasing the lock-in time constant will improve the dynamic range, but it will not improve the SNR. It is suggested that averaging be employed instead of higher time constants to improve the system performance i.e. performing a ten scan average improves the dynamic range by a factor of ten and improves the SNR while increasing the time constant by a factor of ten only improves the dynamic range.

After entering the scan range, step size, time constant and number of scans, the start button may be pressed. A window will pop up to ask if this will be a background scan (Figure 3.5.2).

![Figure 3.5.2](image)

**Figure 3.5.2:** The first scan can be saved as a background scan.

The background scan is necessary if background subtraction is desired. Otherwise, the background scan does not need to be performed and the window can be closed by selecting “No.” If a background scan is performed, it is saved for those specific settings. If any of the settings are changed, including the number of averages, the background scan will be discarded and need to be repeated.

The system will then alert the user that it is “stabilizing” as the lasers are tuned to the proper frequencies (Figure 3.5.3).
Figure 3.5.3: After clicking the start button, the system will stabilize the lasers.

After the system has finished stabilizing, it will begin scanning and the “Smoothed Power” will appear on the first graph (Figure 3.5.4).

Figure 3.5.4: The PB7200 defaults to displaying the Smoothed Power.

The Smoothed Power graph is a record of the square of the voltage measured by the lock-in amplifier and divided by the time constant. It displays the average when more than a single scan is performed. So, if the user has selected to perform a single scan (1) then the PB7200 will scan up in frequency and then down in frequency and average the signals together. This average will be displayed on this first graph. If the user chooses to average twenty scans (20) then the Smoothed Power will continue to change as the
scans occur. Occasionally, a frequency bin has an amplitude of zero (0) power in the averaging. This appears in the graph, but the bins will likely be filled on the second or third scan and will disappear.

The Smoothed Power graph allows the user to smooth the data by changing the value in the lower left hand corner of the graph (Figure 3.5.5).

![Image of the Smoothed Power graph](image)

**Figure 3.5.5:** Smoothing can be used to remove the fringes and more easily visualize large spectroscopic features. When a background scan is recorded it is shown on the same graph as a white trace. Smoothing effects both the background and the data as it is recorded in the data file.

**NOTE:** If a background scan is taken, then it will appear (white trace) with the data (red data) on the Smoothed Power graph.

The smoothing function performs an average with the points to either side of the data point. If the smoothing is performed after the data has been saved a button labeled “Resave” will appear and allow the user to resave the data with the new smoothing amount.

Other graphs that are available and for which data is recorded are the “Raw Voltage” and “Raw Power” (Figures 3.5.6 and 3.5.7); where “Raw” refers to the fact that no smoothing or averaging has been performed.
Figure 3.5.6: The Raw Voltage tab graphs the voltage versus frequency of the detector voltage measured by the lock-in amplifier. It doesn’t show any smoothing nor averaging.

Figure 3.5.7: The Raw Power tab graphs the squared voltage data from the current scan and doesn’t show any smoothing nor averaging.

In the situation where a background has been recorded a fourth tab is present in the graphing area and this is the “Normalized Smoothed Power” which is simply the power of the sample scan divided by the power of the background scan (Figure 3.5.8).
Figure 3.5.8: The Normalized Smoothed Power plot is the sample data divided by the background data and should be less than one. Again, any smoothing applied to the power graph will be on the Normalized Smoothed Power plot.

NOTE: The Normalized Smoothed Power can be misleading if a fringe pattern exists. This is due to the fact that the fringe pattern shifts when a sample is placed in the beam and therefore fringes are not properly subtracted.

The user may either wait for the scan to complete, or they may click on the “Running” button to stop the scan early. If the scan is stopped early with this method, the user is asked if they would like to save the data that was taken to that point.

3.6 TOOLS MENU
There is a menu bar across the top of the PB7200 software which contains: file, tools, graphs and help. Clicking on the tools menu generates a drop down menu with several different selections.

Figure 3.6.1: The Tools drop down menu contents.
“Do Background Scan” will give the user the opportunity to repeat a background scan even if the scan conditions haven’t been changed.

The “Settings” selection brings up another tab which will be discussed in the next section. It may be unselected and the tab hidden by clicking the selection a second time.

The “Monitor” selection brings up another tab which will be discussed in the next section. It may be unselected and the tab hidden by clicking the selection a second time.

“Task Priority” allows the user to set the Windows application priority in case there are issues with other software using up processor cycles and slowing the PB7200 software down. If this should occur choose a high priority for the PB7200 Software. This may require administrative rights.

“COM Ports” allows the user to choose the COM Port if for some reason it has changed upon cycling the PB7200 while adding other hardware to the computer.

“Visualize Calibration” shows the calibration file contents and may be used by the technician for trouble shooting purposes.

3.7 SETTINGS TAB
Clicking on the “Settings Tab” from the drop down menu adds a tab to the left side labelled settings and reveals user controlled options (Figure 3.7.1).

![Figure 3.7.1: The user configurable settings are displayed in the settings tab.](image-url)
Besides being able to alter the colors of the graph traces (which can be reset to the defaults by clicking the “Default” button) the panel also has three radio control buttons at the bottom of the panel: “Display Graphs as (cm⁻¹),” “Save Basic Data Only” and “Fast Stabilize.”

Although the default units for the PB7200 are GHz, they may be switched to display wavenumbers. Regardless of the units displayed, both units are saved in the data files.

The PB7200 defaults to the “Save Basic Data Only.” In this configuration only a single data file is recorded and contains the averaged and smoothed data that is graphed in the “Smoothed Power” tab. If this check box is deselected (no check) then the PB7200 will save all the data that is taken in raw form as well as the data averaged and smoothed.

The PB7200 defaults to the “Fast Stabilize” option upon startup. This setting will only work when the PB7200 is plugged into an AC outlet. It applies a slight temperature offset to the lasers while idle making the system respond more quickly to changes to temperatures. It, in effect, helps the lasers stabilize for the very first scan. If the system is operating from battery or this check-box is deselected, the system will still stabilize the lasers, it will just take longer.

### 3.8 MONITOR TAB

Clicking on the “Monitor Tab” from the drop down menu adds a tab to the left side labelled settings and reveals data about the system (Figure 3.8.1).

![Image](image.jpg)

**Figure 3.8.1:** The monitor tab shows the conditions of various system parameters.

This tab is used primarily for trouble shooting and determining system operational issues. Selecting any of the check boxes except the laser temperatures will slow the system down as more
communication calls are required. The default settings on this tab should be left alone, but the user may be asked to look at them by a technician if there are issues.

4 DATA, FORMAT AND FILE LOCATIONS
The PB7200 GUI is intended as an interface for operating the spectrometer. It is not intended for analyzing nor plotting the data that is recorded by the spectrometer. Instead, the data is saved in comma separated values in (CSV) tables that are stored on the computer hard drive in the following directory:

C:\PB7200\Data

The data for a particular day is saved under a folder in this directory with the date as the title. For instance, data taken on December 15th, 2013 would be saved in a folder labelled:

C:\PB7200\Data\2013.12.15

Inside the date stamped folder are data files that are time stamped. If a data set was recorded on December 15th, 2013 at 17 hours 22 minutes and 30 seconds (24 hour time), the file would be:

C:\PB7200\Data\2013.12.15\17.22.30 Scan Data.csv

If the check box for “Basic Data” on the Settings Tab is checked (Section 3.6) then the data will be saved as a single data file titled “%date% Scan Data.csv” and a single notes file titled “%date% Notes.txt” (Figure 4.1.1).

![Figure 4.1.1: The folder contents after a single scan with the “Basic Data” check box checked.](image-url)
If, however, the check box for “Basic Data” on the Settings Tab is un-checked, two more files are recorded; “%date% Scan Data (Avg).csv” and “%date% Scan Data (Raw).csv”.

![Figure 4.1.2](image)

Figure 4.1.2: If the “Basic Data” box is unchecked all of the data is recorded in two extra files.

The Notes.txt file may be opened and viewed with any text editor and will contain the test parameters as well as the notes that were written in the notes box by the user. The “%date% Scan Data.csv” file can have up to eleven columns if a background scan is recorded (Table 4.1.1).

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Wavenumber (cm⁻¹)</th>
<th>Average Voltage (arb)</th>
<th>Average Power (arb)</th>
<th>Smoothed Average Voltage (arb)</th>
<th>Smoothed Average Power (arb)</th>
<th>Background Average Voltage (arb)</th>
<th>Background Average Power (arb)</th>
<th>Background Smoothed Average Voltage (arb)</th>
<th>Background Smoothed Average Power (arb)</th>
<th>Normalized Average Voltage (arb)</th>
<th>Normalized Average Power (arb)</th>
<th>Normalized Smoothed Average Voltage (arb)</th>
<th>Normalized Smoothed Average Power (arb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>201</td>
<td>6.704638313</td>
<td>7318.774678</td>
<td>5356462.79</td>
<td>5356462.79</td>
<td>5356462.79</td>
<td>7343.307186</td>
<td>53924160.43</td>
<td>53924160.43</td>
<td>0.996659202</td>
<td>0.993329564</td>
<td>0.993329564</td>
<td></td>
<td></td>
</tr>
<tr>
<td>202</td>
<td>6.737994723</td>
<td>7226.253859</td>
<td>52218744.84</td>
<td>52218744.84</td>
<td>52218744.84</td>
<td>7301.517126</td>
<td>53312152.34</td>
<td>53312152.34</td>
<td>0.989692106</td>
<td>0.979490464</td>
<td>0.979490464</td>
<td></td>
<td></td>
</tr>
<tr>
<td>203</td>
<td>6.771351133</td>
<td>7144.138802</td>
<td>51038708.94</td>
<td>51038708.94</td>
<td>51038708.94</td>
<td>7250.146002</td>
<td>52564617.05</td>
<td>52564617.05</td>
<td>0.985378512</td>
<td>0.970970813</td>
<td>0.970970813</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.1.1: A display of the first three rows of the data in the Scan Data file.

The first four columns of the Scan Data file contain the frequency in GHz, the wavenumber in cm⁻¹, the average voltage and the average power in arbitrary units. The Smoothed Average Power column displays the power with the smoothing applied. The remaining columns repeat the voltage, power and smoothed power for the background scan, and then the normalized scan which is the voltage or power divided by the background voltage or power.

NOTE: A zero (0) voltage or one (1) power is indicative of a missing datapoint. These are frequent at the beginning of scans.

NOTE: In order to average scans, it is necessary to “bin” the frequencies. Therefore, the “%date% Scan Data.csv” displays frequencies that are rounded to the nearest resolution element. The “(Raw)” data files that are recorded if the “Save Basic Data” button is unchecked will have the actual frequencies to the best of the system to measure.
As previously mentioned, if the "Save Basic Data" button is unchecked two more CSV files are generated (Figure 4.1.2). The first is titled "%date% Scan Data (Raw).csv" and it contains each scan as a separate series of four columns with Frequency, Wavenumber, Voltage and Power (Table 4.1.2).

<table>
<thead>
<tr>
<th>Frequency Requested</th>
<th>Wavenumber Requested</th>
<th>Frequency Actual (0) (GHz)</th>
<th>Wavenumber (0) (cm⁻¹)</th>
<th>Voltage (0) (arb)</th>
<th>Power (0) (arb)</th>
<th>Frequency Actual (0.5) (GHz)</th>
<th>Wavenumber (0.5) (cm⁻¹)</th>
<th>Voltage (0.5) (arb)</th>
<th>Power (0.5) (arb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>6.671281904</td>
<td>210.4564132</td>
<td>7.0201</td>
<td>-7145.918423</td>
<td>51064150.11</td>
<td>200.5741261</td>
<td>6.6904</td>
<td>7338.192407</td>
<td>53849067.8</td>
</tr>
<tr>
<td>201</td>
<td>6.704638313</td>
<td>210.4581026</td>
<td>7.0201</td>
<td>-7151.99886</td>
<td>51151087.7</td>
<td>201.5425163</td>
<td>6.7227</td>
<td>7279.690129</td>
<td>52993888.38</td>
</tr>
</tbody>
</table>

Table 4.1.2: A display of the first three rows of the data in the Scan Data (Raw) file illustrating the different column labels

The number in parenthesis after each title refers to the scan number as displayed next to the Scan Setting (Figure 3.5.4). For instance, the very first scan up in frequency is referred to as the "0" scan and the first scan down in frequency is referred to as the "0.5" scan since the scan up and then back down in frequency constitutes the first complete scan.

Finally, the last file generated "%date% Scan Data (Avg).csv" will have the data as binned for each scan up and back down in frequency and the columns are labeled to match.

Any plotting software may then be used to plot the different columns relative to the frequency and obtain the plots realized in the software.
5  APPENDIX A: FIBER INSPECTION

The most common problem with the PB7200 is due to poor fiber maintenance. The optical fiber patch cords that connect the control body to the THz heads are polarization maintaining single mode fiber that has a core that is only 5.6 micrometers in diameter. If any dirt or debris gets onto the fiber tip it can prevent the proper optical coupling and can cause permanent damage to the optical fiber face. Figure 2.2.1 illustrates a clean fiber (left) and a fiber with a burned core (right).

![Figure 2.2.1: Images of the fiber tips. The left image shows a clean fiber with a dark core while the image shows a damaged core. Note the white spot where a dark core should be.](image)

We suggest using a high quality fiber inspection scope with oblique illumination (JDSU FM-E200) to inspect the fiber end faces. Please note that you must make sure that the system is in the off and disabled state before performing a fiber end face exam.

![DANGER](image)

NOTE: The PB7200 contains two Class IIIb lasers. Laser light (780nm or 855nm, 50mW) is emitted from the optical ports of the PB7200 chassis during operation. Ensure that the
system is unplugged AND turned off before inspecting an fiber end faces. These wavelengths and power levels will damage or blind the unprotected eye.

NOTE: The PB7200 is battery operated! Unplugging the unit does not necessarily mean that the lasers are disabled. You must make sure the unit is powered off and the enable key is in the off position before inspecting any fibers.
6  APPENDIX B: NOISE LEVEL

One of the most critical PB7200 performance specifications is the dynamic range. The PB7200 has been designed very carefully to minimize what has historically had the greatest impact on dynamic range: electronic signal pick-up. With the previous THz system, the PB7100, it was discovered that when the source head and the detector head cables were near each other the high voltage lock-in amplifier signal fed to the source head would be picked up by the detector PCS cable going to the amplifier and would cause a “false” signal. This false signal contributed up to 20 dB of noise. With the latest THz system, the PB7200, this potential problem is circumvented through an improved design. However, it is still advisable to keep the source and detector head cables separated from each other and avoid looping them. Only employ a cable that is as long as is necessary to further avoid pick up.

For samples or conditions in which the signal level drops significantly, it is possible to increase the dynamic range by increasing the time constant. This will increase the length of time required for the scan linearly but will significantly improve the dynamic range. Increasing the time constant by a factor of ten will improve the dynamic range by a factor of ten.

The noise level and system performance can be measured by completely blocking the THz beam to the detector and running a scan. Because the THz radiation may bounce around, we typically employ a piece of metal foil to cover the entire front of the detector head while making this measurement.
7 APPENDIX C: WATER VAPOR TRANSITIONS

It is fairly typical on broad bandwidth scans to use the THz transitions of atmospheric water vapor to further refine the calibration on the frequency. These transitions are clearly visible in the following plot (Figure 7.1.1).

![Graph showing water vapor transitions](image)

**Figure 7.1.1:** A 1700 GHz scan of atmospheric water vapor in a 1 ft. path length with 1 GHz resolution and a 1 sec time constant as compared to a scan with a blocked path. Inset is a rescan at higher resolution clearly showing the five water transitions.

The strongest transitions and their corresponding frequencies are listed here.

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Integrated Intensity (nm² MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>556.936</td>
<td>-0.81</td>
</tr>
<tr>
<td>752.033</td>
<td>-1.00</td>
</tr>
<tr>
<td>1097.364</td>
<td>-0.32</td>
</tr>
<tr>
<td>1113.342</td>
<td>-0.83</td>
</tr>
<tr>
<td>1162.911</td>
<td>-0.28</td>
</tr>
<tr>
<td>1207.638</td>
<td>-0.78</td>
</tr>
<tr>
<td>1228.788</td>
<td>-0.85</td>
</tr>
<tr>
<td>1410.618</td>
<td>-0.37</td>
</tr>
<tr>
<td>Frequency</td>
<td>Intensity</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>1602.219</td>
<td>-0.69</td>
</tr>
<tr>
<td>1661.007</td>
<td>-0.27</td>
</tr>
<tr>
<td>1669.904</td>
<td>0.10</td>
</tr>
<tr>
<td>1716.769</td>
<td>0.07</td>
</tr>
<tr>
<td>1794.788</td>
<td>-0.95</td>
</tr>
<tr>
<td>1797.158</td>
<td>-0.82</td>
</tr>
<tr>
<td>1867.748</td>
<td>-0.33</td>
</tr>
<tr>
<td>1919.359</td>
<td>-0.57</td>
</tr>
</tbody>
</table>

Water has many transitions in the THz frequency regime. For the complete list for water and other compounds visit the Jet Propulsion Laboratory Molecular Spectroscopy data base at: http://spec.jpl.nasa.gov/
APPENDIX D: DC THZ SOURCE BIAS

The PB7200 employs a lock-in amplifier which requires that the THz source photomixer bias be modulated at 6 kHz. The peak-to-peak bias level is 40V and switches between a forward bias of 20V and a reverse bias of 20V. For power detectors, this poses a problem since the average current through the photomixer antenna is zero. In order to make the PB7200 more versatile, the source photomixer may be biased with a constant 20V DC bias simply by removing the cover from the head and switching the electrodes that the PCS is attached to (Figures 7.0.1, 7.0.2, 7.0.3).

NOTE: Please ensure that the system is powered down before disconnecting the head units.

Figure 7.0.1: A picture illustrating the position of the AC and DC Pins

Figure 7.0.2: An image showing the PCS bias connected to the AC bias pins. This is the default position and is required for using the PB7200 detector head.
Figure 7.0.3: An image illustrating the PCS bias connected to the DC pins.

**NOTE**: Be extremely careful when working near the optical fiber and avoid pinching it or kinking it as this may cause it to break.

This configuration may be useful for the researcher who would like to employ the PB7200 as a source for THz radiation. Be very careful not