



Gentec-EO USA

T-RAD-USB Users Manual

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System Overview

Welcome to the T-Rad-USB Application Software. This software, when coupled with a Gentec-EO T-Rad-USB, provides the user with a versatile measurement system. There are multiple sensors available for the system. When a sensor is mated to the USB module, the module reads the sensor type, sensor calibration, sensor wavelength response, and configures the hardware appropriately. When the Application software is started it queries the T-Rad-USB and configures itself for the appropriate measurement system. For this reason the application software will not always show all control and indicators, i.e., it will not have Trigger controls and indicators for an Optical Power Meter.

The Applications Software communicates with the host PC via a USB port. The system uses the T-Rad-USB Command Set to do this.

Data is sent to the host PC when the instrument has had its data gate turned on. The sampled data is sent to the application at 1 kHz. The Lock In algorithm is implemented in the application.

Lock In Amplifier Theory of Operation

The operation of a Lock In Amplifier can seem mysterious given its ability to pull a useful signal out of noise and interference, but the basics of operation are not complex. A lock in amplifier's operation can be explained in three ways: mathematically, in the time domain, or in the frequency domain. While all explanations are equally useful, the one that makes sense to the user is the most useful, so a brief description of all three will be presented.

Mathematical Description of a Lock In Amplifier.

Fourier Theory tells us that all repetitive signals can be broken down into a series of sine's and cosines. Because of this fact, we can describe the lock in operation using a signal that is a pure cosine wave. To go further, even if the input signal is not a pure cosine wave, the lock will extract the pure cosine wave component of the signal anyway, so the approach is justified. Consider an input signal, $v(t)$, given by:

$$v(t) = A \cdot \cos(\omega \cdot t) \quad \omega = 2 \cdot \pi \cdot f$$

Now consider a second signal, the reference signal, given by:

$$v_{ref}(t) = B \cdot \cos(\omega \cdot t + \phi) \quad \omega = 2 \cdot \pi \cdot f \quad \phi \text{ is the phase difference between the two signals}$$

This reference signal is at the same frequency as the input signal and is supplied by the lock in.

If we multiply the two signals, we get:

$$\begin{aligned}
 v(t) \cdot v_{ref}(t) &= V_{psd}(t) A \cdot \cos(\omega \cdot t) \cdot B \cdot \cos(\omega \cdot t + \phi) \\
 V_{psd}(t) &= A \cdot B \cdot \cos(\omega \cdot t) \cdot [\cos(\omega \cdot t) \cdot \cos(\phi) - \sin(\omega \cdot t) \cdot \sin(\phi)] \\
 V_{psd}(t) &= A \cdot B \cdot [\cos^2(\omega \cdot t) \cdot \cos(\phi) - \cos(\omega \cdot t) \cdot \sin(\omega \cdot t) \cdot \sin(\phi)] \\
 V_{psd}(t) &= A \cdot B \cdot \left[\left(\frac{1}{2} + \frac{1}{2} \cdot \cos(2 \cdot \omega \cdot t) \right) \cdot \cos(\phi) - \frac{1}{2} \cdot \sin(2 \cdot \omega \cdot t) \cdot \sin(\phi) \right] \\
 V_{psd}(t) &= \frac{1}{2} \cdot A \cdot B \cdot \cos(\phi) + \frac{1}{2} \cdot A \cdot B \cdot \cos(2 \cdot \omega \cdot t)
 \end{aligned}$$

If we set B to unity and hold it constant, then the result is a signal that is:

1. Proportional to the A, the amplitude of the input signal.
2. Proportional to the cosine of the phase angle between the two signals.
3. Modulated at two times the input signal frequency.

If we set the phase difference to zero degrees then the resulting signal can be passed through a low pass filter with a time constant of tau and the result will be:

$$V_{out}(t) = \frac{1}{2} \cdot A \cdot \left(1 - e^{-\frac{t}{\tau}} \right)$$

This shows that once the filter has settled, the signal is a DC representation of the original input. We can now set the filter time constant as high as needed to block out unwanted noise and interference. The details of how the lock in implements this math can be found in the literature.

One subject of interest arises from the requirement to set the phase difference to zero degrees. In practice, the phase difference is not known. Since the cosine function returns values between one and negative one as the phase is changed, the phase is simply adjusted until the signal maximizes. It is actually easier to adjust the phase until the signal goes to zero and then shift the phase by 90 degrees. If the signal goes negative, shift the phase 180 degrees. The signal will now be maximized.

If this seems like a bother, it is. The Gentec-EO Lock In Amplifier uses a dual phase approach which relieves the user of the need to adjust the phase. A sine wave signal is generated by the instrument at the reference frequency, and at the reference frequency plus 90 degrees, or pi divided by 2. The input signal is multiplied by both reference signals. The results of those multiplications are then squared, summed, and the square root is taken. Look at the final equation for the output after the multiplication, ignoring the second term:

$$V_{psd}(t) = \frac{1}{2} \cdot A \cdot B \cdot \cos(\phi)$$

The output of the second multiplication will be:

$$V_{psd}(t) = \frac{1}{2} \cdot A \cdot B \cdot \cos\left(\phi + \frac{\pi}{2}\right) = \frac{1}{2} \cdot A \cdot B \cdot \sin(\phi)$$

If we square these and add them together we obtain:

$$V_{sum}(t) = \frac{1}{4} \cdot A^2 \cdot B^2 \cdot \cos^2(\phi) + \frac{1}{4} \cdot A^2 \cdot B^2 \cdot \sin^2(\phi)$$

$$V_{sum}(t) = \frac{1}{4} \cdot A^2 \cdot B^2 \cdot (\cos^2(\phi) + \sin^2(\phi)) = \frac{1}{4} \cdot A^2 \cdot B^2$$

Now taking the square root gives:

$$V_{psd}(t) = \frac{1}{2} \cdot A \cdot B$$

The output of the multiplication is no longer phase dependant.

Time Domain Description of a Lock In Amplifier.

The input signal has peak amplitude of 5V (10V peak to peak) and a frequency of 25Hz and is shown in figure 1.

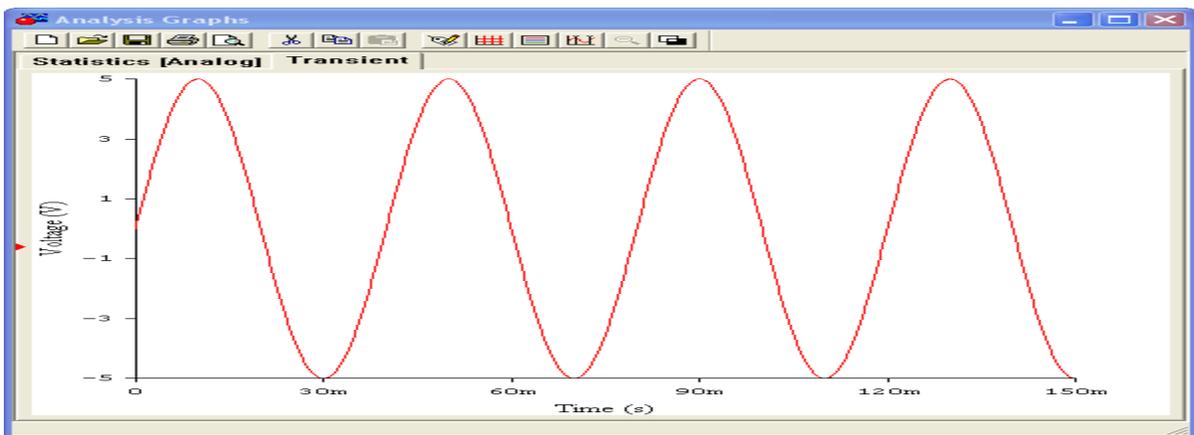


Figure 1, Input Signal

The reference signal supplied by the lock in signal has peak amplitude of 1V and a frequency of 25Hz and is shown in figure 2.

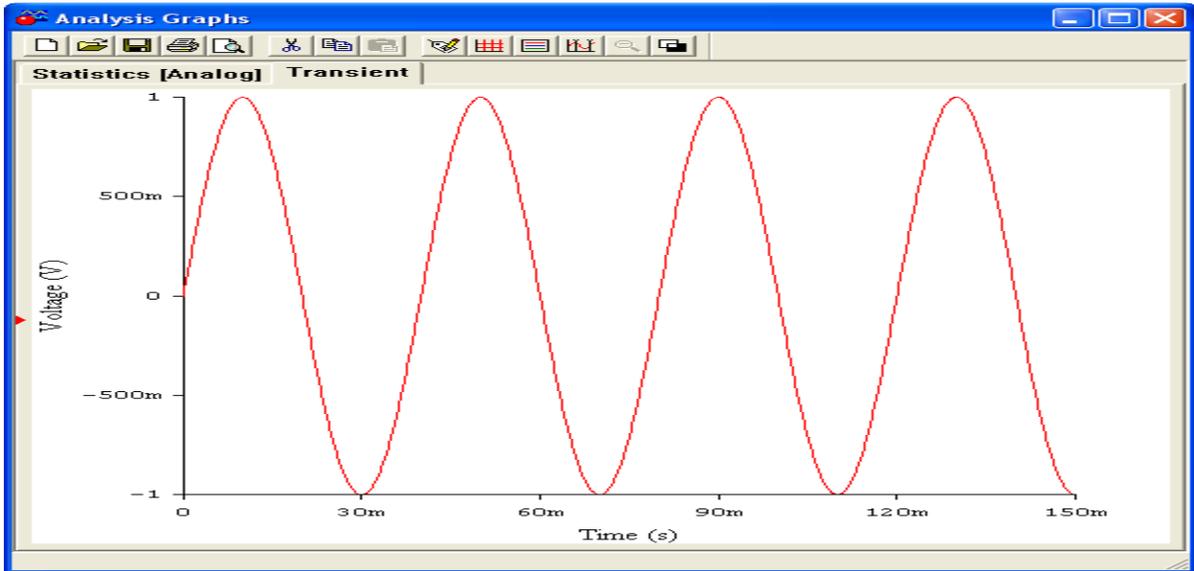


Figure 2, Reference Signal

After multiplying the two signals using a circuit called a Phase Specific Detector in an analog lock in, or by direct math in a digital lock in, the output signal is shown in figure 3. Note that its peak to peak amplitude is 5V, or $\frac{1}{2}$ of the input and its frequency is 50Hz, or twice the input frequency. Also note it now has a DC offset of the peak voltage of the input signal divided by 2 as predicted. This DC offset is what the low pass filter will pull from figure 3.

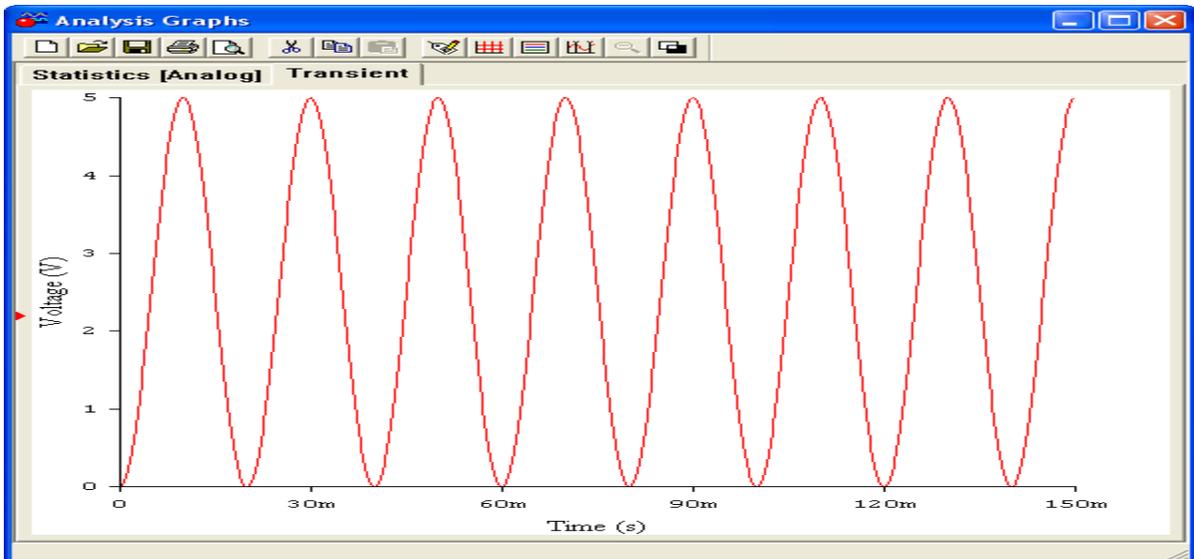


Figure 3, Result of Multiplication

Figure 4 shows the output using a 100ms time constant. Note that the ripple is still visible on the DC level.

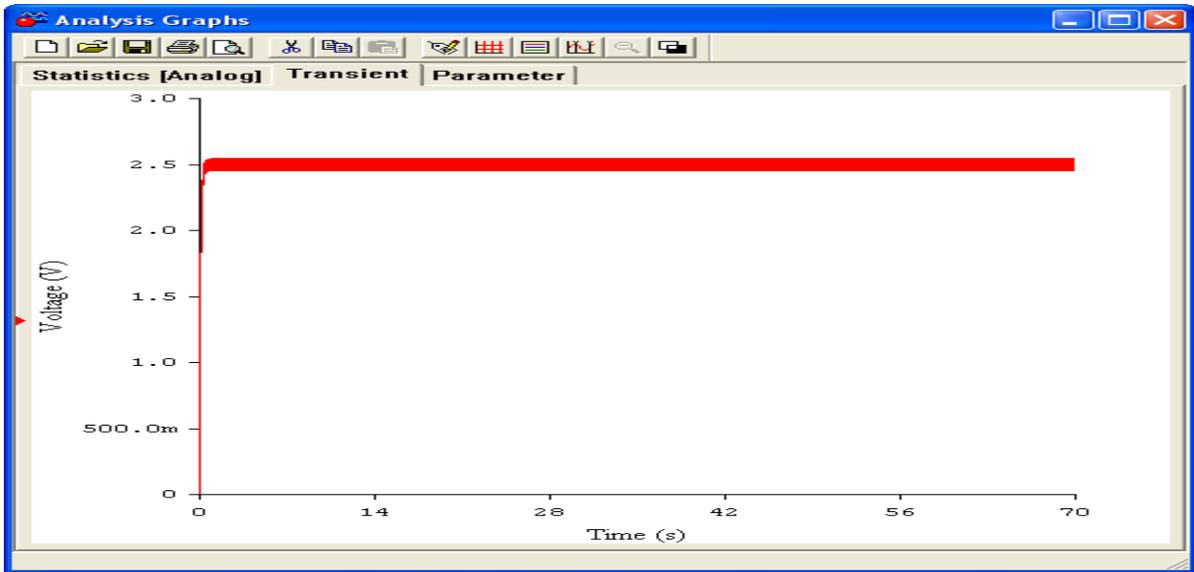


Figure 4, Output with 100ms Time Constant

Figure 5 shows the output using a 1s time constant. Note that the ripple is greatly reduced.

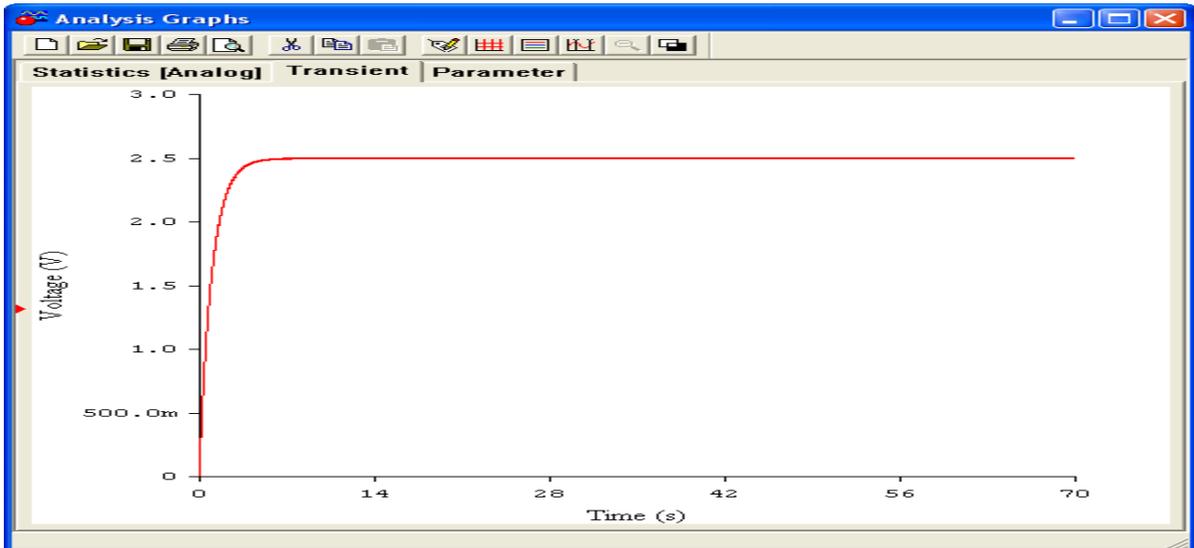


Figure 5, Output with 1s Time Constant

Frequency Domain Description of a Lock In Amplifier.

Figure 6 shows the frequency contents of a 25Hz square wave with a 60Hz interference signal and broadband noise at about 1% of the signal.

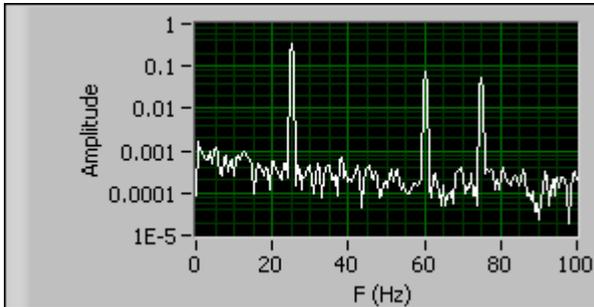


Figure 6, Corrupted Input Signal

Since the input is a square wave, there are only odd harmonics. The fundamental is seen at 25Hz, the 3rd harmonic is seen at 75Hz, and the 60Hz interference is seen. Remember when we said that even if the input signal is not a pure sine wave, the lock will extract the pure sine wave component of the signal? Figure 6 shows why this is so. The reference signal is a pure sine wave at the same frequency as the input signal so only the fundamental sine wave component of the input signal is extracted. Of course this statement depends on the purity of the reference sine wave. In an analog system, a pure sine wave cannot be generated due to distortion and phase noise as well as frequency jitter. All of these combine to decrease the accuracy of the instrument. Since the Gentec-EO Lock In Amplifier is a digital device, the reference sine wave is pure to a much greater extent and these errors are minimized.

Figure 7 shows the spectrum of the signal after it has been passed through a band pass filter set to 25Hz.

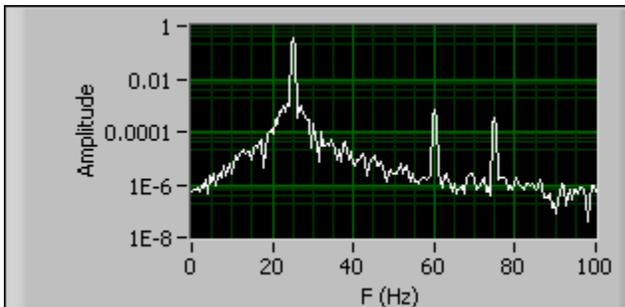


Figure 7, Band Pass Filtered Corrupted Input Signal

Note that the relative amplitude of the 60Hz and 75Hz signals have been reduced by the band pass filter. The noise floor has also taken on the shape of the filter. Figure 8 shows the spectrum of the multiplied signal.

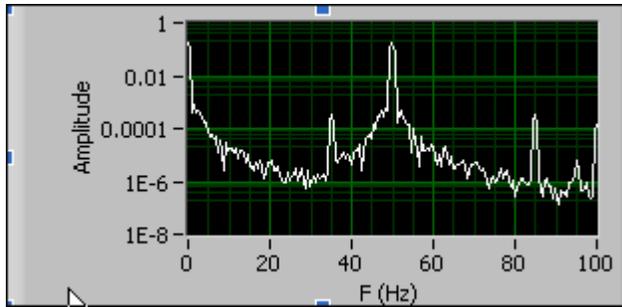


Figure 8, Phase Specific Detector Output Signal

The multiplier action moves the signal to the frequencies at the sum and difference of the signal and the reference frequency at 25Hz. Therefore the signal at 25Hz will move to 0Hz and 50Hz, as seen. The 60Hz interference will move to 85Hz and -35Hz, not shown here. The odd harmonic of the input signal at 75Hz moved to 100Hz and 50Hz, where it will add to the frequency shifted signal. These signals can now be low pass filtered to extract the DC component.

Communications with Host PC

The T-Rad-USB communicates with the host PC via a USB port. The device supports full speed USB 2.0. The implementation of the port in the host PC is accomplished via a Virtual Com Port, or VCP. This in effect mimics a standard com port so that the user can take advantage of the ease of developing custom applications with existing terminal emulators.

The Ports Settings are:

Baud Rate : 921600
Data Bits : 8
Stop Bits : 1
Parity : None
Flow Control : None

The host PC must have a terminal emulator as well as the T-Rad-USB USB drivers installed. These drivers are installed by the disc supplied with the T-Rad-USB instrument.

Data Format

Measurement Data is sent from the T-Rad-USB as an Hexadecimal string.

The format is: DDDDCRLF

Where DDDD is a 12 bit value representing the ADC counts and terminated by a carriage return followed by a line feed. The Lock in Amplifier algorithm is implemented in the Applications Software.

Instrument Connections

The T-Rad-USB is connected to the host PC with a supplied USB cable. The instrument communicates with the host PC via this cable, and the host PC supplies the power required by the instrument.

There are two BNC's and one Lemo connector on the instrument. The probe in use is plugged into the Lemo connector and must be plugged in before connecting the USB cable. One BNC is labeled Detector Output, the other is labeled External Trigger In.

The Detector Output BNC supplies a buffered signal that is the same value sampled by the instrument's ADC. The output impedance of this connector is 100Ω.

The External Trigger Input is the connection for the reference chopping frequency. This signal's frequency is measured by the instrument and used to generate the reference sine wave described in the Theory of Operation section. This BNC should be connected to the Sync Output BNC of the chopper controller in use.

Using the Instrument

To use the T-Rad-USB, connect the probe to the instrument first, then plug the instrument into the USB connector on the PC that is running the Applications Software. Connect the chopper frequency reference to the External Trigger Input BNC. Now start the software. A window will appear, as shown below.



Press the Proceed button. The software will examine the available communications ports and establish communications with the instrument. When the WAIT prompt disappears from the data display, the software and instrument are ready to use. The T-Rad-USB is not a triggered device. It is always taking data, but it will not send data to the application until asked to do so. Pressing the Data Collection Button causes data to be sent to the application where the lock in algorithm is implemented. The user need only select an appropriate range and filter time constant.

The Frequency Range indicator will display the correct chop rate to use. If the range is 24.5 HZ to 25.5HZ, set the chopper to 25Hz. The instrument will extract the signal at the reference frequency. Note that if there is any other signal with components at the reference frequency, they will be measure along with the desired signal. The longer the filter time constant, the longer it will take to settle on a reading, but the more noise and interference will be rejected. The user must make a tradeoff between measurement time and accuracy when using a lock in amplifier. It will

take 5 time constants for the reading to settle to 1%, 7 time constant for the reading to settle to 0.1%. Fluctuations in the signal after this amount of time are not due to the lock in settling time but are real signal variations.

The subsequent sections explain in detail how to use the Applications Software to makes measurements.

Using the Applications Software

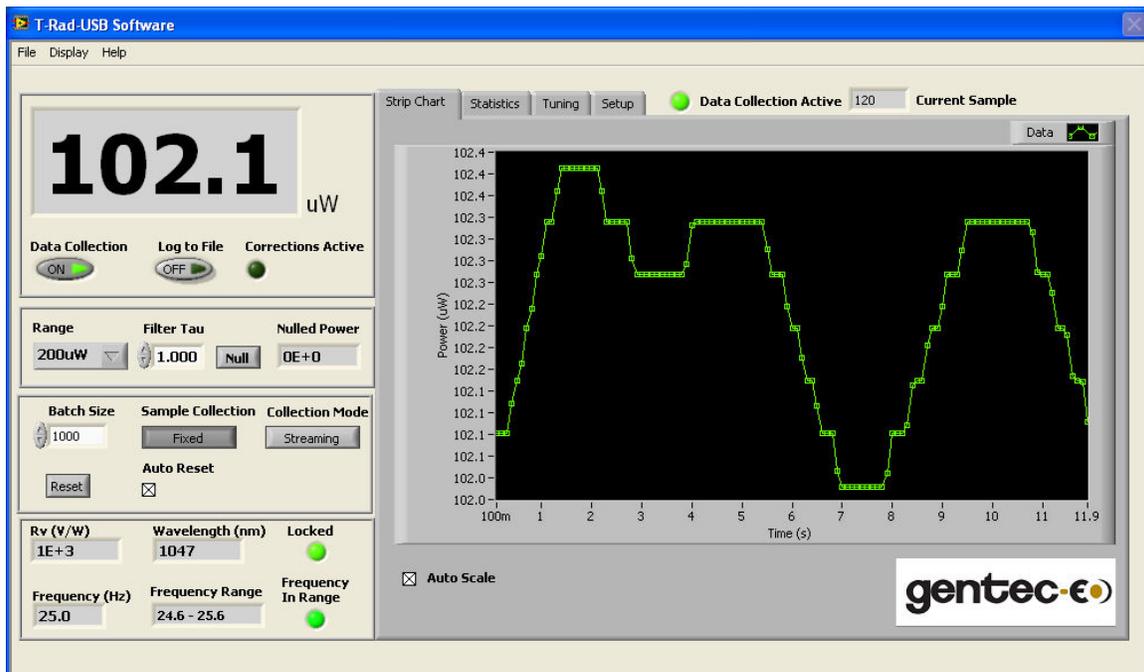
The Main Display Panel

The Main Display Panel has five display regions. They are:

1. The Digital Display which is always visible.
2. The Strip Chart, which is on a user selectable tab.
3. The Statistics Display, which is on a user selectable tab.
4. The Tuning Needles, which are on a user selectable tab.
5. The Setup Controls, which are on a user selectable tab.

The Digital Display

The Digital Display is always visible to the user. It contains Controls and Indicators. A control is an input to the application set by the user. An indicator is an output from the application for use by the user.



Digital Controls

The Controls on the Digital Display area are:

Data Collection
Log to File
Range
Filter Tau
Null
Batch Size
Reset
Auto Reset
Sample Collection
Collection Mode
Time Interval

Data Collection

Data Collection Control. When active the data is collected for display if the device is triggered. Data Collection is suspended if another control is activated, then resumed when the other control is released. This is done to prevent the communications buffers from overflowing.

Do Not disconnect the device when Data Collection is active.

Log to File

Log data to selected file. if no file is currently open, a prompt will request the file to log data to. Data files can be opened, saved, closed and viewed via the File menu.

Range

Selects the desired device measurement range.

Filter Tau

Sets the time constant of the low pass filter used in the Lock In Amplifier.

Null

Subtracts the value of displayed Power or Irradiance when pressed from the subsequent measured values. Releasing the control returns to normal measurements.

Note that the total maximum displayed measurement, that is the measured value plus the Nulled value, cannot exceed the selected Range when Null is active.

Batch Size

The Batch Size to collect in Fixed Sample Collection Mode. Resets with the Reset Button or Auto Reset.

If the Current Sample exceeds the Batch Size when Fixed Sample Collection is selected, a Reset must be issued to start the new batch.

Reset

The Reset button resets the current data set in all collection modes.

Auto Reset

Resets the batch when the Current Sample meets the Batch Size if in Fixed Sample Collection mode.

Sample Collection

Sample Collection is:

Continuous. Data is streamed whenever Data Collection is on.

Fixed. Data is collected whenever Data Collection is on until the Current Sample meets the Batch Size.

Collection Mode

Collection Mode is:

Streaming. Data is streamed at the data frequency rate.

Time Interval. Data is collected when the selected time interval is met. The Time Interval control is shown when Collection Mode is set to Time Interval.

Time Interval (s)

The Time Interval to wait between taking a data point. Intervening data points are discarded.

Digital Indicators

The Indicators on the Digital Display area are:

Live Data
Rv
Wavelength (nm)
Frequency (Hz)
Frequency Range
Frequency In Range
Locked
Current Sample
Corrections Active

Live Data

The Main Display for:

Power (W) or Irradiance (W/cm²) .

Rv

Responsivity in V/W of the sensor for the selected Range.

Wavelength (nm)

The wavelength of the light source being measured. Enter this value on the Setup Tab.

Frequency (Hz)

The frequency of the measured data in Hz. Resolution is 0.1Hz.

Frequency Range

The allowed range of chopper (Radiometers) frequencies.

Frequency in Range

Illuminates when the Frequency is within the calibrated range.

Locked

Illuminates when the device is Locked to the synthesized reference frequency used by the Digital Lock In algorithm and Data Collection is active.

Current Sample

The current sample in the batch. Resets with the Reset Button or and Auto reset in Fixed Sample Collection Mode.

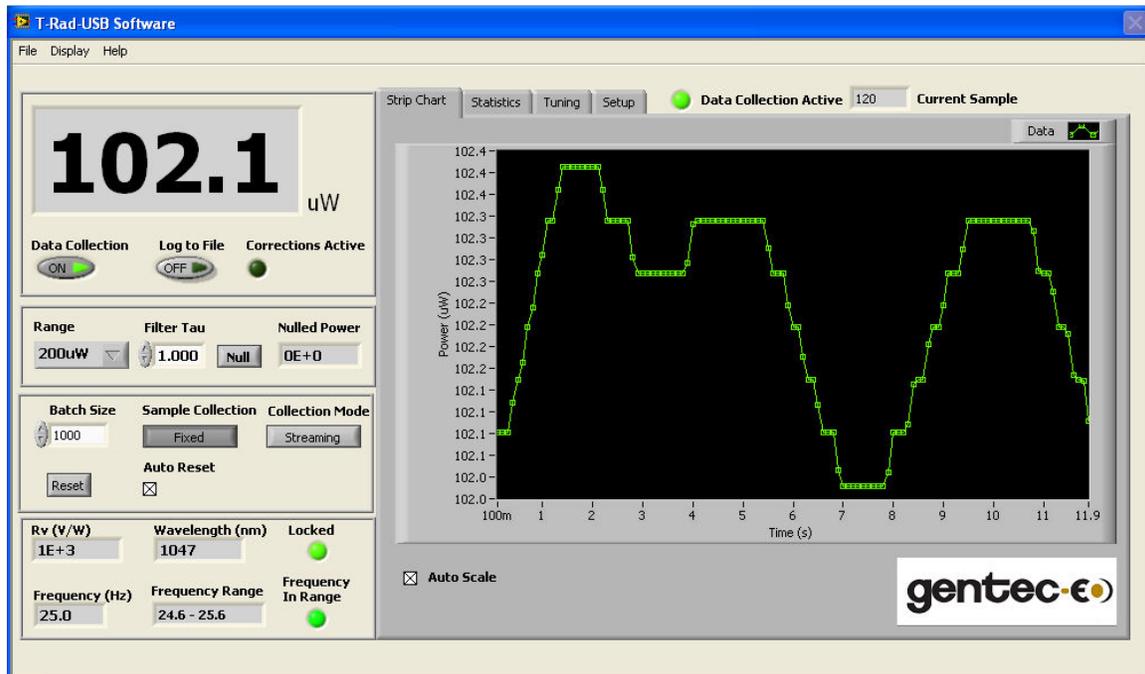
If the Current sample exceeds the batch size when Fixed is selected, a Reset must be issued to start the new batch.

Corrections Active

Illuminates when Wavelength Corrections or Transmissivity Corrections or Area Corrections are active.

The Strip Chart Display

The Strip Chart Display is visible to the user when its tab is selected. It contains Controls and Indicators for the Strip Chart.



Strip Chart Controls

The Controls on the Strip Chart area are:

Auto Scale

There are more Strip Chart Display controls available in the Display Options Menu

Auto Scale

Auto Scales the Strip Chart Display to the running minimum and maximum values in the data set.

Strip Chart Indicators

The Indicators on the Strip Chart area are:
Strip Chart Plot

Strip Chart Plot

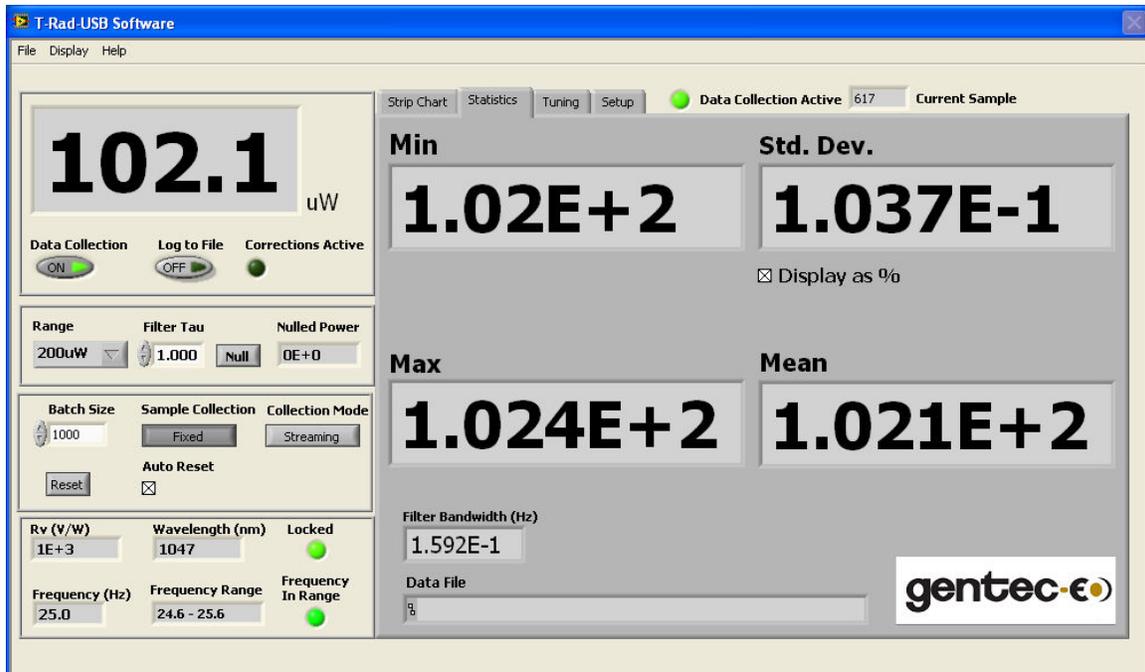
Displays each data point as it is acquired.
In Continuous Mode the plot functions as a strip chart and fills until Data Collection is turned off.
In Fixed Mode the plot functions as a strip chart and fills until Batch Size is met. On Reset the chart clears and refills with the new batch.

Right click on the Data Icon to set the Plot Options.
Right click on the X-Axis set the X-Axis Options.
Right click on the Y-Axis set the Y-Axis Options.

Min and Max Tracking Cursors can be set using the Display Options Menu.

The Statistics Display

The Statistics Display is visible to the user when its tab is selected. It contains Controls and Indicators for the statistics on the data set.



Statistics Controls

There is a single control on the Statistics tab; Display as %.

Display as %

Displays the Std. Dev. as a percentage of the Mean.

Statistics Indicators

The Indicators on the Statistics tab are:

Min
Max
Mean
Standard Deviation
Filter Bandwidth
Data File

Min

The minimum value of the current data set. Resets with the Reset button or an auto reset when in Fixed Sample Collection mode. Updates on each sample.

Max

The maximum value of the current data set. Resets with the Reset button or an auto reset when in Fixed Sample Collection mode. Updates on each sample.

Mean

The Mean of the current data set. Active in Fixed Sample Collection mode. Updates when the Batch Size is met. Resets with the Reset button or an Auto Reset when the Batch Size is met.

Standard Deviation

The standard deviation of the data set. This can be interpreted as the RMS noise.

Standard Deviation and Variance Details:

The VI calculates the output values using the following equations.

$$\mu = \sum_{i=0}^{n-1} [X_i / n]$$

where μ is mean and n is the number of elements in X .

standard deviation = Q^2

$$Q^2 = \sum_{i=0}^{n-1} [(X_i - \mu)^2 / (n - 1)]$$

where Q is variance, μ is mean.

Filter Bandwidth

The filter bandwidth that results from the selected filter Tau.

Data File

The path of the currently open data file. If the indicator is empty, no file is currently open to log data.

The Tuning Needles Display

The Tuning Needles Display is visible to the user when its tab is selected. It contains Controls and Indicators for the Tuning Needles.



Tuning Needles Controls

The Controls on the Tuning Needles area are:

Tuning Scale

T-Rad-USB Operating Instructions

121-201795

11/15/2010

Page 17 of 24

Reset Needles

Tuning Scale

Use this button to select the scaling range of the tuning meter.

Min - Max: sets the low end of the scale range to the Minimum value in the data set and the high end of the scale range to the Maximum value in the data set since the last Reset Needles.

Zero - Max: sets the scale range from Zero to the Maximum of the measurement Range.

Reset Needles

Resets the Minimum and Maximum to the value of Current.

Tuning Needles Indicators

The Indicators on the Tuning Needles area are:

Tuning Needles
Current
Minimum
Maximum
Current Sample
Data Collection Active

Tuning Needles

Displays the Maximum (**Red Needle**), Minimum (**Blue Needle**) and the Current (Black Needle) measured value. Scale Range is set with the Tuning Scale control.

Minimum and Maximum are reset when Reset Needle is pressed.

Current

The Current Measured Value.

Minimum

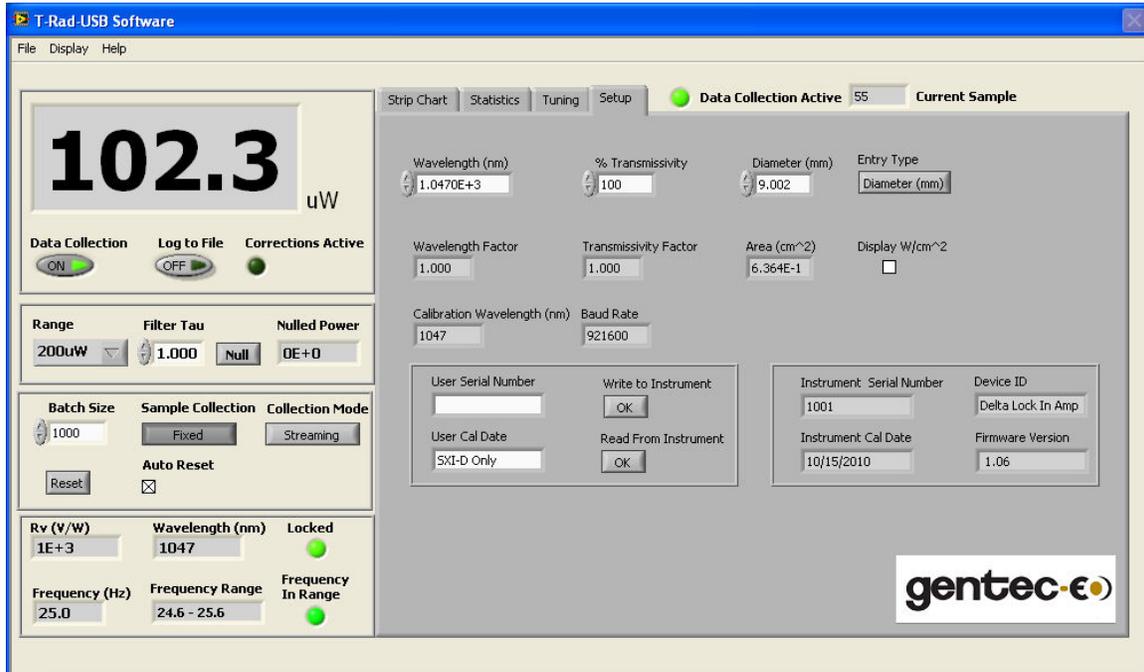
The Minimum Measured Value.

Maximum

The Maximum Measured Value.

The Setup Display

The Setup Display is visible to the user when its tab is selected. It contains Controls and Indicators for the Setup.



Setup Controls

The Controls on the Setup area are:

- Wavelength (nm)
- % Transmissivity
- Diameter (Area)
- Entry Type
- Display W/cm²
- User Serial Number
- User Calibration Date
- Write to Instrument
- Read From Instrument
- Zero Baseline
- Reset Instrument

Wavelength (nm)

Enter the Wavelength of the light source being measured.

Wavelengths other than the calibration wavelength may result in wavelength corrections being applied. If corrections are applied, the Corrections Active LED will illuminate.

To view the wavelength response of the sensor, use the Display menu item.

% Transmissivity

Enter the Transmissivity of external optics being used.

Diameter (mm) or Area (cm²)

Enter the Diameter or the Area, based on the Entry Type, of the light source or external aperture being used.

Entry Type

Change the Diameter control to an Area control.

Display W/cm²

Toggles the data displays from Watts to Irradiance. Uses the Area indicator to compute the values.

User Serial Number

The User Serial Number. Stored in persistent memory

User Calibration Date

The User Calibration Date. Stored in persistent memory

Write to Instrument

Writes the User Serial Number and the User Cal Date to the persistent memory of the device.

Read From Instrument

Reads the User Serial Number and the User Cal Date from the persistent memory of the device.

Setup Indicators

The Indicators on the Setup area are:

Wavelength Factor
Transmissivity Factor
Area (cm²)



T-Rad-USB Serial Number
T-Rad-USB Calibration Date
Device ID
Firmware version

Wavelength Factor

The correction factor for the current Wavelength.

Transmissivity Factor

The correction factor for the current Transmissivity.

Area (cm²)

The current Area of the measured beam.

T-Rad-USB Serial Number

The Factory Serial Number.

T-Rad-USB Calibration date

The Factory Calibration Date.

Device ID

The Device ID of the instrument plugged into the USB.

Firmware Version

The Device Internal Firmware Version.

Application Menus

The T-Rad-USB Application Software has three main menu items, each with its own sub menus. They are:

The File Menu
The Display Menu
The Help Menu

The "File" Menu

The **File** menu is used to open, close, and view data sets. The menu items are:

- Open Data File
- Close Data File
- View Existing Data File
- Print Window
- Exit

Open Data File

Opens a File too write data to. User is allowed to name a new file or overwrite an old one.

Close Data File

Closes the currently open data file.

View Existing Data File

Allows the user to choose an existing data file for viewing with the Data Analysis Panel.

Print Window

Prints the current window.

Exit

Exits the Application. Closes all open files and stops the T-Rad-USB data stream. Exit saves the state of all Application Controls and restores them on restart.

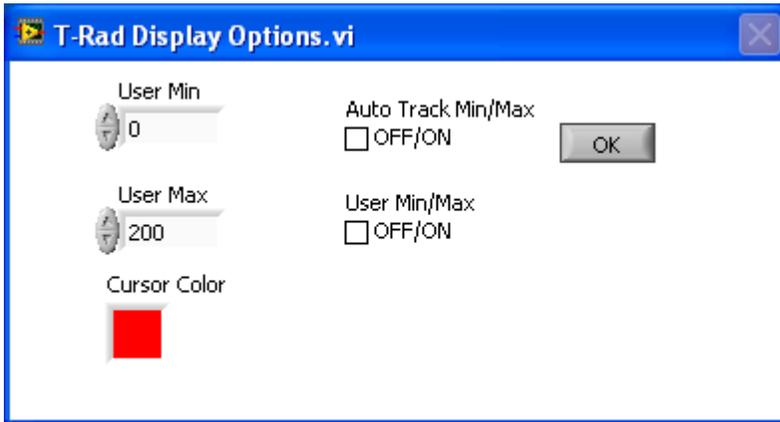
The "Display" Menu

The **Display** menu is used to modify the characteristics of the Digital Display and the Strip Chart. It also displays the Wavelength Correction Table stored in the sensor. The menu items are:

- Display Options
- View Wavelength Correction Table

Display Options

Calls new panel that allows the user to set Cursors on the Strip Chart, Cursor Colors, and Cursor Range.



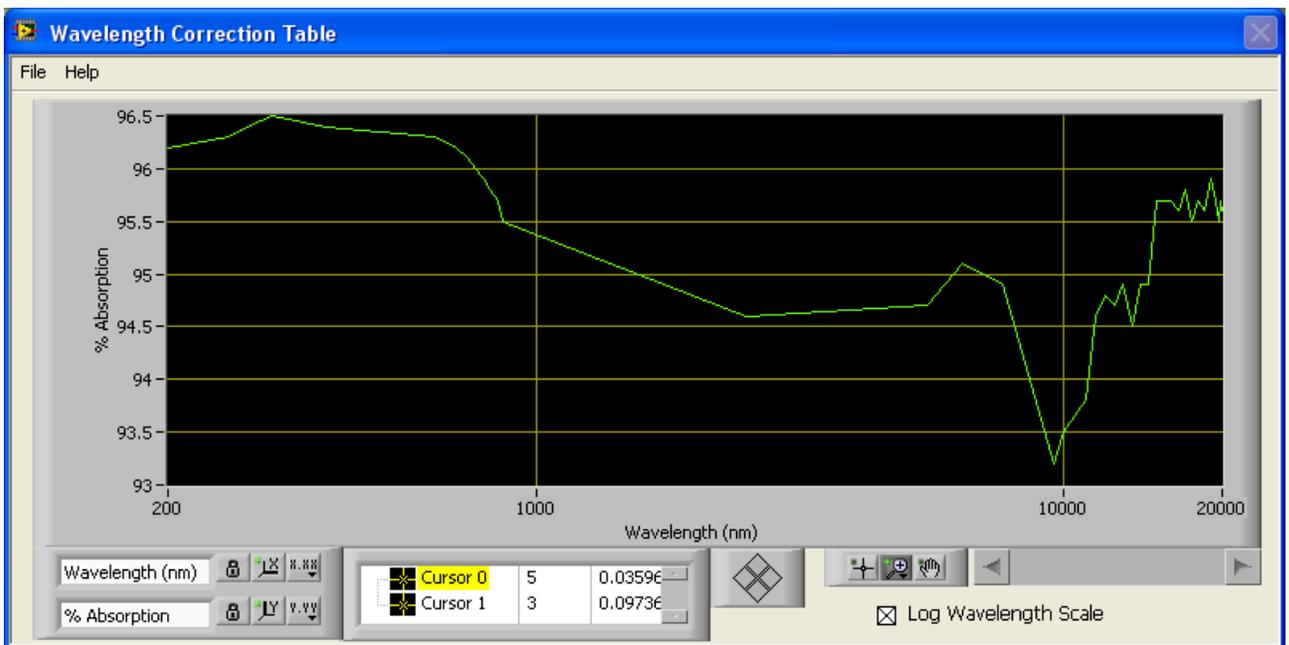
If Auto Track Min/Max is selected, then the Cursors track the min and max values in the data set.

If User Min/Max is Checked, then User Min and User Max sets the Cursor Range.

Right click on the Cursor Color Box to display a color palette.

View Wavelength Correction Table

Calls new panel that allows the user to View the Sensor Wavelength Correction Curve.



The "Help" Menu

The **Help** menu is used to display help for the Application. The menu items are:

Help
Show Context Help
About

Help

Calls this Help file.

Show Context Help

Shows a Context Sensitive Help Window when the Mouse Cursor is over a Control or Indicator.

About

Application Information is Displayed.