LISST-Tau

High-Precision Transmissometer

User's Manual

Version 1.33

July 27, 2021

Store Software USB Card Here

2700 Richards Road, Suite 107
Bellevue, WA 98005-4200
Tel: +1 (855) 753-3313

This page intentionally blank.

LISST-Tau High-Precision Transmissometer

Technical assistance

For technical assistance please contact your local Distributor or Sequoia. Please be sure to include the instrument serial number with any correspondence.

Sequoia Scientific, Inc. contact information:
Telephone: +1 (855) 753-3313
Email: Support@sequoiasci.com

This page intentionally blank.

Table of Contents

I. INTRODUCTION AND TUTORIAL 1

A. GENERAL DESCRIPTION 1

B. QUICK START TUTORIAL 2

II. OPERATION DETAILS 5

C. STEP BY STEP PROCEDURES 6

1. Installing LISST-Tau Software 6

2. Establishing Communication with the LISST-Tau 7

3. Using the LISST-Tau software 9

4. Cleaning Windows 13

5. Clean-water Baseline Measurement (Calibration) 14

D. INSTRUMENT COMMUNICATION 15

E. SERIAL COMMANDS 16

F. ANALOG OUTPUT 19

APPENDIX A: TECHNICAL SPECIFICATIONS 20

APPENDIX B: DATA OUTPUT FORMAT 22

APPENDIX C: PARSING SERIAL DATA STRING 24

APPENDIX D: ELECTRICAL CONNECTIONS 25

APPENDIX E: MEASUREMENT DESCRIPTION 26

REVISION HISTORY 28

This page intentionally blank.

I. Introduction and Tutorial

A. General Description

Instrument Description

The LISST-Tau measures the transmission (and inversely, attenuation) of light in water, at a single narrow wavelength range centered on either 532 or 650 nm. Its rugged aluminum housing and high-resolution digital electronics provide outstanding measurement quality in any in-situ application at depths up to 2000 meters.

LISST-Tau generates a beam of light from an LED, formed by a lens into a uniform, low-divergence beam. The LED is modulated at 1000 Hz. 532-nm LISST-Tau models also have a spectral filter to control the spectral bandwidth. A beam splitter and reference detector measure the beam intensity before it enters the water. On the receiver side, a lens and pinhole capture all the light arriving at angles less than 1.0 degree. The receiver electronics sample the incoming light at 1000 Hz, synchronously with the modulation of the LED source, rejecting light from solar background or other sources.

A digital controller receives the digitized signals and applies appropriate calibration factors to generate the final transmission and attenuation values. The processing includes applying corrections for the small residual effects of temperature on the measurements. Factory calibration of every LISST-Tau includes measuring its response across the full temperature range.

The controller transmits digital data, once per second, via its RS-232 serial interface at 19200 baud. The digital data stream includes calibrated, temperature-corrected transmission and beam attenuation, as well as raw signal values, temperature, etc. LISST-Tau also produces an analog voltage proportional to transmission, for compatibility with any analog-input CTD or logging system.

Included Accessories

The LISST-Tau is shipped pre-calibrated and tested in a Pelican ship case. Included with the instrument are a USB power and communication cable, instrument stands, User's Manual and USB card with software. The supplied USB cable provides both power and communication for the LISST-Tau, when used with any PC or tablet running Microsoft Windows.

The LISST-Tau Windows application communicates with the instrument, displays and records data, and allows simple checking of operation before deployment. The software provides real-time display of transmission or beam attenuation, and a function for recording the clean-water baseline.

B. Quick Start Tutorial

Contents of Shipping Case

Let us assume that you are opening the LISST-Tau shipping case for the first time. Inside you will find the following:

- LISST-Tau instrument,
- User's Manual,
- USB Communications and Power cable,

USB memory card (credit card size) with the software.

1: Remove Instrument from Shipping Case

WARNING: The LISST-Tau can easily roll from a table or other hard, flat surface. Place it on something soft, such as a towel, or position it where it will be blocked from rolling. Connecting the cable will also reduce the chances of rolling.

2: Attach Communication and Power Cable

Remove the Communications cable from the ship case. Remove the dummy plug (cap) from the underwater connector on the LISST-Tau. Connect the cable to the LISST-Tau, being careful to match the orientations of the connectors. Plug the USB cable into the computer. Please note that USB drivers may automatically install the first time the USB cable is plugged into the computer. If the driver installed correctly, you should see the green light on the USB cable blinking. For more information on establishing and troubleshooting communication with the LISST-Tau see *Instrument Communication* on page 15.

Once the cable is operating properly, you should be able to place a piece of paper in the path of the LISST-Tau and see the green (532 nm) or red (650 nm) beam.

3: Install LISST-Tau Software

A USB memory card (the size of a credit card) is included with the instrument. The card contains the LISST-Tau software, and digital copies of this manual and other support files. Flip open the memory card's USB connector and insert it in a USB port on your PC to install the software. The software requires Microsoft Windows 7 or later (it is not compatible with macOS or Linux).

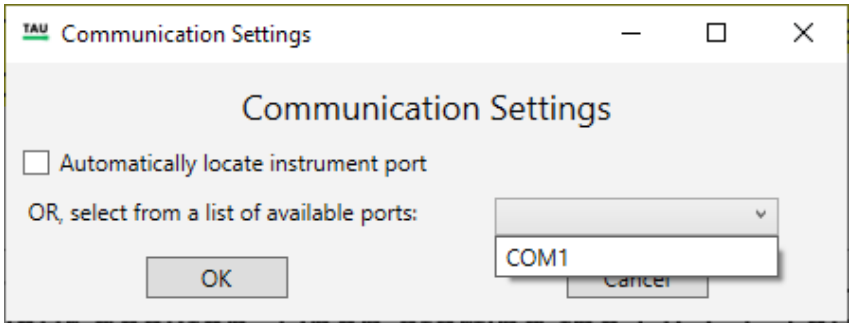
On the memory card you will find the 'Install_LISST-Tau_VX_X.exe.' Double click the installer executable to begin installing the software. Follow the onscreen instructions and the installer will transfer the necessary files to your computer and place a shortcut on your desktop

and start menu. Do not remove the memory card from your computer until the installation is complete.

4: Start LISST-Tau Application and Establish Communication with the LISST-Tau

Start the LISST-Tau software by selecting the shortcut the installer placed on your desktop. Upon starting the LISST-Tau software will attempt to automatically detect a serial port that is connected to a LISST-Tau.

If a port is not automatically detected when the program starts or if you have multiple LISST-Tau instruments connected to the PC you can manually select the serial port by clicking on the Settings icon (Gears) in the lower right corner of the window and choosing Communications Settings. The short cut to Communications Settings is Ctrl-R. Uncheck the Automatically locate instrument port and select from the list of available ports in the drop-down list. It is possible to open multiple copies of the LISST-Tau software to simultaneously communicate with multiple instruments.



5: Verify Operation

After connecting to the LISST-Tau, the software begins displaying the beam attenuation, updated every second. You can also switch the display to show transmission rather than attenuation. If the instrument is in air, the beam attenuation may be negative, or the transmission greater than 100%. These readings would be nonsensical in water, but are normal in air, since air has less attenuation than water.

If you block the beam, you should see the transmission drop to near zero, or the attenuation to go to a very high value.

6: Clean windows

For a quick cleaning, rinse the windows with lukewarm water and a mild soap solution (e.g. hand soap, liquid dish soap) and then rinse off all soap residue with clean, particle free water such as deionized water, distilled water or bottled purified drinking water. The windows can also be wiped clean with a soft cloth (e.g. a lens cloth) or glass cleaner. Do NOT use stronger solvents such as acetone or toluene, and DO NOT use any abrasive cleaner or wipes. Treat the windows as you would an expensive camera lens.

More detailed instructions for cleaning the windows can be found on page 13.

Step 8: Ready to Deploy

The LISST-Tau is now ready to deploy. You can disconnect it from the computer at any time and mount it to the deployment system, or return it to its carrying case.

Preparing for transport or storage

Although the LISST-Tau is robust, handle it with the care you would any sensitive measuring instrument. Always transport it in its original shipping case, or a similarly rugged and well-padded container. If it has been immersed in salt water, thoroughly rinse it with fresh water before storage. Allow it to dry before closing it in its case. Especially, clean the windows after use in natural water, so that any residue will not harden in place on the windows.

II. Operation Details

Section Organization

This section contains detailed instructions for performing various procedures. These are either in the form of step-by-step instructions or detailed descriptions of the various aspects of instrument operation (e.g. command list, instrument mounting and deployment).

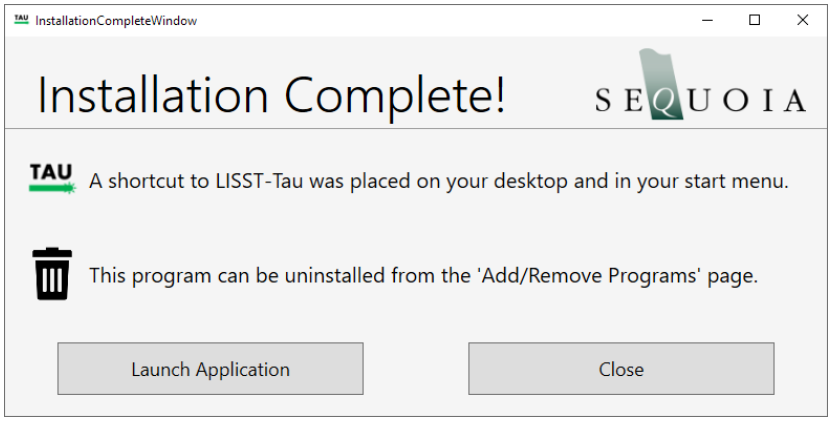
General Precautions

- LISST-Tau is a sensitive optical instrument - please handle it gently as you would handle an expensive camera.
- Critical alignment may be disturbed if the instrument is subjected to shock or rough handling.
- Evidence of shock/rough handling will void the warranty.
- Whenever in transit, store the instrument in the provided padded shipping case.
- Clean and dry the instrument, including the windows, before storage.

C. Step by Step Procedures

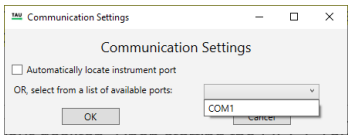
1. Installing LISST-Tau Software

The Sequoia-supplied LISST-Tau software for Windows is used to configure the LISST-Tau and downloading data.

STEP	ACTION	RESULT
1	• The LISST-Tau comes with a USB memory card. Plug the provided memory card into a USB port on a computer running Microsoft Windows 7 or later. Locate the 'Install_LISST-Tau_V1_4.exe' executable on the memory card.	Installer was found on LISST-Tau memory card
2	• Double click the 'Install_LISST-Tau_V1_4.exe' program and follow the onscreen instructions. The installer will transfer the necessary files to your computer and place a shortcut on your desktop and start menu. Do not remove the memory card from your computer until the installation is fully completed.  If you wish to uninstall the LISST-Tau software, nagivate to the Apps & Features section of the Windows Settings page. Or navigate to Add/Remove Programs from the Control Panel page. Find the entry for the the LISST-Tau program and select Uninstall.	Installation of software is complete

2. Establishing Communication with the LISST-Tau

Establish communication with LISST-Tau using the supplied software and USB cable. Communicating with the LISST-Tau via the provided software should be automatic. Should there be a problem you can use these step-by-step instructions to troubleshoot the problem.

STEP	ACTION	RESULT
1	• If the software is open, close the program, then plug the USB communication cable to the LISST-Tau and to a USB port on your computer.	LISST-Tau will be powered on
2	• After plugging the USB cable into your computer, the drivers for the USB to serial converter should install automatically. You should see a notification on the task bar that drivers are being installed. If you are unsure if the drivers installed you can install the drivers manually by running 'CDM USB Drivers.exe' located on the memory card that came with your instrument.	Computer is now set up to communicate with the LISST-Tau
3	• After the driver installation is compete, open the LISST-Tau software.	LISST-Tau software appears onscreen
4	• The LISST-Tau software will automatically search the available COM ports until it is able to communicate with a LISST-Tau. The serial port that is being used will be shown in the lower left of the screen. • To manually selected a different COMM port, click on the Settings icon (Gears) in the lower right corner of the window and choose Communications Settings. The short cut to Communications Settings is Ctrl-R. • Uncheck the *Automatically locate instrument port* checkbox and select from the list of available ports in the drop-down list. • If you have trouble finding the right port, open the Device Manger on your computer. Unplug and then re-plug the USB cable into your computer. The port that appears in the Device Manger when you plug in the USB cable is the port you need to select in the LISST-Tau software. If no port appears, go back to step 2 and reinstall the USB drivers.	Software will be configured to connect to the LISST-Tau 
5	• The data from the LISST-Tau should now be displayed on the screen at a rate of once per second.	LISST-Tau and software are now communicating

6	• If using an alternate software or instrumentation to communicate with the LISST-Tau make sure that the serial port settings are set to the following: o Baud Rate: 19200 o 8 Bits, no parity, 1 stop bit For example code for parsing the serial data string that is output by the instrument, see Appendix C: Parsing Serial Data String on page 24.	

3. Using the LISST-Tau software

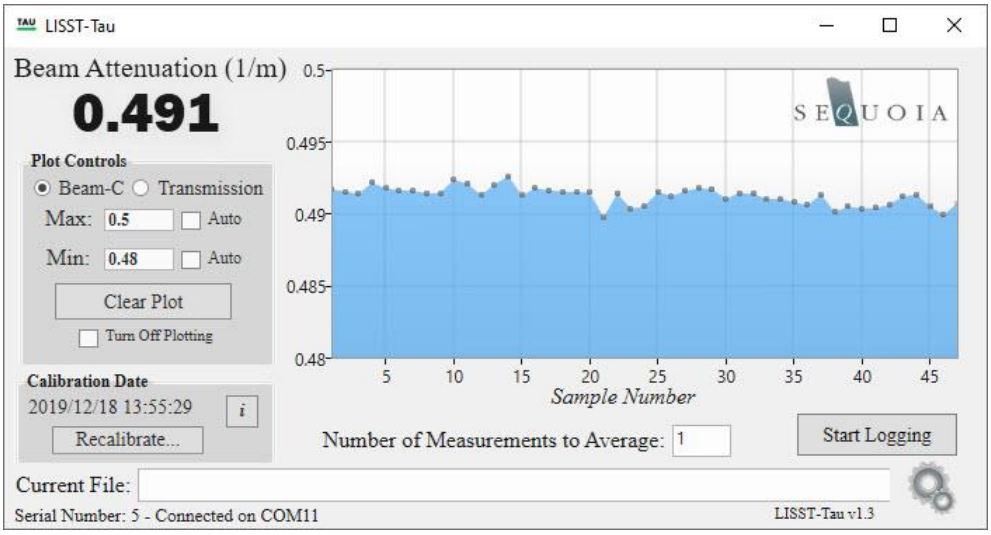
Introduction

The LISST-Tau software is a simple tool used for:

1. Viewing Data
2. Saving data to the computer in a text file
3. Configuring the instrument (setting the clock, measure clean-water baseline, etc.)

Viewing Data

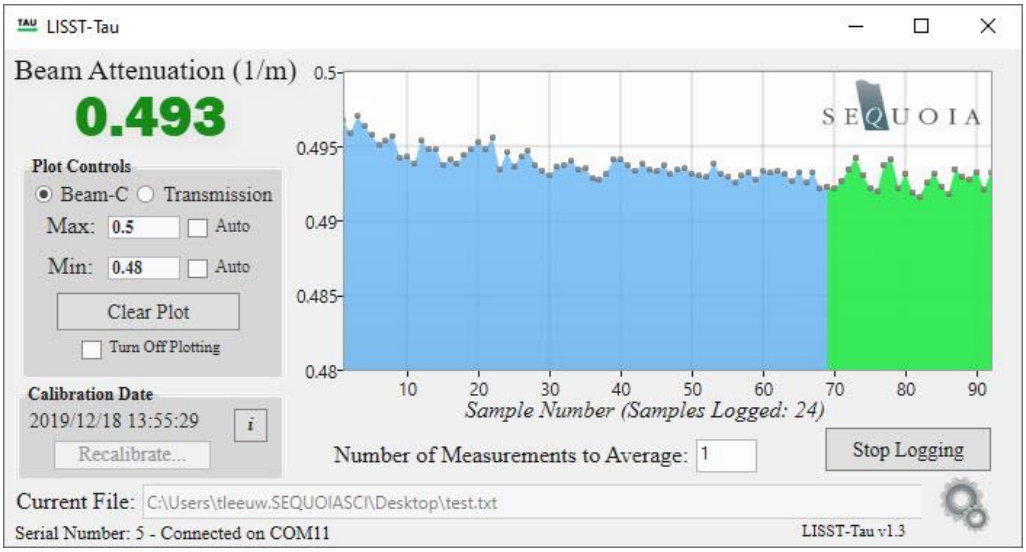
After connecting the LISST-Tau instrument (also see *Instrument Communication* on page 15), data will automatically be displayed to the screen. The Type of data displayed, beam attenuation or optical transmission, can be selected using radio buttons the left side of the window. The most recent value is displayed as a number in the upper left of the window. The last 15 minutes of data will be displayed in the strip chart.



In the 'Plot Controls' group box, you can customize the scale of the current plot, clear out the existing data, or turn off plotting all together. Turning off the plotting option may be useful if computer resources are limited.

Saving Data

Data can be saved to a text file by selecting the 'Start Logging' button. You will be prompted for a location to save the data. After selecting a location and filename, data will be continually saved to this file until 'Stop Logging' is selected or the program is closed. The plot color will change to green, indicating this data was saved to a file.

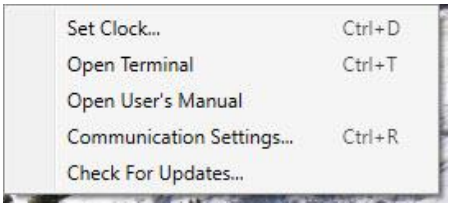


Configuring the Instrument

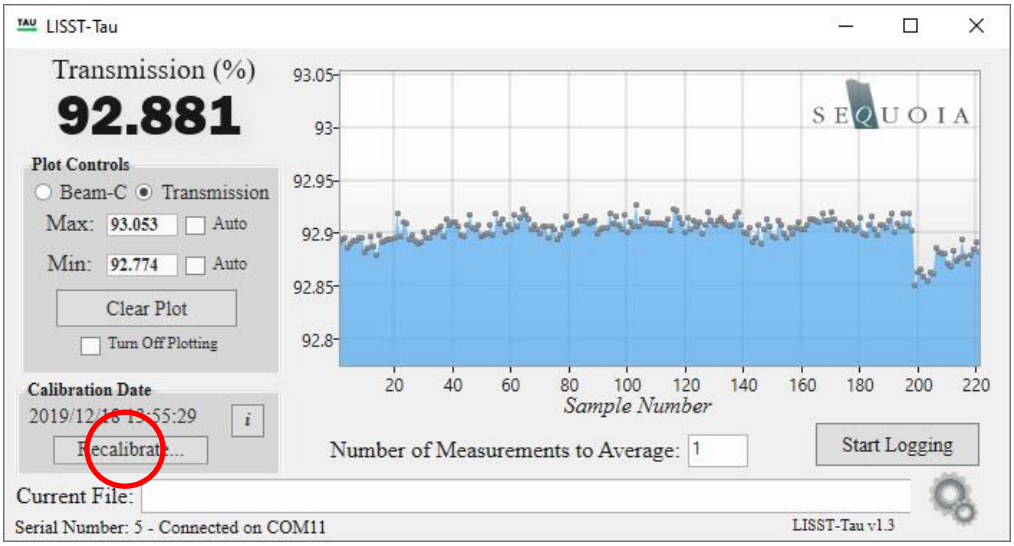
The LISST-Tau software provides the ability to:

1. Set the clock
2. View calibration information
3. Recalibrate (measure baseline)
4. Access the LISST-Tau command line interface

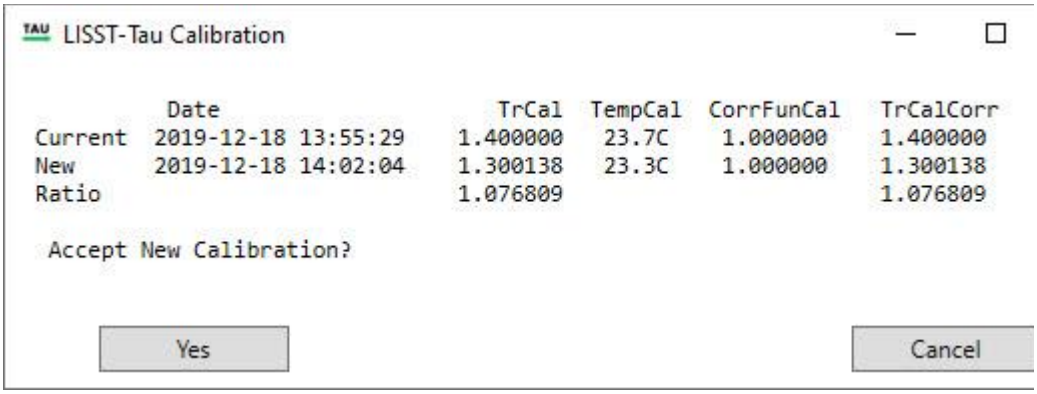
The clock can be set by selecting the gear icon in the lower right corner. A context menu will provide you with several options. The set clock option will sync the clock on the LISST-Tau to the current date and time on your computer.



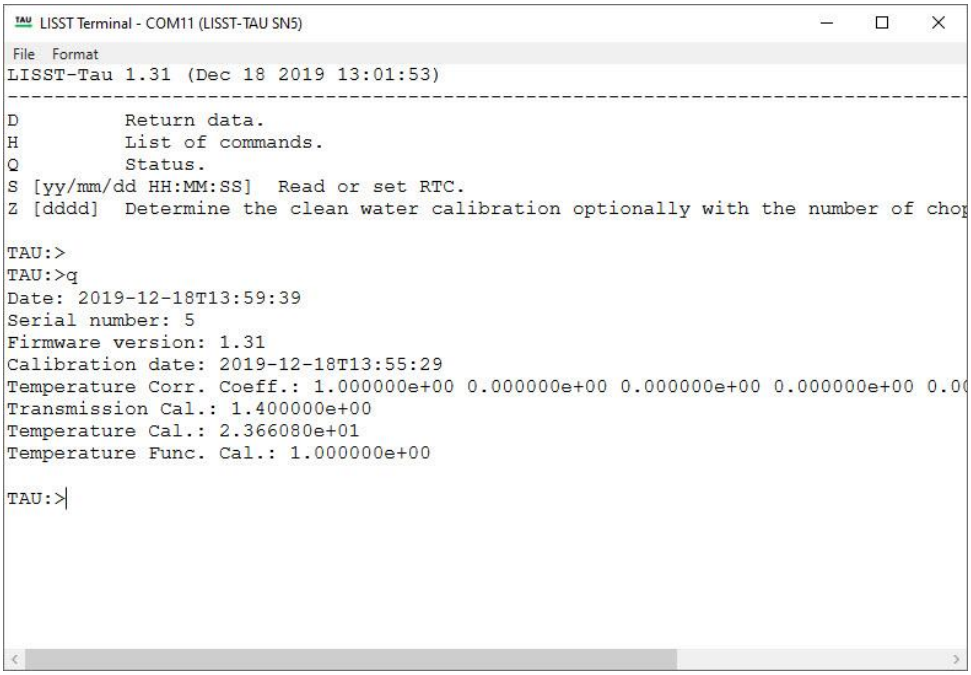
General instrument and calibration information can be viewed by pressing the ‘I’ button next to the calibration date.



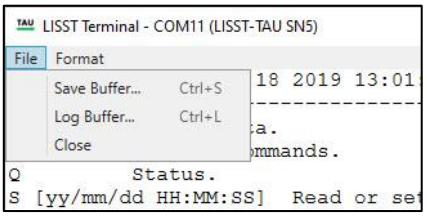
The instrument can be recalibrated through an automated procedure by selecting the recalibrate button. See *Clean-water Baseline Measurement (Calibration)* on page 14 for more information on this process. If you proceed with recalibrating the instrument you will be asked to confirm the new calibration coefficients. **The previous calibration coefficients will be overwritten and are not recoverable!**

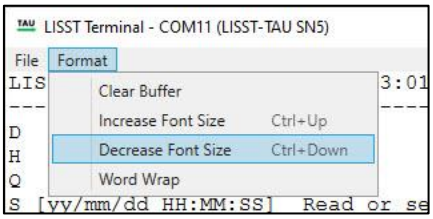


The LISST-Tau command line interface can be accessed by selecting the gear icon in the lower right and selecting ‘Open Terminal’. A serial terminal window will be opened, and list of LISST-Tau commands will be displayed to the screen.



The ‘File’ and ‘Format’ items in the menu bar offer several options for formatting the displayed texted and saving or logging the command line output.





4. Cleaning Windows

Accurate measurements of transmission depend directly on the cleanliness of the LISST-Tau's windows. Regularly clean the windows according to this procedure.

STEP	ACTION	RESULT
1	• Rinse the windows with clean water to wash away any large particles.	Windows are ready to be cleaned.
2	• For best results, wear clean latex or nitrile gloves. • Cleaning can be done with 90% or greater isopropyl alcohol and/or a non-foaming detergent (such as Liquinox). Cleaning with both solutions will provide the best results; the procedure is the same for both. • Gather gloves, lens paper, cleaning solution, and clean water	Cleaning supplies are ready
3	• While wearing gloves, wet a piece of lens paper with alcohol or detergent. • Gently dab the windows with the wetted lens paper. • A gentle wiping action can be used if the windows are particle and grit free (be careful not to drag large particle grains across window surface). • Use a dry piece of lens paper to wipe away the cleaner. • Repeat this procedure if the lens paper appears visually discolored.	Grease and grit removed using alcohol and/or detergent.
	• Use a spray bottle of clean water or lens paper wetted with clean water to wash away any residue from the alcohol or detergent. • Dry the windows with a piece of lens paper • Optionally, a can of compressed air can be used to blow away any fibers or dust that may have been left on the window.	Windows are clean and dry
	• Inspect the newly cleaned windows for any remaining dirt or debris. • Visual inspection can be facilitated by shining a flashlight on the window from the opposite side of your view. • Repeat the cleaning procedure if the window surface does not appear totally uniform and slightly reflective; or if there are visible debris still clinging to the windows.	Windows are visually inspected and cleaning is competed.

5. Clean-water Baseline Measurement (Calibration)

The LISST-Tau baseline is measured using very clean water at the factory and may not need to be measured in the field. However, periodic baseline measurements assure the highest measurement accuracy, and correct for factors such as scratched windows or rough handling that can affect the performance of the instrument. The procedure shown below provides the necessary steps needed to measure a new baseline. Note: Accurate results require careful work and very clean water supply.

STEP	ACTION	RESULT
1	• The instrument will need to be submerged in the water used for its baseline, so start by cleaning the entire exterior of the LISST-Tau. • Clean the windows as discussed in *Cleaning Windows* on page 13. Clean windows are essential for an accurate baseline measurement.	Windows and instrument very clean
2	• Fill a clean container with highly filtered, degassed water. The container must be large enough to fully submerged the LISST-Tau. It is recommended that the water be continuously recirculated through a 0.2-micron filter while monitoring the beam attenuation. • Monitor the attenuation as the water is filtered and the temperature is equilibrating. Decreasing attenuation means the results are improving. • For best results, clean the windows repeatedly until the attenuation is the same after each cleaning.	Flow Through Chamber installed or clean water container prepared.
3	• Once a stable value has been obtained press the Recalibrate button on the LISST-Tau software. • Averaged values will be obtained and displayed on the screen. Press Yes to accept the current values and reset the baseline. Press Cancel to stop the procedure and not make any changes. • WARNING: Once re-calibrated the instrument cannot be returned to the previous calibration. • See Section 3 for more details on using the LISST-Tau software.	Values are stable and re-calibration can begin
4	• The instrument has been recalibrated and the values being display will be using the new baseline.	Instrument has been re-calibrated

D. Instrument Communication

Overview

The standard adapter cable for the LISST-Tau sends data through a USB port. However, the LISST-Tau itself communicates through RS-232 serial protocol. The 6-pin male connector on the LISST-Tau carries the RS-232 signals (and power). The cables incorporate adapters that convert between RS-232 and USB.

If you use a different cable that does not include the RS-232-to-USB adapter, you can use an external adapter, or connect directly to an RS-232 port if your computer has one (which is rare on any recent computer). In Windows, both RS-232 and USB connections will appear as COM ports. To establish communication with LISST-Tau or other software, you must set the software to communicate with the correct COM port.

If interfacing to a data logger or controller system other than a Windows computer, you will likely also use a direct RS-232 connection.

The RS232 link communicates at 19200 baud, 8 data bits, No parity, and 1 stop bit.

The format and definitions of the output quantities are listed in *Appendix B: Data Output Format* on page 22.

Using the LISST-Tau Terminal Window

In the LISST-Tau software you can open a terminal window to directly view communications with the LISST-Tau and enter commands. When the LISST-Tau is connected and the terminal window is activated, the LISST-Tau should respond to pressing the enter key with the LTau:> prompt. The Terminal window can be opened by clicking on the Gear icon in the lower right of the LISST-Tau window and selecting Open Terminal.

Direct Commands

In most cases, LISST-Tau software will be used to configure and operate the LISST-Tau. However, some functions are available only through direct commands in the terminal window. Also, in some applications the LISST-Tau may need to communicate to another datalogger or custom program. For this purpose, a large set of commands is available to operate the instrument. See the following section for detailed descriptions of each command.

E. Serial Commands

Command Summary

NOTE: Command are shown in upper case for clarity but are not case-sensitive.

Commands

D	Start continuous data output
H	Display Help on available commands
Q	Display instrument configuration data such as Serial Number and calibration information.
S	Set Clock using format yy/mm/dd HH:MM:SS
Z	Start clean water re-calibration

Command Details

D	**Start Continuous Data Output**
Syntax:	D
Description:	Starts continuous data output at 1Hz. Output will be in format described in Appendix B: Data Output Format. Data output can be stopped by sending a CTRL-C.
Example:	input: D output: LTAU2 2000-01-01T00:00:49 38932 39434 1.0015 0.9355 0.4442 26.9 26.3 24.7 11.29 1.31 2019-12-23T11:39:04 1.08139 21.79442 1.01021

H	**Display Help**
Syntax:	H
Description:	Display list of commands.
Example:	input: H output: LISST-Tau 1.31 (Dec 18 2019 13:01:53) ---------- D Return data. H List of commands. Q Status. S [yy/mm/dd HH:MM:SS] Read or set RTC. Z [dddd] Determine the clean water calibration optionally with the number of chops.

Q	**Display Current Configuration**
Syntax:	Q
Description:	Display current instrument configuration and calibration parameters
Example:	input: Q output: *Date: 2000-01-01T00:55:56* *Serial number: 1* *Firmware version: 1.14* *Calibration date: 2019-12-13T17:20:11* *Temperature Corr. Coeff.: 1.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00* *Transmission Cal.: 1.015291e+00* *Temperature Cal.: 2.552717e+01* *Temperature Func. Cal.: 1.000000e+00*

S	**Set Clock**
Syntax:	S [yy]yy/mm/dd HH:MM:SS
Description:	Set internal Real Time Clock. Where *yy*= year (may include the century, however, century is ignored), *mm*= month, *dd*= day of month, *HH*= hour (00 to 23), *MM*= minute, *SS*= second. For example, September 29, 2019 at 10:12:14 would be 19/9/29 10:12:14. Note that the Real Time clock will be reset to January 1, 2000, 00:00:00 upon power up. Sending S only will display the current clock value.
Example:	input: S output: 2000-01-01T00:03:31 input: S 19/12/31 11:59:59 output: RTC set to 2019/12/31 11:59:59

Z	**Start Clean Water Re-Calibration (Baseline Measurement)**
Syntax:	Z
Description:	Re-calibrate the Beam-C and Transmission measurements to be relative to current values. Instrument is powered up for 30 seconds before an average is obtained to compute the calibration.
Example:	input: Z output: Warming for 30 seconds. 30 29 … 3 2 1 Calibrating with 1000 samples. This will take about 1 seconds. Press <Ctrl>C to cancel. LTAU1 2000-01-01T00:58:56 3513 42424 52308 9884 43042 11245 54288 74.47 42.45 1.014574 1.000000 1.014574 0.999294 0.00471 2000 4000 0 1211 1206 1220 1233 23.7 24.4 22.3 10.70 0 0 0.00000 0.00000 1.14 2019-12-13T17:20:11 1.015291 25.52717 1.000000 Date TrCal TempCal CorrFunCal TrCalCorr Current 2019-12-13 17:20:11 1.015291 25.5C 1.000000 1.015291 New 2000-01-01 00:58:56 1.014574 22.3C 1.000000 1.014574 Ratio 1.000707 1.000707 Accept new calibration? [y|N] Calibration updated.

F. Analog Output

Applications

Although the serial digital output provides the best precision and overall data quality, some applications call for the simpler interfacing provided by an analog signal. Many existing CTD rosettes and other profiling systems already provide for an analog-output transmissometer as one of their standard sensors. For these cases, the LISST-Tau provides an analog output on pin 6 of its main connector.

Scaling and Voltage Range

The output voltage is proportional to transmission. Although the LISST-Tau circuitry can produce up to 5.0V on this output, we set the 100% full-scale output to 4.5 V. That is, the output is 4.5V when the transmissometer is properly calibrated and measuring pure water. The extra range from 4.5V to 5.0V is reserved as a way to indicate a problem with the pure-water baseline [see Clean-water Baseline Measurement (Calibration) on page 14], by showing transmission greater than 100%.

Update rate

The analog output is updated once per second, synchronously with the digital output data.

Appendix A: Technical Specifications

These specifications are for LISST-Tau units specifically qualified for use on Teledyne glider systems.

General / Electrical

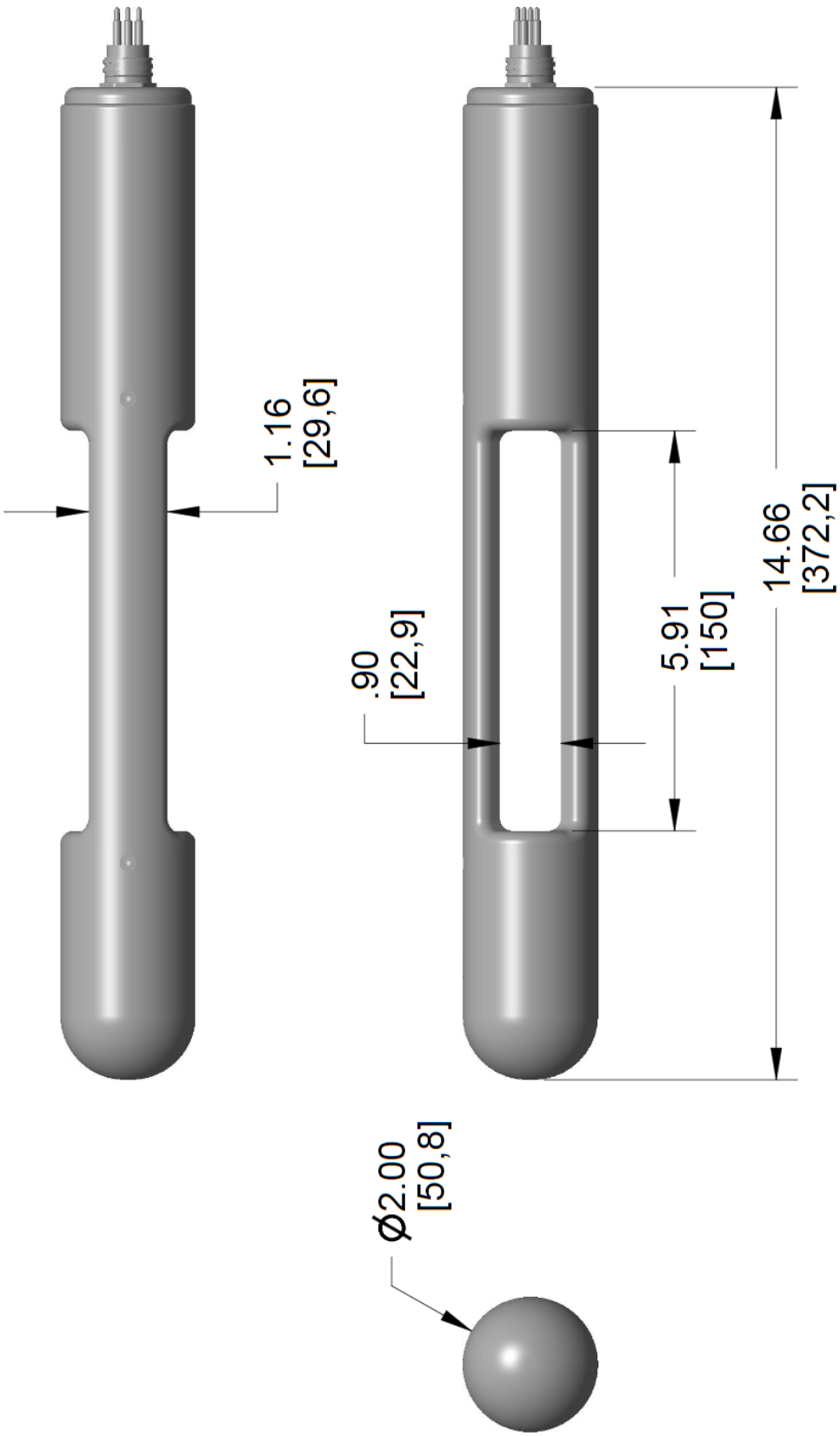
Parameters Measured/Derived	Optical transmission Beam attenuation
Data Interface	RS-232 serial, 19200 baud, 8 bits, no parity, 1 stop
Analog output	0 – 5 V, proportional to transmission (4.5V = 100%)
Sample Rate	1 output per second (standard)
Input Voltage	7 to 25 V
Current Draw	42 mA @ 12 V (typical, average during sampling)

Mechanical / Environmental

Operational Temperature Range	-3 to 40 °C
Storage Temperature Range	-20 to 60 °C
Dimensions **(See figure on following page)**	5.1 cm [2.00 in] diameter; 40.6 cm [16 in] overall length
Weight in Air	1.14 kg [2.5 lb]
Weight in Water	0.59 kg [1.3 lb]
Depth Rating	2000 m

Optical / Measurement

Optical Pathlength	15 cm
Digital resolution	16 bits; higher with averaging
Measurement Range	~0 to 30 m^{-1} (>99% linearity in concentration)
Source Wavelength	532 or 650 nm nominal
Source Spectral Bandwidth	10 (FWHM)
Acceptance Angle	1.0° (half angle, in water)
Short-Term Stability/Precision **(1 min Standard Deviation)**	~0.0022 %FS transmission; ~0.00015 m^{-1} beam attenuation
Long-Term Stability **(6 Hour Test)**	~0.0034 %FS/hour transmission; ~0.00023 m^{-1}/hr beam attenuation


1.16
[29,6]
.90
[22,9]
5.91
[150]
14.66
[372,2]
Ø2.00
[50,8]

Appendix B: Data Output Format

Serial Data Output Format

The values transmitted via the serial connection are shown below. Output occurs every 1 second. Values are tab delimited and each line is terminated with a <CR><LF>. Data saved by LISST-Tau software will be a TXT file in this format.

The LISST-Tau supports other special-purpose data formats, which are not described here. Contact Sequoia Scientific for details.

Example:

```
LTAU1234G<tab>2021-03-01T13:10:59<tab>0.3642<tab>0.9468<tab>
34427<tab>42488<tab>21.8<tab>12.18<tab>1.33<tab>
2021-01-23T10:17:35<tab>1.30319<tab>21.01677<cr><lf>
```

Field	Name	Description	Data Type, resolution
1	ID	Identifies instrument “LTAU<SN>”. SN is a 4-digit number (1234 in example) followed by one character indicating a model variant, G for 532 nm or R for 650 nm).	String
2	*Timestamp*	Date-time of sample in ISO 8601 format (yyyy-mm-ddThh:mm:ss) (e.g. 2021-03-01T13:10:59)	String
3	*Beamc*	Beam attenuation [units 1/m], *Beamc = (–1/Pathlength)*ln(Tau),* e. g. 0.3642, Pathlength = 0.15 [m]	Decimal 0.0001
4	*Tau*	Transmission, *Tau = (Tr/TrCal) * (CorrFunCal/CorrFun(Temp))*, e. g. 0.9468	Decimal 0.0001
5	*RefNet*	Net raw reference counts, *RefNet = RefLedOn – RefLedOff*, e. g. 34427	Decimal integer
6	*SigNet*	Net received signal counts, *SigNet = SigLedOn – SigLedOff,* e. g. 42488	Decimal integer
7	*Receiver Temperature*	Receiver Board temperature in °C, e. g. 21.8	Decimal 0.01
8	*Vsupply*	Input supply voltage in volts, e. g. 12.18	Decimal 0.01
9	*FW version*	Version of instrument firmware, e. g. 1.33	Decimal 0.01
10	*TimestampCal*	Date-time of the current clean-water baseline, in ISO 8601 format, e. g. 2021-01-23T10:17:35	String

11	*TrCal*	Raw transmission clean-water baseline, *SigLedOn* – *SigLedOff*) / (*RefLedOn* – *RefLedOff*) e. g. 1.30319.	Decimal 0.00001
12	*TempCal*	Temperature of clean-water baseline, e. g. 21.01677	Decimal 0.00001

Appendix C: Parsing Serial Data String

Below is pseudo code that shows how the serial data string can be parsed into individual variables. This is how the LISST-Tau windows program captures and displays real time data from the LISST-Tau instrument.

```
// Assumes instrument is connected to a serial com port and is currently sampling in user mode.

// Read line from the serial port
string serialString = TauComPort.ReadLine();

// Split serial string using tab as the delimiter
string[] stringVariables = serialString.split('\t');

// Load substrings into variables (see Appendix B: Data Output Format in User's Manual)
string name             = stringVariables[0];
DateTime timestamp      = DateTime.Parse(stringVariables[1], '"yyyy-MM-ddTHH:mm:ss");
float beamc             = stringToFloat(stringVariables[2]);
float tau               = stringToFloat(stringVariables[3]);
int netRefrence         = stringToInt(stringVariables[4]);
int netSignal           = stringToInt(stringVariables[5]);
float tempRcvr          = stringToFloat(stringVariables[6]);
float supplyVoltage     = stringToFloat(stringVariables[7]);
float firmwareVersion   = stringToFloat(stringVariables[8]);
DateTime calTimestamp   = DateTime.Parse(stringVariables[9], '"yyyy-MM-ddTHH:mm:ss");
float transmissionCal   = stringToFloat(stringVariables[10]);
float tempCal           = stringToFloat(stringVariables[11]);
```

Appendix D: Electrical Connections

Bulkhead male on LISST-Tau
Subconn MCBH6M

Female on mating cable
Subconn MCIL6F

Contact number	Function
1	Ground
2	RS-232 Data In (to LISST-Tau from computer)
3	Reserved for future use
4	Power In (8 to 24V)
5	RS-232 Data Out (to computer from LISST-Tau)
6	Analog output, 0 to 5V, proportional to transmission (4.5V = 100%)

Appendix E: Measurement Description

The LISST-Tau follows a common direct-path collimated beam transmissometer design comprising an open sample volume flanked with two pressure windows, the first allowing a collimated beam to enter the sample volume, and the second allowing the transmitted beam to be measured. The transmit optics assembly consists of an LED combined with a pinhole to approximate a point source, a collimating lens, spectral bandpass interference filter, and a beam-splitter with reference photodiode to measure the beam power entering the sample volume. The receive optics consist of a focusing lens, pinhole, and transmitted power photodiode. The receive optics are designed for an acceptance angle of $\sim 1.0°$, half-angle in water. For ambient light rejection, the source LED is modulated on-off at kHz frequency and the net signals are considered. Beam transmission through the sample volume is defined as the ratio of power received (Φ_S, units W) to the power entering the sample volume (Φ_R, units W), measured by the reference detector.

The net (difference between LED on and LED off value) measurements from the two photodiodes with front-end amplifier circuits and analog to digital conversion are,

$$\Phi_S = G_S(V_S - V_{S0})$$
$$\Phi_R = G_R(V_R - V_{R0}).$$

V_S and V_R are the net signal (transmitted) and net reference, in digital counts; V_{S0} and V_{R0} are "dark" offsets that may be present in the electronics, also in counts. G_S and G_R are scaling factors relating the digital counts to radiant spectral flux (units of W count^{-1}). The dark offsets are slowly varying in time and considered to be system constants stored in firmware. The scaling factors G_S and G_R are also system constants that are obviated through the process of pure water calibration (see below).

Raw uncorrected transmission (unitless) is calculated using the digitized signals as

$$\phi = \frac{V_S - V_{S0}}{V_R - V_{R0}},$$

and, again, beam transmission is defined as the ratio of received (transmitted) to reference power,

$$\tau = \frac{\Phi_S}{\Phi_R} = \frac{G_S}{G_R}\frac{(V_S - V_{S0})}{(V_R - V_{R0})} = G\phi,$$

and depends on the pathlength L through which the beam is attenuated ($L = 0.15\ \mathrm{m}$ for the LISST-Tau). According to Beer's Law, the beam attenuation coefficient (units of m^{-1}) is then defined as

$$c = -\frac{1}{L}\ln(\tau),$$

where $\ln(\cdot)$ is the natural logarithm. Furthermore, beam attenuation is the sum of attenuation due to pure water (c_w) and all of the suspended and dissolved material other than the water (c_{pg}),

$$c = c_{pg} + c_w.$$

Most often we consider beam attenuation and transmission measurements in terms of the substances other than water, i.e.,

$$c_{pg} = c - c_w$$
$$\ln(\tau_{pg}) = \ln(\tau) - \ln(\tau_w) = \ln\left(\frac{\tau}{\tau_w}\right),$$

leading to

$$\tau_{pg} = \frac{\tau}{\tau_w} = \frac{G\phi}{G\phi_w} = \frac{\phi}{\phi_w}.$$

In practice, raw transmission measurements are corrected for instrument temperature effects (e.g., temperature dependence of photodiodes and LED spectral output, analog electronics), so for a given measurement of raw transmission (ϕ), instrument temperature (T, units of ℃) is also measured. An instrument temperature correction function ($C(T)$, unitless) is defined such that corrected raw transmission is

$$\phi_{corr} = \frac{\phi}{C(T)}.$$

For measurement of a water sample at instrument temperature T, both the raw transmission of the sample, and the pure water blank must be corrected for temperature. The pure water blank is corrected for the instrument temperature at which it was collected:

$$\tau_{pg} = \frac{\tau}{\tau_w} = \frac{\phi_{corr}}{\phi_{corr,w}} = \frac{\phi}{\phi_w}\frac{C(T_w)}{C(T)}.$$

Beam attenuation for the sample is then calculated:

$$c_{pg} = -\frac{1}{L}\ln(\tau_{pg}).$$

Revision History

Version 1.33 **July 27, 2021**	General editing throughout; add section F, Analog Output.
Version 1.32 **April 16, 2021**	Restore Appendix D: Electrical Connections
Version 1.31 **April 16, 2021**	Add “model variant” character to serial number in output format.
Version 1.3 **April 8 2021**	Revised data format; minor edits and formatting.
Version 1.2 **March 2021**	Initial public release.