LISST-VSF

Multi-angle Polarized Light Scattering Meter

User's Manual

Version 3.0

(December 2016)

SEQUOIA

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LISST-VSF

FEATURES:

- In-situ measurements of P_{11} (VSF), P_{12} and P_{22} elements of the scattering Mueller matrix from 0.1-155^o (nominal) in water, to maximum depth of 50m.
- Auto shut-off at depth greater than 50m, and auto resume when depth <50m.
- VSF (P_{11}) at small angles, 0.1 to 15^o (nominal) in 32 logarithmic steps in angles
- Integration of 0.1-155^o VSF provides a good estimate of total scattering coefficient *b.*
- Beam attenuation measured with LISST-100X optics.
- Eyeball™ optics permit 1^o resolution in scattering angles between 15 -155^o
- Daylight rejection in eyeball data by laser modulation.
- Data from small and large angles in a single data stream, including depth, temperature, date and time.
- Approximately 4 sec. per measurement set [involves 2 turns of Eyeball with vertical, and horizontal laser polarization].

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SPECIFICATIONS:

Parameters measured

Small-angle VSF in 32 log-spaced angles, from 0.1 to 15^{o}(nominal)
VSF, P_{12} and P_{22} over 15-150^{o} in 1^{o} steps (nominal)
Beam attenuation
Temperature from –5° to 50°C with 10 mdeg resolution
Depth (50 m max operational depth; 8 cm resolution)

Operating Concentration range

Beam attenuation from 0.13 to 20 m^{-1} (based on 98%<transmission<30%)

Technology

Fiber Coupled TE-cooled Laser Diode @ 515 nm
Ring Detector for small-angle VSF
Roving Eyeball and Photomultiplier (PMT) for 15-150^{o} (nominal)

Mechanical and Electrical

LISST-VSF Instrument

Dimensions 13.3 cm (5.25”) diameter, 86 cm (34”) L , plus 10 cm (4”) Standoff.
Weight: 13 kg (28 lbs) in air; 8 Kg (17lb) in water.
Depth rating: 300 m survival depth (50 m operational depth)
External power input: 12VDC nominal, max 20VDC
Sampling rate: 4 seconds for a full measurement of P11, P12, P22
Power drain: 700 mA measuring / 170mA quiescent
Data storage: 128GB, equivalent to 40,000? measurements

Battery Housing and Capacity

Dimensions 10 cm (4”) diameter, 52 cm (20.5”) long including handle
Weight: 6.5 kg (14.3 lbs]) in air; 2 kg (2.2 lb) in water
Voltage: 14.4 V nominal; 16 V fully charged; 12 V min. operating.
Capacity: 14 Ahr, 200 Whr.

Welcome to the LISST-VSF!

Using this manual

This manual is divided into two sections.

Section One contains an introduction to the LISST-VSF instrument and the principles of its operation.

Section Two provides instructions for operation

Section Three provides instructions on programming**.**

Appendices provide further details …

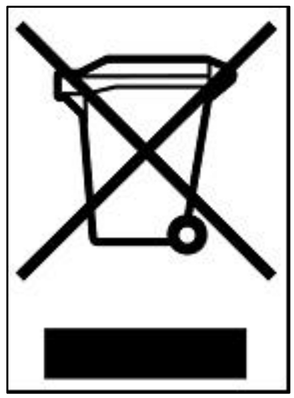
Instrument Specific Constants

These are included in a MATLAB file, named lisstvsf_getcal.m.

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(425) 641-0944
Email: info@SequoiaSci.com



Waste Electrical and Electronic Equipment

Smaltimento di apparecchiature elettriche ed elettroniche da rottamare

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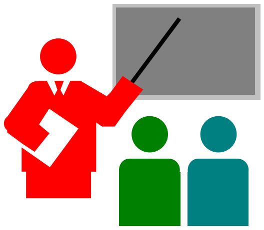
Section I: LISST-VSF Instrument

I.1 Introduction

Thank you for purchasing a LISST-VSF instrument, and congratulations on your new purchase.



The **LISST-VSF** delivers a powerful suite of measurements for marine optical scientists, all from one package. It delivers the Volume Scattering Function (VSF) from small forward angles to wide angles, depolarization parameters, and the beam attenuation coefficient *c.* An excellent estimate of the beam scattering coefficient *b*, and by difference, the beam absorption coefficient *a* can also be derived from the data. All properties are measured at a laser wavelength of 515nm. The forward angles in water, from, 0.088 to 14.36^0 at which VSF is measured are spaced logarithmically. The intermediate and large angles (>15-deg) are linear, with 1-deg resolution. The 1^0 angular resolution of this instrument permits examination of enhanced scattering by bubbles in the ~80-deg region.

Light Scattering and VSF

The Volume Scattering Function (VSF) describes the distribution of scattered light energy as a function of scattering angle. VSF is defined for unpolarized light source and no discrimination of polarization in the scattered light. However, scattering of light by particles *always* produces changes in polarization state of the scattered rays. The state of polarization is described by the Stokes vector **I**, with elements I,Q,U,V. The Stokes vector of the scattered light and that of the incident light $\mathbf{I_i}$ are related through a matrix product:

$$\mathbf{I_s = P\ I_i}$$

where **P** is the scattering Mueller matrix. **P** is a 4 x 4 matrix. It contains information regarding particle scattering characteristics. The elements of **P** are often denoted by P_{ij}. The first element, P_{11} is identical to the volume scattering function, VSF. Elements [1,2] and [2,2] relate to changes in the linear polarization properties I and Q. For example, element P_{12} produces depolarization. Element P_{22} is known to be an indicator of sphericity of particles; so that P_{22} =1 everywhere implies that particles are spheres. With the LISST-VSF, it is assumed that symmetry forces elements P_{13} and P_{14} to zero, and that P_{12} and P_{21} are equal. Thus only 3 unknowns describe the Mueller matrix **P.**

At small forward angles, scattered light mostly maintains its original polarization, so that depolarization is small. This instrument does not measure depolarization at angles smaller than 15^o, because there the VSF is measured by a set of ring detectors, identical to our familiar LISST-200X instrument. A different instrument, **LISST-Stokes** has been developed for small-angle depolarization studies. If interested, please contact us.

Instrument Overview

The small-angle part of VSF is measured using ring detectors, identical to the ones used in our LISST-200X instrument. Each ring detector measures the VSF into a small angle range. The range of angles covered by the rings is 0.088 to 14.8^0. (e.g. Agrawal & Pottsmith, 2000; included on the USB card)

For larger angles, and to measure the VSF and depolarization components, it is necessary to measure the intensity and polarization state of the scattered light. The LISST-VSF employs a single linearly polarized laser and two PMT detectors. One PMT measures scattered light into perpendicular polarization and the other into parallel polarization. The laser polarization is alternated between vertical and horizontal by insertion or removal of a ½-λ plate. In this way, a total of 4 measurements is made at each scattering angle, see Fig.1

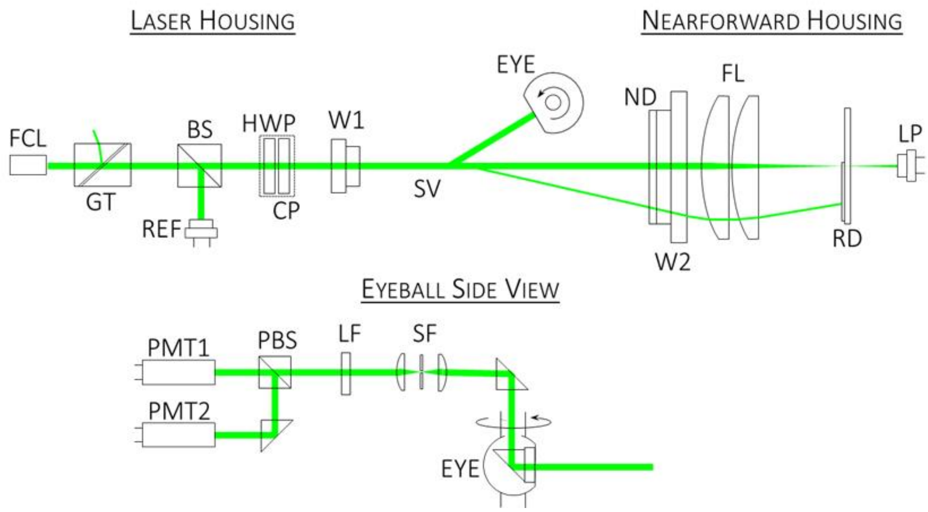


Figure 1: Schematics of the optics. Top shows collimated laser (FCL) passing through a polarization 'purifier' (GT), a beam-splitter (BS), ½-λ plate (HWP), and pressure window (W1). The eyeball (EYE) rotates and views scattering along the beam (SV). An ND filter on the receive window (W2) is incorporated to reduce glow from the receive optics. It is followed by receiving lens for the ring detector optics (RD), and transmission sensor (LP). The lower figure shows the folded path of received light, a spatial filter (SF), a laser line filter (LF) and polarizing beam splitter (PBS) which delivers light to the two PMT's.

Past VSF instruments have either employed a fixed set of detectors viewing a common scattering volume, or a telescope that views a scattering volume and rotates around it. These systems are not suitable for autonomous use. In contrast, the **LISST-VSF** instrument uses a rotating eyeball. This eyeball is placed to the side of the laser beam. As it rotates, it views different parts of the laser beam (Fig.1, *top*), i.e. at different angles. At each angle, 4 measurements are made - scattering in two polarizations for parallel and perpendicular polarization of the laser. This produces the desired VSF, P_{12}, and P_{22}. The splitting of the received scattered light is shows in lower Fig.1.

The eyeball makes the LISST-VSF instrument compact, autonomous, and manageable underwater. As a result, this instrument may be left on a tripod or mooring.

As explained in Appendix A, due to the rotating eyeball receiver, the stored scattered light signals are a mix of the 3 parameters P_{11}, P_{12} and P_{22}. The convenience of the eyeball thus involves a price – solving for these quantities.

We provide software to perform this function. For details, please see Appendix A. The physical layout of the instrument is shown in Fig.2 below.

The Instrument

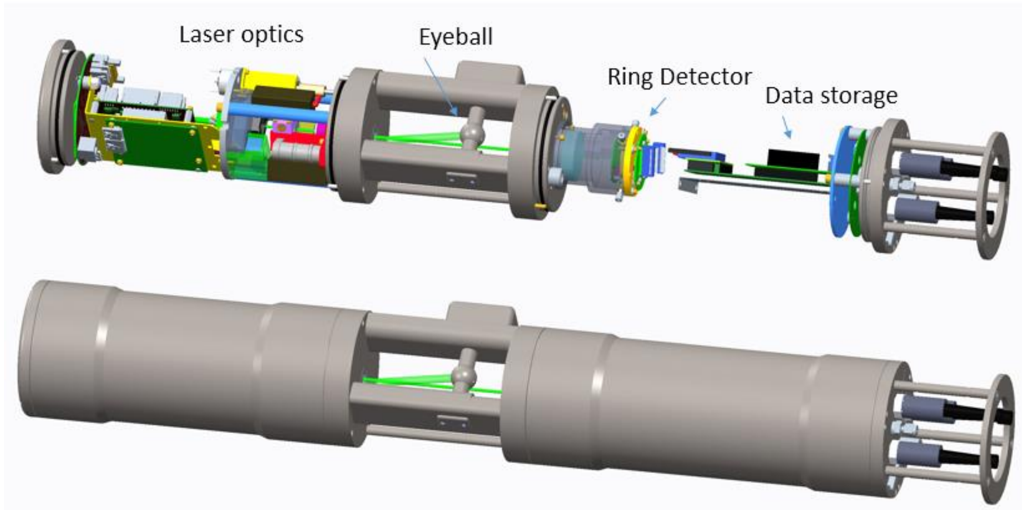


Figure 2: The internal arrangement and housing of the LISST-VSF. The endcaps on this instrument are NOT to be opened without consent of the factory.

Electro-Optic Components

The instrument employs a single 515nm TE-cooled diode laser. Two miniature, compact PMT's are used to sense scattered light. Beginning with SN 1660, firmware automatically controls the gain of these two PMT's. Alternately, the gain can be adjusted with software commands. The output of PMT's is digitized and stored in data files.

Depth and Temperature Sensors

A depth sensor is mounted to the instrument connector endcap. A temperature sensor is also thermally bonded to this endcap. Please note that the temperature sensor is therefore slow.

Communication

A cable is provided to connect the underwater connector on the instrument endcap to a PC. Communication is at 9600baud, except when downloading data, when it automatically switches to 115Kbaud.

Data Acquisition sequence

When commanded to capture data, the following sequence begins: the laser is turned on for a short period to reach stable power. After this warm-up, the eyeball starts rotating. When the optical encoder, which reads eyeball position reads 15^0, the two PMT data are captured at 1^0 intervals. Between 15^0 and 40^0 of eyeball position, the laser is dimmed by the laser controller. This is done because this scattering is stronger; dimming reduces demand on the PMT dynamic range. At 41^0 encoder position, laser power is returned to full. Eyeball data are recorded till encoder reads 150^0. For the duration of eyeball data capture, the laser is chopped for ambient light rejection. After 150^0, laser chopping is turned off, laser power is set to full for ring data capture. When ring data have been captured, the combined ring and eyeball data are written to data file. Immediately thereafter, a half-wave plate is inserted in the laser beam, so that during the next turn, PMT data would be captured with laser polarization rotated by 90^o. The measurement cycle repeats for the second rotation, only now the half-wave plate is removed at end. This is illustrated in Fig.3.

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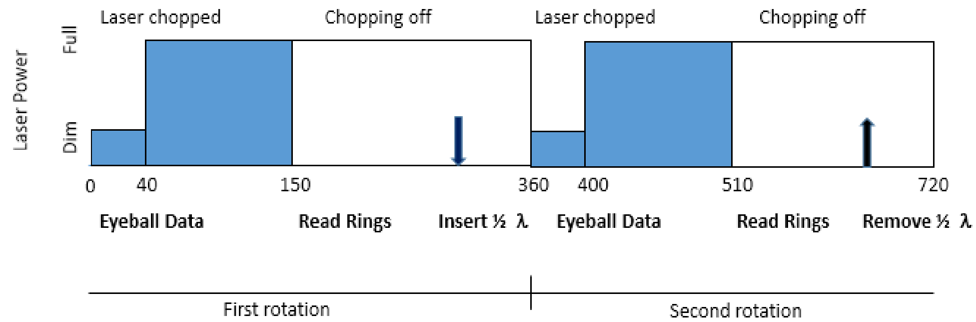


Figure 3 – Simplified description of timing of data acquisition. In each of 2 rotations of the eyeball, laser is dimmed for 15- 40-degree positions of eyeball, then full power is turned on. Shading represents chopping of laser power for ambient light rejection. After eyeball data are acquired, rings are read at full laser power, following which the ½-λ plate is inserted(arrows) for the second rotation, and the cycle repeats, ending with removal of ½-λ plate.

Auxiliary Data and Checks

Also stored in each rotation are auxiliary parameters - depth and temperature, battery voltage, date and time. Not shown in Fig.3. are two significant tests – if current depth exceeds 50m, and if battery is depleted. If the depth is exceeded, a new cycle of data collection pauses until depth is again less than 50m. If battery is depleted, the current cycle is completed, data saved, and then instrument drops into low power mode.

The number of sets of data is controlled from PC commands.

Background Data

As with our LISST-200X instruments, measurement of background light on ring detectors from optics is an essential part of getting good data. Similarly, background light from scattering by water molecules constitutes the background for eyeball data. These backgrounds are saved prior to each use, and subtracted from total scattering observed from particle laden water. Note that eyeball background data depend on PMT control voltage. Consequently, backgrounds are saved at a set of control voltages for use with corresponding particle data.

One-step Data Processing

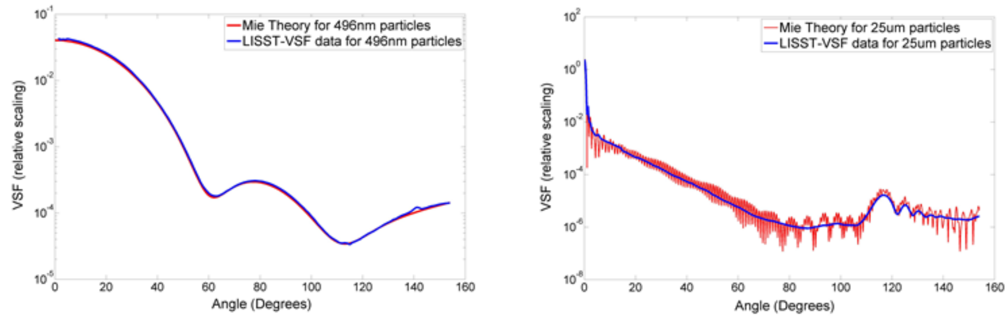
Data processing is performed in MATLAB. A single function **lisstvsf_makep** produces the desired end result: P_{11}, P_{12}, and P_{22}, beam_c and beam_b.

Detailed Data view

For convenience, a few other functions are provided, e.g. **lisstvsf_view** to view data files, and others to simulate the VSF from Mie theory. The expected measurement from, say, single size polystyrene beads can be computed using this simulation for comparison with actual data.

See the data processing section for detailed processing steps.

Example Results We show below VSF obtained with 0.5 and 25-micron polystyrene spheres, contrasted with Mie theory. Note that due to the 1-deg resolution of the LISST-VSF, the very high resolution oscillations for 25mm particles are averaged.



Use in Laboratory or Field The instrument can be used in the laboratory, using a provided water chamber, or in the field. It can be operated with an External Power Supply, or using the supplied rechargeable battery. To become familiar with the instrument, laboratory use is highly recommended first, before attempting a field deployment.

In battery-powered field usage, the instrument can be used from a wire in a profiling mode, or it can be mounted on a tripod or mooring for a time-series observation.

PRECAUTIONS

NEVER INSERT ANYTHING REFLECTIVE IN THIS SPACE. THE LASER POWER IS APPROXIMATELY 5mW. IT WILL DAMAGE EYES.

The windows and endcap faces should be clean if doing laboratory work. If deploying in the ocean, make sure both windows are clean. Use lens cleaner or soap and water. **DO NOT USE ABRASIVE CLEANERS**.

Rechargeable NiMH Battery Pack The instrument power source is a rechargeable NIMH pack. With all systems on, the instrument draws about 0.7 A current. The fully charged battery can power continuous operation of the instrument for up to ~20 hours. Note that the instrument checks the state of battery before capturing each set of data. If the battery is low, a graceful shutdown is executed.

A battery charger is provided. **While the battery is being charged, it cannot power the instrument**.

External Power Supply A separate external power supply, with an underwater connector that mates with the instrument housing is provided for use in the laboratory.

I.2 General Precautions

Handling the Instrument

The LISST-VSF is a delicate instrument. It contains precision, highly aligned optics, and electronics. It is designed for the rigors of field use, however it should be handled with care at all times.

Mounting the instrument, either in the laboratory or on a frame for field use must make sure that the instrument is not subjected to bending as that will cause loss of alignment.

AVOID SHOCK at all times.

CAUTION
LASER RADIATION

WARNING
The LISST-VSF uses a Class 3B green laser emitting a maximum of 10 mW of visible light at a wavelength of 515 nm. The laser beam under normal circumstances is not a threat. However, if reflective objects are placed in the path of the laser beam, the light could be reflected into an eye causing permanent damage.

Do Not Open Instrument Cases

You should never have to open the LISST-VSF pressure case. Doing so may void the Manufacturer's Warranty!

Connecting Cables

Always connect cables to the instrument first, then connect the other end to the battery pack, bench-top power source, or PC.

CAUTION
RISK OF FIRE

A BATTERY CHARGER IS PROVIDED WITH THE LISST-VSF.

NEVER USE ANY OTHER CHARGER FOR BATTERY CHARGING. THIS MAY DAMAGE THE BATTERY AND VOID THE WARRANTY.

EXTREME CAUTION IS ADVISED IN CLOSING THE BATTERY PRESSURE CASE AFTER BATTERY CHARGING.

I.3 Quick Start

Section summary

In this section, we provide a condensed version of full operation, from opening the instrument case as received, to data collection and processing. A detailed description is included in Section II.

Contents of shipping case

Let us see what is in the box!

Open the shipping case containing the instrument. You should see the following items inside (see also Appendix H):

1. Lexan Sheet (for forming the water chamber in lab use)
2. Clamps to hold the lexan sheet wrapped aound the sample volume (2)
3. Communications Cable (5-pin underwater female to USB)
4. Battery Cable (3-pin male to female underwater cable)
5. Battery Charger
6. Power Supply
7. Power Supply adapter cable (adapts to 3-pin underwater female)
8. Instrument Stands (2 for LISST-VSF, 2 for battery pack), for use on laboratory bench.
9. USB memory card with software and electronic documents
10. Manual
11. Spare O-rings
12. Mounting Clamps
13. Battery housing
14. LISST-VSF instrument

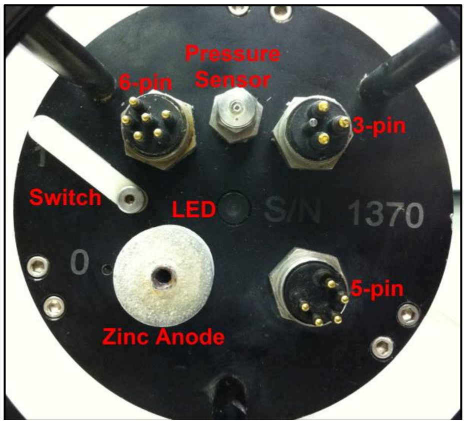
Set Up on the Bench Top

1. First place 2 instrument stands approximately 1m apart.
2. Remove the instrument and cradle it on these stands.
3. Similarly place the battery case on the two other stands.

Do not connect the two instrument cases with the power cable yet! It is important to become familiar with the various parts first.

No LISST-VSF end-caps should be opened by the user. Only recharging the battery requires opening one end of the battery case. The user should never try to loosen or disassemble any of the other components attached to either endcap. Doing so could immediately void the warranty.

Connectors on Instrument Endcap



There are 3 connectors on the endcap. The 3-pin connector is for power (from battery or line power supply). The 5-pin connector is for communication. The 6-pin connnector is for auxiliary use.

See Appendix D.

Battery Housing Endcap

There is only one connector on the battery housing endcap. See Appendix D for pin-outs.

Checking for Clean Windows

In preparation for getting started, at this time, check the optical windows to make sure that they are clean. There are three windows: Two are on the inner endcaps, and one is on the eyeball.

The best way to check the windows is by using a flashlight. By shining light from one side, almost parallel to the window surface, and viewing from the other, the surface of the windows can be easily checked for cleanliness. If there is dirt or fingerprints on the windows clean them first by rinsing them with lukewarm water and a mild soap solution (e.g. mild hand soap, liquid dish soap) and then rinsing off all soap residue with clean, particle-free water such as de-ionized water, MilliQ water or distilled water. The windows can also be wiped clean with a soft cloth (e.g. a lens cloth) and alcohol. It is not recommended to use stronger solvents, such as acetone or toluene. Also, do not use any abrasive cleaners or wipes. Treat the windows as you would an expensive camera lens.

Attach Communications Cable

Remove the Communications cable from the shipping crate. It is the 2 meter cable with the 9-pin DB-9 connector on one end and the 5-pin underwater connector on the other. Remove the underwater cap from the Communications connector. The connectors will all look similar. The Communication connector is the only 5-pin connector. It is located below the engraved serial number. After removing the cap install the cable making sure that proper alignment of the cable is maintained, so that the connectors are not bent.

Install LISST File Transfer Software

An installer for the software is provided on the USB card that was shipped with your instrument. Double click on ‘LISST File Transfer Setup.exe’ and follow the onscreen instructions. A program icon will appear on your desktop and under the Sequoia folder in your All Programs menu.

This software will allow you to download data files from the instrument. You can also use this software to open a terminal window for direct communication with the LISST-VSF.

The MATLAB *.m files provided on the USB card should be copied to a local folder for data processing. Make sure this folder is in your Matlab path.

Form the Laboratory Test Chamber

The LISST-VSF is provided with a flexible clear plastic sheet with sealing gaskets and quick-release band-clamps. This chamber has the advantages of quick and easy installation and laboratory use. Install with rectangular encoder housing facing up [This is the bump above the eyeball in Fig. 2 (*top*)] Fill with clean, particle-free water (0.2 micron filtered).

Check out the Sequoia Scientific YouTube channel for a video showing how to assemble the flexible test chamber.
http://www.youtube.com/user/SequoiaScientific

NOTE: An improved test chamber for laboratory and flow-through use is in development.

Connect Power

Connect the LISST-VSF to the battery pack with the supplied underwater cable, or to the power supply provided with the instrument.

Start LISST-VSF Program

Launch the software by double-clicking the icon on your desktop. The software will automatically search and connect to the LISST-VSF instrument. If the software fails to find your instrument, go to Help menu and explore the LISST File Transfer Help document.

Open Terminal Window

Under the Communications menu, select Open Terminal. This will open a window within the software window. If you hit <enter> on the PC, the instrument will respond with a LISST-VSF> prompt.

Note: The instrument communicates at 9600 baud through this window. However, when downloading data, the transfer rate automatically changes to 115k.

Basic Commands

Basic commands will be printed to the screen when the Terminal window is opened. You can see a list of these commands again by sending an ‘HE’ command. [HE is for *help*]

Acquire Background Scattering File

Now try to acquire a background file. The Laboratory Test Chamber should be nearly full with clean water (so that both of the windows on inner end-caps are submerged, and the strut on which the eyeball encoder is mounted is partially submerged). Make sure that the water is well-mixed (give it a stir) else temperature variations or turbulent microstructure (scintillation) will affect the small-angle measurements. At the `L-VSF:>` prompt, type the command

```
L-VSF:> zs
```

and hit <enter>.

This command will initiate an approximately 10-minute sequence during which backgrounds will be acquired at a discrete set of PMT gains. First, the laser will turn on for about 15 seconds for power stabilization. Then, the eyeball will start rotation and 10 sets of data will be collected (20 eyeball turns). Next, the PMT gain setting will be changed, and approximately 10 sec will be allowed for the new gain to stabilize and 10 more sets of data will be collected. Again, the PMT setting will be changed and so on. When finished, the laser will turn off. This is the entire background data.

The instrument will save a background file with name ZDDDHHMM.VSF. You can download this new file by closing the terminal window and pressing the refresh button in the upper left of the LISST File Transfer Window. Your new file should then appear in the list box under ‘Files on LISST.’ Choose an offload directory using the controls on the right side of the window. Then highlight the .VSF file and press the green arrow to download the file.

Collecting Particle Data

Drop some particles in the test chamber (use fine particles, e.g. 0.3 micron or 1 micron polystyrene beads from Duke Scientific, Inc.). Mix the water well to homogenize the suspension. *Mixing particles is very important as the method of using the eyeball assumes a homogeneous mixture*!

In the command window, type the commands:

```
L-VSF:>  pd 16
L-VSF:>  go
```

The first command specifies to grab 16 sets of scans (again, recall each set is two rotations of the eyeball). The second command means start data acquisition. Note that PMT gains are automatically adjusted. PMT setting for each data set of 2 eyeball turns is stored in the data file. When finished, the instrument will shut down, and you will know that because the laser will be out. The command window will return to the `L-VSF:> prompt`.

To collect data in a field deployment, you will need to program the instrument, i.e. set the starting delay, sample rate, length of data collection etc. This is explained in Section II.

Downloading Data

From the main window of the LISST File Transfer software you will see a listing of files stored onboard the LISST-VSF and a listing of files in a local directory. Use the controls on the right of the window to select an offload directory. You can use the shift or ctrl keys to select multiple .VSF files to offload. Once selected, press the green arrow to offload the files. Two progress bars will keep you informed on the offload status.

Cleaning the Instrument

Before putting the instrument away, clean the inner endcaps (with transmit and receive windows) and also clean the windows. Drain the test chamber, wipe and dry the windows.

Instrument stand-by current drain

The LISST-VSF does not have a deep sleep mode such as is provided in our LISST-100X/200X; as such when not taking data, it is in the read and standby mode, with the screen showing list-vsf> prompt.

In this standby condition, the instrument draws about 150mA current. For this reason, if you do not intend to use the instrument for an extended period, simply disconnect the power source.

Section II: Operation

Section Overview

This section contains detailed instructions for the operation of instrument and collection and processing of data. Some of the information in Section I.3 is repeated for completion and in greater detail.

Section Organization

This section is divided into these subheadings:

1. Instrument mounting, storage and maintenance
2. Charging and Connecting the NIMH battery pack
3. Bench-testing and collecting background data
4. Offloading and erasing data files from instrument memory
5. Recording and storing a sample data file
6. Data Processing

II.1 Instrument Mounting, Storage and Maintenance

Horizontal Mounting It is recommended that the instrument be mounted horizontally while in use or storage. This ensures that particles will not settle on windows and degrade data quality.

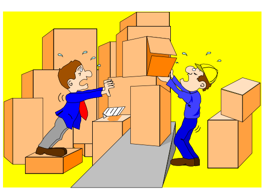
Precautions for mounting **Do not mount the instrument in a way that over-constrains it. No bending moments apply on the instrument. Bending moments will degrade alignment, causing degradation of data at small angles.**

Isolate from other Metals To reduce corrosion of aluminum parts a zinc anode is attached to the Connector endcap. This anode must be exposed to the water for it to be effective.

When mounting the instrument be sure to electrically isolate the instrument from all other metal. Any contact with other metal can greatly increase the rate of corrosion. Isolate the instrument with rubber or plastic to keep the LISST-VSF from becoming the sacrificial anode for the mounting hardware. Failure to properly isolate the instrument from all other metal will void the warranty.

A set of stainless steel clamps with rubberized interiors ships are part of the instrument package. Use these or the plastic clamps for mounting, and make sure that no metal is in direct contact with the pressure housing or other components of the instrument. If you lose the spare clamps, replacement clamps are available for purchase from Sequoia. See Appendix H for: Accessories.

Long-Term Storage The LISST-VSF is a sensitive instrument. When not in use for longer periods, the instrument should be stored in its shipping case.



Clean and dry the instrument before storage.

Avoid storing the instrument in excessive heat or humidity. Do not store the instrument in freezing temperatures, or in environments with wide temperature fluctuations.

When storing the instrument, unplug the battery pack. It is recommended that the venting plug on the battery case be left open for any gases to escape. .

Maintenance Long-term use of the instrument requires only that the state of charge of the battery be monitored. The battery should not be allowed to stay in a state of deep discharge.

The LISST-VSF instrument does not need its O-rings serviced. NEVER open the instrument case endcaps. It will void the warranty.

II.2 Charging and Using the Battery Pack

About the Recharge-able Battery Pack

The LISST-VSF is supplied with a submersible, rechargeable battery pack. Specifications:

- Dimensions: 10 cm (4”) diameter, 41.4 cm (16.3”) cylinder length, 52 cm (20.5”) including handle.
- Weight: 6.5 kg (14.3 lb) in air, 2 kg in water
- Voltage: 14.4 V nominal; 16 V fully charged; 12 V min. operating.
- Capacity: 14 Ahr, 200 Whr.

The battery pack connects to the LISST-VSF through a 3-pin wet-mateable connector (MCBH-3-FS).

The NiMH cells in the battery can be damaged by discharging to too low a voltage. Therefore, the pack includes a circuit that cuts off the output when the battery is exhausted and its voltage falls below approximately 11.5V. The cutoff circuit will reset when the battery is recharged.

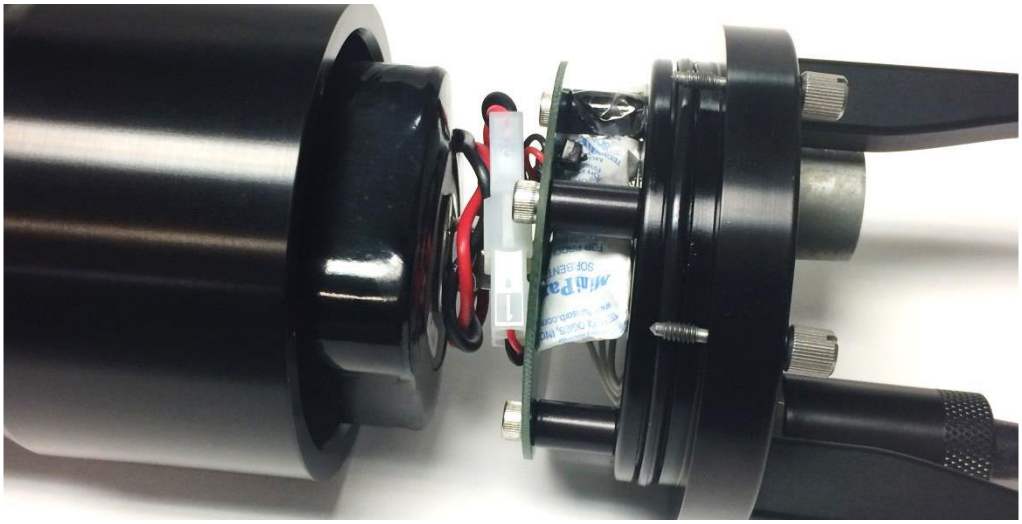
Charging the Battery Pack

IMPORTANT: Charge the battery pack only with the charger supplied by Sequoia Scientific, and follow the instructions given here carefully. Improper charging can create a fire hazard.

Charging requires opening the pressure housing for access to the charging connector. This is a precaution to eliminate the (unlikely) possibility of a pressure buildup inside the housing due to a charging fault.

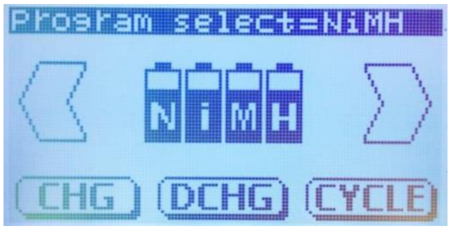
To open the pack, loosen the four knurled screws on the connector end cap. They should only be finger-tight. Do not completely remove the screws; they can remain captive in the end cap when the end cap is removed.

Lay the battery case on its side, and gently work the end cap out of the cylinder:



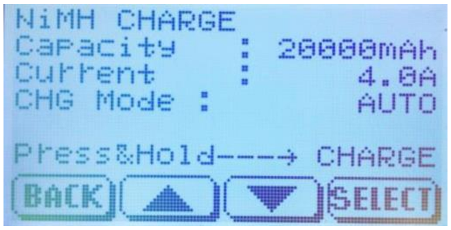
Disconnect the white battery connector, and connect the charger using the supplied adapter.

On the charger display, use the left and right arrows to select the NiMH battery type.



Verify that the Capacity is set to 20000mAh, the Current is set to 4.0A, and the CHG Mode is set to AUTO.

To start, press and hold the word CHARGE.



When the charge is complete, the charger will automatically sound an alarm and stop charging. A full charge may require up to 4 ½ hours, or may be much shorter depending on the battery's state of charge. It is normal for the battery pack to become warm during extended charging. . **NOTE: do not attempt to "top off" the battery by starting another charge after the charger stops. This will overheat the battery and reduce its capacity.**

II.3 Bench Testing and Collecting Background Data

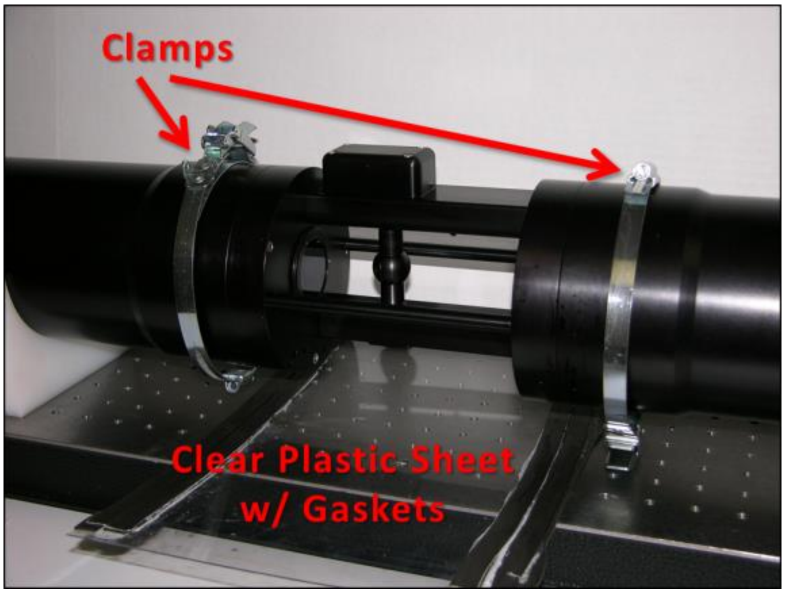
Bench Setup

The LISST-VSF instrument should be set up on the two white plastic mounting blocks, placed roughly between the middle of each pressure case on either side of the eyeball.

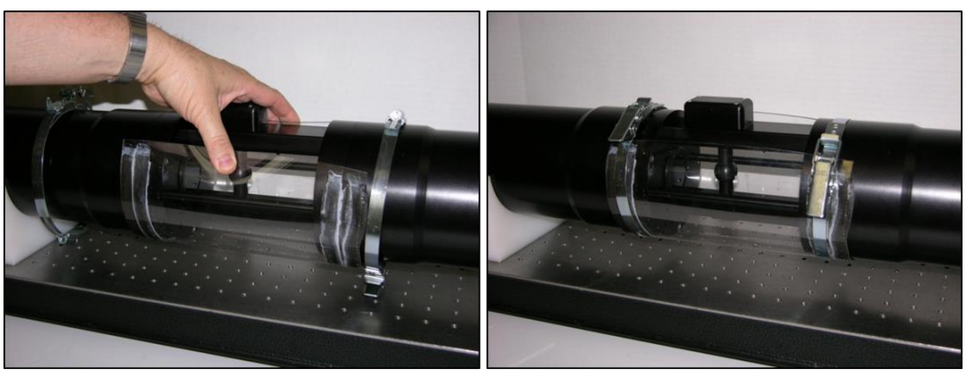
Make sure that you do not add bending moments on the pressure case. Bending will cause loss of alignment, and loss of data at small angles. Photos below show instrument on a test bench, with one plastic support block showing on left.

Install Sample Chamber

The LISST-VSF is provided with a flexible clear plastic sheet with sealing gaskets and quick-release band clamps. This chamber has the advantages of quick and easy installation and the ability to inspect the sample being measured. View video at http://www.youtube.com/user/SequoiaScientific . Else, follow along as here.

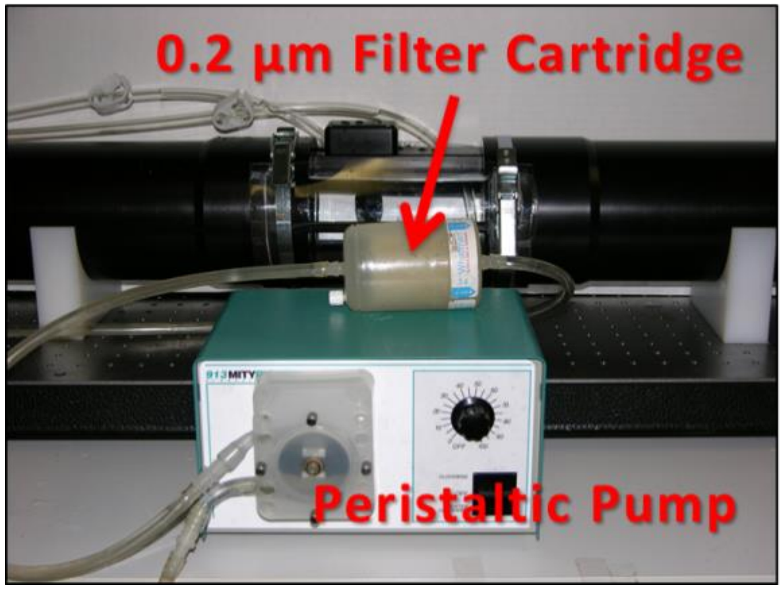


Wrap the plastic sheet around the sample volume and install clamps over the gasket strips to secure the chamber to the LISST-VSF instrument. Verify that that there are no leaks. Adjust clamps and/or replace gasket material if needed.



Fill with Clean Water

Fill the sample volume with organic-free, degassed, particle-free water. Clean water should reach a level approximately 1-2 cm above the optical windows. Sequoia recommends using distilled or reverse-osmosis water which has undergone 0.2 micron (or smaller) filtration. Superior lab results have been obtained by continuously recirculating (pumping) the clean water contained in the sample volume through a 0.2 micron capsule filter (e.g., Whatman PTFE, PALL Supor, GE Memtrex) for ~1 hour before sampling.



Record and Store Background Scattering File

Connect the communications cable. Connect battery or benchtop power supply. Run the LISST File Transfer software and open a terminal window by going to Communication > Open Terminal.

The LISST-VSF ring data is sensitive to ambient light. Therefore, it is suggested that the sample volume be covered with a felt sheet or other opaque barrier during sampling. When ready, type the command:

```
L-VSF:> zs
```

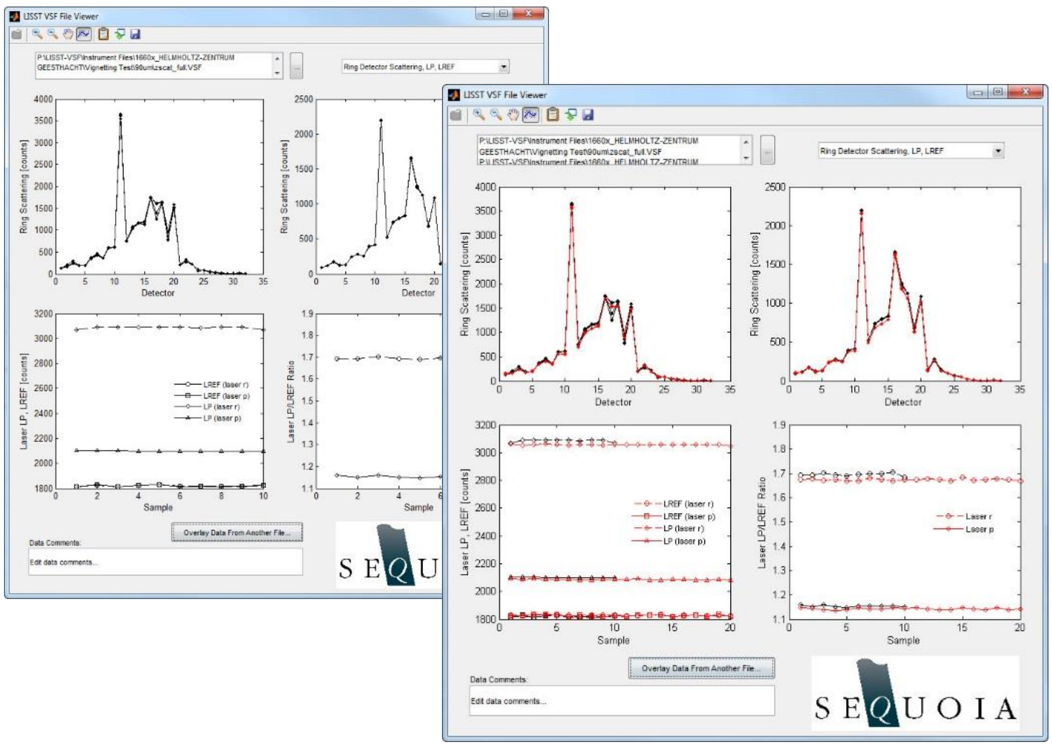
and hit <enter>.

This command will initiate an approximately 10-minute sequence during which backgrounds will be acquired at a discrete set of PMT gains. First, the laser will turn on for about 15 seconds for power stabilization. Then, the eyeball will start rotation and 10 sets of data will be collected (20 eyeball turns). Next, the PMT gain setting will be changed, and approximately 10 sec will be allowed for the gain to stabilize. Next, 10 more sets of data will be collected. Again, the PMT setting will be changed and so on. When finished, the laser will turn off. This is the entire background data.

The instrument will save a background file with name ZDDDHHMM.VSF. You can download this new file by closing the terminal window and pressing the refresh button in the upper left of the LISST File Transfer Window. Your new file should then appear in the list box under ‘Files on LISST.’ Choose an offload directory using the controls on the right side of the window. Then highlight the .VSF file and press the green arrow to download the file.

You can compare your background to the factory background using the ‘lisstvsf_view’ Matlab GUI provided on the USB card. Start by running the ‘lisstvsf_view.m’ file in Matlab. Read in your newly collected background file by clicking on the ellipses button near the top.

You can then overlay a factory background on top of your existing data by pressing the ‘Overlay Data From Another File…’ button. The file you select will appear in red. Use the dropdown box in the upper right to view comparisons of ring or eyeball data. Factory backgrounds are provided on your USB card.



II.4 Offloading and Erasing Data Files from Instrument

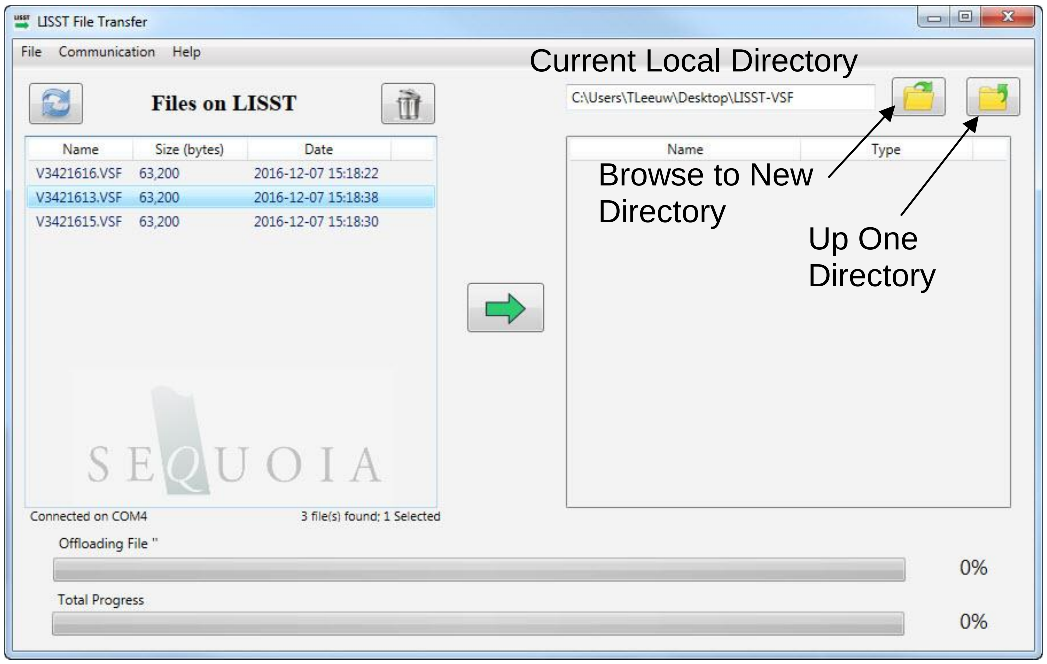
Connect Instrument and Start LISST File Transfer Software

Connect communications cable. Connect battery or benchtop power supply. Run LISST File Transfer Software.

The software will automatically search and connect to the LISST-VSF instrument. If the software fails to find your instrument, go to Help menu and explore the LISST File Transfer Help document.

Select Files to Offload

A list of files stored on the instrument will be displayed on the left of the screen



Choose the files to offload by clicking on the file name. Multiple files can be selected by hold down the CTRL key while clicking on files. Use the SHIFT key to select a range of files.

Select Download Destination folder

The list box on the right displays the contents of a local directory on your computer. Use the buttons on the top right to navigate to the directory you would like to offload your files to.

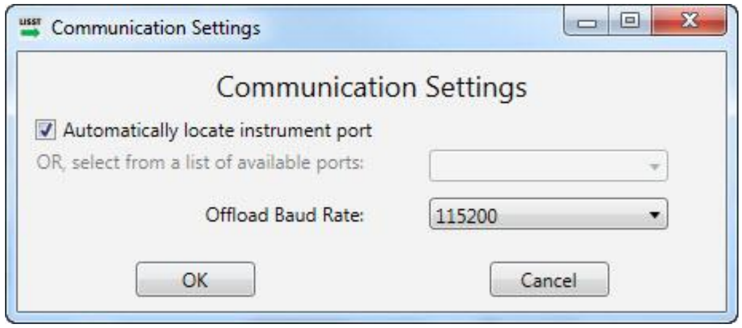
The file names will remain the same as on the compact flash card.

A status bar will be displayed for each file offloaded. Text in the lower left corner will display the current file being offloaded.

Changing Offload Baud Rate

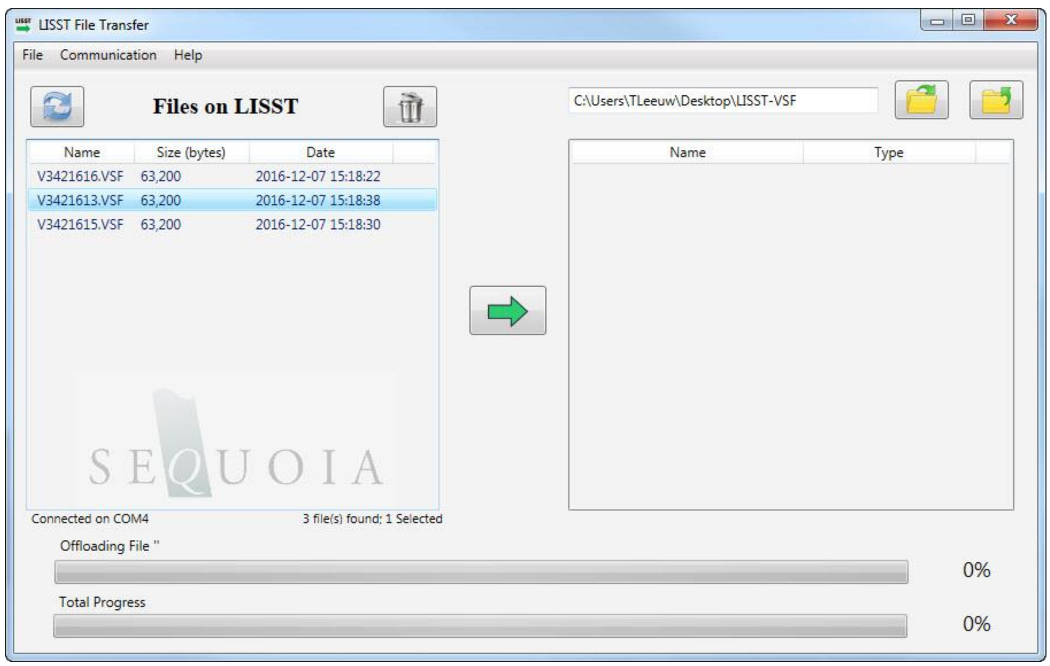
The standard offload baud rate is 115K. If you are using a long offload cable (i.e., >20 m cable), this value may be too high and cause errors during offloading. If an offload error occurs, you can change the offload baud rate as follows:

Go to Com. Settings in the Communication Menu. In the Offload Baud Rate drop down menu, choose a lower baud rate and try again.



Deleting Files from LISST-VSF Memory

When connected to instrument as described above, select the files you would like to delete. Press the trash icon to delete this files. You will be asked to confirm deletion of the files.



WARNING: Once a file has been deleted it cannot be recovered. Make sure that the file has been properly offloaded before deleting any files.

II.5 Recording and Storing a Sample Data File

In the Laboratory

Connect communications cable. Connect battery or benchtop power supply. Run LISST File Transfer software and open a terminal window from the Communication menu.

Install the test chamber and fill with clean filtered water as described in Bench Testing and Collecting Background Data (page 31).

Chopping to reject ambient light has not been implemented for ring detectors. Therefore, we recommend draping the instrument with black cloth.

Set the sampling parameters to start immediately on command, save a specified number of measurements, and stop sampling by issuing the following commands:

Command	Response
`ST 5<ENTER>`	`New Start Condition Setting: Delay Start`
`TD 0<ENTER>`	`New Start Condition data = 0` `Start Condition: Delay Start with 0 minute delay`
`SP 5<ENTER>`	`New Stop Condition Setting: Fixed Number Stop`
`PD 20<ENTER>`	`New Stop Condition data = 20` `Stop Condition: Fixed Number Stop at 20 samples`

This configures the LISST-VSF to collect 20 sets of scattering data (each including both laser polarization states). The number specified with the PD command can be changed to collect a different number of sets.

Finally, issue the GO command to start acquisition of background scattering file. After brief warm-up period, 20 sets of scans will be saved to a file Zdddhhmm.VSF, where ddd, hh, and mm, are the day of year, hour, and minute, respectively.

Offloading and Processing the Acquired Scattering File

The data offloading procedure is identical to that described in Section II.4.

For data processing, see Section II.6.

Configuring Sampling Parameters for Field Deployment

Field deployment of the instrument requires settings for delay before starting, start and stop conditions, number of samples to save etc. See **Section III.2.**

II.6 Data Processing

Datafile Format

The datafile consists of **sets** of data. Each set contains data for two rotations of the eyeball. Each rotation contains the following variables:

Variable no.	Variable Name
1-32	Rings
33	Laser transmission
34	Battery voltage
35	PMT control voltage
36	Laser Transmission
37	Depth
38	Temperature
39-40	Date and Time
41-791	150 pairs of [angle PMT1on PMT1off PMT2on PMT2off]

The on and off values refer to laser being on or off for chopping. For more information, see Appendix D.

Data Processing Sequence

The following steps are implemented in software for data processing:
.

1. Reading the datafile;
2. Reading the corresponding background file;
3. Subtracting the background from the data at equal PMT sensitivity;
4. Application of laser power dimming factor at 40^{th} data in eyeball rotation
5. Finding the relative gain of the two PMT's
6. Calculation of the eyeball p11,p12,and p22;
7. Calculate ring-detectors net scattering (similar to LISST-100X)
8. Apply ring area and vignetting corrections to ring data
9. Match the rings and eyeball data at 15-deg scattering angle
10. Compute composite P11, as [small angle and eyeball angle]
11. Plots of VSF, p12 and p22.

For convenience, a one-step processing function is provided as below.

One-Step Processing

A single command in MATLAB is set up to process datafiles and produce the VSF and depolarization parameters. This assumes that the datafile is good. The command is:

lisstvsf_makep.m

```
proc  =  lisstvsf_makep(SN, Data, background, Alpha, Plotting);
```

Inputs to lisstvsf_makep function are: the serial number of the instrument, the data file (.VSF), the background file (.VSF), an optional value for α, and a flag (0 or 1) to turn on or off data plotting. Only data that does not contain PMT saturation will be plotted. The parameter α is the ratio of two photomultiplier sensitivities. If you would like the software to estimate the value of alpha, put an empty array in the alpha input ("[ ]"). *We recommend using automatic route.*

The function returns the structure "proc" which has the following fields:

Field	Description
procver	Software version
procdate	Date the data was processed
timestamp	Timestamp of measurements in Matlab datenum
tempC	Temperature in Celsius
depth	Depth in meters
batt_volts	Battery voltage
pmt_gain	PMT gain setting
qc_saturated	Quality control flag that indicates PMT saturation in the eyeball data (1 = saturation; 0 = no saturation)
tau	Percent light transmission through the sample volume
beamc	Beam attenuation coefficient m^{-1}
rings	Structure containing ring data
angles	Angles in degrees measured by the eyeball
rp	Raw scattering from rotated incident polarization measured by parallel PMT
rr	Raw scatting from rotated incident polarization measured by rotated PMT
pp	Raw scattering from parallel incident polarization measured by parallel PMT
pr	Raw scatting from parallel incident polarization measured by rotated PMT
alpha	Alpha as entered by the user or estimated by the software
rr_scaled	rr after scaling by alpha
pr_scaled	pr after scaling by alpha
p11_scale_factor	Factor used to correct for change in laser gain during eyeball rotation
p11	VSF for eyeball angles
p12	P12 element of Mueller matrix
p22_1	P22 calculated using method 1*
p22_2	P22 calculated using method 2*
Angles	Angles for merged ring and eyeball data
P11	VSF for merged ring and eyeball data
beamb	Scattering coefficient m^{-1}

*P22 calculations are still experimental, see explanation in Appendix A. See the code for the difference in calculation between method 1 and 2.

IMPORTANT: you must check the qc_saturation flag in the proc structure to determine which measurements contain saturation (1 = saturation; 0 = no saturation). Data containing PMT saturation will produce incorrect results. The LISST-VSF automatically adjusts PMT gain to avoid saturation, however, when conditions are changing some measurements are expected to contain saturation.

Step by Step Data Processing

The following sub-sections describe a more detailed processing of LISST-VSF data. Although these steps are identical to the sequence in lisstvsf_makep.m it gives you access to intermediate results.

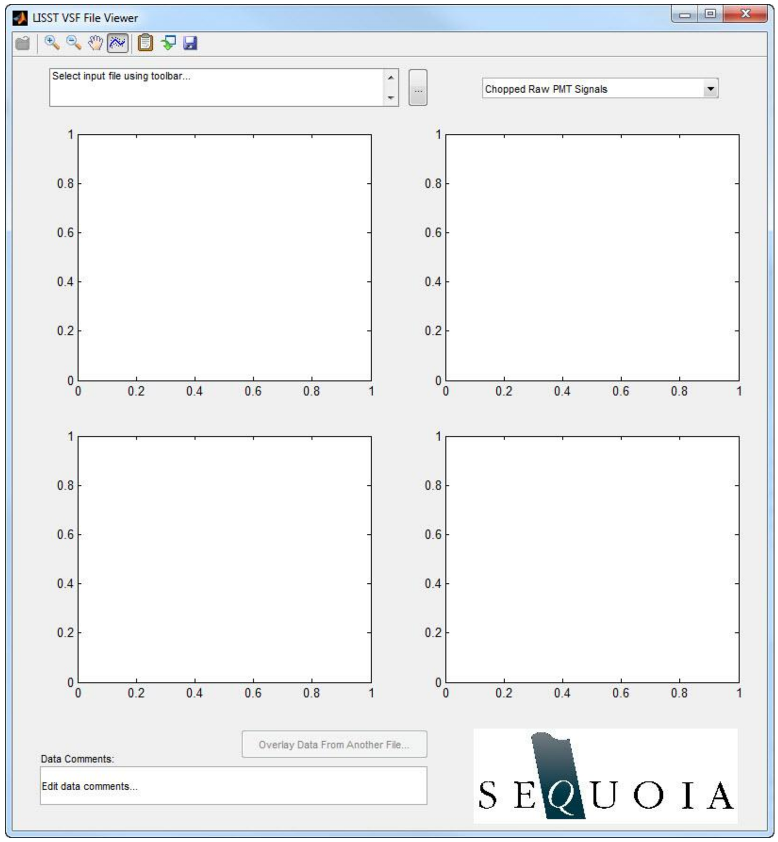
Lisstvsf_view.m

The lisstvsf_view command in Matlab command window will open a Matlab GUI that will allow you to view the contents of a raw data file. It is suggested you view the raw data before processing the data file using the one-step lisstvsf_makep function. *You should view the raw data from your background file to ensure it appears near the factory background level. You should also view the raw data of the scattering file to look for data quality issues, such as PMT saturation (discussed below*). In Matlab command window, type:

```
lisstvsf_view;
```

When this script is run, the Matlab GUI will appear. In this 4-window plot, you can display all raw data. You can even overlay data up to 4 different files.

Since a data file has not been selected yet, the plots will be empty.



Click on the ellipsis button near the top left to read in a data file. The drop down menu on the top right will allow you to view different parameters.

Only the following raw data parameters become available for viewing:

Net Raw PMT Signals
Net (light minus dark, e.g. PMT1_on – PMT1_off) signals recorded by the PMTs.

Chopped Raw PMT Signals

Raw signals recorded by the PMTs. You will typically see groupings of lines, one corresponding to the light readings (laser 'on') and one corresponding to the dark readings (laser 'off'').

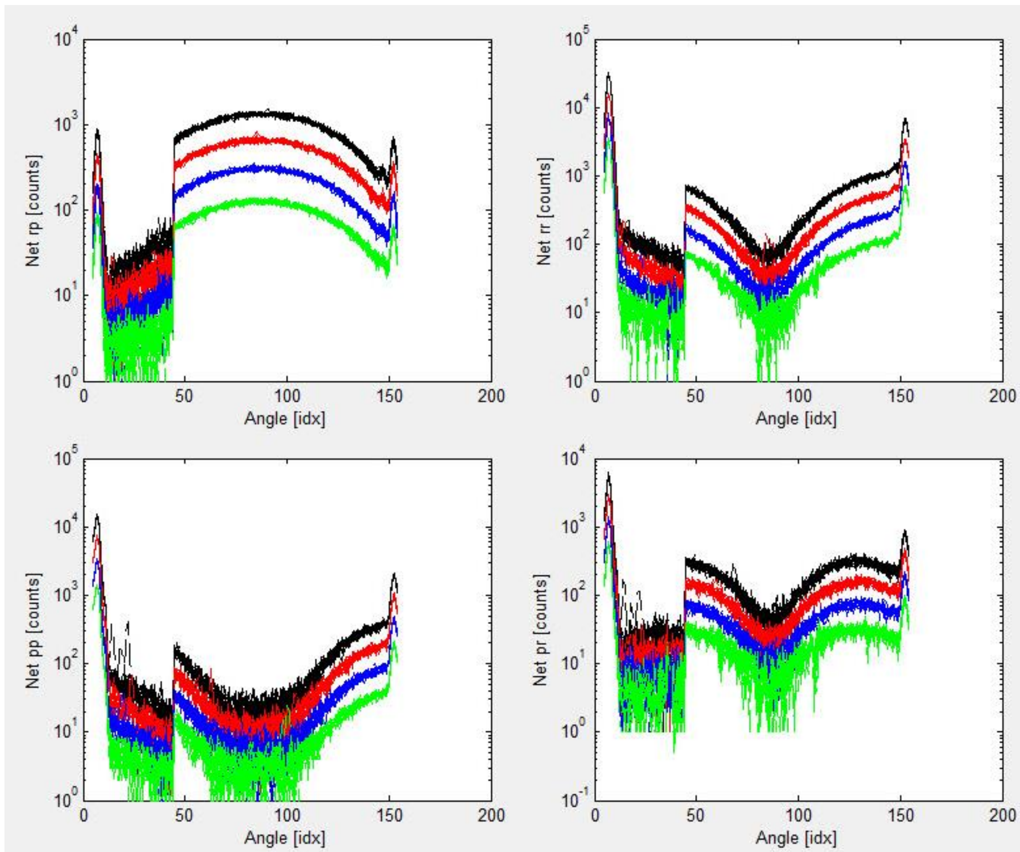
Ring Detector Scattering, LP, LREF
Raw signals from the ring detector as well as from the laser power (LP), and laser reference sensors (LREF).

Auxiliary Parameters
Depth, Temperature, and Battery Volts.

To overlay parameters from 2 or more files, press the 'Overlay Data From Another File' button (lower left). You can overlay data from up to four different files. This feature is especially useful to compare a background file to the factory background, or eyeball backgrounds.

Below is an example of eyeball data collected from pure water at four different PMT gains displayed in the lisstvsf_view GUI. Note that the step at 40^o is due to the dimming/un-dimming of the laser. The 'dimming factor' can be easily estimated from such data but only when the signals are clean. The pure water plots below show symmetry abound 90^o which is expected for pure water scattering

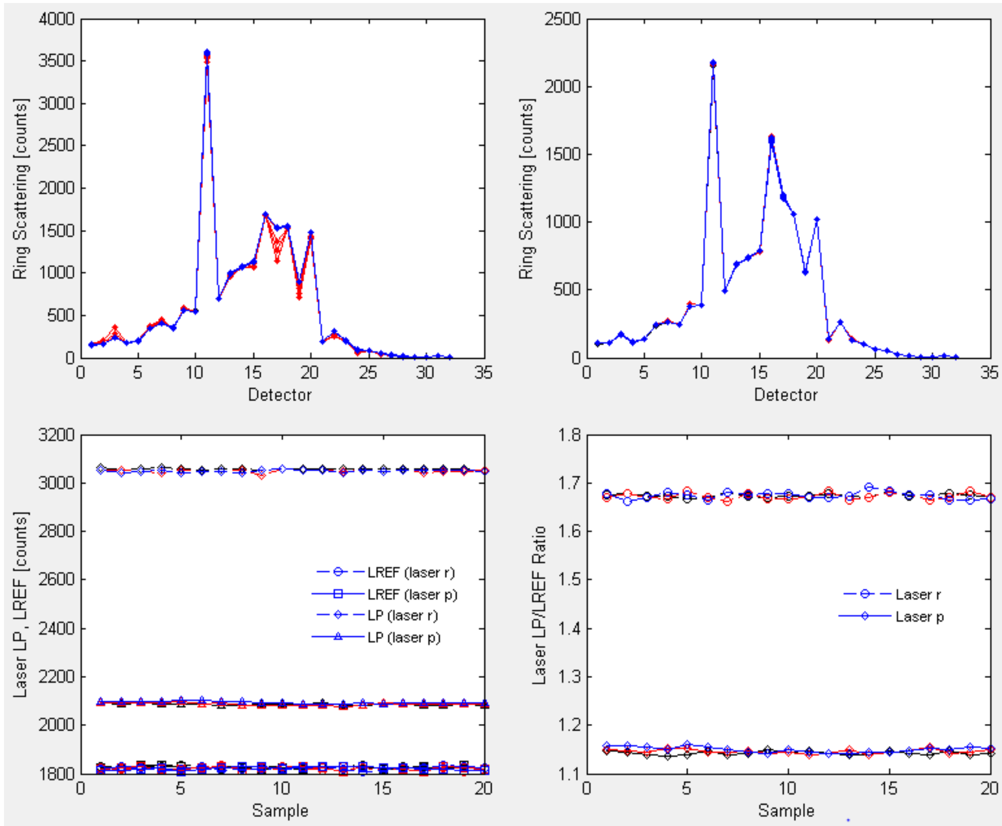
.



Any of the parameters selected in this manner can be viewed in this GUI.

Data from up to 4 files can be overlaid in this manner.

By selecting ring detector, Lp,LREF in the GUI parameter options, the rings data and time series of transmitted laser power and laser reference can be viewed.



Output of ring detectors for the two polarizations of laser.

The left and right plots are for perpendicular and parallel polarization of the laser. In this figure, one can see the rings on top, LP and LREF in the bottom. Figures on left are for one state of polarization, and those on right for the other state.

In pure water, LP should be stable with minimal variation. If variation can be seen, it could imply that the water is either turbid, or there are temperature fluctuations in it.

We do not show the use of this GUI to view the auxiliary parameters. We encourage the viewer to do so.

lisstvsf_getcal.m

This function contains calibration information specific to your instrument. The instrument serial number (SN) is passed as the input and the function returns a structure containing the calibration values. This function is used by the lisstvsf_makep function.

```
calfact = lisstvsf_getcal(SN);
```

lisstvsf_readdat

Similar to lisstvsf_view GUI, this command reads a raw datafile, passes the scattering, angle and aux data as output parameters, but does not provide output plots of the data (most commonly, this command is used in the lisstvsf_makep function to read in a file without displaying extra plots of the raw input data). Generally this function will only be used by power users, as it contains raw data values that require calibration and interpretation.

Usage:

```
dat = lisstvsf_readdat(filename);
```

The variable ‘dat’ will be a structure containing the raw data. It will have the following fields.

Field	**Description**
procver	Version of script
procdate	Date script was run
filename	File name of data file
filedate	Date data was collected
nangles	Number of angles measured with eyeball
nsets	Number of measurements
batt_volts	Battery volts in counts
pmt_gain	PMT gain setting
angles_idx	Raw angle values from encoder
raw	Raw PMT signals
qc_saturated	QC flag for PMT saturation
rp	Net PMT signal from rotated incident polarization measured by parallel PMT
rr	Net PMT signal from rotated incident polarization measured by rotated PMT
pp	Net PMT signal from parallel incident polarization measured by parallel PMT
pr	Net PMT signal from parallel incident polarization measured by rotated PMT
LP	Laser power in counts
LREF	Laser reference in counts
rings1	Raw signals on ring detector, rotated polarization
rings2	Raw signals on ring detector, parallel polarization
depth	Depth in counts
tempC	Temperature in counts
time	Timestamp in Matlab datenum

Detailed Walkthrough of lisstvsf_makep.m

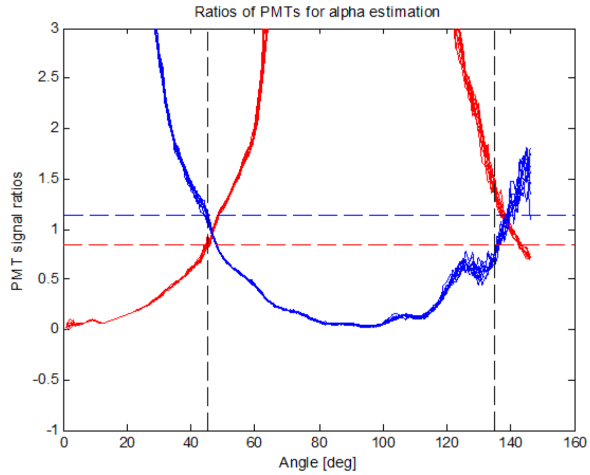
You may familiarize yourself with the details of the lisstvsf_makep processing by viewing the code. The code is well commented. It is here that the jump in raw data at 40^o (seen with the view_rawfile command) is removed; laser power variation is normalized out, sample volume stretching is compensated, etc.

Adjusting PMT Relative Gain (α)

In lisstvsf_makep.m, an automated procedure is used to find the relative gain (α) of the two PMT's. Noisy data may require adjusting the relative gain. This is the only adjustable parameter in the lisstvsf_makep function.

Tweaking α

To adjust the relative gain, enter a value for alpha when calling the lisstvsf_makep function (fourth input variable). When alpha is correct, the ratio of the PMT signals at 45 and 135 degrees should be one. Therefore, adjusting alpha is best done iteratively.



Making Plots

Plots of final variables such as P11, P12, P22 can be made with simple Matlab commands. Note that the ring data are on a logarithmic angle axis, whereas eyeball data are on linear angle axis. To emphasize small angle VSF, use a logarithmic angle axis; to emphasize large angle VSF, use linear angle axis.

Scattering angles in water for rings and eyeball are provided in Appendix C.

Mie Theory Comparisons

We have provided other software that makes it easy to compare your data with Mie theory, when working with single size particles.

fastmie.m

Calculates Mie theory prediction of scattering at specified angles, for given particle size and refractive index. Usage:

[S1,S2,Qsca,Qext,Qback] = FASTMIE(x,nrel,ang);

We also provide a Matlab script called DataProcessingExample.m that will help you get started with processing and comparing your data to Mie theory.

SUMMARY

To recap:

1. A single step function 'lisstvsf_makep.m' can be used to process a set of datafiles comprising of (a) particle data; and (b) background data.

2. It is possible to view each datafile using the lisstvsf_view GUI or lissvsf_readdat functions.

3. The break in p22 at 45 and 135^{o} is caused by the nature of these data with the rotating eyeball (explained in Appendix A).

Section III: Instrument Communication and Programming

Overview

The LISST-VSF supports various options for data collection, such as different conditions to start and stop logging, and rates of sampling. Section III.1 describes these options and parameters. Section III.2 describes all the commands used to control data collection and other aspects of instrument operation.

Communication Basics

The LISST-VSF communicates through the 5-pin underwater connector on its end cap (see Appendix D), using RS-232 at 9600 baud (data files are downloaded at higher speeds). The cable supplied with the instrument adapts the 5-pin connector to a standard USB-A connector.

The instrument has a simple text-based command interface that can be used with either the Sequoia-supplied software, or a generic text terminal.

Communication Software

The LISST File Transfer software supplied with the LISST-VSF is the simplest way to connect and communicate with the instrument. It automatically detects a connected instrument, and provides a graphical interface for offloading files. It also provides a terminal for using the command-line interface to set up data collection.

You can install LISST File Transfer from the USB card provided with the instrument, or with a download from www.sequoiasci.com.

If connecting to the LISST-VSF with software other than the supplied LISST File Transfer program, the connection will appear as a COM port at 9600 baud, 8 data bits, No parity, and 1 stop bit. Data file transfer is normally done using a YMODEM transfer at 115K baud.

Two Letter Commands

Once connected to the LISST-VSF, type HE at the L-VSF:> prompt to see a list of commands, and read the following sections for complete details.

Sampling Parameters

Start Condition

Two letter commands (in a terminal window or other RS-232 link) can configure the LISST-VSF with one of five Start conditions: Depth, Time, External Mechanical Switch, External Digital Input, and Time Delay. The details of each condition are described below.

Depth Start

The built-in depth sensor of the LISST-VSF is used to check the current depth to determine if the desired start depth has been exceeded. The instrument is powered up and 5 measurements of the depth are averaged over a two-second period. If the depth exceeds the threshold the program will proceed to the data collection routine. If the depth does not exceed the threshold the instrument will power down and wait 28 seconds before checking the depth again. The program will continue checking until the depth is exceeded or until the program is stopped.

Time Start

The program will check the current time every second and compare it to the Start Time. If the Start Time is equal to or earlier than the current time the program will go directly to the data collection routine. It will continue checking the time until the Start Time is reached or until the program is stopped.

External Mechanical Switch Start

The LISST-VSF has a white plastic lever on the endcap. This lever has a magnet imbedded in it. This magnet can activate a switch inside the pressure case. The base program looks at the status of this switch once a second. If the switch is in the on or “1” positions the program will go directly to the data collection routine. It will continue checking the switch status until the switch is moved to the “0” position or until the program is stopped. When in the “0” position the lever is up against the zinc anode.

External Digital Input Start

The LISST-VSF is equipped with auxiliary inputs on the 6-pin underwater connector. Pin 2 of the 6-pin connector is the DIG 1 input (see Engineering Drawings). The program will check the status of the digital input once a second. If the voltage at the DIG 1 input is greater than 2 volts (relative to Digital Ground, Pin1) the program will go directly to the data collection routine. It will continue checking the status of the digital input until voltage exceeds 2 volts or until the program is stopped.

WARNING: The maximum permissible input voltage on the digital input line is 3.3 volts.

Time Delay Start

The time delay start condition will cause the program to wait the specified number of seconds before continuing on to the data collection routine.

Stop Condition

The LISST-VSF can be configured with one of six Stop conditions: Depth, Time. External Mechanical Switch, External Digital Input, Fixed number of samples, and Maximum Memory or Low Battery. The Stop conditions are checked after each measurement set (two rotations of the eyeball). The details of each condition are described below.

Depth Stop

The built-in depth sensor of the LISST-VSF is used to check the current depth to determine if it is less than the desired Stop depth. The averaged depth from the last sample acquired is used as the current depth. If the depth is less than the threshold the sampling will stop. If the depth is not less than the threshold the program will continue sampling as per the configuration. If the Start Condition is a Depth Start the program will wait 30 seconds and then return to looking for the Depth Start Conditions. The delay is to keep the instrument from starting and stopping too quickly as the instrument is moving up and down. If the Start Condition is Depth Start the Base program will return to checking for the Start Conditions. For all other Start Conditions the when the current depth is less than the threshold the program will stop and return to the L-VSF:> prompt.

Time Stop

The program will check the current time after each sample or burst and compare it to the Start Time. If the Start Time is equal to or later than the current time the program will stop and return to the L-VSF:> prompt.

External Mechanical Switch Stop

After each measurement set the status of the Switch lever is checked. If the switch lever is in the off or “0” position sampling will stop. If the Start Condition is a Switch Start the program will return to checking the start condition. For all other Start conditions the program will stop and return to the L-VSF:> prompt.

External Digital Input Stop

The status of the Dig 1 input is checked after each sample or burst. If the voltage at the input is less than 0.7 volts the sampling will stop. If the Start Condition is a Digital Input Start the program will return to checking the start condition. For all other Start conditions the program will stop and return to the L-VSF:> prompt.

Fixed Number of Samples Stop

The program will acquire a fixed number of samples before stopping. The number of samples saved is checked after each measurement set is saved. When the number of sample to be saved has been reached the program will stop and return to the L-VSF:> prompt.

Maximum Memory or Low Battery Stop

The Maximum Memory or Low Battery Stop condition will continue to sample until the memory capacity has been reached or when the battery voltage has dropped to less than 12 volts. The program will continue to sample until one of these conditions is met. It will then return to the L-VSF:> prompt.

III.2 Command Details

List of Commands

Display Commands

DB	Display Current Battery Voltage
DD	Display current Disk Directory
DS	Display current status information
DT	Display Current Time and Date
HE	Display general help messages and command list

Setup Commands

ST x	Set Start Condition.
TD x	Set Start Condition Data
SP x	Set Stop Condition
PD x	Set Stop Condition Data
SI x	Set Sample interval
MA x	Set number of ring detector measurements per average
SC *mm/dd/yy hh:mm:ss*	Set Clock with time and date, where *mm*=month, *dd*=day, *yy*=year, *hh*=hour(24 format), *mm*=minute, *ss*=seconds, Example: ST 01/05/2005 21:05:03
AS	Autostart Setting
SD	Store Current Settings as Default
ZD	Reset Depth Sensor Offset

Acquisition/Action Commands

DL filename	Delete File
GO	Start Data collection using current parameters
ZS	Collect background scattering and store in a file

Display Commands

DB	Display Battery Voltage
Syntax:	DB or db
Description:	Displays the current battery voltage. Note that the instrument will turn on the eyeball motor and laser briefly in order to determine the battery voltage under load.

DD	Display Disk Directory
Syntax:	DD or dd
Description:	Display current disk directory in DOS type format. Includes total bytes used and bytes available.

Example:	input: DD
	output:
	`LISST-100X Disk Directory`
	`Volume in drive C is NONAME`
	`Volume Serial Number is 778B-155`
	`Directory of C:\DATA`
	`V0403054.VSF 4,136 03-05-04 6:30p`
	`Z1837055.VSF 1,672 03-05-04 6:37p`
	`2 file(s) 5,808 bytes`
	`0 dir(s) 15,933,440 bytes free`
	`L-VSF:>`

DS	Display current status information
Syntax:	DS or ds
Description:	Displays the instrument serial number, firmware version, and other important settings. Note that the laser and eyeball motor will run briefly in order to measure the supply voltage accurately.

Example:	input: DS
	output:
	`LISST-VSF Current Status and Settings`
	`Serial number = 1425`
	`Firmware Version 0.920 Jul 23 2012 17:34:17`
	`.`
	`. [ various parameters and settings]`
	`.`
	`Battery Voltage is 10.75`
	`Current Date/Time: Tuesday, August 07, 2012 16:18:36`
	`Current Day of the Year: 220`

HE	Display general help messages and command list
Syntax:	HE or he
Description:	Displays the list of command to the screen.

Setup Commands

MA	**Set measurements per average**
Syntax:	MA x or ma x Where x = number of samples per average
Description:	Each recorded or displayed measurement is based on an average of measurements. The number of measurements per average is set using the SA command. If no value follows command, prompts will be displayed for the value.
Example:	input: MA 10 output: New Measurements per Average: 10
Cautions:	None

ST	**Set Start Condition**
Syntax:	ST x or st x, where x is the start condition code described below
Description:	The ST command sets the start condition to be used when the GO command is issued. The start condition options are: 1 = Depth Start 2 = Time/Date Start 3 = Mechanical Switch Start 4 = Digital Input Start 5 = Delay Start If no value follows command, prompts will be displayed for the value.
Example:	input: ST 5 output: New Start Condition Setting: Delay Start

TD	**Set Start Condition Data**
Syntax:	TD x or td x, where x is the start condition data described below
Description:	The TD command sets the start condition data to be used when the GO command is issued. The start condition data is used with the Start Condition setting as follows: • If the Start Condition is Depth Start (option 1) the input will be start depth in meters. • If the start condition is set to Time/Date Start (option 2) the input for TD will be the start date and time. • If the Start Condition is Delay Start (option 5) the input will be time delay in seconds. • The TD setting is ignored for Mechanical Switch Start (option 3) or Digital Input Start(option 4). If no value follows command, prompts will be displayed for the value.
Example:	input: TD 3 (if Start Condition = 1 (Depth Start)) output: New Start Condition data = 3 Start Condition: Depth Start at 3 meters input: TD 12/31/05 23:59:59 (if Start Condition = 2 (Time/Date Start)) output: New Start Condition data = 12/31/05 23:59:59 Start Condition: Time Start at 12/31/05 23:59:59 Input: TD 2 (if Start Condition = 5 (Delay Start))

	Output: New Start Condition data = 2 Start Condition: Delay Start with 2 minute delay

SP	**Set Stop Condition**
Syntax:	SP x or sp x, where x is the stop condition code described below
Description:	The SP command sets the stop condition to be used when collecting data. The stop condition options are: 1 = Depth Stop 2 = Time/Date Stop 3 = Mechanical Switch Stop 4 = Digital Input Stop 5 = Fixed Number of Samples Stop 6 = Maximum memory or Low Battery Stop If no value follows command, prompts will be displayed for the value.
Example:	input: SP 5 output: New Stop Condition Setting: Fixed Number Stop

PD	**Set Stop Condition Data**
Syntax:	PD x or pd x, where x is the stop condition data as described below
Description:	The PD command sets the stop condition data to be used when the collection data. The stop condition data is used with the Stop Condition settings as follows. • If the Stop Condition is Depth Stop (option 1) the input will be stop depth in meters. • If the stop condition is set to Time/Date Stop (option 2) the input for PD will be the stop date and time. • If the Stop Condition is Fixed Number Stop (option 5) the input will be the number of samples to collect before stopping. • The PD setting is ignored for Mechanical Switch Stop (option 3), Digital Input Stop (option 4) or Maximum memory or Low Battery Stop (option 6).

Example:	input: PD 3 (if Stop Condition =1 (Depth Stop))
	output: New Stop Condition data = 3
	  Stop Condition: Depth Stop at 3 meters
	
	input: PD12/31/05 23:59:59 (if Stop Condition = 2 (Time/Date Stop))
	output: New Stop Condition data = 12/31/05 23:59:59
	  Stop Condition: Time Stop at 12/31/05 23:59:59
	
	input: PD 2 (if Stop Condition = 5 (Fixed Number of Samples Stop))
	output: New Stop Condition data = 2
	  Stop Condition: Fixed number Stop at 2 samples

SI	**Set Sample Interval**
Syntax:	SI x or si x, where x is the number of seconds between samples, from 1 to 10,000.
Description:	The sample interval is the minimum number of seconds between two consecutive samples. Note that a complete sample of ring and eyeball data from the LISST-VSF requires 3 to 4 seconds. Therefore SI values lower than 4 will be ignored.
Example:	input: SI 5

	output: New Seconds between Samples: 5

SC	**Set Clock with time and date**
Syntax:	SC mm/dd/yy hh:mm:ss or sc mm/dd/yy hh:mm:ss Where mm=month, dd=day, yy=year, hh=hour (24 hour format), mm=minute, ss=seconds If no values follow the "**SC**" or "**sc**" command, prompts for entering the time and date will be displayed.
Example:	input: SC 01/05/2001 21:05:03 output: Command Data in SC is: 01/05/01 21:05:03 Current Date/Time: Friday, January 05, 2001 21:05:03

AS	**Autostart Setting**
Syntax:	AS x or as x, where x is 1 (yes) or 0 (no)
Description:	With Autostart enabled, the firmware will immediately start the sampling program that is stored in the EEPROM of the Persistor datalogger upon power up of the instrument. Use the SD command to store the current settings as default values to be used in conjunction with the AS command.
Example:	input: AS 1 output: AutoStart will occur upon power up!
Cautions:	1) If Autostart is enabled, but you wish to stop or prevent it from running, send a control-C character during the startup delay. 2) Make sure the current program settings are as desired and saved as default settings (see SD).

SD	**Store Current Settings as Default**
Syntax:	SD or sd
Description:	Issue the SD command to verify the current settings. Then confirm (1 = yes, 0 = no) that these settings should be burned into the EEPROM to be used with the AutoStart setting.
Example	input: SD output: LISST-100X Current Status and Settings Serial number = 1335 Firmware Version 1.997 Feb 16 2011 14:18:45 Start Condition: Delay Start with 3 minute delay Stop Condition: Fixed Number Stop at 2 samples Measurements per Average: 10 Sample Interval: 5 Battery Voltage is 12.28 Current Date/Time: Wednesday, August 17, 2011 12:24:14 Current Day of the Year: 229
Cautions:	If you change any of the settings after issuing the SD command you must reissue the SD command to save the updated settings.

ZD	Reset Depth Sensor Offset
Syntax:	ZD or zd
Description:	The ZD (or zd) command resets the depth sensor offset so that the sensor reads a depth of 0m at zero depth (in air). You must issue the ZD command, then select 1 (yes) or 0 (no) to reset depth sensor
Example:	input: ZD output: Depth Sensor Offset Reset Procedure Started. Instrument must be at zero depth and similar temperature to field conditions. Do you wish to reset Depth Sensor offset? (1=yes,0=no): [0] ? 1 Previous offset was -14.03. New offset is -13.87. Previous Depth was -0.15 meters. New Depth using corrected offset is 0.00 meters.
Cautions:	None

Acquisition & Action commands

DL	Delete file from Flash Memory
Syntax:	DL *filename* or dl *filename* where *filename* is the name of the file to be deleted.
Description:	DL command is used to delete files from the flash memory. Wildcards such as *.* can be used.
Example:	Input: DL L159*.dat Output: Are you sure (Y/N)…
Cautions:	WARNING: Make sure that the file being delete has already been offloaded before deleting the file. Once the file is delete it can not be recovered.

GO	Start Data Collection using current Settings
Syntax:	GO or go
Description:	Starts Fixed Rate or Burst Mode Data collection using current settings.
Example:	Input: GO Output: Waiting for start conditions…
Cautions:	To stop data acquisition before it is complete press the Stop button or **CTRL-C**.

ZS	Collect Ring and Eyeball Background Scattering
Syntax:	ZS or zs (plus optional value *N*)
Description:	Acquires 10 (or *N* if specified) measurement sets at each PMT gain and saves the results to Zdddhhmm.DAT. A file of this type is required for processing LISST-VSF data.
Example:	Input: ZS [*N*] Output: <*Status information during sampling*>
Notes:	To acquire accurate background readings, the LISST-VSF must be set up with water that is completely free of particles and bubbles.

Appendix A: Method of Extracting P11, P12 and P22

The Signals:

The forward model is that, following Figure 2, the scattered light, with Mueller scattering matrix P is first multiplied with the Stokes vector of the laser. Then, the light reflected by the lower prism is rotated by the same angle as the scattering angle to make it's polarization axes normal to the second prism. A final matrix product with the Mueller matrix of a linear polarizer is performed to separate the two components of this light.

The Laser Stokes vectors are: (note only the second element changes)

$$S = \begin{bmatrix} 1 \\ \pm 1 \\ 0 \\ 0 \end{bmatrix}.$$

The Mueller matrix of scattering is (following data displayed by Voss and Fry, 1984, Figure 1, we set the off block diagonal elements to zero):

$$P = \begin{bmatrix} P11 & P12 & 0 & 0 \\ P12 & P22 & 0 & 0 \\ 0 & 0 & P33 & P34 \\ 0 & 0 & P43 & P44 \end{bmatrix}$$

Rotation matrix is:

$$R = \begin{bmatrix} 1, & 0, & 0, & 0 \\ 0, & \cos(2*\phi), & \sin(2*\phi), & 0 \\ 0, & -\sin(2*\phi), & \cos(2*\phi), & 0 \\ 0, & 0, & 0, & 1 \end{bmatrix}$$

And transmission through the two analyzers in front of the PMT's is represented by the Mueller matrix:

$$L_{1,2} = \frac{1}{2} \begin{bmatrix} 1 & \pm 1 & 0 & 0 \\ \pm 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

The light transmitted by the two polarizers has a Stokes vector: L*R*P*S.

Case I: Perpendicular Polarization

PMT1H: $a = P11 - P12 + \cos(2\phi) * [P12 - P22]$ (B2a)

PMT2H: $c = \alpha\{P11 - P12 - \cos(2\phi) * [P12 - P22]\}$ (B2b)

where α is the relative gain of the two photomultipliers. α is not known a priori, it is determined from data.

Determining the Relative Gain of the Two Photomultipliers:

α is estimated from the convenient result that at $\phi = \pi/4$ and $\phi = 3\pi/4$, equations B2a and B2b reduce to:

PMT1H: a = P11 – P12, at $\phi = \pi/4$ and $\phi = 3\pi/4$, (B2c)
PMT2H: $c = \alpha\{P11 - P12\}$ at $\phi = \pi/4$ and $\phi = 3\pi/4$, (B2d)

So that:

$\alpha = c/a$; at $\phi = \pi/4$ and $\phi = 3\pi/4$ yields two estimates of α. (B3)

Case II: Parallel Polarization

PMT1V: $b = P11+P12 + \cos(2\phi) * [P12 + P22]$ (B4a)
PMT2V: $d = \alpha\{P11+P12 - \cos(2\phi) * [P12 + P22]\}$ (B4b)

So that, in a manner identical to eq. B3, another estimate of the photomultiplier relative gain is obtained from:

PMT1V: b = P11+P12 at $\phi = \pi/4$ and $\phi = 3\pi/4$, (B4c)
PMT2V: $d = \alpha\{P11+P12\}$ at $\phi = \pi/4$ and $\phi = 3\pi/4$, (B4d)

$\alpha = d/b$; at $\phi = \pi/4$ and $\phi = 3\pi/4$ yields two estimates of α. (B5)

Extracting VSF (P11):

It follows from summing Eqs. B1a,b

$$a + b + [c + d]/\alpha = 4\,P11, \quad \text{(B6)}$$

Extracting P12:

From B2 and B4, it follows that:

$$[b - a + (d - c)/\alpha] = 4\,P12 \quad \text{(B7)}$$

Extracting P22:

Note that P22 always occurs in combination with P12 in Eqs. B2a,b and B4a,b. Thus, only a best estimate of P22 is extracted. Usually, this involves fine-tuning the relative gain factor α. Also, note from Eqs.2a-d, at 45 and 135^o , the measurement contains no information on P_{22}. In reverse, solving for P_{22} blows up at these angles.

Extracting P_{22} does sometimes require the tweeking of the relative gain of the photomultipliers. This can be done within the lisstvsf_makep function. Experienced MATLAB users will know how. We will provide a description shortly.

These equations are implemented in the MATLAB function lisstvsf_makep.

Absolute Calibration of P11: Since P12 and P22 are conventionally displayed after normalization by P11, only the absolute calibration of P11 is required.

The calibration is performed by matching P11 from PMT data with the P11 from Ring 32 of the forward small-angle VSF. The latter is absolutely calibrated from measured responsivity (A/W) of the silicon ring detectors, as reported in: Agrawal YC, Mikkelsen O. A (2009): Empirical forward scattering phase functions from 0.08 to 16 deg. for randomly shaped terrigenous 1-21 µm sediment grains. Optics Express 17:8805–8814.

Appendix B: MATLAB Software

The MATLAB functions perform these functions:

Lisstvsf_readdat	Reads a raw data file and outputs *uncalibrated* variables;
lisstvsf_view	Reads a raw data file, displays PMT and ring signals and aux data, and outputs *uncalibrated v*ariables. Optional overlay of data from several fies.
lisstvsf_makep	Reads particle data file and background data file (.VSF) and outputs the parameters P11, P12 and P22, depth, temperature, date, etc.. P11 includes small angle VSF for angles of Appendix D.
fastmie.m	Function to compute Mie scattering for arbitrary sphere diameter and relative refractive index (may be complex)
lisstvsf_getcal	Returns calibration factors for a specified instrument serial number

Variable Names:

The datafile contains **two** *rotations* of 40 + 5*150 16-bit values, per *set*. In each rotation, the first 40 variables are identical in format to our LISST-100X, i.e these contain the output of ring detectors for forward scattering, laser transmission, battery voltage and PMT control voltage (new for LISST-VSF), laser reference, depth, temperature, and date and time. Then for each of 150 angles, a 5 parameter subset follows. Each subset contains PMT1_ON, PMT1_OFF, PMT2_ON, PMT2_OFF, ANGLE. The 'on' and 'off' refer to PMT outputs in digital counts summed for several cycles of laser chopping. See **Appendix D** for full details.

variable name	laser polarization	PMT polarization
rp	perpendicular	PMT1: parallel
rr	perpendicular	PMT2: perpendicular
pp	parallel	PMT1: parallel
pr	parallel	PMT2: perpendicular

Appendix C: Observation Angles, Data Format and Variable Names

Angles in Water at which VSF is measured

The following Table shows 32 angles at which small-angle VSF is measured, and eyeball angles beyond. 'Lower' and 'Upper' refer to angle range covered by each ring detector. **These angles are in degrees in water**.

Ring #	Lower	Upper	Median
1	0.0813	0.0959	0.0883
2	0.0959	0.1132	0.1042
3	0.1132	0.1336	0.1230
4	0.1336	0.1576	0.1451
5	0.1576	0.1860	0.1712
6	0.1860	0.2195	0.2021
7	0.2195	0.2590	0.2384
8	0.2590	0.3057	0.2814
9	0.3057	0.3607	0.3320
10	0.3607	0.4256	0.3918
11	0.4256	0.5023	0.4624
12	0.5023	0.5927	0.5456
13	0.5927	0.6994	0.6439
14	0.6994	0.8253	0.7598
15	0.8253	0.9739	0.8966
16	0.9739	1.1492	1.0580
17	1.1492	1.3559	1.2484
18	1.3559	1.5999	1.4730
19	1.5999	1.8875	1.7379
20	1.8875	2.2267	2.0504
21	2.2267	2.6266	2.4189
22	2.6266	3.0977	2.8533
23	3.0977	3.6525	3.3651
24	3.6525	4.3053	3.9677
25	4.3053	5.0725	4.6769
26	5.0725	5.9727	5.5103
27	5.9727	7.0267	6.4882
28	7.0267	8.2571	7.6332
29	8.2571	9.6876	8.9698
30	9.6876	11.3413	10.5237
31	11.3413	13.2388	12.3202
32	13.2388	15.3941	14.3814
Angles 33 to 182			6-155

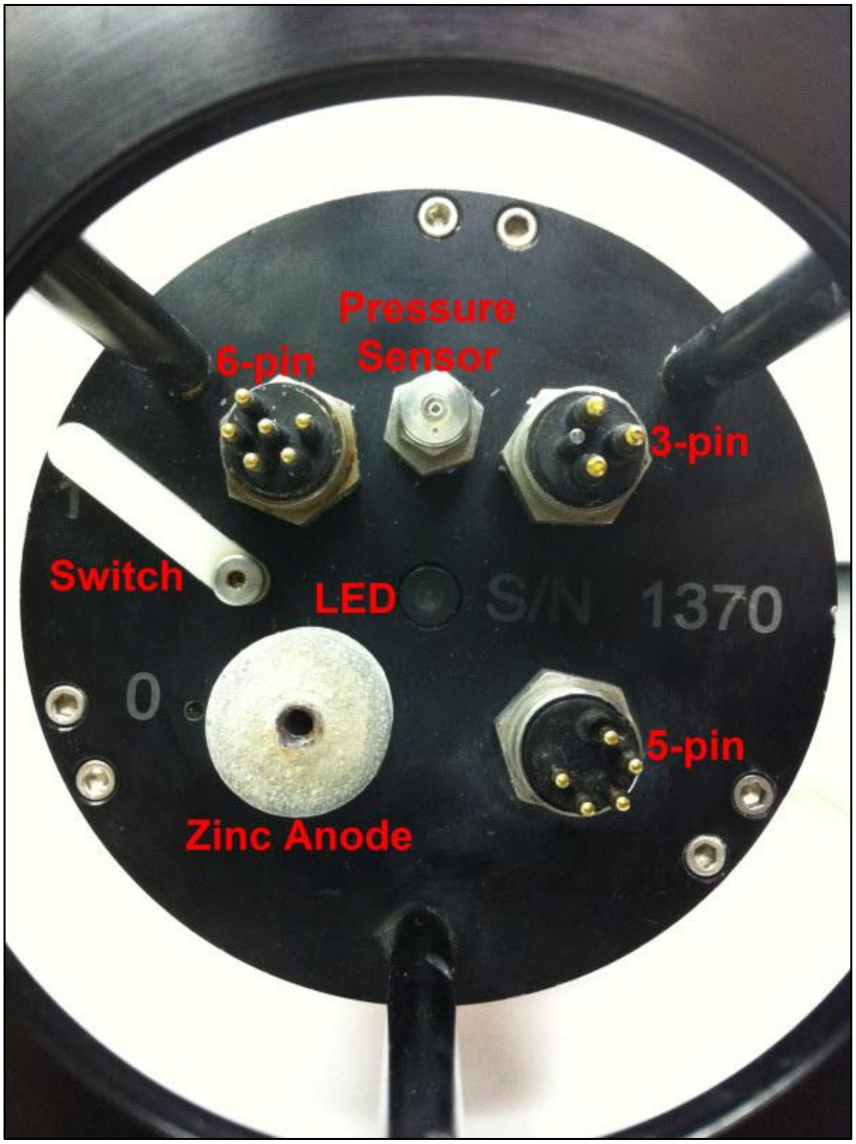
Raw Data Storage Format The values in the binary raw data file (.VSF extension) are stored in the order shown in the table below.

The raw data file is binary, of type *.VSF. Each VSF requires two rotations of the eyeball, so that two **records** are stored per measurement of VSF. One record is with laser polarization being vertical, the second is with polarization rotated horizontal.
[Note: *vertical* and *horizontal* terms are used here simply to donate polarizations with respect to the instrument optical bench; they are not meaningful with respect to true horizontal!.]

Each **record** represents one full turn of the eyeball. It contains these data: 40 variables for rings data and aux measurements, and 150 **sets** of 5 measurements each for each degree of eyeball rotation. Each **set** being: PMT1_on, PMT1_off, PMT2_on, PMT2_off, angle. The 'on' and 'off' refer to laser being modulated on or off. Both 'on' and 'off' values are stored so that saturation of A/D may be recognized as an error.

Elements	Parameter
Record 1:	**First eyeball rotation with laser polarized perpendicular**
1:32	Light intensity of ring detectors, 1-32
33	Laser transmission sensor (used in beam-c computation)
34	Battery voltage
35	PMT Control Voltage [e.g. 550 means 0.550V; max can be 1V]
36	Laser reference sensor (monitors laser emission), raw counts
37	Pressure, in digital counts, each count is 0.1m
38	Temperature in units of 1/100th of 1^{o} C
39	(Day*100 + Hour) at which data taken
40	(Minutes*100 + seconds) at which data taken
41-790	150 sets of [angle, PMT1_on, PMT1_off, PMT2_on, PMT2_off]
Record 2:	**Second eyeball rotation with laser polarized parallel**
1:32	Light intensity of ring detectors, 1-32
33	Laser transmission sensor (used in beam-c computation)
34	Battery voltage
35	PMT Control Voltage [e.g. 550 means 0.550V; max can be 1V]
36	Laser reference sensor (monitors laser emission), raw counts
37	Pressure, in digital counts; each count is 0.01m
38	Temperature in units of 1/100th of 1^{o} C
39	(Day*100 + Hour) at which data taken
40	(Minutes*100 + seconds) at which data taken
41-790	150 sets of [angle, PMT1_on, PMT1_off, PMT2_on, PMT2_off]

Appendix D: Connector Pinouts for LISST-VSF

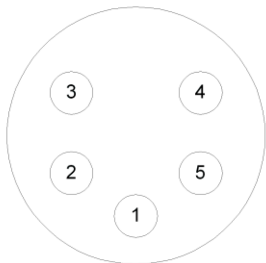


The LISST-VSF has 3 separate underwater connectors: A 5-pin, a 6-pin, and a 3-pin connector. The photograph shows the placement of each connector. The following text describes the detailed wiring for each connector. xxx

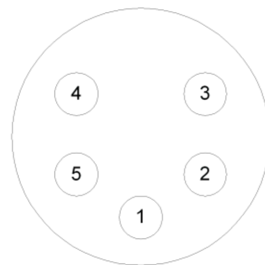
Communications Connector (5 pin connector)

Connector Manufacturer: Impulse Enterprise, Inc. San Diego, CA, USA
Connector Part Number (Bulkhead): MCBH (WB)-5-MP Stainless Steel
Mating Cable Part Number: MCIL-5-FS xxx

Connector Pin #	Use
1	Serial Ground
2	No Connection
3	Serial Ground
4	Serial Out (to DB-9 Pin 2)
5	Serial In (to DB-9 Pin 3)



Bulkhead Endview

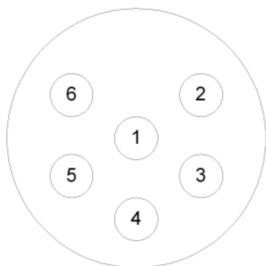


Cable Endview

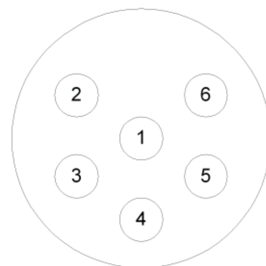
Auxiliary Input Connector (6 pin connector)

Connector Manufacturer: Impulse Enterprise, Inc. San Diego, CA, USA
Connector Part Number (Bulkhead): MCBH (WB)-6-MP Stainless Steel
Mating Cable Part Number: MCIL-6-FS xxx

Connector Pin #	Use
1	Digital Ground
2	Digital In #1
3	Digital In #2
4	No Connection
5	Analog In (0 to 2.50V max)
6	Analog Ground



Bulkhead Endview

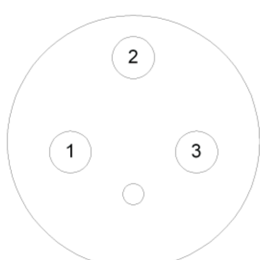


Cable Endview

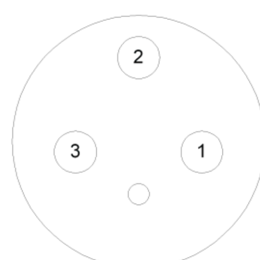
Battery/Power Connector (3 pin connector)

Connector Manufacturer: Impulse Enterprise, Inc. San Diego, CA, USA
Connector Part Number (Bulkhead): MCBH (WB)-3-MP Stainless Steel
Mating Cable Part Number: MCIL-3-FS xxx

Connector Pin #	Use
1	Power Ground
2	Custom NIMH Battery Charger Input, 14.8V nom.
3	Power Out (12V nom. 9V-16.9V actual)



Bulkhead Endview



Cable Endview

Appendix E: LISST-VSF Accessories

a. USB
b. Manual
c. Sediment Samples
d. Spare O-rings
e. Mounting Clamps (4 sets)
f. Lexan Sheet for Background chamer
g. Background chamber clamps (2)
h. Communications Cable
i. Battery Cable
j. Battery Charger
k. Power Supply
l. Stands (2)
m. Installation

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SEQUOIA's liability (whether in contract, tort, or otherwise; and notwithstanding any fault, negligence, strict liability or product liability) with regard to any Product (including, but not limited to, any breach of or default by SEQUOIA) will in no event exceed the purchase price paid by Customer to SEQUOIA for such Product. Further, SEQUOIA will not be liable for, or be in breach of or default on account of, any delay or failure to perform as a result of any cause, condition or circumstance beyond SEQUOIA's reasonable control.

8. Indemnification by Customer
Customer acknowledges that the Products are designed and manufactured for use in non-critical, monitoring situations. If Customer chooses to purchase a Product or Products for use in applications that could result in damages in excess of the price of the Product if the Product does not operate properly or otherwise fails, Customer acknowledges and agrees that it is Customer's responsibility to provide for redundancy and/or other safety or back-up measures sufficient to assure that failure of a Product(s) will not cause such damages. Customer agrees that it will defend and hold SEQUOIA harmless from any and all claims and costs (including but not limited to attorney's fees and other costs of defense against such claims) in excess of the price of the Products arising directly or indirectly from such Customer's use of the Products. Such indemnification is a critical part of the consideration being provided by Customer (over and above the price paid for the Product(s)) for the right to use the Products for such purposes and Customer shall not use a Product or Products for such purposes if it is unwilling or unable to provide such indemnification.

9. Statute of Limitations
Customer will not commence any action based on breach of warranty with respect to any Product more than 18 months after SEQUOIA's delivery of such Product.

10. Software
The Products may include or be delivered with certain computer programs, databases or other software that is proprietary to SEQUOIA. SEQUOIA hereby grants Customer a nonexclusive license to use such software solely for the purpose of operating Products. Customer will not: use any such software for any other purpose; modify, adapt, translate, or create derivative works based on any such software; or disassemble, decompile or reverse engineer any such software. No title to or ownership of any software or intellectual property rights are transferred to Customer.

11. U.S. Government Restricted Rights Notice
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12. Controlling Document
In the event of any conflict or inconsistency between any provision of this Statement of Limited Warranty and any other provision of the Order, the provision of this Statement of Limited Warranty will control.

13. Controlling Law
This Statement of Limited Warranty will be governed by the laws of the State of Washington without reference to its rules relating to choice of law for the purpose of applying another jurisdiction's law. The U.N. Convention on Contracts for the International Sale of Goods will not apply.

Document History

Revision	Date	Description	Author
A	2012/08/28	Draft document	YCA/WHS/RS
B	2013/03/08	Updated for non-AOM units	RS/WHS
3.0	2016/12/11	Update for GT prism models, auto PMT,…	YCA/DD/TL