Appendix B. Argonaut-SL Principles of Operation

This *Argonaut-SL System Manual* appendix provides an introduction to the operating principles of the SonTek/YSI Argonaut Side-Looking (SL) acoustic Doppler current meter (**Figure B-1**). It does not attempt to provide a detailed discussion of all technical issues, nor does it provide a detailed description of SL operation. To learn more about specific SL applications, please refer to other sections within the *Argonaut-SL System Manual* or contact SonTek/YSI.

Figure B-1. SL500, SL1500, and SL3000 Low-Profile Argonaut-SL Systems

B-1. Overview

The Argonaut-SL (commonly referred to as the "SL") is a Doppler current meter designed to measure precise water velocities in a horizontal layer (**Figure B-2**). In addition to velocity measurements, the SL provides stage and flow measurements in the field. The SL (like the rest of SonTek's Argonaut current meter product line) provides the technological advantages of complex/expensive current profilers in a simple, inexpensive, and easy to use package. SL attributes include:

- Horizontally integrated velocity measurement
- Invariant factory calibration — no periodic recalibration required
- Vertical acoustic beam for stage measurement
- Simple operation (very few user entries needed)
- Excellent performance for low and high flows
- Accuracy — 1% of measured velocity
- Built-in temperature sensor

Typical applications for which the SL is used include:

- River discharge monitoring
- Velocity indexing
- Irrigation
- Flood alert systems
- Water supply
- Environmental monitoring
- Vessel traffic
- Offshore platforms
- Ship berthing

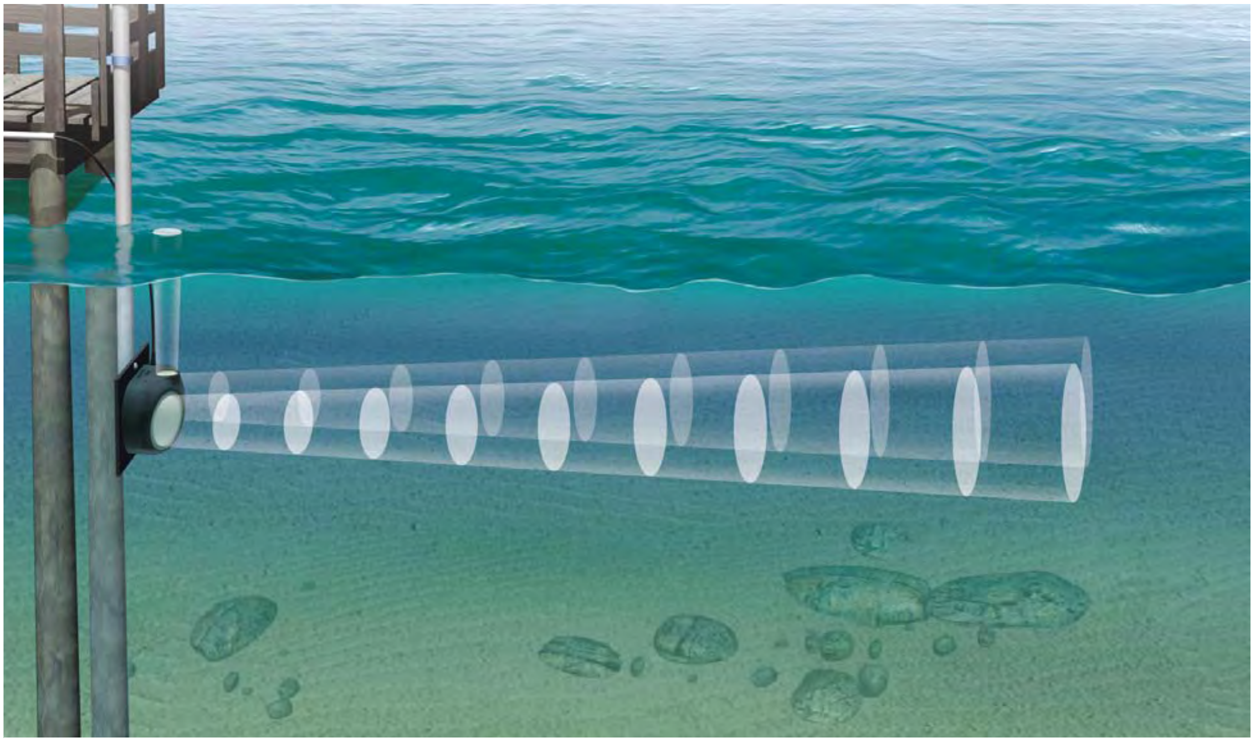


Figure B-2. Typical Argonaut-SL Application

B-2. The Doppler Shift and Monostatic Current Meters

The SL measures water velocity using a physical principle called the Doppler shift. This principle states that if a source of sound is moving relative to the receiver, the frequency of the sound at the receiver is shifted from the transmit frequency. For a Doppler current meter, this can be expressed as:

$$F_d = -2F_0 \frac{V}{C}$$

where

F_d = Change in received frequency (Doppler shift)
F_0 = Frequency of transmitted sound
V = Represents relative velocity between source and receiver (i.e., motion that changes the distance between the two); +V means the distance from source to receiver is increasing.
C = Speed of sound

The SL is a *monostatic* Doppler current meter. **Figure B-3** depicts the operation of a monostatic Doppler current meter.

- Monostatic means the same transducer is used as both transmitter and receiver.
- The transducer generates a short pulse of sound at a known frequency (F_0), which then propagates through the water.
- The transducer is constructed to generate a narrow beam of sound where the majority of energy is concentrated in a cone a few degrees wide.
- As the sound travels through the water, it is reflected in all directions by particulate matter (e.g., sediment, biological matter, bubbles).
- Some reflected energy travels back along the transducer axis, where the transducer receives it.
- The SL electronics measure the change in frequency of the received signal.
- The Doppler shift measured by a single transducer relates to the water velocity along the axis of the acoustic beam of that transducer.
- If the distance between the transducer and the target is decreasing, frequency (F_D) increases; if the distance is increasing, frequency (F_D) decreases. Motion perpendicular to the line connecting source and receiver has no effect on the frequency of received sound.

The location of measurements made by a monostatic Doppler current meter is a function of the time at which the return signal is sampled.

- The time since the pulse was transmitted determines how far the pulse has propagated, and thus specifies the location of the particles that are the source of the reflected signal.
- By measuring the return signal at different times following the transmit pulse (T_P), the Argonaut measures the water velocity at different distances from the transducer.

It is important to note that the SL measures the velocities of particles in the water, and not the water velocity itself.

- The velocity of particles in the water is assumed to match the velocity of the water. This assumption has been tested extensively and found to be very reliable.
- If there is no particulate matter in the water, the system cannot measure velocity. In general, the practical limitation of clear water is not whether the system can make velocity measurements, but what is the maximum range (distance from the system) at which the system can measure velocity. In clear water, the maximum measurement range may be reduced. Note: *Clear water* is a relative term; visual inspection is not a good way to determine particle concentration. Use the *SonUtils* Beam Check module to make this determination.

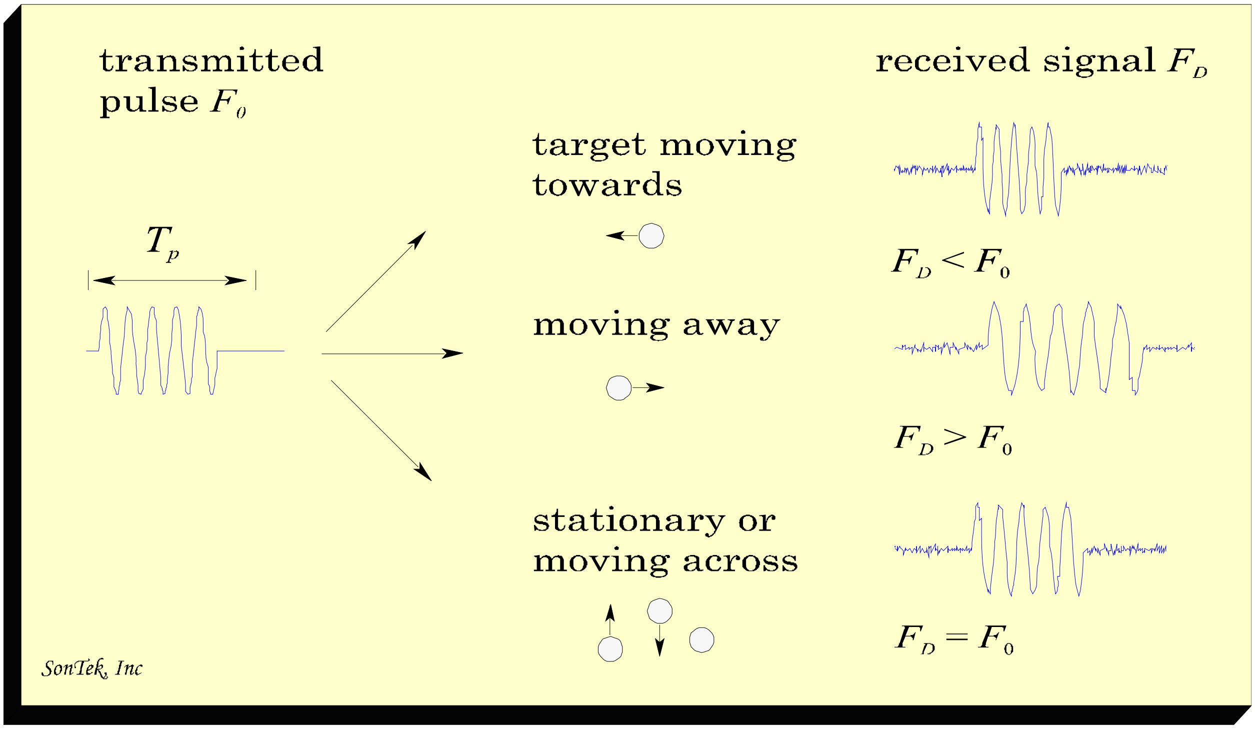


Figure B-3. Measuring target velocity with a monostatic Doppler system

B-3. Beam Geometry and 2D Velocity Measurements

The SL is designed for horizontal operation from underwater structures such as bridge pilings and channel walls.

- The system measures velocity in a horizontal layer (parallel to the water surface) away from the flow interference generated by the structure.
- The system uses two acoustic beams in a single plane, each slanted 25° off the instrument axis. This beam geometry is designed for side-looking applications, giving the optimal balance between 2D velocity response and total measurement range (**Figure B-4**).
- The velocity measured by each beam is referred to as the *along-beam velocity*.
- Beam velocities are converted to XY (Cartesian) velocities using the beam geometry.
- In most applications, the orientation of the SL is known and XY velocities are used directly.
  - XY velocities are reported relative to the orientation of the SL; if the SL is looking across a stream, X is parallel to the direction of flow and Y is across the stream (§**B-9.2**).
  - Some SL systems include an internal compass/tilt sensor. This allows the SL to report velocities in Earth (East-North-Up or ENU) coordinates, independent of system orientation.
- All new SL systems include a vertical beam to measure the distance from the system's transducer head to the water surface; some older SLs do not include the vertical beam.

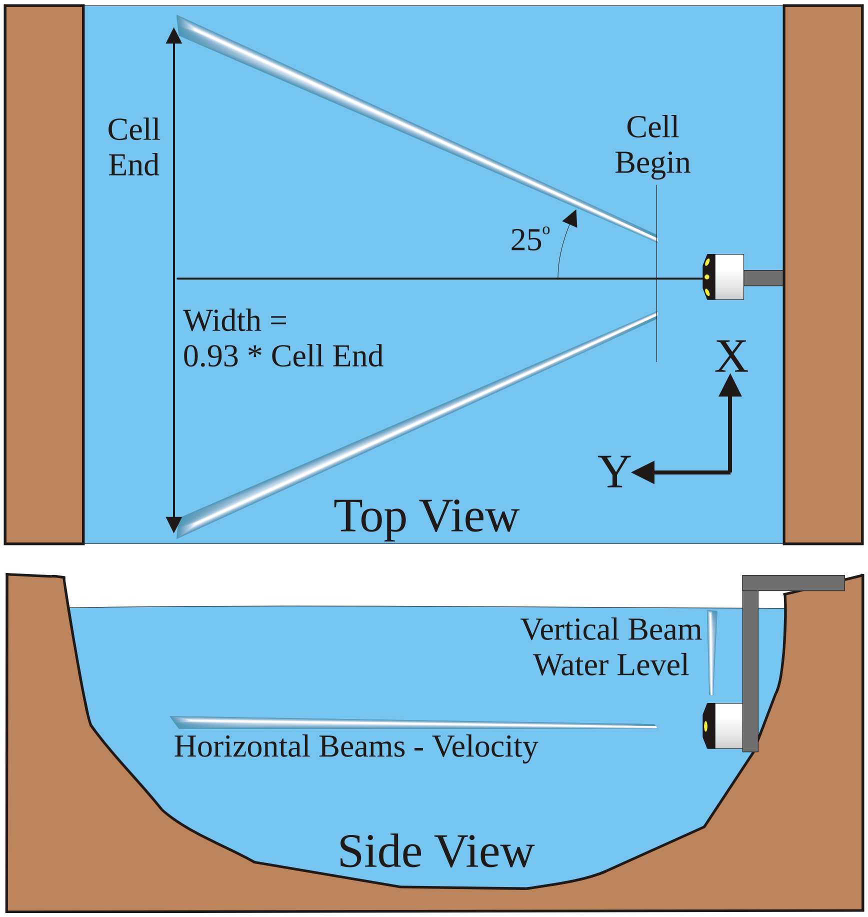


Figure B-4. Argonaut-SL Beam Geometry

B-3.1 Measurement Volume Definition and Location

The size and location of the Argonaut measurement volume is a function of the system configuration and user operating parameters. In all cases, the basic shape of the measurement volume is determined by beam geometry.

- The SL is designed for horizontal side-looking operation from underwater structures, but can also be used for vertical up or down-looking installations in narrow channels.
- The measurement volume is a V-shaped wedge in the plane defined by the two acoustic beams. The sides of the V are sloped 25° off the horizontal axis of the instrument. The width of the V is equal to 0.93 times the range from the transducer head. Example: At 4 m, the width is 3.7 m.
- The limits of the measurement volume are determined by user-selected parameters (see §**B-9.1** for guidelines). This range is defined by two parameters – *Cell Begin* (CB) and *Cell End* (CE). Both are given in distance from the transducers along the central axis of the instrument.
- The precise weighting within the measurement volume is determined by the convolution of the acoustic pulse with the receive window during which the return signal is sampled. The pulse length is a function of system frequency, as defined in **Table B-1**. The receive window is based on the settings of CB and CE. The measurement volume weighting function of the SL is shown in **Figure B-5**.

Table B-1. Argonaut-SL Pulse Length

Frequency	Pulse Length
500 kHz	2.0 m
1500 kHz	0.5 m
3000 kHz	0.25 m

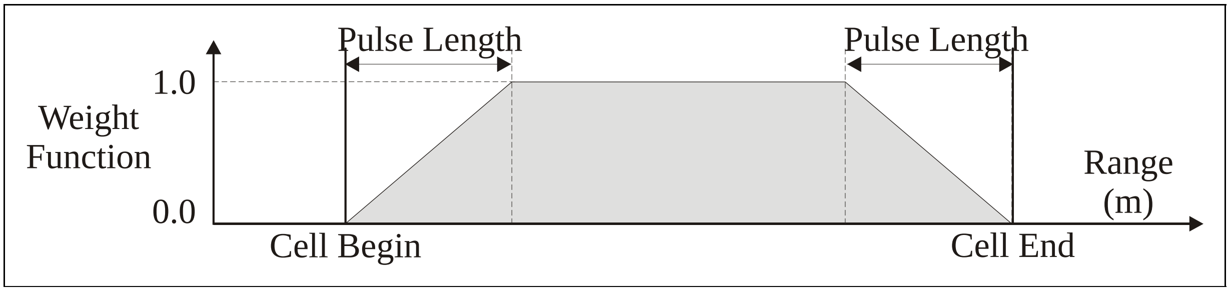


Figure B-5. Argonaut-SL Measurement Volume Weighting Function

B-4. Stage Measurement (Vertical Acoustic Beam)

All new SL systems have a vertical acoustic beam to measure stage (**Figure B-2**).

- The vertical beam sends a short pulse of sound and listens for the reflection from the surface.
- The surface reflection is strong and clearly defined, allowing the SL to precisely measure the time at which the return reflection is received.
- To convert the reflection time to surface range, the SL needs to know the speed of sound in water at the survey site, which is primarily a function of temperature and salinity.
    - The SL's internal temperature sensor automatically compensates for changing conditions by continually updating the sound speed used for surface range calculations.
    - Salinity is user defined (i.e., the SL does not automatically adjust for salinity variations).
- The vertical beam also works under ice, measuring the range to the bottom of the ice. This determines the water depth beneath the ice as needed for discharge monitoring.
- The vertical beam's operating range varies with acoustic frequency as shown in **Table B-2**.

Table B-2. Vertical Beam Operating Range

Frequency	Minimum Depth	Maximum Depth
500 kHz	0.40 m	18 m
1500 kHz	0.25 m	10 m
3000 kHz	0.10 m	5 m

B-5. Flow Calculations

One of the primary functions of an SL with a vertical beam is to provide real-time flow data. The SL combines water velocity data (from the slanted beams) and stage data (from the vertical beam) with user-supplied channel geometry information about the installation site. The SL supports flow calculations for two primary types of environments.

- Natural streams (defined by a series of survey points)
- Regular (trapezoidal) channels (typically concrete lined)

The SL combines channel geometry with stage to calculate the cross-sectional area. The area is then multiplied by the mean channel velocity to determine flow. The relationship between the velocity measured by the SL and the mean channel velocity can be determined two ways.

- Theoretical flow calculations (§**B-5.1**)
- Index velocity calibration (§**B-5.2**)

B-5.1 Theoretical Flow Calculations

Theoretical flow calculations are used when no reference flow data are available; that is, only channel geometry and data measured directly by the SL are available. For theoretical flow calculations, the SL makes use of the following information.

- The largest variations of velocity occur with changing depth within the channel.
- Based on the supplied channel geometry, the SL can determine the vertical location of the velocity measurement within the water column. The system assumes the river follows a power-law velocity profile model with a 1/6 power-law coefficient.
- Using this model, combined with the location of the SL velocity measurement, the SL estimates a relationship between the measured velocity and the mean channel velocity.
- The relationship between measured and mean channel velocity will change as water depth changes, since the location of the SL measurements within the water column is also changing.

- The theoretical velocity calculation of the SL should provide good results for regular, concrete lined channels (typically rectangular or trapezoidal in shape) where the SL is installed near the midpoint of the water depth.
- For natural streams or sites with large variations in water depth, SonTek recommends developing an index velocity calibration (§**B-5.2**) to provide accurate flow data specific to that site.

B-5.2 Index Velocity Calibration

An index velocity calibration is a popular technique for monitoring discharge when reference discharge measurements are available.

- Discharge measurements are made at a variety of water levels and flow conditions.
- SL water velocity data and stage data are collected at the same time as reference discharge measurements.
- The data are analyzed to empirically determine a relationship between the SL measured velocity and the mean channel velocity.
- This relationship is then input into the SL, which outputs calibrated flow data in real time.
- The empirical index relationship uses the following form:

$$V_{mean} = V_{intercept} + V_{meas} * (V_{slope} + (StageCoef * Stage))$$

where

V_{mean} = mean velocity in the channel
$V_{intercept}$ = user-supplied* velocity offset (cm/s or ft/s)
V_{meas} = SL measured velocity
V_{slope} = user-supplied* velocity scale factor (no units)
StageCoef = user-supplied* water depth coefficient (1/s)
Stage = measured stage (total water depth) (m or ft)

*Note: These constants are empirically derived coefficients based on a number of user-made, independent discharge measurements. These coefficients relate SL measured velocity to mean channel velocity as determined by the independent measurements. The details of how these constants are derived are beyond the scope of this appendix. For information, contact SonTek.

An index velocity calibration will usually supply more accurate flow data than a theoretical flow calculation. However, an index calibration requires extensive reference data and data analysis expertise to construct — for some applications, this is not practical. In these situations, the theoretical flow calculations can provide good quality flow data.

B-6. Argonaut-SL Data

B-6.1 Sampling Strategy

The SL averages data for a fixed interval for each reported water velocity sample.

- The SL samples velocity (i.e., *pings*) each second. The type of velocity ping depends on whether **`PowerPing`** is enabled. Using **`PowerPing`** provides improved performance, but increases power consumption. Refer to the *Argonaut-SL System Manual* for **`PowerPing`** details.
- The SL pings the vertical beam once per second to measure stage data.
- Pings are accumulated over a user-specified averaging interval (typically 1 to 15 minutes), and average values for velocity, stage, and a variety of diagnostic data are reported.
- The sampled data are normally recorded to the SL internal recorder, and can also be reported to an external data logger (§**B-9.3**).
- The SL can operate continuously (i.e., start the next sample immediately after completing a sample), or it can enter a low-power (i.e., "sleep") state between samples to conserve power.
- See (§**B-9.5**) for sampling strategy considerations.

B-6.2 Velocity Data

In general, SL velocity data are used directly without any post-processing.

- The SL can measure water velocities from less than 0.01 m/s to 6.0 m/s.
- The velocity response will not change or drift with time; the SL never requires recalibration.
- The SL measures flow direction and will accurately report reversing flow.
- 2D velocity data are normally output in Cartesian coordinates (XY) relative to SL orientation.
  - See (§**B-9.2**) for more information about the SL's coordinate system.
  - Some systems may include an internal compass, allowing velocity data to be output in Earth (ENU or East-North-Up) coordinates (§**B-9.2**).
- Velocity data are accurate to 1% of the measured velocity (after accounting for random noise; see §**B-7.2**).
- The SL provides diagnostic parameters with each sample to verify the quality and accuracy of the data (§**B-7**).

B-6.3 Accuracy of Velocity Data

When discussing the accuracy of the SL water velocity data, we are referring to the presence of any bias in mean velocity measurements. Velocity data may have random short-term variations (noise) that do not reflect a bias to velocity data (§**B-7.2**). Two factors influence accuracy of SL velocity data — sound speed and beam geometry.

- The effect of sound speed is described in §**B-9.4**. With properly specified salinity data, sound speed errors are negligible (less than 0.25%).
- Beam geometry is fixed during system construction, and will not change with time (unless there is catastrophic physical damage to the system).
- The SL calibration is specified to ±1.0% of the measured velocity.
- There is no potential for zero offset or drift in velocity measurements. There is no inherent minimum measurable velocity.

B-6.4 Multi-cell Velocity Profiling Data

This SL feature can record the measured velocity profile using more than one cell (**Figure B-6**).

- The profile can include up to ten (10) independent velocity cells.
- The user specifies the following three parameters.
  - Blanking distance: distance (m) to the start of the first cell
  - Cell size: length (m) of each cell
  - Number of cells

The multi-cell water velocity data are calculated separately from the standard, single cell (i.e., Integrated Velocity Cell in **Figure B-6**) reported by the system. There does not need to be any specific relationship between the multi-cell parameters and the parameters for the fixed velocity cell (CellBegin and CellEnd).

- The location of multi-cell velocity data is fixed based on the user-specified operating parameters — blanking distance, cell size, and number of cells.
- Unlike the single integrated velocity cell, multi-cell velocity data are not automatically screened for low signal-to-noise ratio (SNR) values (§**B-7.1**).
- SNR values are recorded with each velocity cell.
- The user needs to monitor SNR data and consider the location of each velocity cell before using the multi-cell velocity data.

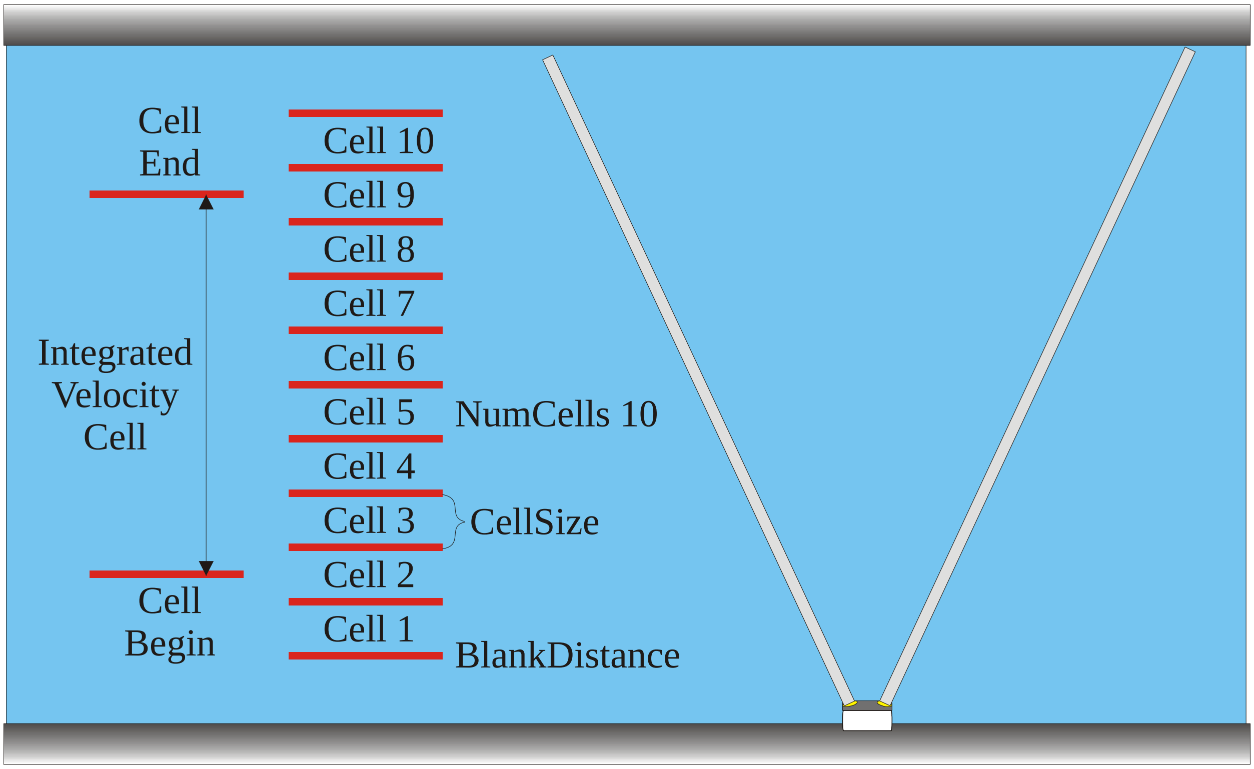


Figure B-6. Multi-cell velocity profiling

B-7. Quality Control Data

The SL records quality control data with each sample to evaluate the quality of velocity data.

- Signal-to-noise ratio (SNR) – §**B-7.1**
- Standard error of velocity – §**B-7.2**

B-7.1 Signal-to-Noise Ratio (SNR)

The Argonaut-SL measures velocity by looking at the reflections of an acoustic pulse from particles in the water.

- The magnitude of the reflection is called signal strength. It varies with the amount and type of suspended material, and with the distance from the transducers.
- Signal strength decreases with distance from the transducer due to geometric spreading and sound absorption.
- The distance at which signal strength approaches the electronics noise level determines the maximum measurement range of the SL.
- Signal strength is commonly used as the signal-to-noise ratio (SNR), which compares the magnitude of the received signal to the ambient electronics noise level. SNR is reported in a logarithmic scale.
- Signal strength data are measured and recorded in internal logarithmic units called counts.
  - Signal strength and noise level are recorded in counts; one count equals 0.43 dB.
  - Signal strength is converted to SNR by subtracting the noise level and converting to dB.
- The SL requires a minimum SNR (≈3 dB) to make accurate velocity measurements.

For the SL, the location and size of the measurement volume is variable depending on system frequency and operating parameters.

- Signal strength and SNR reported are the mean value over the measurement volume.
- Signal strength decreases with range from the transducers and will vary with conditions in the water. For good operating conditions, SNR should be greater than 3 dB.

In some cases the SL may adjust the size of the measurement volume based on SNR.

- With each sample, the SL monitors the SNR profile within the measurement volume.
  - In most conditions, the SL is able to measure to its specified maximum range (**Table B-3**).
  - If at any point the signal strength is too low for reliable velocity measurements, the SL will end the measurement volume at that range. In this situation, the system will automatically cut off the measurement volume at the maximum effective range. The exact limits of the measurement volume are recorded with each sample.

Table B-3. Typical Maximum SL Measurement Range

Frequency	Maximum Range
500 kHz	120 m
1500 kHz	20 m
3000 kHz	5 m

Signal strength is primarily a function of the amount and type of particulate matter in the water.

- While signal strength cannot be immediately converted to sediment concentration, it provides an excellent qualitative picture of sediment fluctuations and, with proper calibration, can be used to estimate sediment concentration.
- For more information about this application, please contact SonTek.

B-7.2 Standard Error of Velocity Data

Each velocity sample recorded by the Argonaut-SL is the average of a number of pings.

- The SL records the standard error of velocity based on data from all pings.
- The type of ping depends on whether **`PowerPing`** is enabled. PowerPing can reduce the uncertainty of velocity measurement, but may increase power consumption.
- Standard error is the standard deviation of velocity divided by the square root of the number of pings. It is a direct, statistical measure of the accuracy of the mean velocity data.
- Measured standard error includes instrument generated noise and real variations in velocity.
- Instrument-generated velocity noise can be estimated based on operating parameters. This is useful in planning deployments, particularly for determining the operating parameters required for a desired accuracy.
- Typically, measured standard error agrees with predicted values to within about 20%.

Standard error is a function of the size of the measurement volume, the averaging interval, and the effect of **`PowerPing`**. The formulas in **Table B-4** are used to predict the standard error of SL velocity data based on these parameters. The formula can also be used to predict the standard error of multi-cell velocity data. Note: Formulas are based on the acoustic frequency of the system.

Table B-4. Argonaut-SL Standard Error Prediction Formula

Frequency	Standard Error Prediction Formula
500 kHz	$\sigma V = \frac{29}{\sqrt{AI}\sqrt{CS}}$
1500 kHz	$\sigma V = \frac{19}{PP\sqrt{AI}\sqrt{CS}}$
3000 kHz	$\sigma V = \frac{14}{PP\sqrt{AI}\sqrt{CS}}$

where
σV = Predicted standard error of Velocity (cm/s)
PP = PowerPing factor (see below)
AI = Averaging interval (seconds)
CS = Cell size (m)

The effect of `PowerPing` depends on the maximum range of the system – the value of CellEnd. Refer to the *Argonaut-SL System Manual* for a complete description of how to use PowerPing to improve system performance. **Table B-5** shows the effect of PowerPing for various settings.

Table B-5. Effect of PowerPing Settings

Frequency	PowerPing Setting	CellEnd	PowerPing Factor (PP)
1500 kHz	OFF	Any value	1.0
1500 kHz	ON	≤ 10.0 m	2.4
1500 kHz	ON	20.0 m	2.0
3000 kHz	OFF	Any value	1.0
3000 kHz	ON	≤ 4.0 m	2.4
3000 kHz	ON	8.0 m	2.1

For the integrated velocity cell, cell size is calculated as follows (refer back to **Table B-1** for the SL's pulse length).

```
CS = CellEnd – CellBegin – PulseLength
```

For multi-cell velocity profile data, cell size is simply the user-specified value. **Table B-6** lists predicted standard error values for various combinations of frequency, cell size, and averaging interval.

Table B-6. Argonaut-SL Typical Predicted Velocity Precision (Standard Error)

500-kHz Argonaut-SL				
Averaging Interval	**PowerPing**	**10-m Cell**	**30-m Cell**	**100-m Cell**
1 minute	NO	1.2 cm/s	0.7 cm/s	0.4 cm/s
5 minutes	NO	0.5 cm/s	0.3 cm/s	0.2 cm/s
1500-kHz Argonaut-SL				
Averaging Interval	**PowerPing**	**2-m Cell**	**5-m Cell**	**15-m Cell**
1 minute	NO	1.7 cm/s	1.1 cm/s	0.6 cm/s
5 minutes	NO	0.8 cm/s	0.5 cm/s	0.25 cm/s
1 minute	YES	0.7 cm/s	0.5 cm/s	0.3 cm/s
5 minutes	YES	0.3 cm/s	0.2 cm/s	0.15 cm/s
3000-kHz Argonaut-SL				
Averaging Interval	**PowerPing**	**0.5-m Cell**	**2-m Cell**	**5-m Cell**
1 minute	NO	2.5 cm/s	1.3 cm/s	0.8 cm/s
5 minutes	NO	1.1 cm/s	0.6 cm/s	0.4 cm/s
1 minute	YES	1.1 cm/s	0.5 cm/s	0.3 cm/s
5 minutes	YES	0.5 cm/s	0.2 cm/s	0.15 cm/s

B-8. Flow Data

With each sample, SLs that have a vertical beam can record cross-sectional area and flow.

- Cross-sectional area depends on the user-supplied channel geometry and stage.
- Typically, the accuracy of area data is most strongly influenced by the accuracy of channel geometry, rather than uncertainty in stage data.

The accuracy of flow data depends on a few factors.

- Accuracy of cross-sectional area
- Accuracy of velocity data (§**B-7.1**)
- Method used to relate measured velocity to mean channel velocity (§**B-5**)

In general, the primary factor in determining the accuracy of flow data is the method used to relate measured velocity to mean velocity. Some guidelines:

- A well-established index calibration can give real-time flow accuracy on the order of 2-3% of the measured flow.
- Theoretical flow calculations in a regular channel (i.e., trapezoidal, concrete lined) may give accuracy on the order of 3-5%. This can be strongly affected by nearby intake or outlet structures, or by nearby changes in channel geometry (including bends in the channel).
- Theoretical flow calculations in natural streams are difficult. They can provide reasonable results in streams with a simple, uniform cross section, but are notably limited in wide, shallow streams where velocity can vary dramatically across the width of the stream.

The SL can also be programmed to calculate total volume in addition for flow rate.

- Total volume is the cumulative sum of flow rate multiplied by elapsed time, and represents the total volume of water that has passed the SL.
- Total volume is normally accumulated over the full span of each data file. Methods are provided to reset total volume (restart the accumulation at zero) within a data file, if required.
- Total volume can be output in a variety of measurement units as required by the user.

B-9. Special Considerations

This section lists some considerations you should be aware of when using an SL.

B-9.1 2D Horizontal Current Measurement

The SL measures the 2D water velocity in the plane formed by its two acoustic beams, parallel to the water surface (**Figure B-2**). The SL is typically installed near mid-water depth and can measure over a range up to 120 m (depends on system frequency). This allows the SL to be installed on an underwater structure, but still measure the water velocity away from any flow interference generated by the structure.

The definition of the SL measurement volume was given in §**B-3.1**. It is critical that no underwater obstacles are within the measurement volume as they may seriously affect velocity data accuracy. Before a deployment, you should perform a site survey (including data collection with the *SonUtils* BeamCheck utility) to check for beam obstructions, and to verify operating parameters.

Although SL transducers concentrate most of their acoustic energy in a narrow beam, some energy is transmitted in all directions. A portion of this energy will take a direct path to the boundary (e.g., the opposite bank) and the reflection will return while the main beam is still some distance from the boundary. This is known as side lobe energy, and the reflections are called side lobe interference.

Although side lobe energy levels are very small, reflections from the opposite boundary may be much stronger than the return signal from the water, potentially affecting velocity measurements. The potential for side lobe interference exists in the last 10% of the measurement range. To avoid interference, the end of the measurement volume should be placed no closer than 10% of the total distance to the boundary (e.g., if opposite boundary is at 10 m, the end of the volume should be at 9 m). The SL includes software (BeamCheck module in *SonUtils*) to perform a site survey that helps you determine the maximum effective range for a particular installation.

When determining the maximum measurement range of the SL, you must also consider the aspect ratio, which relates measurement range to depth.

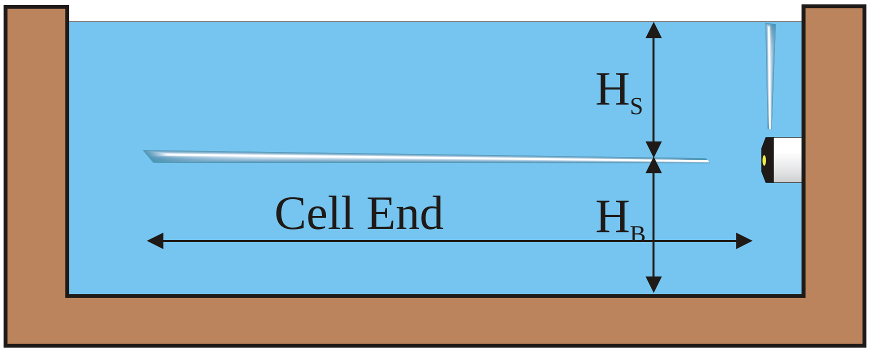
- Aspect ratio (**Figure B-7**) is the ratio of the horizontal measurement range (typically the Cell End parameter) to the vertical distance to the nearest boundary, either the surface or bottom.
- If operating in a river with variable depths, you should consider the aspect ratio at the shallowest parts of the stream, and not just the aspect ratio at the end of the measurement volume.
- In general, the SL will provide highly reliable data for aspect ratios up to 15-20. In some cases, it can provide reliable data at aspect ratios up to 40, but significant caution should be taken in these situations to verify the SL is not seeing any interference from the boundary.
- It is critical, especially with larger aspect ratios, to ensure the SL is installed level. If the SL beams are tilted up or down, this could cause the beams to hit the surface/bottom and may affect velocity data even at ranges where the aspect ratio is not particularly high.
- A careful site survey is critical to the proper setting of SL operating parameters.

B-9.2 Coordinate System

The SL supports three coordinate systems for velocity data — ENU (East-North-Up), XYZ, and Beam. The coordinate system setting is determined through a software setting in either the *ViewArgonaut* program or the `CoordSystem` direct command (§**C-8**) via *SonUtils*.

Here is a brief description of the coordinate systems used by SonTek.

- ENU – Requires an internal compass/tilt sensor. Allows velocity data to be recorded in ENU (East-North-Up) coordinates. Using the ENU coordinate system allows the SL to report velocity data independent of instrument orientation.
- XYZ – When using the XYZ coordinate system, velocity measurements are stored using a right-handed Cartesian coordinate system relative to the SL.
- BEAM – This coordinate system reports the along-beam velocity. Positive velocity is away from the SL; negative velocity is towards the SL.



$$\text{If } H_S<H_B\text{, Aspect Ratio} = \text{Cell End} / H_S$$

$$\text{If } H_B<H_S\text{, Aspect Ratio} = \text{Cell End} / H_B$$

Figure B-7. Argonaut-SL Aspect Ratio

ENU (East-North-Up) Coordinate System

For systems with a compass/tilt sensor, velocity can be recorded in Earth or ENU (East-North-Up) coordinates. Using the ENU coordinate system allows the SL to report velocity data independent of instrument orientation.

Most SL systems do include a compass/tilt sensor, and velocity data are normally recorded in the XYZ coordinate system (see below). Even when the SL does include a compass/tilt sensor, velocity data is often recorded in XYZ coordinates as the X-axis is commonly aligned with the primary flow direction of the river.

The translation of velocity data from XYZ to Earth (ENU) coordinates is enabled or disabled through commands to the SL and is transparent to the user. Selection of the coordinate system is through the **`CoordSystem`** command (§**C-8**) or through the *ViewArgonaut* program. When the compass is installed, heading, pitch, and roll data are stored with each sample.

When using ENU, velocity is reported in Earth coordinates regardless of the physical orientation of the SL. An SL mounted with an unknown orientation will provide velocity data consistent with the direction and speed of the water current itself. Since the SL is a 2D velocity sensor, the rotation to ENU velocity coordinates is only accurate if the SL is installed reasonably close to level (with the beams looking horizontal). If the SL is installed looking vertically up or down (such as in a narrow channel), the ENU velocity rotation will not be accurate.

The SL (with optional compass) does not perform vector averaging of data during each sample. Compass/tilt sensor data are sampled once at the beginning of each averaging period. These instruments assume a stable orientation for the duration of the sample and apply the rotation from XYZ to ENU coordinates only once. As such, the SL should not be installed on a buoy or other object that will move during the course of an averaging interval.

XYZ Coordinate System

When using the XYZ coordinate system, velocity measurements are stored using a right-handed Cartesian coordinate system relative to the Argonaut.

- The positive X-axis is stamped into the transducer head for easy reference.
- The positive Y-axis lies along the axis of the sensor housing away from the transducer head.
- The orientation of the positive X-axis can be changed using the **`ReverseXVelocity`** command (§**C-8**). The use of this command allows the SL to report positive X-velocity for downstream flow regardless of which side of the river the SL is installed.

Beam Coordinate System

When using the BEAM coordinate system, the SL reports along-beam velocity — positive velocity is away from the SL; negative is towards the SL. The X-axis stamped on the transducer head always points to beam number 1. Beam velocities are normally used only for system testing at the factory, and are rarely used for field installations.

B-9.3 Real-Time Data Output

The SL offers several options for real-time data output.

- Only one output type (RS232, RS422, SDI-12, Modbus, analog outputs) can be used at a time.
- Both RS232 and RS422 can output the complete velocity and diagnostic data set (§**B-6**).
- The SDI-12 serial bus can output a portion of the SL sample data, including velocity and limited diagnostic data. Multi-cell velocity data (§**B-7.2**) can also be output in real-time.
  - For SDI-12 operation, the SL is programmed using the RS-232 serial bus, and then switched into SDI-12 mode.
  - The SL's SDI-12 interface is compatible with SDI-12 revisions 1.0, 1.1, 1.2, and 1.3. Options are provided to allow integration with a variety of data logger types.
  - When using SDI-12, the external data logger controls the timing of SL data collection.
- Using the Modbus Interface Module (**Appendix I**) to access data on a Modbus data collection network allows full access to all velocity and diagnostic data.
  - The Modbus protocol provides a standardized means to acquire reliable digital data form a variety of sensors.
  - Using the MIM allows the SL to be integrated with a Modbus data collection network.
- The SL can optionally be set up to generate analog output signals (**Appendix F**).
  - The SL can generate up to two analog output signals at the same time.
  - Analog outputs can be either 4-20 mA or 0-5 VDC (only one analog output type can be used on a single system at any given time).
  - An external analog converter is required to generate the analog output signals. One converter is required for each analog output signal.
  - Each analog output signal can represent one variable. The following variables are available: flow, total volume, stage, X-velocity, Y-velocity, velocity magnitude, SNR, temperature, and cell end location.
  - The user specifies the range of values represented by the analog output signal, customizing the output range to the particular environment.

The SL can record data to the internal recorder at the same time as any of the above real-time data outputs are being used. SonTek encourages users to record, regularly download, and archive data from the internal recorder to ensure full access to diagnostic data.

B-9.4 Sound Speed Considerations

The SL uses sound speed to convert the Doppler shift to water velocity. This section describes how to correct SL velocity data for errors in the sound speed used for data collection.

- The SL uses an internal temperature sensor for automatic sound speed compensation; user corrections are rarely needed.
- Sound speed corrections are normally required only if salinity has been incorrectly specified.

Speed of sound is a function of temperature and salinity. As a general rule, a temperature change of 5°C or a salinity change of 12 parts per thousand (ppt) results in a change in sound speed of one percent. The full range of typical temperature and salinity levels (from -5 to 50°C and 0-60 ppt) gives a sound speed range of 1375-1600 m/s (total change of 14%).

SL velocities scale directly with sound speed; that is, a 1% error in sound speed results in a 1% error in velocity measurements. The following formula is used for post-processing corrections and can be directly applied to the output velocity data of the SL.

$$V_{true} = V_{orig} \, (C_{true} / C_{orig})$$

where

V_{true} = Corrected velocity measurements
V_{orig} = Uncorrected (original) velocity measurements
C_{true} = True speed of sound
C_{orig} = Speed of sound used in original calculations

Errors in sound speed also affect the physical location of the SL's measurement volume, although these errors are generally very small. To calculate the correct location of the SL's measurement volume, use the following formula.

$$Z_{true} = Z_{orig}\,(C_{true} / C_{orig})$$

where

Z_{true} = Corrected measurement volume location
Z_{orig} = Uncorrected (original) measurement volume location
C_{true} = True speed of sound
C_{orig} = Speed of sound used in original calculations

B-9.5 Argonaut-SL Sampling Strategy Considerations

This section describes the sampling strategies supported by the SL (**Figure B-8**) — continuous sampling, reduced duty cycle sampling, and burst sampling. The terms used here are defined in **Appendix A** (Glossary) and **Appendix C** (Direct Commands) of the *Argonaut-SL System Manual*.

Continuous Sampling – Continuous sampling is used for real-time data collection when there are no power supply or data limitations. For continuous operation, `SampleInterval` is set to the same value as `AvgInterval`, burst sampling is disabled (`BurstMode NO`), and the SL continually collects data. The duty cycle for continuous operation is 100%.

Reduced Duty Cycle Sampling – For many autonomous deployments, the SL uses a reduced duty cycle where `SampleInterval` is greater than `AvgInterval`, and burst sampling is disabled (`BurstMode NO`). When the SL is not collecting data, it enters a low power state where power

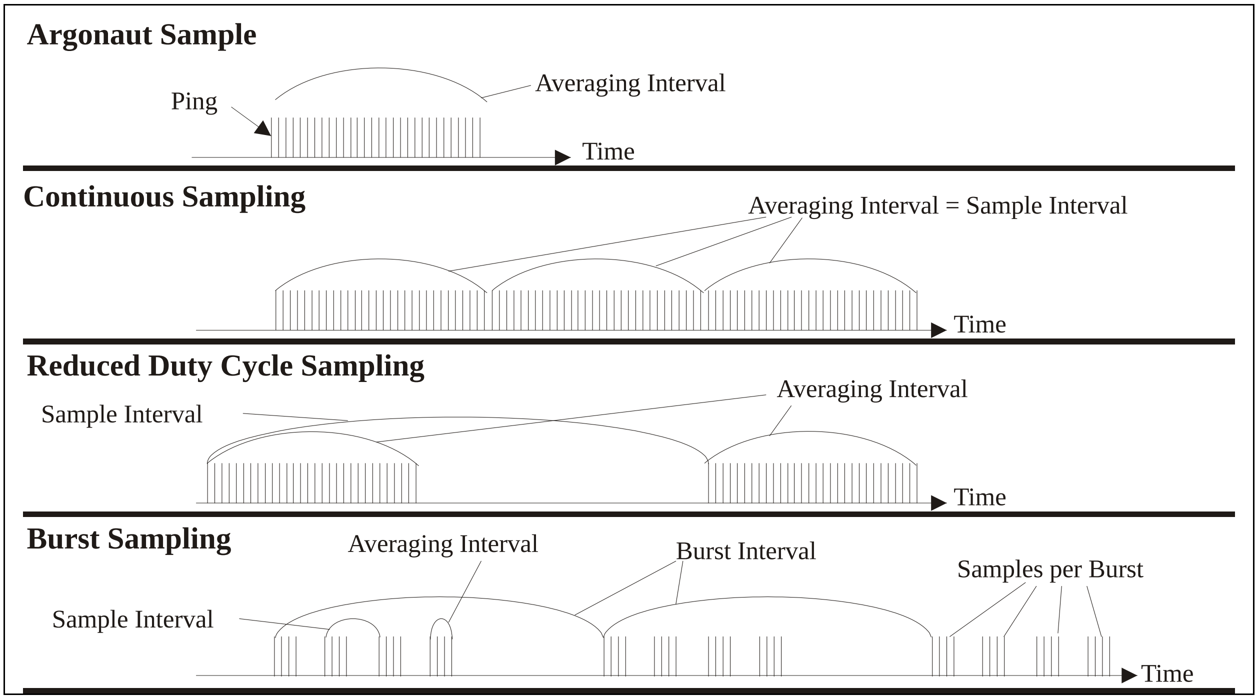


Figure B-8. Argonaut-SL Sampling Strategies consumption is less than 1 mW. Duty cycle is calculated as the ratio of **`AvgInterval`** to **`SampleInterval`**. Battery life is extended by the inverse of the duty cycle. Example: an **`AvgInterval`** of 300 s (5 minutes) and a **`SampleInterval`** of 900 s (15 minutes) yields a 33% duty cycle and extends battery life by a factor of three.

```
Duty cycle = AvgInterval / SampleInterval
```

Burst Sampling – Burst sampling lets you obtain information about short-term flow variation without requiring continuous operation. In this mode, the SL collects a number of samples in rapid succession, and then enters a sleep mode to conserve power. Duty cycle during burst sampling is calculated by the following formula.

```
Duty cycle = (SamplesPerBurst * AvgInterval) / BurstInterval
```

An example of burst sampling: set **`AvgInterval`** to 60 seconds, **`SampleInterval`** to 60 seconds, **`BurstMode`** to **`YES`**, **`BurstInterval`** to 900 seconds, and **`SamplesPerBurst`** to 5. With these settings, the SL will collect five one-minute samples in a row, and then enter a low power state for ten minutes. This gives a duty cycle of 33%, extending battery life by a factor of three. Burst sampling is used when there are no significant data storage limitations, but there are power limitations (so continuous sampling is not practical), and the user is interested in the short-term variation of velocity data.

B-10. Contact Information

Any questions, concerns, or suggestions can be directed to SonTek by telephone, fax, or email. Business hours are 8:00 a.m. to 5:00 p.m., Pacific Standard Time, Monday through Friday.

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See our web site for information concerning new products and software/firmware upgrades.