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Acoustic Doppler Profiler (ADP^{TM}) Principles of Operation

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1. Introduction

The SonTek Acoustic Doppler Profiler (ADP) belongs to a group of instruments known as acoustic Doppler current profilers (ADCPs).

- Since the 1980s, ADCPs have become established as the preferred method for measuring currents in the open ocean.
- Since its introduction in 1994, the ADP has expanded the use of ADCPs into shallow water applications.
- The ADP is the first ADCP designed specifically for shallow-water applications, reducing cost and improving performance for coastal areas, estuaries, lakes, and rivers.

This document presents the operating principles of the ADP. It does not attempt to provide a detailed discussion of all technical issues, nor a detailed description of ADP operation. To learn more about specific applications, please contact SonTek.

2. The Doppler Shift

The ADP measures the velocity of water using a physical principle called the Doppler effect.

- 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 Doppler current meters, we look at the reflection of sound from particles in the water.
- The change in frequency is proportional to the velocity of the water.

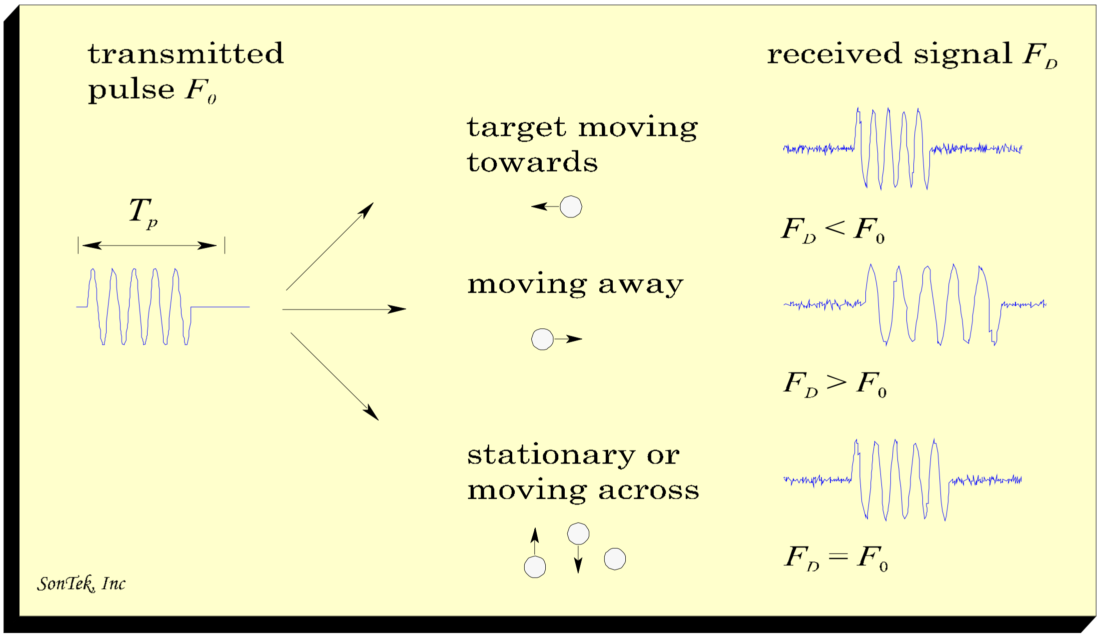

Figure 1 – Doppler Shift for Reflected Sound

Figure 1 shows the basic operation of a Doppler current meter. The change in frequency is calculated by the equation below.

$$F_{doppler} = -2F_{source}\frac{V}{C}$$

where

$F_{doppler}$ = Change in received frequency (Doppler shift)
F_{source} = Frequency of transmitted sound
V = Relative velocity of particles
C = Speed of sound

The velocity (**V**) represents the relative speed between the source and scatterers.

- If the distance between the two is decreasing, frequency increases.
- If the distance is increasing, frequency decreases.
- Motion perpendicular to the line connecting the two does not introduce a Doppler shift.

2.1. Monostatic Current Meters

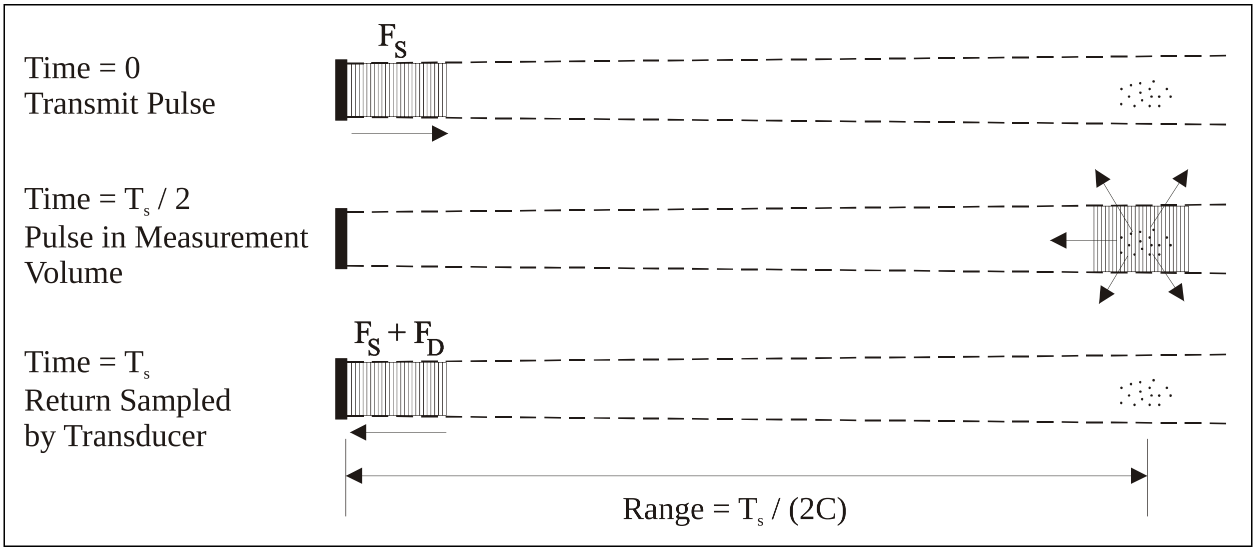

Figure 2 – Monostatic Current Meter

Figure 2 shows the basic operation of a monostatic Doppler current meter such as the ADP.

- Monostatic means the same transducer is used as transmitter and receiver.
- The transducer is designed to generate a narrow beam of sound.
- The transducer generates a short pulse of sound at a known frequency.
- As the sound travels through the water, it is reflected in all directions by particulate matter (sediment, small organisms, bubbles).
- Some portion of the reflected energy travels back along the transducer axis. It is received by the ADP, which measures the change in frequency of the received signal.
- The Doppler shift measured by a single transducer reflects the velocity of the water along the axis of its acoustic beam.

The measurement location 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 traveled, and specifies the location of the particles that are the source of the reflected signal.
- By measuring the return signal at different times, the ADP measures the water velocity at different distances from the transducer.
- The profile of water velocity is divided into range cells, where each cell represents the average of the return signal for a given period. For example, a 1-m range cell corresponds to an averaging time during which the range to the measurement volume moves one meter.

3. Current Profiling and 3D Velocity Measurements

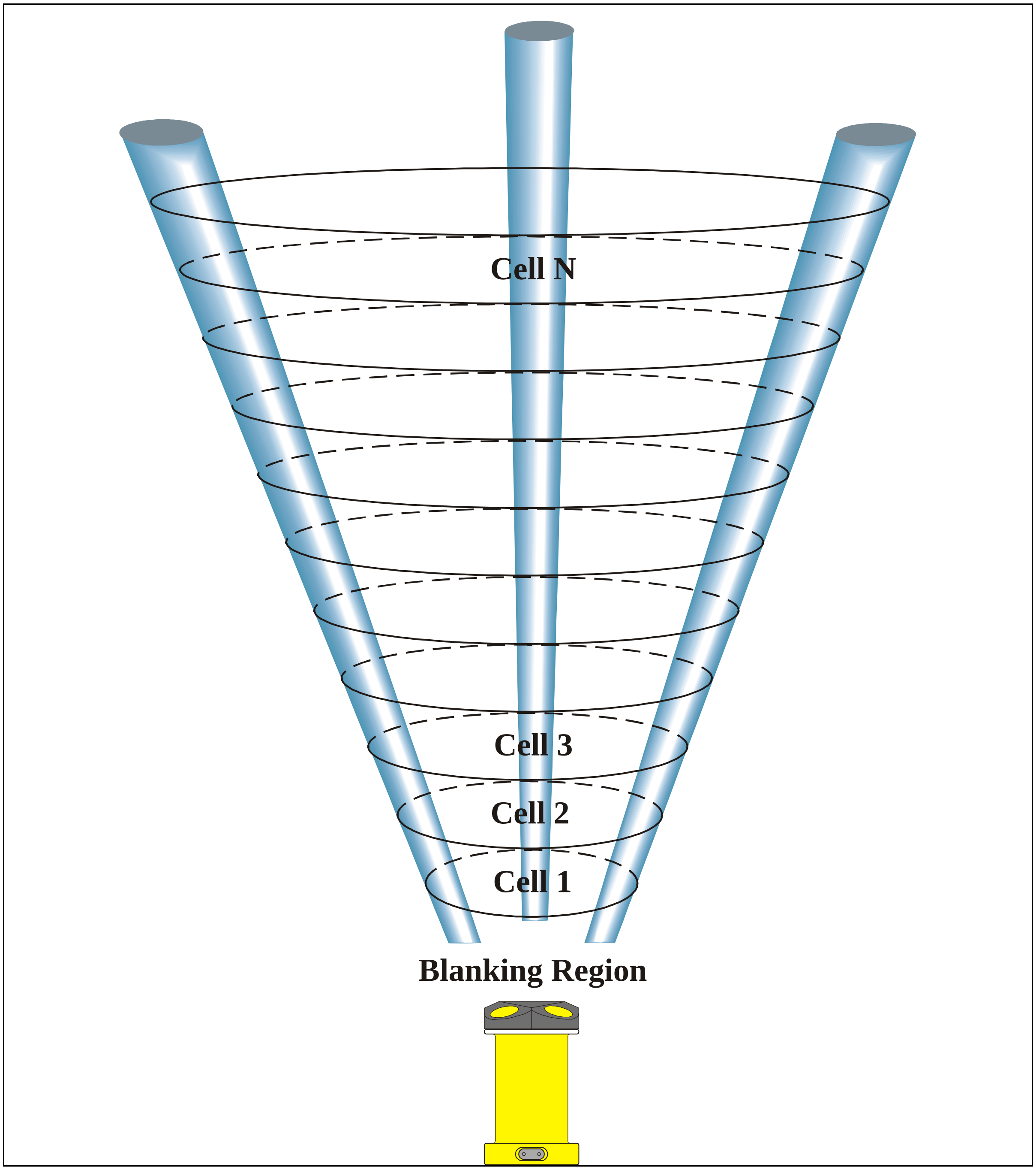

Figure 3 – ADP Beam Geometry and Current Profiling

Figure 3 shows the operation of the ADP for 3D (i.e., 3-axis) current profiling.

- While shown looking up, the ADP can be used for up, down, or side-looking operation.
- The velocity measured by one ADP transducer is the projection of the 3D velocity onto the axis of the acoustic beam.
- The standard ADP uses three beams oriented 25° off the vertical axis, equally spaced at 120° relative azimuth angles.
- The ADP combines the three along-beam velocities and uses the relative orientation of the transducers to calculate the 3D water velocity.
- Modified beam configurations (e.g., 2-beam, 4-beam) are available for special applications.

The ADP measures the 3D current profile as follows.

- Each transducer generates a short pulse of sound and measures the Doppler shift (velocity) versus time.
- Velocities measured by each beam are called beam velocity data, and are the projection of the 3D velocity onto the axis of the acoustic beam.
- The three beam velocities are combined at each range cell to calculate the 3D velocity in that depth layer. Velocity data is in a Cartesian (XYZ) coordinate system relative to the ADP.
- For many applications, the ADP includes an internal compass/tilt sensor to measures the orientation of the ADP. This allows the ADP to rotate velocity data from the XYZ coordinate system to an Earth (East-North-Up or ENU) coordinate system independent of ADP orientation.
- The ADP samples (or “pings”) as rapidly as possible over a user-specified averaging time and reports the mean 3D current profile. The mean profile includes velocity and a variety of associated data, as described in Section 6.

When analyzing ADP data, it is important to understand the inherent spatial averaging.

- To calculate the 3D velocity for a given layer, the ADP uses data from each of the three acoustic beams at the same range.
- The ADP assumes the flow field is uniform across the area covered by the three beams. That is, the water current across each beam is moving at the same speed in the same direction.
- For the standard configuration, the diameter of the area covered by these beams is 0.93 times the distance from the ADP. For example, if deployed on the bottom in 10 m of water, the velocity measurements near the surface are averaged over an area with a diameter of about 9 m.
- Because of the spatial averaging, current profilers are designed to make velocity measurements in environments where there are no strong horizontal flow gradients, and vertical variations are of primary interest.

4. Profiling Range and Spatial Resolution

The ADP profile is divided into different regions, as shown in Figure 3 and Figure 4.

- In front of the transducers is a small region where measurements cannot be made, called the blanking region. This allows the transducers to recover electronically from the transmit pulse and prepare to receive the return signal.
- The remainder of the profile is divided into range cells. Velocity data is averaged according to the user-specified range cell size.

The profiling range and spatial resolution (range cell size) of an ADP is primarily a function of the acoustic frequency.

- Low frequencies provide longer profiling ranges.
- Higher frequencies give shorter profiling ranges with better spatial resolution (reduced range cell size).
- The maximum profiling range is also a function of the amount of acoustic scattering material in the water (see Section 6.3).
- ADPs are available in five frequencies for operation in a wide range of water depths.
- Within the physical limitations of the system, the profiling range and resolution of the ADP are user-specified parameters.

The table below shows the profiling range, resolution, and blanking for various ADP frequencies.

- Maximum profiling range is a range of values to account for variations in the operating environment (different amounts of scattering material in the water).
- Typical resolution shows a range of cell sizes commonly used.
- The blanking distance is the region immediately in front of the transducer where no measurements can be made while the transducers recover from the transmit pulse.
- Minimum depth indicates the shortest profiling range for operation.

ADP Frequency	**Maximum Profiling Range**	**Typical Resolution**	**Blanking**	**Minimum Depth**
3000 kHz	3-6 m	0.15 - 0.5 m	0.2 m	0.5 m
1500 kHz	15-25 m	0.25 - 1.0 m	0.4 m	0.9 m
1000 kHz	25-40 m	0.4 - 2.0 m	0.5 m	1.3 m
500 kHz	70-120 m	1.0 - 5.0 m	1.0 m	3.0 m
250 kHz	120-180 m	1.0 - 10 m	1.5 m	3.5 m

5. Range Cell Location and Definition

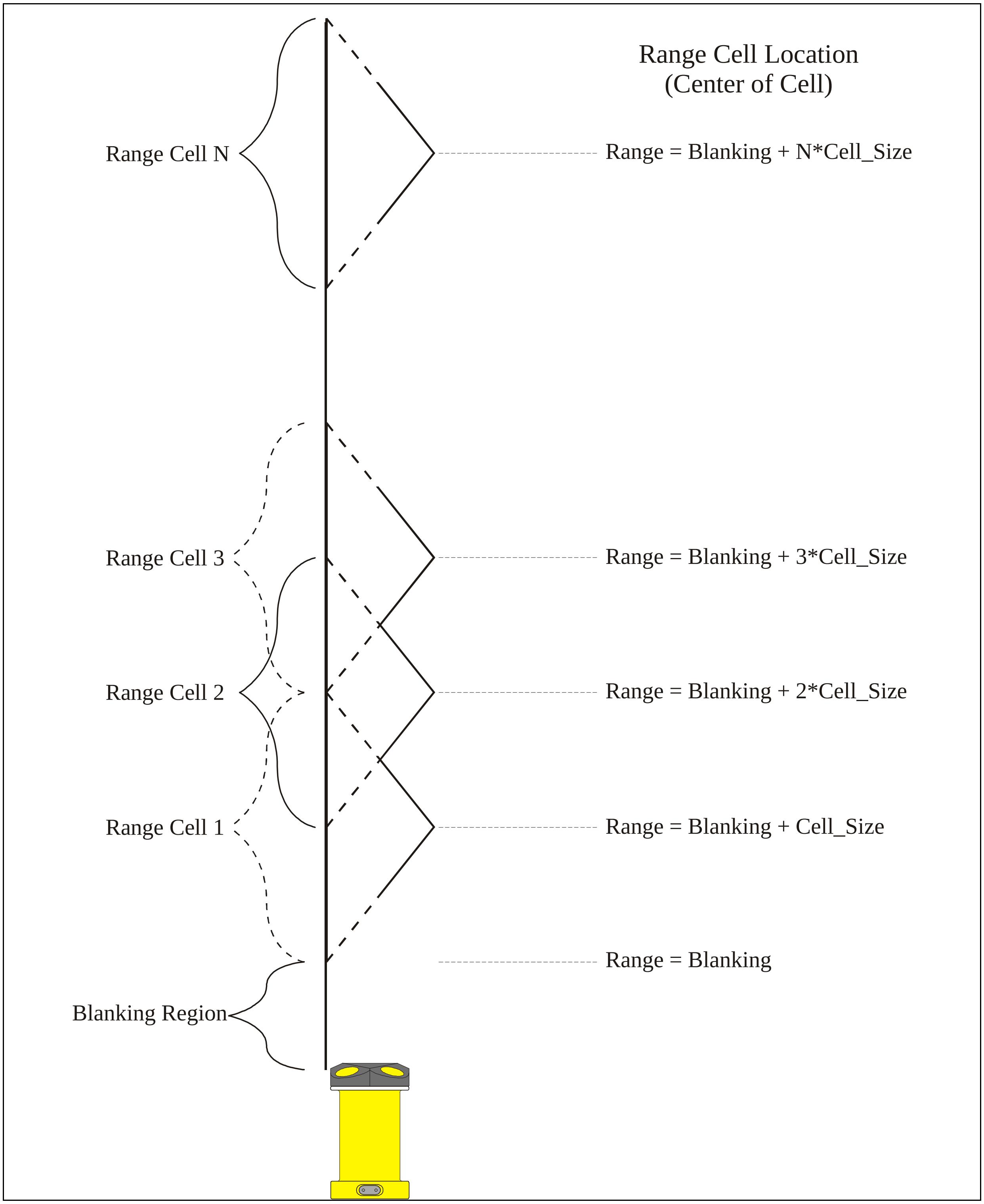

Figure 4 – ADP Range Cell Location

Figure 4 shows the location of range cells within an ADP profile. The location is different than might be expected because of the true spatial definition of an ADP range cell.

- For most applications, range cells can be considered distinct measurements with the dimension set by the user-specified cell size.
- Only specialized applications need to account for the true range cell definition.
- The true spatial definition of a range cell is determined by the convolution of the acoustic pulse length and the receive window over which the return signal is averaged. The ADP uses the same value for pulse length and receive window. This results in a triangular weighting function where the width of the triangle (the true spatial extent of the range cell) is twice the user-specified range cell size.

We are not including a detailed explanation of the range cell definition in this document; additional information is available on request. The most important conclusions are below.

- The location of the center of each range cell is as shown in Figure 4.
- The true spatial definition of each range cell has a triangular weighting function, with the total width of the triangle twice the user-specified range cell size.
- Adjacent cells overlap, such that the centers of adjacent cells are separated by the user-specified cell size.
- The triangular weighting function is a result of the physical length of the acoustic pulse, and does not indicate weighting within the ADP Doppler processing.
- Each ADP range cell is calculated completely independently. No filtering among adjacent range cells nor assumptions about flow patterns are used.
- While each cell is calculated independently, adjacent cells have 25% overlapping spatial information.

6. ADP Data

The ADP records the following data with each profile.

- Date and time from the ADP's internal clock
- Three velocity values for each range cell, one for each 3D component (see Section 6.2)
- Three signal strength values for each range cell, one for each transducer (see Section 6.3)
- Three standard error values for each range cell, one for each velocity component (see Section 6.4)
- Temperature sensor data
- Compass/tilt sensor data, if installed
- Bottom-track data, if enabled (see Section 7.1)
- GPS data, if enabled (see Section 7.1)
- Pressure sensor data, if installed (see Section 7.6.1)
- Wave spectra data, if installed (see Section 7.6.1)
- SeaBird MicroCat sensor data, if installed (see Section 7.6.2)
- External analog sensor data, if installed (see Section 7.6.3)

6.1. Sampling

The following describes the ADP sampling strategy.

- An individual measurement of the 3D velocity profile is called a ping.
- The ADP pings as rapidly as possible (4 to 20 times per second depending upon frequency; see Section 6.4).
- Pings are averaged over the user-specified averaging interval to produce a mean 3D velocity profile.
- Increasing the averaging interval decreases the uncertainty in each mean profile. See Section 6.4 for a discussion of measurement noise in ADP velocity data.

6.2. Velocity

The ADP Doppler processing provides several important performance advantages.

- It can measure 3D water velocities from 0.1 to 1000 cm/s.
- The ADP calibration will never change; that is, no re-calibration is required.
- For most applications, velocity data can be used without any postprocessing corrections.
- Velocity data is output in either (1) Cartesian coordinates (XYZ) that are relative to probe orientation, or (2) Earth coordinates (East-North-Up or ENU) for systems with a compass/tilt sensor.
- The only time postprocessing corrections are required is when sound speed has been incorrectly specified (see Section 7.4).

Factors that affect velocity data include accuracy and noise.

6.2.1. Accuracy

ADP accuracy is specified as follows.

- Accuracy refers to bias in velocity measurements after removing noise (see Section 6.4).
- Two factors influence the accuracy of the ADP: sound speed and beam geometry.
- The effect of sound speed on velocity measurements is discussed in Section 7.4. Sound speed errors are typically negligible (less than 0.1%); larger errors (which are uncommon) can be corrected in postprocessing.
- Beam geometry is fixed during manufacturing; no re-calibration is required.
- Velocity accuracy is specified to ±1.0% of the measured velocity.
- There is no potential for zero offset in velocity measurements, giving excellent low-flow performance.

6.2.2. Short-Term Uncertainty (Noise)

All Doppler velocity systems have inherent measurement noise.

- The noise is a result of the physical process by which the sound waves are scattered from particles in the water, and is referred to as Doppler noise.
- Doppler noise is random and can be assumed to follow a Gaussian distribution.
- Averaging multiple data points converges to the true value without introducing bias.
- Noise decreases with the square root of the averaging interval. (i.e., data using a 4-minute averaging interval has half the noise of a 1-minute averaging interval [$0.5 = \sqrt{(1/4)}$]).

Section 6.4 describes how to predict Doppler noise in ADP velocity measurements.

6.3. Signal Strength

Signal strength is a measure of the magnitude of the acoustic reflection from the water.

- Signal strength decreases with range due to geometric spreading and absorption.
- Signal strength is accessed as raw signal amplitude (using internal units called counts, where one count equals 0.43 dB) or as a signal-to-noise ratio (SNR in dB).
- The maximum profiling range is determined by the range where signal strength approaches the noise level (see Section 6.2.2), or by the range at which the pulse hits a boundary (surface or bottom).
- The maximum profiling range of the ADP (without a boundary present) is a function of the acoustic frequency and the strength of the scattering return from the water.

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

- Signal strength can be used as a measure of sediment concentration.
- While ADP signal strength data 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, contact SonTek.

The primary use for signal strength data is to determine the range over which the instrument can accurately measure velocity. There are several distinctive features in a profile of signal strength.

- At the transducer, signal strength typically starts at 120-180 counts (SNR 40-60 dB).
- Signal strength follows a logarithmic decay as distance from the transducer increases.
- If a boundary (surface or bottom) is within range, a spike will be seen corresponding to the reflection of the acoustic pulse. The shape and height of the spike varies with distance from the transducer and the nature of the boundary.

Factors limiting the profiling range of the ADP include return signal decay and boundary interference.

- At some range, signal strength reaches the noise level and the ADP cannot measure velocity. This range is a function of acoustic frequency and the conditions in the water.
- Generally, the end of the profile is the point where the SNR drops below 3 dB.
- If a boundary (surface or bottom) is within range, the end of the profile is determined by where the ADP sees the reflection from the boundary.

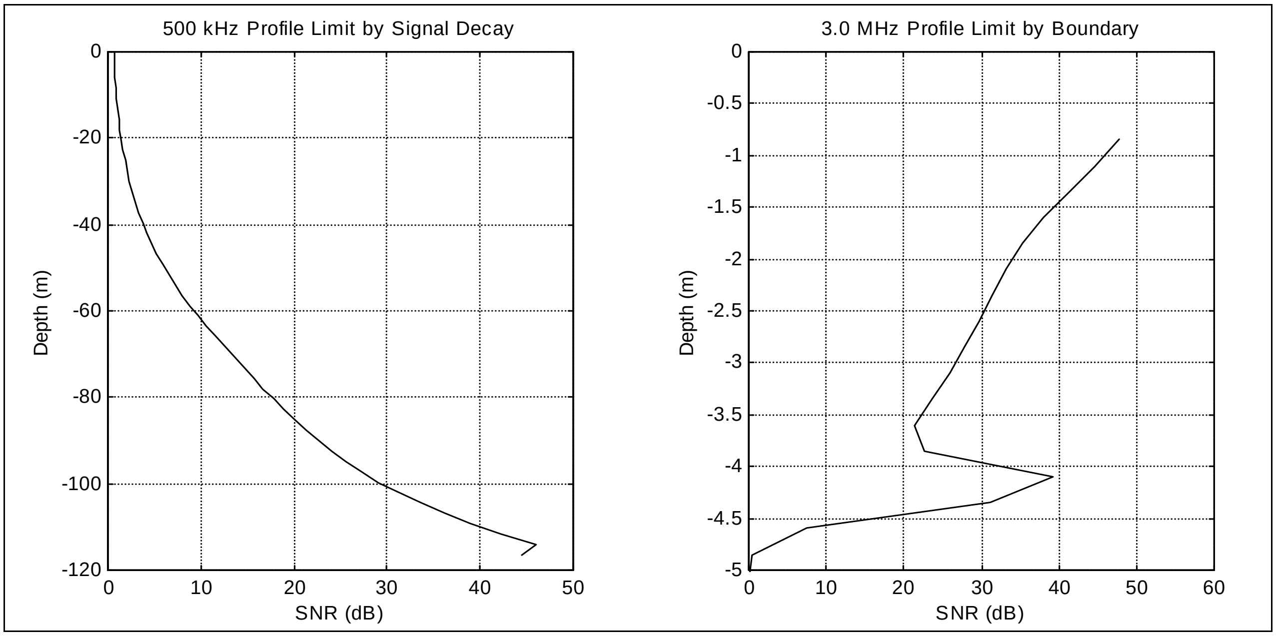

Figure 5 – ADP Example Signal Strength Profiles

Figure 5 shows examples of how profiling range is determined.

- The plot on the left shows the SNR (for one beam) from a 500-kHz ADP looking up from a depth of 120 m. The maximum profiling range is the point where SNR drops below 3 dB (at a depth of about 20 m). Data beyond this point cannot be used.
- The plot on the right shows the SNR from a 3000-kHz ADP looking down in about 4 m of water. The effective profiling range is determined where the ADP sees the reflection from the bottom. For this example, the peak bottom reflection occurs at a depth of about 4.1 m; the last good measurement is the cell located at about 3.6 m.

Signal strength varies considerably with the operating conditions of the ADP.

- The features shown here should be distinguishable, but some variation should be expected.
- The signals measured by the ADP are very small – ambient electronic noise and obstructions in the water can have a significant affect. Deployments in areas with large structures (piers, docks, etc.) should be carefully planned to avoid interference.
- The typical maximum profiling range for various ADP frequencies was shown in Section 4.

6.4. Standard Error

The ADP provides a standard error of velocity value that is a direct measure of the quality of velocity data.

- The ADP reports one standard error value for each velocity component for each range cell (in the user-specified coordinate system, XYZ or ENU).
- Standard error can be directly interpreted as an estimate of the accuracy of velocity data.
- Standard error includes instrument-generated uncertainty (Doppler noise), real variations in water velocity, and motion of the ADP installation (e.g., if mounted on a buoy or mooring line, or if used from a moving boat).

Standard error is calculated as follows.

- A number of pings are averaged during the user-specified averaging interval.
- A mean velocity value is reported.
- The standard deviation of velocity for all pings is divided by the square root of the number of pings to compute standard error.
- Predicted Doppler noise (described below) reflects only instrument-generated uncertainty (it does not account for real variations in water velocity or motion of the ADP installation).

The profile of standard error should be essentially constant where SNR is greater than 3 dB and no boundary is present.

- As SNR decreases below 3 dB, standard error increases rapidly; this increase can be used to determine the end of the effective profiling range in situations without a boundary.
- It is difficult to predict the standard error at the boundary, as these values will vary depending upon the nature of the reflected signal.

Doppler noise is a function of the ADP system configuration, acoustic frequency, range cell size, and the number of samples (pings) used to calculate the mean velocity profile.

For the standard 3D ADP, Doppler noise is estimated as

$$\sigma = \frac{235}{F \Delta z \sqrt{N}}$$

For a 2D side-looking ADP (see Section 7.5), Doppler noise is estimated as:

$$\sigma = \frac{205}{F \Delta z \sqrt{N}}$$

where

σ = Doppler noise of horizontal velocity measurement (m/s)
F = Acoustic frequency (kHz)
Δz = Range cell size (m)
N = Number of samples

To calculate the Doppler noise, the ping rate must be known.

- The number of samples is simply the averaging interval (in seconds) multiplied by the ping rate (in samples per second).

Frequency	Profiling Range (m)	3D ADP Ping Rate	2D Side-Looking ADP Ping Rate
3000 kHz	3-6	20	30
1500 kHz	15-25	9	13
1000 kHz	25-40	6 / 12 (see below)	8
500 kHz	70-120	2.0 / 4.5 (see below)	3.0
250 kHz	120-180	1.2-2.0 / 2.9-4.0 (see below)	1.7-2.7 (see below)

Two different ping rates are shown for the 1000, 500, and 250-kHz 3D ADP.

- The lower ping rate is for standard systems intended for stationary deployment (i.e., bottom-mounted).
- The higher ping rate is for systems used from a moving boat. These systems are modified to increase the ping rate to allow higher resolution.

The ping rate of the 250-kHz ADP varies with the user-specified measurement range (based on range cell size and the number of cells). Ping rate for the 250-kHz ADP can be calculated for a particular measurement range (in meters) using the formulas below.

- For standard 3D, 250-kHz ADPs used in stationary deployments:

$$PingRate = \frac{250}{25 + MeasurementRange}$$

- For 3D, 250-kHz ADPs used from a moving boat:

$$PingRate = \frac{750}{75 + MeasurementRange}$$

- For 2D, 250-kHz side-looking ADPs (used only in stationary deployments):

$$PingRate = \frac{375}{37 + MeasurementRange}$$

The following tables show predicted Doppler noise for various ADP frequencies at two range cell sizes. Tables are provided for both the standard 3D ADP and for the 2D side-looking ADP (see Section 7.5). The tables list Doppler noise for a single ping, and the time required to reach a noise level of ±1 cm/s.

The predicted values reflect only instrument-generated uncertainty (Doppler noise).

- Real variations in water velocity will increase the measured standard error values.
- Any motion of the ADP (e.g., when installed on a buoy or mooring line, or when used from a moving vessel) will increase the standard error of velocity measured by the ADP.
- In some applications, uncertainty due to motion of the ADP can dominate the standard error of velocity measurements.

For standard 3D ADP systems:

Frequency	**Range Cell (m)**	**Single Ping Doppler Noise**	**Averaging Time for σ <= ± 1 cm/s**
3000 kHz	0.25	31 cm/s	50 s
	0.50	16 cm/s	15 s
1500 kHz	0.50	31 cm/s	110 s
	1.0	16 cm/s	30 s
1000 kHz	1.0	24 cm/s	100 / 50 s *
	2.0	12 cm/s	25 / 15 s *
500 kHz	2.0	24 cm/s	280 / 130 s *
	4.0	12 cm/s	80 / 35 s *
250 kHz	4.0	24 cm/s	280-460 / 140-190 s *
	8.0	12 cm/s	70-120 / 35-50 s *

* See discussion about 1000, 500, and 250-kHz ping rates above.

For 2D side-looking ADPs (see Section 7.5):

Frequency	**Range Cell (m)**	**Single Ping Doppler Noise**	**Averaging Time for σ <= ± 1 cm/s**
3000 kHz	0.25	27 cm/s	30 s
	0.50	14 cm/s	10 s
1500 kHz	0.50	27 cm/s	60 s
	1.0	14 cm/s	15 s
1000 kHz	1.0	21 cm/s	60 s
	2.0	10 cm/s	15 s
500 kHz	2.0	21 cm/s	150 s
	4.0	10 cm/s	40 s
250 kHz	4.0	21 cm/s	160-250 s *
	8.0	10 cm/s	40-70 s *

* See discussion about 250-kHz ping rates above.

7. Special Considerations

7.1. Moving-Boat Operation

A powerful application of the ADP is current measurements from a moving boat.

- The ADP is mounted looking down from a boat or towed platform.
- The ADP measures the profile of water velocity relative to the boat.
- The ADP uses bottom-tracking to measure the speed of the boat relative to the bottom.
- The boat speed (from bottom-track data) is subtracted from the measured water velocity to give the absolute current profile independent of boat motion.

ADP moving-boat applications offer the ability to make measurements that cannot be made with any other type of current meter.

- Measuring the absolute current profile from a moving boat allows the ADP to perform current surveys over large areas in a short amount of time.
- Integrated GPS position gives a map of the water currents over the area of interest.
- The ADP simultaneously measures bottom depth, adding bathymetry to the data set and providing a built-in means to determine the end of the ADP velocity profile.
- The robustness and ease of use of the ADP lets you collect data with a minimum of preparation, reducing costs and ensuring the best quality data possible.

ADP moving-boat applications are described in detail in a separate technical note; please contact SonTek for details.

7.2. River Discharge Measurements

A subset of ADP moving boat applications is river discharge measurement.

- The ADP is mounted from a small boat or towed platform.
- The ADP measures the absolute currents using bottom-track data to account for vessel motion.
- The boat or platform is moved slowly from one side of a river to the other side.
- The ADP combines all velocity and bottom-track data to compute the total river discharge. The ADP simultaneously reports detailed bathymetry information and the distribution of currents across the river.

ADP measurements of river discharge offer the following advantages.

- Rapid, accurate measurement of river discharge.
- Simple, robust operation with minimal training required.
- A complete, integrated package including a towed catamaran (the RiverCat) is available.

ADP river discharge measurements are discussed in detail in a separate technical note; please contact SonTek for details.

7.3. Near-Boundary Data Collection

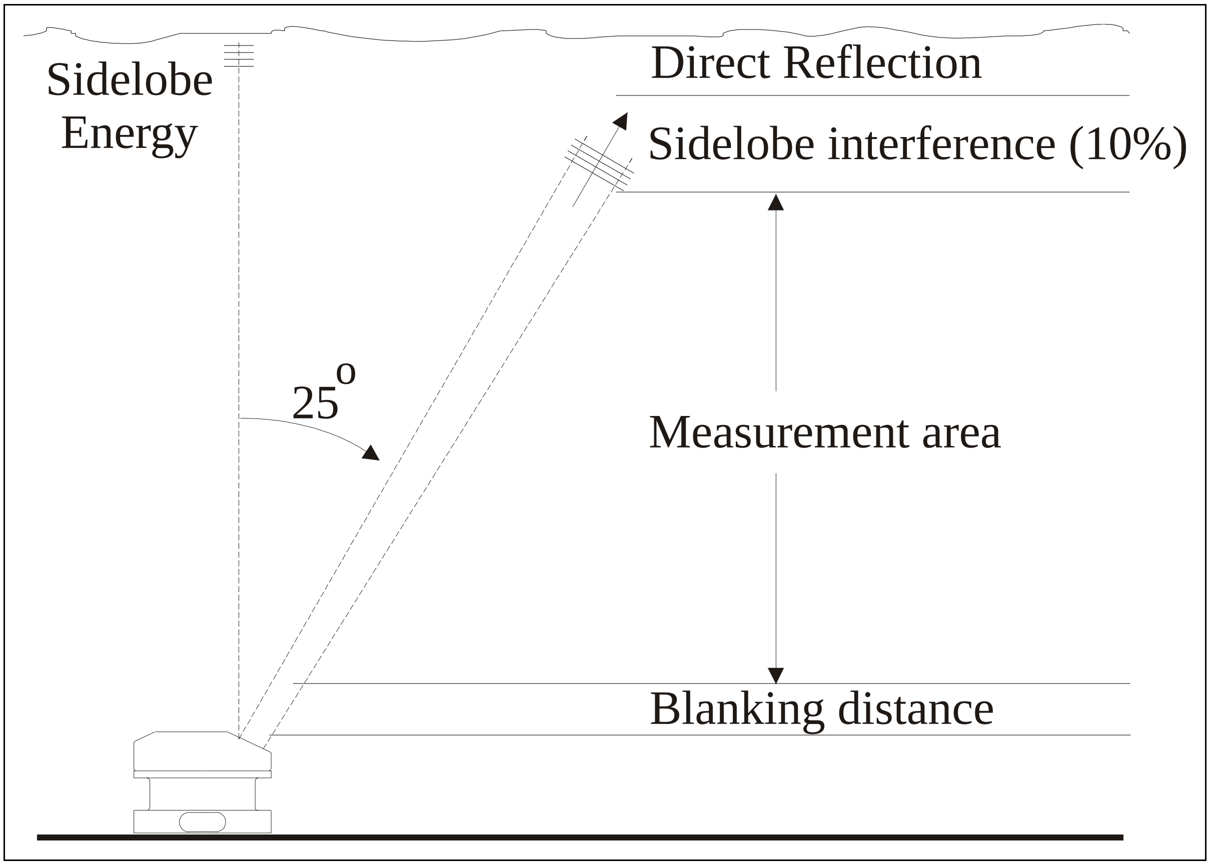

Figure 6 – ADP Near-Boundary Operation

Figure 6 shows an upward looking ADP near a boundary (the surface). For near-boundary operation, the profile is divided into several areas.

- Following the blanking region, the ADP makes velocity measurements in range cell sizes selected by the user.
- As the profile approaches the boundary, there are two potential sources of interference: direct reflection of the pulse from the boundary, and the reflection of side-lobe energy taking a direct (shorter) path to the boundary.
- The same considerations apply to a down-looking system near the bottom.

ADP transducers are designed to concentrate most of the acoustic energy in a narrow beam; however, some energy is transmitted in all directions.

- As shown in Figure 6, some energy takes a direct (shorter) path to the boundary and reflects off the boundary while the main portion of the beam is still in clear water.
- This is called side-lobe energy and the reflections from a boundary are called side-lobe interference.
- Although side-lobe energy levels are much lower than the main beam, the reflection from the boundary is much stronger than the reflection from particles in the water. Thus, side-lobe reflections can potentially bias velocity measurements.
- Side-lobe interference may affect the last 10% of the velocity profile (for the standard ADP with a 25° beam-mounting angle).
- The extent to which the side-lobe reflections affect the velocity measurements is a function of the boundary conditions, the scattering return strength from the water, and the acoustic properties of the transducers.

SonTek has made considerable advances in designing transducers with reduced side-lobe levels.

- Reduced side-lobe energy levels decrease the possibility of side-lobe interference.
- Our experience has shown that in most conditions, SonTek ADPs do not see any identifiable evidence of side-lobe interference and do not lose the last 10% of the velocity profile.
- There is always a potential for side-lobe interference, and any near-boundary data should be analyzed carefully.

As previously described, Figure 5 shows a typical signal-strength profile with boundary reflection.

- The peak reflection occurs in the cell whose center is closest to the bottom.
- The cell immediately before the peak usually sees some portion of this reflection. Cells before this should be looked at carefully for signs of interference.
- In areas with significant wave action, the lowest surface height can potentially extend several cells below the peak.
- The peak cell, and the cell immediately before the peak, should always be discarded. The next few cells should be examined closely for signs of increased signal strength (caused by reflections from the boundary) or for unusual features in the velocity and standard error data.

7.4. Sound Speed

The ADP uses sound speed to compute velocity from the measured Doppler shift. This section discusses how to correct ADP velocity data for errors in the sound speed value used during data collection. Sound speed errors are typically small; postprocessing corrections are rarely required.

The speed of sound in water is primarily a function of temperature and salinity.

- The ADP includes a temperature sensor (±0.1° C) for automatic sound speed corrections.
- A user-input value of salinity is used in the sound speed calculations.

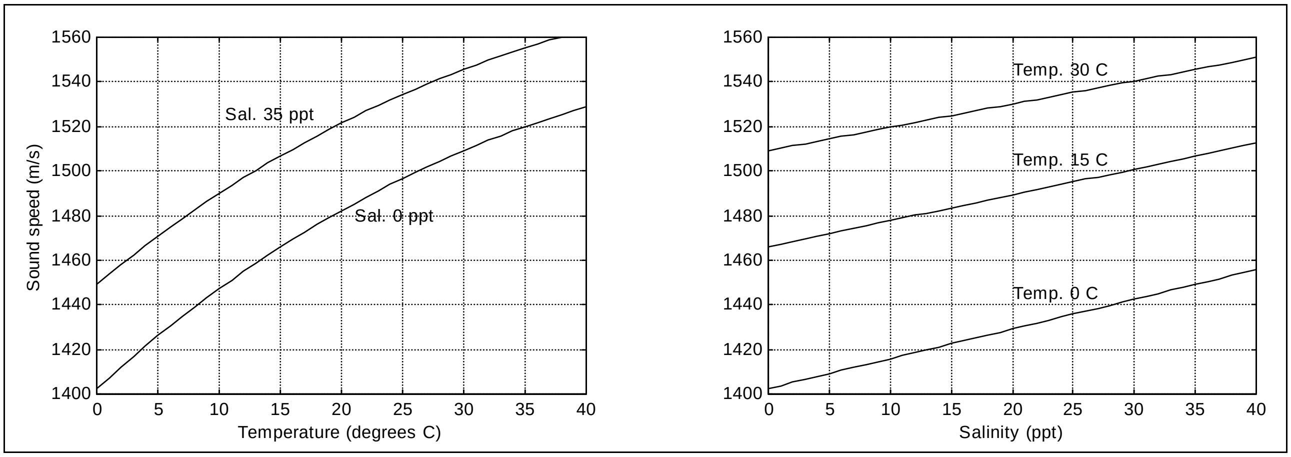

Figure 7 – Sound Speed as a Function of Temperature and Salinity

Figure 7 shows sound speed as a function of temperature at different salinity levels (left panel) and salinity at different temperature levels (right panel). As a general rule:

- A temperature change of 5° C results in a sound speed change of 1%.
- A salinity change of 12 ppt results in a change in sound speed of 1%.
- The full range of typical temperature and salinity levels (-2 to 40°C and 0 to 40 ppt) gives a sound speed range of 1400 to 1570 m/s (total change of 11%).

For the ADP, output velocities (in any coordinate system - Beam, XYZ, or ENU) scale directly with sound speed; a 1% error in the sound speed results in a 1% error in velocity measurements. The following formula is used for postprocessing corrections, and can be directly applied to the output velocities of the ADP:

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

where

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

Changes in sound speed also affect the physical location of ADP range cells, although these errors are generally small. To correct the position of ADP range cells, use the following:

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

where

Z_{true} = Corrected range cell location (range from transducer)
Z_{orig} = Uncorrected range cell location (range from transducer)

7.4.1. Stratified Flow

A common question is how a stratified water column (changes in sound speed with depth) affects ADP operation. Figure 8 illustrates this question.

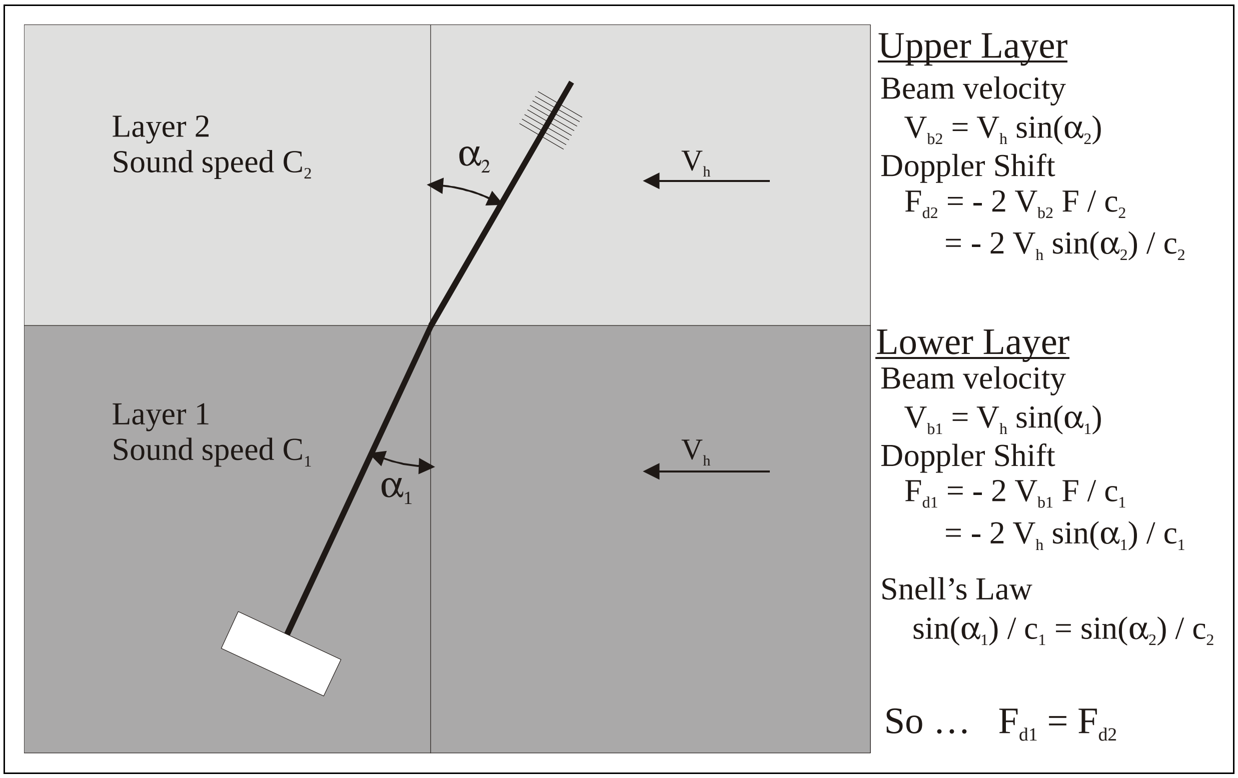

Figure 8 – ADP Operation in Stratified Flow

The answer is that variations in sound speed through the water column have no effect on ADP horizontal velocity measurements.

- The ADP only needs to know the sound speed at the transducers.
- The refraction of the acoustic beam at the interface of two layers has a geometric effect equal and opposite to the effect of changes in sound speed.
- Figure 8 shows the measured Doppler shift for an identical horizontal velocity in two layers.

7.5. Horizontal Current Profiling

The standard ADP uses three beams for vertical current profiling, looking up or down. There are several applications where a current profiler can be used looking horizontally. These applications require a two-beam ADP that measures the 2D velocity profile in a horizontal layer.

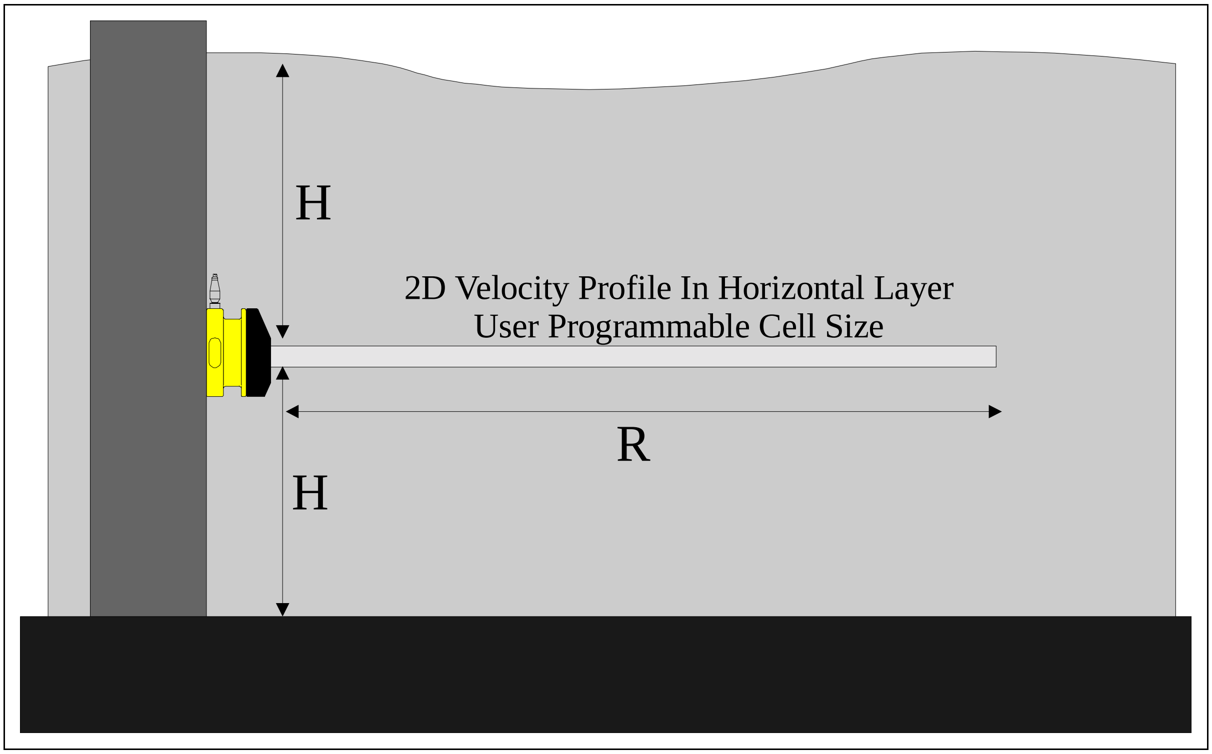

Figure 9 – ADP Horizontal Current Profiling

A 2D ADP is typically mounted from some type of underwater structure (e.g., bridge piling).

- The two beams are mounted in a plane parallel to the surface and bottom.
- This instrument operates exactly like a standard ADP except that the two beams measure the profile of water velocity with horizontal range, and return the two horizontal velocity components.

The primary limitation of horizontal profilers is the maximum range relative to depth.

- This is expressed as the aspect ratio between profiling range and the distance to the nearest boundary (R / H as pictured in Figure 9).
- While ADP transducers generate very narrow beams, these beams will spread, and after some distance, will begin to see interference from the boundaries (surface, bottom).
- Experience has shown that the ADP can operate without interference to an aspect ratio of about 10 in almost all conditions, and in some situations to aspect ratios of 20 or higher. For example, a 500-kHz 2D ADP installed at mid-water depth in 5 m of water has reliably worked to ranges over 60 meters (an aspect ratio of about 24).

7.6. External Sensor Integration

The ADP has been designed to allow integration of other sensors with all data stored in a single file. Three primary sensor types are available (in addition to the temperature sensor included standard with all systems).

- Pressure (strain gage or RPT)
- CTD (SeaBird MicroCat)
- Analog sensors

7.6.1. Pressure Sensor – Surface Level and Wave Spectra

A pressure sensor provides an integrated measurement of deployment depth / surface level, and a simple means for determining the end of the profile for up-looking ADP installations. Two types of pressure sensors can be added to the ADP.

- Strain gage pressure sensor: ±0.1% of full scale, 10 to 600-m depth ranges.
- Resonant pressure transducer (RPT) sensor: ±0.01% of full scale, 20-m depth range.

The ADP pressure sensor can also include special software to collect and record estimates of wave frequency spectra.

- Spectra are estimated from the 1-Hz pressure time-series over the averaging interval.
- The estimation uses standard methods appropriate to simple linear theory – segmentation of the data in 256-point segments with at least 128-point overlap between consecutive segments; application of Hanning window to each segment with constant energy correction; and correction for sensor/water depth using general first order dispersion relationship for surface waves.
- Wave spectral estimates are presented as an array of coefficients, each giving the mean wave amplitude (square root of the energy) within a period band. Ten bands are used, which correspond to two-second periods ranging over 2 to 20+ seconds.
- Significant wave height and peak wave period are also reported.
- Wave spectral estimates and raw 1-Hz pressure data are recorded with each profile.

For each band, the ADP computes and reports the mean wave amplitude (**A**) for waves within the period range in the band. If $\mathbf{A_i}$ is the amplitude for band ***i***, the total wave energy is given by:

$$\text{Total Energy } (\sigma_A^2) = \Sigma(A_i^2) \text{ for i=1 to 10}$$

A generally accepted estimate of the significant wave height can be easily obtained from the amplitudes using:

$$H_{mo} = 4 \times \sqrt{(\text{Total Energy})}$$

7.6.2. SeaBird MicroCat CTD

SeaBird is the recognized leader in high-precision temperature and conductivity measurements.

- SonTek has integrated the MicroCat with the ADP to provide the most accurate velocity, temperature, and conductivity measurements in a single integrated package.
- The SeaBird MicroCat offers temperature accuracy of 0.002°C and conductivity accuracy of 0.0003 S/m.
- The ADP controls MicroCat operation (using a built-in RS232 serial interface) and collects one synchronized CT sample with each velocity sample.
- The data is stored in the same file as the ADP velocity data for easy analysis.

7.6.3. Analog Sensors

The ADP has the ability to sample up to three additional analog voltage inputs from external sensors.

- Each input must be in the range 0-5 VDC.
- The ADP uses a 12-bit analog-to-digital (A/D) converter to sample the input voltages.
- Each voltage is sampled once per second during the user-specified averaging time; mean and standard deviation are recorded with each profile.
- Depending on sensor requirements, the ADP may be able to provide power to the sensor.
- Special wiring and software modifications are required for external analog sensors.
- The data is stored in the same file as the ADP velocity data for easy analysis.

A variety of sensors can be integrated with the ADP.

- Turbidity (OBS)
- Transmissometer
- Fluourometer
- Dissolved oxygen

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