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Authors: Peter J Rusello - NortekUSA
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A Practical Primer for Pulse Coherent Instruments

Peter J. Rusello

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I. Background

Pulse coherent profilers have been commercially available for over a decade and have seen a steady increase in use as more user friendly software simplifies setup, making high quality data easily achievable. Pulse coherent systems are typically used for difficult measurement situations such as turbulence measurements, very slow, low energy flows, and rapidly varying flows requiring high single ping accuracy. They can work well in areas with high shear, near boundaries, under breaking waves, and many other situations. Pulse coherent data from single or small ensemble average measurements are useful because of the individual measurement accuracy and low noise. Pulse coherent profilers can measure in far smaller cell sizes (on the order of 1 cm) providing far more details of the flow than standard Doppler systems.

Nortek AS has manufactured acoustic Doppler current profilers and velocimeters since their founding in 1996. The first Nortek pulse coherent profiler was sold in 1998 (HR-NDP) with a second version introduced in 2006 (High Resolution Aquadopp Profiler or HR Profiler). Pulse coherent processing was also used in the original Nortek velocimeter (NDV) and is presently used in the Vector and Vectrino velocimeters.

This document will provide a brief review of pulse coherent processing principals, as well as provide the user with more practical tips and training for pulse coherent instruments, such as the High Resolution (HR) Aquadopp Profiler, Vector, and Vectrino.

II. An Introduction to the Instruments

The HR Aquadopp Profiler consists of three acoustic transducers/receivers arranged in a variety of head configurations (Figure 1a - Other head configurations than the two shown are available). The HR Aquadopp Profiler is available as either a 1 or 2 MHz system based on the Aquadopp Profiler hardware. Special firmware is used to change the internal processing of the standard Aquadopp Profiler to pulse coherent operation. The HR Aquadopp Profiler is equipped with temperature, pressure, pitch, roll, and heading sensors and an internal recorder for autonomous deployments, just like the standard version. It may also be operated in a cabled, real time setup or equipped with a variety of acoustic modems for integration into a data collection platform.

Figure 1. The three pulse coherent systems Nortek currently produces. (a) The Aquadopp/ HR Profiler and two standard head configurations. (b) The Vector with a fixed probe head. (c) The Vectrino with a fixed probe head.

The Vector and Vectrino are shown in Figures 1b and 1c and belong to a class of instruments known as acoustic Doppler velocimeters. The Vector was developed for field deployments and features a titanium probe with the traditional three receiver arms characteristic of acoustic velocimeters. The Vector offers similar internal electronics as the HR and Aquadopp Profilers, including the ancillary sensors and data recorder.

The Vectrino represents the next generation of acoustic velocimeter design and incorporates many features highlighted in (Snyder 1999) as beneficial to increase measurement accuracy and reduce flow disturbance (Rusello 2006). The most obvious change is the addition of a fourth acoustic receiver and a change in the orientation of the arms around a circle, with a 90º separation between arms instead of 120º as in the Vector. The Vectrino was developed primarily for laboratory measurements and is not equipped with ancillary sensors other than a temperature sensor in the probe for speed of sound estimation. No internal recorder is available. A ruggedized field probe is available. Both the Vector and Vectrino are available with a fixed probe head as seen in Figure 1 or with a cabled probe head for more flexible mounting options.

The receiver arms of an acoustic Doppler velocimeter receive Doppler shift measurements from a small volume in space referred to as the Sample Volume. In contrast, the HR Aquadopp Profiler uses divergent acoustic beams and measures at various vertical locations and divides the reported profile into many depth or measurement cells.

III. Basic Operating Principles

Pulse coherent instruments, such as the HR Aquadopp Profiler, Vector, and Vectrino, utilize a pair of acoustic pulses with a known time lag, or separation, to determine a Doppler effect induced phase shift. This measured phase shift is converted to velocity by scaling with the speed of sound in water. The measurement of a phase shift is more accurate than direct Doppler frequency determinations and provides pulse coherent systems with their characteristic low noise measurements. The instrument reports the phase shift converted to an along beam velocity by utilizing the speed of sound in water. We will refer to these velocities as b_i, where $i = 1,2,3,\ldots$ and represents a numbered beam. The size of the separation between pulses determines the maximum unambiguous velocity that can be measured. Longer lags have lower maximum velocities, while shorter lags have higher maximum velocities. Conversely, longer lags will typically have lower noise levels than shorter lags.

The Doppler phase shift is computed using a standard signal processing technique called the covariance method. By computing the complex covariance of the two return signals, the Doppler phase shift can be calculated by taking the arctangent of the real and imaginary parts of the covariance function. The implications of this calculation, specifically with regards to ambiguity in velocity measurements, will be discussed further in the next section.

Along with determining a phase shift, the instrument will also typically compute the speed of sound (needed to change the phase shift to an actual velocity), measure the return signal strength (reported in arbitrary units as counts and output as the variable **Amplitude)**, and measure the attitude sensors such as pitch, roll, and compass heading (if equipped) to aid in the last step in processing, coordinate system transformation.

Coordinate transforms combine beam velocities in various ways to produce either a Cartesian instrument coordinate system (referred to as **XYZ** coordinates) or an Earth normal coordinate system (referred to as **ENU**, or East, North, Up). When handling data, **XYZ** or **ENU** coordinates are the most practical for a user. **Beam** coordinates are used when dealing with ambiguity (phase wrapping) and higher order turbulence calculations.

IV. Phase Wrapping & Velocity Ambiguities

One inherent consequence of pulse coherent systems is the ambiguous determination of the Doppler phase shift (Φ). As mentioned in the previous section, the arctangent, specifically the four quadrant arctangent, is used to calculate Φ. The resultant angle is constrained from $-\pi$ to π or as reported by the planning software, a velocity range such as *0.9 m/s* where π has been scaled to yield the maximum or minimum (when multiplied by -1) ambiguity velocity.

If the absolute value of Φ is greater than π, phase wrapping occurs and the measured phase shift has a value $\Phi_{measured} = \Phi_{actual} - 2\pi$. We see this phase wrapping in a velocity trace as an abrupt, unrealistic change in magnitude, almost always with a change in sign. While it is possible for phase wrapping to occur without a sign change, this would be the result of an extremely large wrap where the phase shift exceeds 2π, in which case decorrelation would likely occur first.

As an example, if the ambiguity velocity is *+/- 1.0 m/s* and the velocity goes to *+1.1 m/s*, the measured velocity will be wrapped around to *-0.9 m/s*. See Figure 2 for an example of phase wrapping from a Vectrino measured in XYZ coordinates.

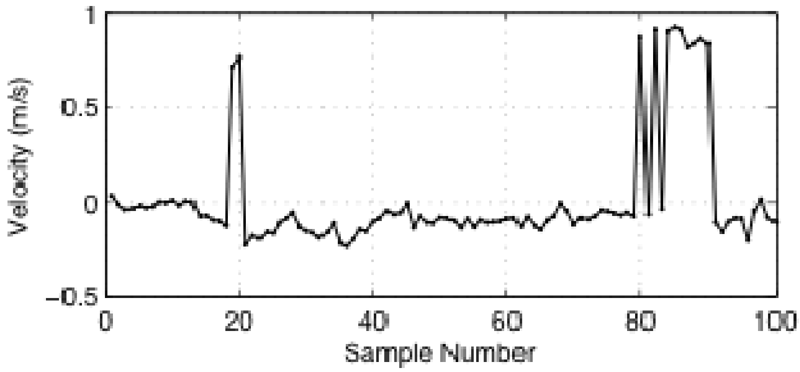

Figure 2. An example of phase wrapping showing an abrupt change from negative to positive velocity. Data was measured with a Vectrino at 50 Hz sample rate in a grid turbulence tank. The **Nominal Velocity Range** was set to *30 cm/s*, yielding a horizontal velocity range of *94 cm/s*. The plotted velocity is from the **X** component of recorded data.

The simplest way to avoid phase wrapping is to have a little prior knowledge of flow conditions and to set up the instrument appropriately for the environment. For the Vector or Vectrino increasing the **Nominal Velocity Range** in the software will change the horizontal and vertical velocity ranges reported in the **Deployment Planning** section of the **Deployment Planning** dialog window. Ensure these values are above the maximum expected flow velocities. For the HR Aquadopp Profiler, a similar method can be used, but the parameter to change is **Profiling Range** rather than **Nominal Velocity Range**. For both instrument types increasing the velocity range decreases the pulse separation and increases the ambiguity velocity.

Adjusting the pulse separation is not always an option for the HR Aquadopp Profiler because of boundary interference (discussed further in the Section **HR Deployment Considerations**). In these cases, another method is used to increase the ambiguity velocity, called Extended Velocity Range. Extended Velocity Range (EVR) utilizes an additional pulse pair to create a set of pulses with two different lags and velocity ranges. The longer lag is the standard pulse coherent lag set by the user, while the EVR lag is shorter and has three times the velocity range. The standard phase shift is compared to the EVR phase shift and corrected so it matches the EVR data if needed.

Information from the EVR data is recorded by the HR Aquadopp Profiler and output in a ***.hr2** file during binary data conversion. The EVR data consists of a single cell (located one third of the way into the profile) and the velocities, amplitudes, and correlations associated with this cell. If ambiguity problems occur when using EVR, it is likely because the EVR data has phase wrapped as well. EVR does not eliminate the possibility of ambiguity problems if velocities exceed the specified velocity range in the Deployment Planning dialog.

There are two constraints to be aware of when using EVR. First, the maximum internal ping rate is lower than non-EVR operation by a factor of two (2) because the pulse-pairs normally used for velocity profile measurement are used for the phase unwrapping scheme. Second, with an additional pulse in the water, pulse interference from boundary echoes can also be an issue. The interference is discussed further in the section **HR Deployment Considerations**. Despite the lower sample rate and potential for boundary interference EVR works extremely well and in many cases and may permit use of the HR Aquadopp Profiler in higher energy environments, such as the surf zone.

If phase wrapping does occur, it is fairly simple to unwrap the data once the ambiguity velocity (the velocity corresponding to π, denoted V_{amb}) has been estimated. A simple estimate of V_{amb} is the average of the absolute values of the maximum and minimum measured velocities. A more accurate expression is $V_{amb} = c / (2 (36*lag))$, where c is the speed of sound. An example of phase unwrapping is presented in the section **Coordinate Transforms** after a discussion of beam velocities.

V. Correlation

Correlation is a measure of the similarity of two pulse echoes being measured by the Doppler instrument. Zero correlation means nothing at all is similar between the two echoes, where as a correlation of 1 means the two echoes are identical. We want high correlation because it gives us confidence the system measured the two pulses it originally sent out and is determining a valid phase shift.

In practice we will never see correlations of zero because of noise due to electronics, temperature fluctuations, and other factors that will always correlate above zero. Correlation reported by the instrument will be on a percent scale from *0-100%*, so simply multiplying the above limits by *100* will place them in the appropriate range.

In the early days of the acoustic Doppler velocimeter, if a user did some tests and determined correlations were above *~70%* then the instrument was considered to be generating good quality data. Many users still use this number for screening out bad data, although a generalization to some universal value is unwarranted and a close examination of the dataset is the best way to set a correlation threshold (if any) for discarding bad data points.

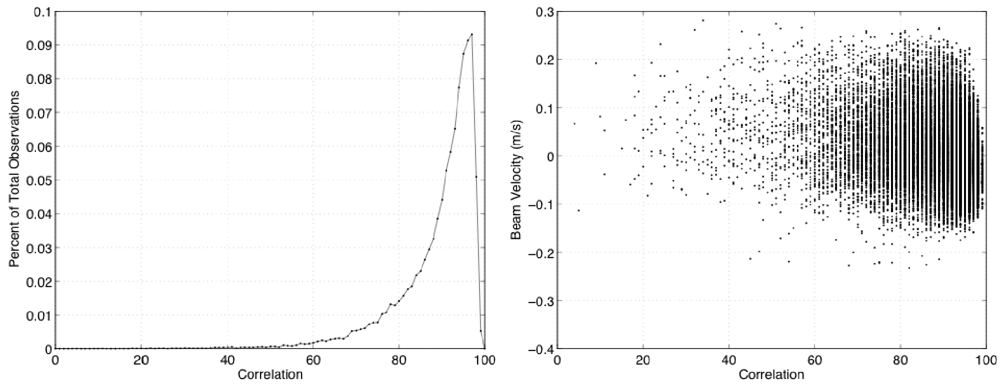

Figure 3. (a) Correlation histogram taken from the Vectrino data set shown in Figure 2. The majority of data is above 90\% correlation. (b) A scatter plot of correlation versus the beam velocity. Removing measurements with correlation below *70%* will remove some outliers but is not an effective outlier screening procedure.

The number reported by Nortek instruments is a normalized correlation value and will always lay in the interval *0-100%*. A typical histogram for Vectrino correlation data is shown in Figure 3a. A scatter plot of correlation versus velocity is shown in Figure 3b. Discarding measurements with correlations lower than *70%* will not significantly reduce the variance of the data set, which is generally the goal of most data screening operations. Removing low correlation measurements is still a good idea because correlation is a strong indicator of data quality in the sense of a valid Doppler phase shift determination. However, high correlation is not always indicative of a valid measurement of the flow. It is also important to note correlation is tied to a specific beam velocity measurement, not to an orthogonal coordinate direction such as **X**, and any screening should take this into account.

VI. Coordinate Transforms and Beam Velocities

The transform of coordinate systems from **beam** to **XYZ** or **ENU** coordinates is both an important and often neglected step when examining Doppler velocity data. Understanding coordinate transforms is important in interpreting velocity data, fixing problems in a data set, and ultimately, obtaining the highest quality data.

Returning to the phase wrapping problem, if we look at **XYZ** coordinate system data (Figure 2) the behavior of the dataset seems very odd. There are obvious phase wrapping issues, but the velocity is near zero when the phase wrap occurs. The maximum positive velocity is near *1 m/s* while the minimum negative velocity is around *0.25 m/s*. The expected minimum velocity is also near *-1 m/s*. To understand why the velocity signal is wrapping when it is so far from the ambiguity velocity, we turn to the Transformation matrix.

The Transformation matrix for an instrument is reported in the header file (***.hdr**) when performing a binary data conversion in the instrument software. For the Vector and HR Aquadopp Profiler it will be a 3 x 3 matrix and for the Vectrino it will be a 4 x 4 matrix. Each row represents a component in the instrument's **XYZ** coordinate system starting with **X** as the top row. The third and fourth rows for the Vectrino Transformation matrix represent the two estimates of vertical velocity produced by this instrument. Each column from left to right represents a beam. Refer to the appropriate instrument manual for beam numbering conventions.

Recall the basics of matrix multiplication:

$$\begin{bmatrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{33} \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix}$$

If we were to write out the matrix multiplication above we would obtain the following system of equations:

$$T_{11}b_1 + T_{12}b_2 + T_{13}b_3 = u_1$$
$$T_{21}b_1 + T_{22}b_2 + T_{23}b_3 = u_2$$
$$T_{31}b_1 + T_{32}b_2 + T_{33}b_3 = u_3$$

Where T_{ij} represents the elements of the Transformation matrix ***T***, b_i are the beam velocities, and u_i are the transformed velocities. From the above equations, we can see how each orthogonal velocity component is a combination of the various beam velocities. See Appendix (Lohrmann 1990) for the equations incorporating pitch, roll and heading data. Here is a typical Transformation matrix from a Vector:

$$T = \begin{bmatrix} 2.68 & -1.36 & -1.33 \\ -0.02 & 2.26 & -2.26 \\ 0.35 & 0.34 & 0.34 \end{bmatrix}$$

Note that many of Nortek's instruments report ***T*** as unscaled integer values. In this case, ***T*** will need to be divided by *4096* to be used in a coordinate transform. Beginning in 2009, most instrument software will scale ***T*** during binary data conversion.

To convert from **beam** to **XYZ** coordinates the only information needed is a set of beam velocity measurements and the instrument Transformation matrix. Using ***T*** from a Vector provided above and referring to Figure 4, we see the **X** component is predominantly measured by b_1 with nearly equal contributions from b_2 and b_3. This makes sense because the instrument's **XYZ** coordinate system is aligned with **X** pointing along one of the receiver arms. Beams 2 and 3 are at some angle *α* to the **X**-axis and measure a component of **X** proportional to *cos(α)*.

The sign convention for beam velocities is with flow towards the receiver is positive. The situation is slightly more complicated for bistatic systems like the Vector and Vectrino, where beam velocities are actually measured along the bistatic axis (NortekAS 2005), but the convention is the same. For the **Y** component, b_1 contributes zero (or very near zero) because the **Y** component is perpendicular to the beam (refer to the center illustration of Figure 4). There is no motion towards or away from the transducer to generate a Doppler shift in this case. Finally, the **Z** component is an equal combination of all three beams since the **Z**-axis is aligned with the central transducer and each beam is at the same angle to the **Z**-axis.

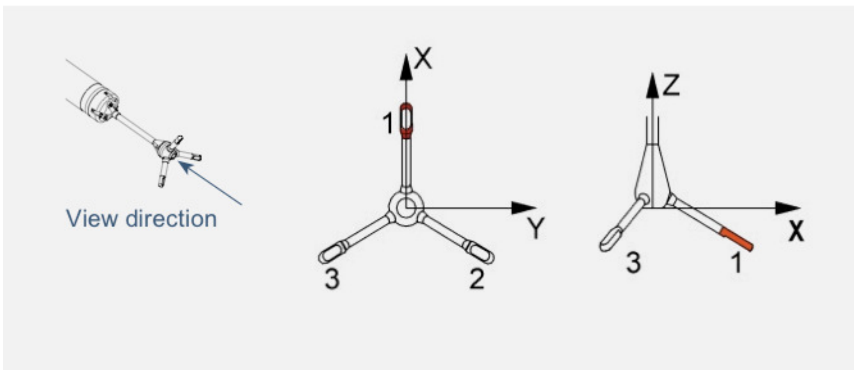

Figure 4. The Vector **XYZ** coordinate system and beam numbering as defined relative to the probe head. Note a positive **X** velocity is defined as flow in the direction Beam 1 is pointing and a positive **Z** velocity is defined as flow into the probe.

Based on the above, the basic workings of the Transformation matrix should be understood.

Returning to the problem of phase wrapping discussed in the section **Phase Wrapping, Ambiguities, and Solutions** and the example presented in Figure 2, we can discover why the **X** component actually phase wrapped even though the reported velocity range indicates it should not have.

Using the appropriate Transformation matrix to convert our data from Figure 2 to beam coordinates ($b_i = \boldsymbol{T}^{-1} u_i$ where $\boldsymbol{T}^{-1}$ represents the inverse of $\boldsymbol{T}$) yields the beam velocity traces seen in Figure 5. The phase wrapping actually occurs because the beam ambiguity velocity is exceeded in one or both of the beams. Vertical and beam ambiguity velocities are very close because of the probe head geometry. The vertical ambiguity velocity reported by the instrument is therefore essentially the beam ambiguity velocity, in this case *23 cm/s*, and we can use this information to correct the phase wrapping in beam coordinates, then transform back to **XYZ** or **ENU** coordinates as needed.

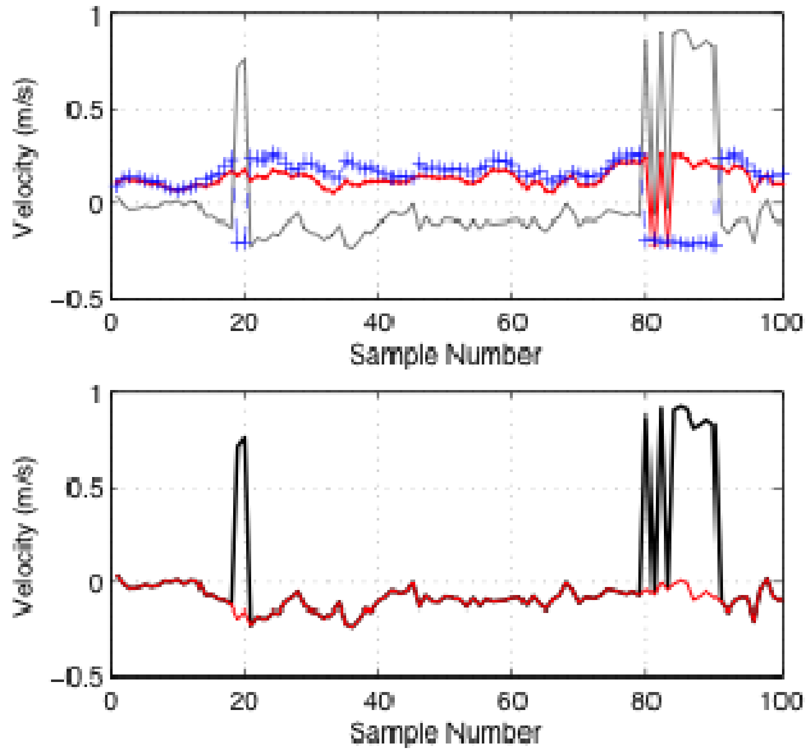

Figure 5. (a) The example phase wrap from Figure 2 as originally plotted (–), along with the two beam velocities (–•–) and (–+–) utilized in the transformation from **beam** to **XYZ** velocities. The two beam velocities are seen to wrap individually causing the phase wrapping observed in the original **X** velocity. (b) Correcting the beam velocities and transforming back to **XYZ** components corrects the original velocity (–) trace so no phase wrapping occurs (–).

The two data quality indicators normally associated with acoustic Doppler data, correlation and the signal to noise ratio (**SNR**), are reported for the beam velocity data. Discarding a measurement due to low correlation (or low **SNR**, or low **Amplitude** which is used to calculate **SNR**) should take into consideration the transformed velocities the low data quality indicator affects. For a three beam system, it is often simplest to discard all three velocities if working in XYZ or ENU coordinate systems and record length permits. The four beam configuration of the Vectrino allows only two components to be affected by a single beam wrapping, while data from the second pair of beams will be unaffected.

For the HR Aquadopp Profiler (and all diverging beam, monostatic profilers), when using **XYZ** or **ENU** coordinate systems, the assumption of horizontally homogenous flow is a requirement to avoid measurement bias. As the beams diverge, the horizontal distance between beams increases. If the flow is not homogenous, then the velocity reported will not be representative of the actual flow and generally biased towards zero because **XYZ** and **ENU** velocities are a spatial average of the three beams.

A final note on coordinate transforms regards any loss of information when transforming between the various systems. Coordinate transforms between the

XYZ and **beam** coordinates can be accomplished with no loss of information because only the instrument's Transformation matrix is involved. When converting to Earth normal coordinates, the instrument compass update rate sets the rate at which coordinate transforms are performed. A typical value for this rate is *1 Hz*, meaning the transform matrix is updated with pitch, roll and heading information every second. If the data rate is *4 Hz*, this means the four samples in each second share the same transformation. If onboard averaging is performed and the instrument is moving during the average interval, it is not possible to recover valid **XYZ** data from an **ENU** average velocity. It is not recommended to collect internally averaged beam or **XYZ** velocity data because of bias due to a moving instrument.

VII. Practical Considerations for HR Aquadopp Profilers

HR Aquadopp Profiler deployment planning involves balancing multiple factors when setting up the profile parameters. The depth cell size, profile length, pulse distance, sample rate, and distance to a boundary (if applicable) will all need to be considered to achieve the highest quality data for a given deployment.

A useful parameter when planning a HR Aquadopp Profiler deployment is the velocity-range product. This is a number with dimensions of L^2/T (length squared over time). As a guideline when planning a deployment for the HR Aquadopp Profiler, this number should not exceed $0.5\ m^2/s$ for the *2 MHz* system and $1.0\ m^2/s$ for the *1 MHz* system. If EVR is used with a *2 MHz* system, the product should not exceed $0.9\ m^2/s$. For example, if you require a profile range of *1.0 m*, then the maximum horizontal current velocity should not exceed *0.5 m/s* (velocity-range product = $0.5\ m^2/s$).

This parameter is simply a way of encapsulating a few of the tradeoffs mentioned above, and primarily deals with the relationship between profile length, pulse distance, and the ambiguity velocity. By staying below this value, the instrument is far more likely to measure good quality data, but it is only a rule of thumb and not a guarantee.

The HR Aquadopp Profiler can measure with a fast sample rate and large measurement cell size, or a slower sample rate and smaller measurement cell size, but not a fast sample rate and small measurement cell size. Fast and slow are of course somewhat relative, but the smallest measurement cell size will not permit measuring at the highest sample rate and vice versa. The HR Aquadopp Profiler has a maximum of *127* measurement cells to divide a profile into and a minimum measurement cell size of *7 mm* at *2 MHz* and *20 mm* at *1 MHz*.

The pulse separation is closely tied to the profile length and distance to the boundary in most deployments. Because pulse coherent processing utilizes a pair of pulses, there is a potential for interference if the two pulses are generating echoes of equal intensity. The velocity profile will have holes (regions of bad data) in regions where interference occurs (Figure 6).

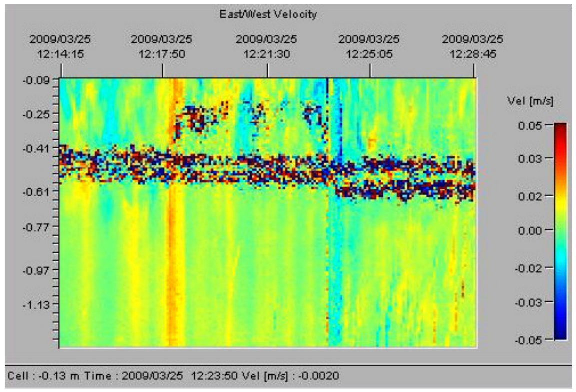

Figure 6. An example of pulse interference during an upward looking deployment of an HR Profiler in a lake.

The following few paragraphs deal with the three common deployment scenarios for an HR Profiler as outlined in the software's Deployment Planning help section, accessed via **Help:Help Topics** menu item and then selecting **Deployment Planning** from the topic list. For reference, the relevant section of the help file is reproduced in the **Appendix**.

When the instrument is pointed towards the bottom or a solid boundary that is not the free surface, the pulse distance is set to slightly larger (*0.1 m*) than the distance to the boundary to keep the pulses from interfering. This is applicable out to about *3 m*, beyond which pulse interference will generally not be an issue for standard pulse coherent setups. If EVR is used, there will be an additional pulse in the water with an automatically set pulse separation of *1/3* the distance used for the main pulse pair. If the EVR pulse separation is less than the distance to the boundary, pulse interference is likely to occur.

If the instrument is pointed towards the free surface and the distance to the free surface is more than twice the desired profile range, the pulse distance can be set according to the desired velocity range (this is the **Up-looking, deep water** option of the Deployment Planning dialog). If the distance to the surface is closer than twice the desired profile range, it can be difficult to avoid pulse interference when trying to profile the full water column.

As an example, consider a deployment in *2 m* of water with the HR Profiler mounted up-looking on a frame on the bottom. The distance to the surface is approximately *2 m* (there’s a bit of offset because of the frame, but we will neglect that right now) and we want to measure the entire water column. The standard setup (i.e. the **Up-looking, shallow water** deployment option) will treat this conservatively and will set the HR Profiler to collect measurements in the lower half of the water column. This is because the echo from the surface is generally very strong and pulse interference will almost certainly occur when the first pulse hits the surface.

In order to capture the entire water column, there is unfortunately no simple rule for setting up the instrument. Test deployments (preferably cabled so parameters can be changed on the fly and multiple setups tested) are the easiest means to identify a working solution. Treating this situation like the down looking setup is a good starting point to work from, but tuning pulse distance will be needed to reduce pulse interference. A changing surface state such as surface waves or tides will make finding a working solution more difficult because the distance to boundary is changing. With a changing water surface elevation, the possibility of pulse interference is more likely. There is likely no setup that will eliminate pulse interference for this type of deployment.

For a final word on pulse distance, recall the earlier discussion of ambiguous velocities and the relationship between pulse distance and velocity range. As the profile distance increases, the pulse distance will also generally increase as outlined above. This results in a smaller maximum unambiguous velocity. Unless the instrument is in deep water (i.e. low energy environment), EVR will need to be used to eliminate phase wrapping caused by the lower ambiguity velocity.

VIII. Practical Considerations for Velocimeters

Other than sample rate, the most common parameter changed on an acoustic velocimeter is the **Nominal Velocity Range**. Setting this to an appropriate value for the flow being measured is the most important instrument parameter in determining data quality. Too large a velocity range will result in very noisy data because the detected phase shift is very small relative to π or the ambiguity velocity. Too low a range will result in de-correlation of the return signals or phase wrapping. The appropriate **Nominal Velocity Range** will generate good quality data minimizing data quality problems. Other factors, such as low **SNR** and high shear in the sample volume, will also affect data quality and need to be evaluated on a case by case basis.

The Vector and Vectrino are pulse coherent systems, and as such, they are also susceptible to pulse interference when measuring near boundaries. Pulse interference for acoustic velocimeters is called a “weak spot” and will show in data as both low SNR and correlation values, as well as noisy velocity traces. Table 1 summarizes the distances where weak spots occur for the Vector and Vectrino indexed to the **Nominal Velocity Range** setting. The cause is the same as discussed for the HR Aquadopp Profiler and the solution is fairly similar, but far easier to carry out. Changing to the next higher or lower velocity range as appropriate will eliminate the problem. Alternatively, moving the instrument (measurement volume) up or down away from the boundary by just a few centimeters can reduce the weak spot effects. Note that the distances to boundaries specified are approximate and will depend on the speed of sound.

Velocity Range (m/s)	Vector (m)	Vectrino (m)
0.01	3.12	
0.01		0.38, 0.75
0.10	0.46	0.23, 0.45
0.30	0.20	0.10, 0.23
1.00	0.08, 0.20	0.05, 0.12
2.00	0.05, 0.09	
2.50		0.03, 0.10
4.00	0.03, 0.06	0.02,0.05
7.00	0.04	

Table 1. Weak spots listed as the distance from Sample Volume to boundary for the Vector and Vectrino. If a cell in the table is blank, the Nominal Velocity Range corresponding to that row is not available for the instrument in question. If two values are listed both distances are potential weak spot locations, this does not indicate a range. Be aware the weak spot location is dependent on the speed of sound and the boundary surface, so the values given are only estimates and weak spots may be encountered a centimeter or more away from these values.

IX. Final Comments

Pulse coherent systems are extremely powerful tools for flow measurement. They are seemingly simple systems but require consideration of many different parameters to produce the highest quality data. The biggest key to their successful use is an understanding of the basic concepts of their operation and the potential problems that can occur when deployed. Experience with the systems is an important factor as well, and the value of test deployments cannot be overemphasized.

The Nortek Forum (www.nortek-as.com/en/knowledge-center/forum) is an invaluable resource for both new and experienced users. Many of the topics discussed in this primer originated from forum posts and the reader is encouraged to utilize them for discussion, further reading, and suggestions on improvements we can make to this document.

X. Appendix

To assist in configuring the HR Aquadopp Profiler, the standard software menu encourages the user to choose between three common mounting scenarios. The software will then automatically select some of the configuration parameters in what we believe is the best possible way. If none of these scenarios properly describes the measurement situation, the user must manually configure the profiler using the advanced menu.

The standard scenarios are:

1) System oriented downward and mounted at a know distance above the bottom.
If practical, this is normally the easiest way to get good data from a HR Aquadopp Profiler. The software will use the distance entered as the key parameter and the spacing between the acoustic pulses is set to be slightly larger than the distance to the bottom. Because the strong bottom echo from the first pulse reaches the transducer right after the second pulses is transmitted, the acoustic interference does not affect the velocity close to the bottom. Also, the first pulse tends to completely die out once it hits the bottom and the instrument can record the echo from the second pulse as it propagates toward the bottom without the least bit of interference from the first pulse. The end result is very clean data and a clear view of the bottom boundary layer.

If the distance to the bottom is set to be smaller than what it actually is during the deployment, the second pulse will be transmitted too early. As a consequence, the profiler will not collect data close to the bottom.

If the distance to the bottom is set to be larger than what it actually is during the deployment, the second pulse will be transmitted too late. The consequence is that data will be lost in a band close to the instrument.

Normally, the data close to the bottom is more important than the data close to the profiler so if the distance is not precisely known, it is better to err on the side of overestimating the distance to the bottom.

If the bottom contains acoustically reflecting material of different size and shape (for example, large rocks, coral, and some types of plants), the bottom will be acoustically ”wider” than a smooth bottom consisting of materials like clay, silt, or sand. This generates results where velocity data close to the instrument is lost. In extreme cases the whole velocity profile can be contaminated especially if the distance to the bottom is short.

2) System oriented upward toward the surface, deep water.

A practical definition here of “deep water” is a little more than twice the desired profiling range. If you choose this configuration the distance between the pulses is set to be a little more than the requested profiling range.

In this situation pulse interference is rarely a problem for high-frequency systems (>1 MHz). The exception is the case where strong acoustic scatters congregate just beyond the profiling range. For example, a fish swimming 1.5 m above the bottom could give interference in the velocity profile if the profiling range is set to 1 m. The interference will show up as an outlier in the data collected at a range of 0.5m (roughly). Since the amplitude data for the HR system is normally recorded while registering the echo from pulse number one, the source of the interference cannot easily be identified.

For low frequency systems, the echo from pulse number 1 dies out more slowly (the acoustic water absorption is lower) and pulse-to-pulse interference can be generated by zooplankton layers in the water column. To alleviate this situation the HR Aquadopp Profiler allows for the possibility of differentiating the transmit power (advanced menu).

3) System oriented upward toward the surface, shallow water.
Shallow water in this case means we have to worry about acoustic interference from the surface echo. Intuitively it may seem this situation is similar to the downward looking scenario (close to the bottom), but two phenomena make the surface acoustically different from the bottom:

- The echo does not die out when it hits the surface.
- The position of the surface can vary over time (tides or waves).

The software planning menu takes a conservative approach to this situation and sets the profiling range to be a little less than half the distance from the instrument to the surface. This ensures it is possible to listen to the echo from both pulses without interference. However, it is only possible to measure the lower part of the water column and data will be lost toward the end of the profile if there is significant surface wave activity. A more aggressive approach in this situation would be to pretend this case is similar to the downward oriented scenario, however, that approach would give high quality data only when the surface is very smooth. If there is significant wave activity the velocity profile can break down completely. Our recommendation is that alternative instrument configurations are considered only after experience has been gained about the exact situation at the deployment site (i.e. test deployments).

XI. References

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