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ACOUSTICAL DOPPLER VELOCIMETER (ADV): SAMPLING VOLUME SIZE AND VELOCITY ACCURACY

1. Introduction

The SonTek ADV is a single point, high resolution Doppler current meter which provides 3-D velocity measurements in a remotely sampled volume. The ADV is a bistatic Doppler current meter. The term bistatic refers to the fact that the ADV uses separate acoustic transducers to transmit and receive sound energy. The ADV transmitter generates sound with most of the energy concentrated in a tight cylindrical volume, while the receivers are the most sensitive to sound coming from a slightly broader angular range (Figure 1). The transducers are mounted such that their beams intersect over a volume located some distance away, called *sampling volume*. This document presents a basic description of the effects of the finite sampling volume on the accuracy of the velocity measurements.

2. Factors Determining Sampling Volume Size

Our considerable engineering efforts allowed us to produce transducers which have very narrow beams. The transmitter beam pattern can be approximated as a cylinder the size of the transmit ceramic (diameter of 4 mm for the 16-MHz MicroADV, 6 mm for the 10-MHz ADV and 12 mm for the 5-MHz ADV Ocean probe). Vertical extent of the sampling volume is defined by the convolution of the transmitted acoustic pulse with the receive window over which the return signal is sampled (assuming that the transmitter axis is oriented vertically, see schematic in Figure 1). Therefore, the size of the ADV sampling volume is mainly determined by the two factors: the lengths of the transmitted pulse and receive window (Figure 1).

Both of these parameters are precisely controlled by the ADV software (within the limits of the transducer bandwidth). In standard configuration the total height of the sampling volume is 4.5 for the 16-MHz MicroADV, 7.2 mm for the 10 MHz ADV and 14.4 mm for the 5 MHz ADV Ocean probe. The vertical edges of the sampling volume can be considered defined to ± 0.3 mm, ± 0.5 mm and ± 1.0 mm for the MicroADV, the ADV, and the ocean prove respectively. Since the pulse length and the receive window are controlled by the ADV software, the height of the sampling volume can be reduced by implementing simple changes in the data acquisition software.

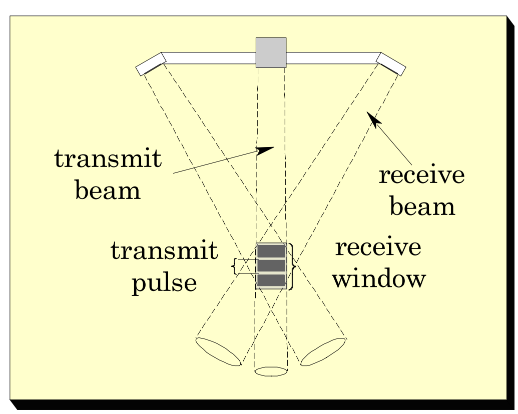

Figure 1: Sampling volume geometry. The sampling volume is cylinder defined by the intersection of the conical receiver beams with an approximately cylindrical transmitter beam.

<u>Sampling volume location.</u> Note, that when the ADV reports location of the sampling volume all the measurements refer to the center of the sampling volume (Figure 2). For example, if the 16 MHz ADV shows the sampling volume to be located 2.0 cm from the boundary, the leading

edge of the sampling volume will be (2.0 cm - 0.5 * (9 mm)) = ~1.5 cm from the boundary.

3. Sampling Volume and Velocity Accuracy

Although velocities measured by the ADV are derived from the phase, the amplitude (or signal strength) of the received signal is also important for accurate velocity measurements. The strength of the signal return depends on the amount and type of particulate matter in the water inside the *sampling volume*. If the water is too clear, the returned signal may not be stronger than the ambient electronics noise level thus reducing the accuracy of the velocity measurements. As signal-to-noise ratio (SNR) decreases, the variance of the velocity measurements increases.

Smaller sampling volume would hence result in a weaker signal return (for the same concentration of the scatterers). In addition to the smaller signal amplitude, fewer scatterers mean increased velocity variance. For example, consider backscatter coming from two sampling volumes $V_1=V$ and $V_2=2\times V$ containing N and $2\times N$ scatterers respectively (provided the concentration of particles is the same). Let assume that all particles move randomly with a velocity variance σ_v. Doppler velocity estimate from the volume V_1 is then an average over twice as many particles as that from the volume V_2, which leads to a smaller velocity variance.

Another consideration for choosing the size of the sampling volume is the size of the turbulence features one needs to resolve. Smaller volumes (shorter pulses) require faster sampling in order to avoid under-sampling of the flow .

3.1. Reduced Sampling Volume

As described above, the across-beam extent of the sampling volume is defined by the transmitter beam pattern and the along-beam extent by the convolution of the transmitted pulse with the receive window. Both the pulse length T_p and the receive window size T_r are controlled by the ADV software. Thus, with software modifications, we can easily change the along-beam extent of the sampling volume. However the effect of changing T_p and T_r on the volume size is not the same as described below. This section describes the changes that can be made, and the tradeoffs associated with them.

In order to reduce altering the along-beam extent of the sampling volume, we can decrease T_p and or T_r or both. Suppose we reduce the length of the transmitted pulse by a factor of 3. This consequently reduces the amount of the transmitted acoustical energy by the same amount and produces a 6-dB loss in the signal-to-noise ratio. However, if wee keep T_r constant the sampling volume stays the same! Hence, in order to achieve reduction of the sampling volume the length of the receive window has to be reduced as well.

There are two major effects associated with reducing the size of the sampling volume. First, by reducing the receive window, we reduce the number of points averaged for velocity calculations and increase the temporal variability (noise) of the measurements. Reducing the receive window to its minimum value increases the noise in individual measurements by a factor of about 2. Increased single ping velocity variance may require longer time averages which in turn limits the time-resolution of the measurements.

The second effect occurs as a result of shrinking the size of the transmit pulse; using a shorter pulse reduces the strength of the return signal from the water. Reducing the length of the acoustic pulse to its minimum level reduces the instrument's SNR by about 6 dB. This is not a concern in applications where signal strength is high (SNR > 15 dB), but it can be a factor in relatively clear water. Assuming that the SNR ratio remains sufficiently high, reducing the length of the transmit pulse has no effect on the noise in velocity measurements. Therefore one needs to assess carefully the implications of the reduced sampling volume before making changes.

There are other factors which may need to be considered when assessing the effects of the sampling volume size on the velocity measurements: scatterers residence time, dominant turbulence scales and. However the details of these are beyond the scope of this document.

3.2. Pre-Defined Settings

In standard configuration the 10-MHz ADV transmits a 3.6-mm long pulse and samples over a 7.2-mm long window, which gives a 7.2-mm volume length L (evaluated at half-power). The distance D from the center point of the volume to the leading edge is 7.2 mm which may affect operations near the boundary (Figure 2). (Because of the cylindrical transmitter beam geometry we define insonified volume in units of length). Note, that all the corresponding parameters for the 16-MHz MicroADV are smaller by a factor of 1.6, reflecting the difference in acoustic frequency between the two systems.

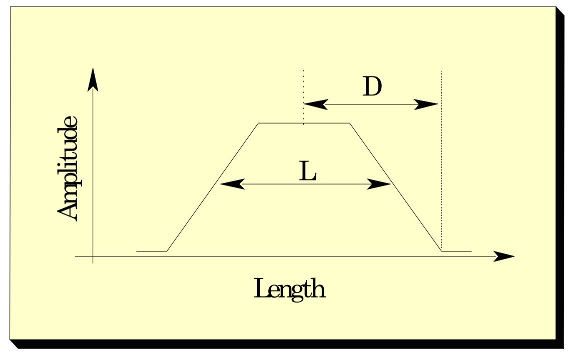

Figure 2: Sampling volume: schematic of pulse timing. L is the pulse width measured at half-power. D is the distance from the leading edge of the pulse to its center.

The standard mode was designed to provide robust performance for most applications. However due to customer demands we are now offering three additional modes, hereinafter referred to as short, median and long. The summary of the timing parameters for all modes is given in Table 1 for both the 10-MHz ADV and 16-MHz MicroADV.

In the *short* mode the ADV achieves the smallest sampling volume of 1.2-mm length. However this mode is subjected to both signal strength and spatial averaging limitations as described above. In the *median* and *long* modes the ADV transmits the standard-length pulse and uses shorter sampling windows: 1.2 and 4.8 mm respectively. Although measurements taken in these modes are not subjected to the SNR decrease they do suffer from the reduced spatial averaging and should be used cautiously.

	ADV					**MicroADV**			
Mode	T_p	T_r [mm]	L [mm]	D [mm]		T_p	T_r [mm]	L [mm]	D [mm]
Standard	3.6	7.2	7.2	7.2		2.25	4.5	4.5	4.5
Short	1.2	1.2	1.2	1.2		0.75	0.75	0.75	0.75
Median	3.6	1.2	3.6	4.2		2.25	0.75	2.25	2.63
Long	3.6	4.8	4.8	8.4		2.25	3.0	3	5.25

Table 1: ADV and MicroADV timing summary.