# AT, an Acoustic Transmissometer

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*Abstract*-**The combination of attenuation measurement with acoustic travel-time current measurement along a common path has produced a new acoustic sensor of suspended particles, the Acoustic Transmissometer (AT). The AT has been deployed in the OASIS experiment, a particle-measuring experiment to determine suspended particle properties resulting from turbulence and current near the seabed. Acoustic transmission at 1.8 MHz, as used in the AT, is a useful complement to optical backscatter or light transmission for assessing particle properties since acoustic transmission loss is the result of acoustic absorption and/or scattering, which depends on particle mass rather than particle area and diameter, as optical measurements do.**

## I. INTRODUCTION

Sediment transport involves erosion, suspension, advection, and deposition of particles. Fluid stress in the turbulent benthic boundary layer is the agent for erosion. This occurs when the stress at a point on the bottom exceeds the strength of the sediment. The instantaneous stress is intermittent and spatially inhomogeneous, making actual measurements difficult. However statistical averages can represent the boundary layer stress, generally represented as Reynolds stress or as a drag law based upon roughness and velocity of the current. Waves add another degree of complexity since the waves are both intermittent and responsible for critical stress in a very thin wave boundary layer. However, whatever forces cause erosion the material is soon broken into suspended sediment that is distributed through a boundary layer where it can be kept in suspension for a longer time than a clump that might have been torn from the bottom but that may soon resettle. The suspended particles also settle at a rate that depends on their density and size and to a lesser degree their shape. But even these quantities are not stationary. Particles bump together and sometimes stick, becoming larger but also in many cases loose amalgamations of smaller pieces. Turbulence subjects amalgamations to stress that can break them apart and change both their size and effective density. This in turn determines the particle settling rates and eventually sediment deposition. The changing nature of the particles, their density and size and perhaps shape is a principal task of project OASIS.

## II. INSTRUMENTATION

### A. *MAVS AT Sensor*

The sensor to measure acoustic transmission is based on the Modular Acoustic Velocity Sensor (MAVS) [1-4], which makes nearly instantaneous measurements of velocity by a differential travel-time technique. In this technique, a short burst of sound is transmitted simultaneously from a pair of transducers and the sound travels in opposite directions between them, arriving first at the downstream transducer. A trigger on each received burst detects the 14th negative-going zero crossing of the signal from the receiving transducer at a voltage comparator. The reason that a zero crossing is used is that this is not sensitive to amplitude, the very thing that the Acoustic Transmissometer seeks to determine. The reason for using the 14th cycle is that the transducers employed to transmit the 1.8 MHz sound have a Q of about 5, meaning that the amplitude has built to 1/e of the steady state amplitude on the 5th cycle. Fifteen cycles of sound are transmitted, allowing the amplitude of the 15th cycle, AT, to be:

$$AT = A * \left(1 - e^{-15/5}\right)$$
$$AT = 0.95A$$

where A is the steady state amplitude.

The technique for a simple determination of the received amplitude in MAVS is the detection of the 15th positive cycle of the received waveform. A small part of the signal delivered through a DC blocking capacitor to the input of the voltage comparator is diverted to charge a peak detecting capacitor through a Shottky diode and a current limiting resistor. The capacitor is followed by an FET input op amp. The output impedance of the op amp is low enough to be a suitable driver for the A/D converter of the single-board computer that is the controller of MAVS. An existing analog channel in the A/D is used to acquire the peak value on the capacitor. In the MAVS differential travel-time measurement an integrating capacitor is reset between bursts with an FET that shorts the capacitor out. The same control signal is used to short out the peak sampling capacitor of the amplitude measuring circuit with a similar FET.

These additions to the MAVS do not affect the velocity measurement or the noise of the velocity measurement. The sensitivity of the acoustic transmission circuit to changes in sediment concentration is not great so to improve the signal to noise ratio, where the noise is the variability of the unattenuated transmission amplitude between pulses, many determinations are averaged for each measurement. Sixty-four samples are averaged for each acoustic transmission determination that is stored with a single measurement of velocity. Although this requires more measurements per sample, the power increase is acceptable and the time required does not impact a sample rate of 5 samples per second.

Observations of AT compared to simultaneous observations of turbidity by optical backscatter in the first OASIS experiment of September 2007 showed high correlation but were not identical. The indication is that the AT is sensitive enough to see the variations in acoustic transmission due to changes in particle concentration and can also distinguish particle properties by a difference in response to that of an optical scattering sensor.

### B. *AT Sensitivity and Noise*

Attenuation of 1.8MHz sound over a path of 10 cm due to suspended particles in the path is quite small so sensitivity is an issue for the AT. By contrast, scattering measurements of sound and of light are less demanding since the scattering signal is contrasted to no signal. But the unattenuated acoustic transmission is a large signal compared to nearly as large a signal with attenuation so the sensitivity must be related to the noise in an unattenuated signal. Fig. 1 is a recording at 5Hz of acoustic transmission in arbitrary units, millivolts (mV), for transmission in a container of fresh water. The variations of reading over several minutes are due to the noise inherent in the detection of transmission amplitude. For sections 50 samples long, the standard deviation is indicated along with the reading of amplitude. Both vary.

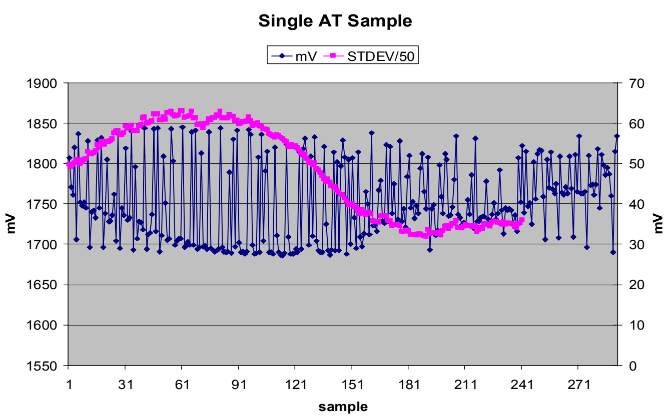


**Fig. 1. Single samples of acoustic amplitude or acoustic transmission. Variations between individual samples are more than 100 mV in some sequential readings. The standard deviation for 50-sample sections is more than 60 mV in some sections although less than 35 mV in other sections.**

*1) Noise Reduction:* Single measurements may have a standard deviation of 40 or 50 mV but by averaging many measurements per sample, the noise due to random Gaussian fluctuations may be reduced proportional to the square root of the number of measurements. Fig. 2 shows this reduction of standard deviation for 64-measurement averaging per sample.

*2) Sensitivity Enhancement:* After the noise has been reduced to the resolution of the digitizer or 1 mV, more sensitivity can be achieved by increasing the gain for each measurement. In actuality, the A/D converter is limited to 12 bits so gain is increased by shifting the 12 bit word two bits

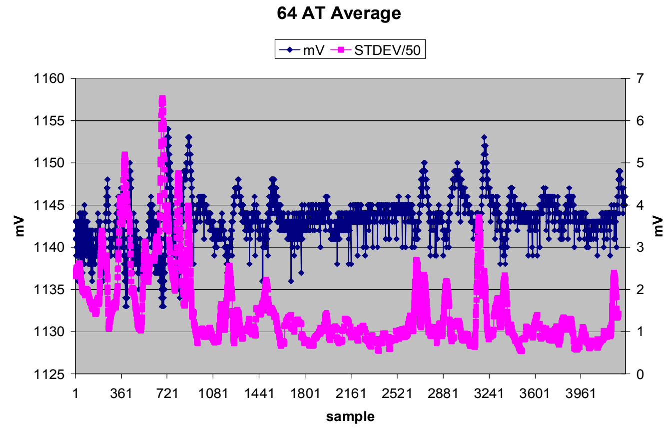


**Fig. 2. Averaging 64 measurements per sample reduces the standard deviation to as good as 1 mV during most of the 13 minutes of sampling shown. There are also episodes where the standard deviation of the sample is more than 6 mV so that there may be need for averaging per sample.**

left or multiplying by 4 before accumulating and later dividing by the number of measurements in the sample for averaging. This is equivalent to dividing the accumulated sample by one quarter of the number of measurements and not scaling each digitization before accumulating. The only danger is overflow of registers where accumulation is accomplished. Fig. 3 is the result of multiplying each measurement by 4 before accumulating. As expected, the standard deviation is four times greater but so is the sensitivity.

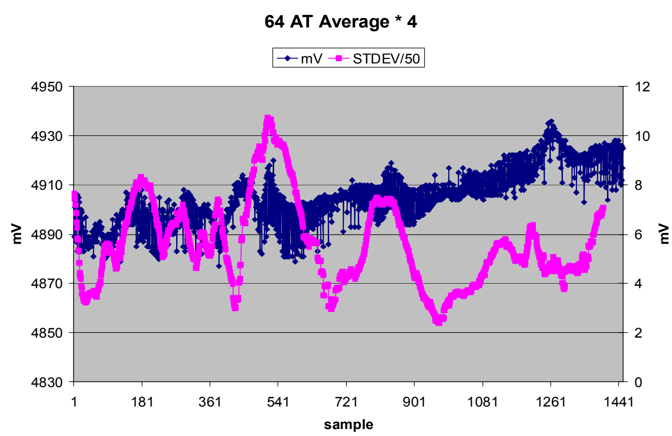


**Fig. 3. Sensitivity can be increased by multiplying each measurement by 4 before accumulating and taking the average of 64 measurements per sample. The standard deviation is also about 4 times as great as the sensitivity.**

*3) Reducing Noise After Enhancement:* Since the standard deviation for the enhanced 64 AT averaged measurements is 4 times the resolution of the sample, it is reasonable to increase the averaging number by a factor of 16 so that the standard deviation will be reduced by the square root of 16 or 4. This is illustrated in Fig. 4.

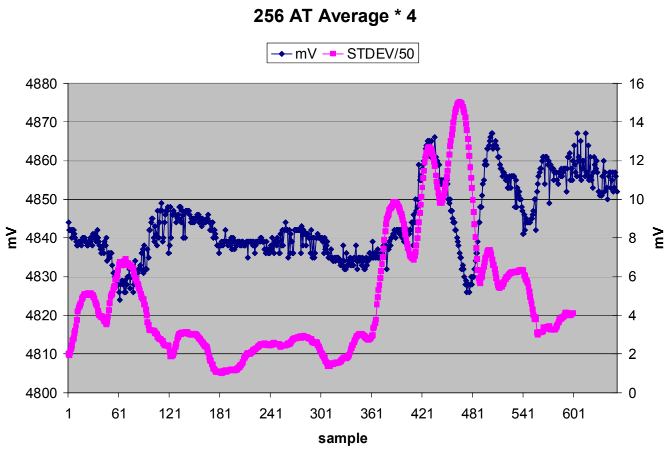


**Fig. 4. Enhanced by a factor of 4 to increase sensitivity and then averaging 256 measurements per sample reduces the standard deviation per sample to at best 1 mV. However there are many other periods in this 10 minute record where 2 mV standard deviation is more common and it can be as great as 15 mV.**

There is more noise in the 256-measurement average than was expected and this may reflect additional noise sources that are not simple Gaussian processes. Fig. 5 shows a run with 512 measurements averaged per sample after being enhanced a factor of four. This demonstrates that an increase in sensitivity by a factor of four is possible. However, while averaging up to 128 measurements can be done at 5 Hz, at 256 measurements the rate is limited to 4 Hz and at 512 measurements the rate is limited to 3 Hz.

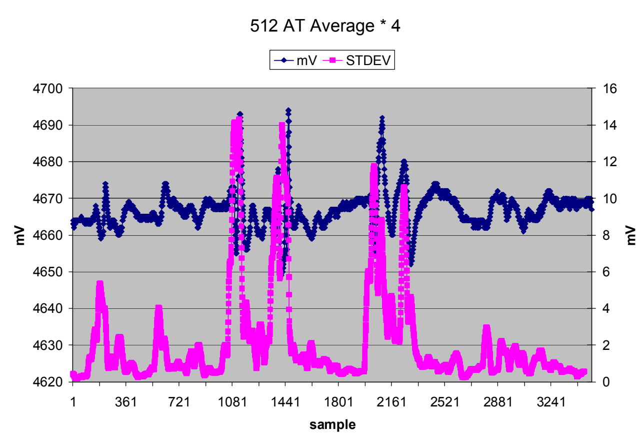


**Fig. 5. The average of 512 measurements per sample with four-fold enhancement of sensitivity displays a standard deviation typically of less than 1 mV. This permits maximum sensitivity.**

*C. Measurement of Amplitude of Transmission*

MAVS measures differential travel times across four acoustic axes to determine 3D current velocity with a resolution of 0.04 cm/s. It is designed to do so without sensitivity to acoustic attenuation as might be caused by bubbles or sediment suspended in the water or by fouling or degradation of the transducers. So it appears that this instrument is singularly ill adapted to measuring acoustic transmission or attenuation of signal due to particles. However, the amplitude instead of the time can be measured to make this determination.

As the acoustic signal transmitted across one of the paths is received by one of the transducers, the signal voltage at 1.8 MHz increases to 95% of the steady state amplitude in 15 cycles, the normally defined measurement moment. So by rectifying the received signal, at the measurement moment, the amplitude can be digitized and is representative of the steady state transmission amplitude. Fig. 6 shows this received signal.

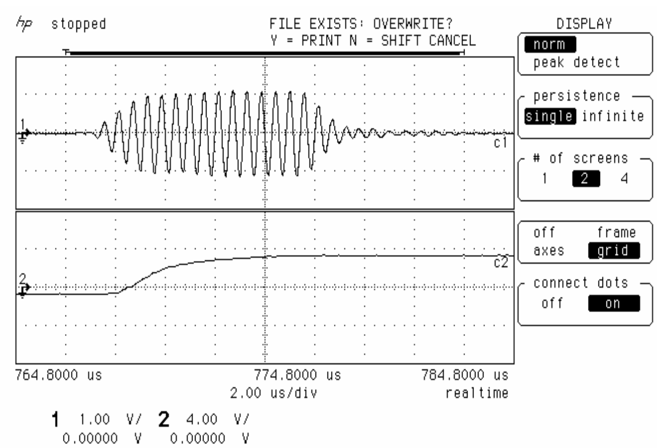


**Fig. 6. The voltage signal from the acoustic pulse that is received on one of the acoustic transducers**

Each acoustic burst has a sequence of 7 digital configurations presented to decoders to set the oscillator on, the transmitter on, the oscillator and transmitter off, the integrating capacitor cleared, three sets of digital pulses to set the integrator capacitor to integrate, and an eighth set of digital control signals is displayed in Fig. 7 that represents the digitization of the analog detected signal level.

During a velocity measurement, a total of 9 bursts of acoustic signal are transmitted over an interval of about 8 ms. The first burst is used to reset counters and discharge the current integrating capacitor that determines the differential time intervals used for velocity measurement. The next set of four pairs of bursts are used to measure the differential travel time along each of the four acoustic axes normally connected and reverse connected, the difference between the two being proportional to the component of velocity along each axis.

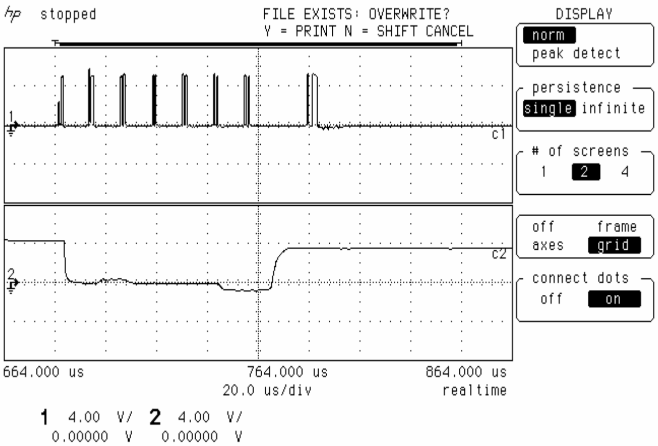


**Fig. 7. The upper trace is the digital configuration clock signal that define how a velocity measurement is made. The seven digital bytes that are output by the seven clock bursts turn the oscillator on, turn the transmitter on, turn oscillator and transmitter off, reset the time integrating capacitor, enable the integrating capacitor for three cycles. The lower trace shows the detector amplitude that begins to ramp up after the seventh digital clock burst. Shortly after reaching the full signal amplitude, an eighth set of clock pulses indicates where the A/D converter is digitizing the detected amplitude.**

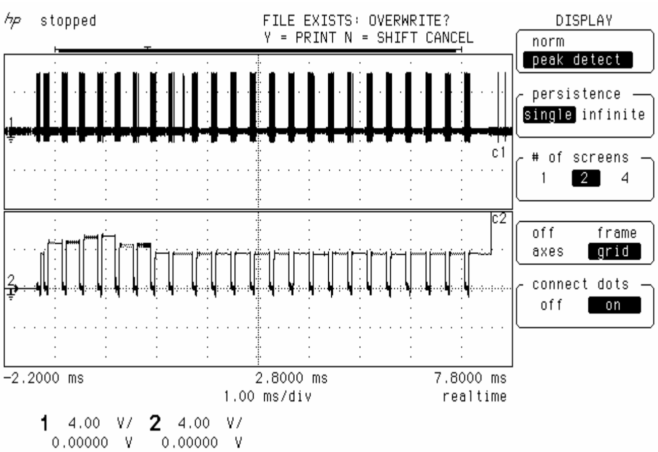


**Fig. 8. After the nine bursts of sets of digital clocks that select each of the acoustic axes for velocity measurements twice, once normal and once reversed plus a preceding burst to reset the integrating capacitor, there are 16 acoustic transmission measurements that are averaged. The lower trace shows the amplitude of the detector.**

Following the set of 9 bursts, succeeding bursts are used for measuring the amplitude of the received burst. Fig. 8 shows a single such acoustic transmission detection. When there are 64 measurements averaged, the trace is as shown in Fig. 9

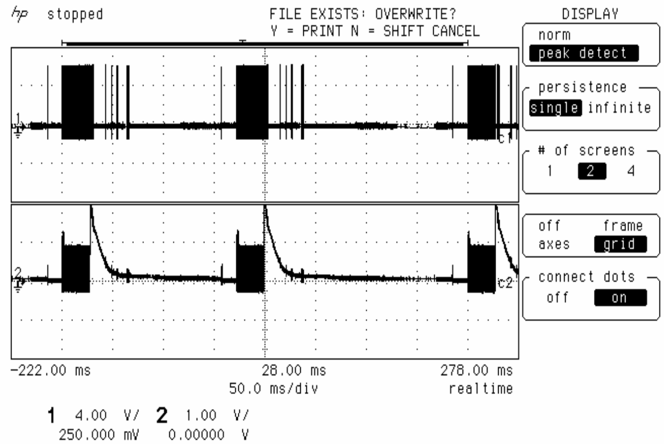


**Fig. 9. When 64 measurements are averaged, the total time taken in measuring is still only one quarter of the time interval at 5 Hz sample rate.**

## III. Field Measurements

The AT MAVS was deployed for two weeks in October 2007 in the OASIS project. Figs. 10-12 show the AT MAVS on the OASIS tripod before deployment. Upon this tripod were placed optical backscatter sensors, optical transmissometers, acoustic Doppler current sensors, the LISST optical particle sizer [5], and the AT MAVS. Deployment was in 12 meters depth south of Martha's Vineyard, MA at the Martha's Vineyard Coastal Observatory [6]. Power and data return were provided by cable from the MVCO 12 meter node. All of the instrumentation was viewed in real time from shore where the data were logged.

Fig. 13 showing data from both one of the optical scattering instruments and from the AT with its readings converted to attenuation is courtesy of Emmanuel Boss, one of the Principal Investigators of OASIS, an ONR funded project. It shows qualitative agreement between the standard optical turbidity measures and the acoustic transmission measurement.

**Fig. 10. AT MAVS mounted on the OASIS tripod before deployment. The two white rings support the acoustic transducers that measure current and acoustic transmission. Other velocity and turbidity sensors are located at the same elevation.**

**Fig. 11. The white rings are the supports for the acoustic transducers that define the measurement path for velocity and acoustic transmission.**

**Fig. 12. The MAVS is supported on the OASIS tripod with its sensor at the same height as optical scattering sensors and an acoustic Doppler velocimeter.**

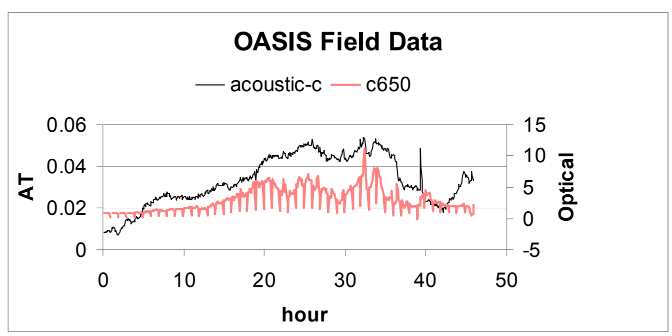


**Fig. 13. Field data from OASIS shows qualitative agreement between the AT measurement of particle attenuation of transmission and optical measurement of the particles.**

## IV. Laboratory Measurements

### D. *Temperature and Salinity Sensitivity*

The Acoustic Transmissometer is sensitive to changes in temperature of fresh water and also to changes in salinity of the water. Fig. 14 is a plot of the reading of the 512 AT average with four fold enhancement of sensitivity of samples of water at varying temperature and at varying salinity. The effect of temperature is possibly due to changes in acoustic transmission in the water at 1.8 MHz but is also likely to result from changes in the acoustic beam at the transducer where the sound enters the water. The same is true for salinity where there is certainly dependence of acoustic attenuation by salt but perhaps of greater import is the change in acoustic impedance and index of refraction at the transducer face. All of these effects are important to remove from apparent changes in transmission due to particles. However, in many cases there are changes in acoustic transmission from particles that are not accompanied by changes in temperature or salinity.

There are phenomena in addition temperature or salinity focusing of the acoustic beam that may be responsible for variations in the readings. The rectification and storing of the peak voltage of the received burst is after all only the largest of 15 cycles in the burst. Variations in the amplitude as detected by the A/D converter is granular and a particular transmission may have a maximum amplitude that is just at the edge of one of the digital bins of the A/D. Then as thermal noise moves it back and forth across the bin, there is a jump of one bit and it may vary with undetectable external influences.

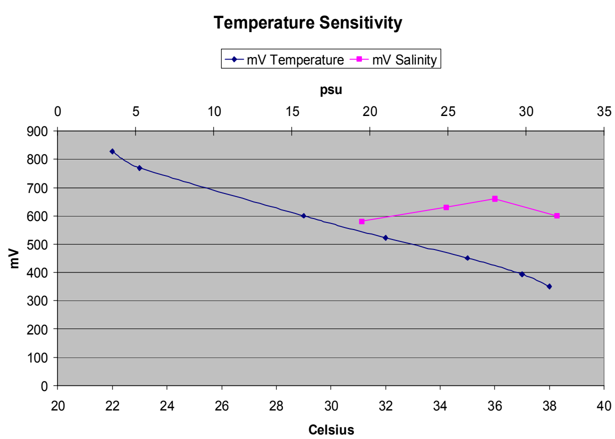


**Fig. 14. Temperature effects the AT measurement as shown by the decrease from 850 mV at 21C to 350 mV at 38C. Salinity also effects sensitivity but in a less marked way. The reading with 32 psu water from Woods Hole Harbor gave a reading of 600 mV at 21C. As the salt water was diluted with fresh, the reading rose to 660 at 28 psu and then dropped to 580 at 20 psu, all at 21C.**

### E. *Further Work*

Sensitivity to particle concentrations of specific composition and structure will be the next study. This will be done at University of Maine in the lab of Emmanuel Boss. Particles will be formed by processes that simulate the formation of marine snow in the sea as well as with well defined targets such as latex spheres and Formazin as used in characterizations of sensitivity of optical sensors of turbidity.


## Acknowledgment

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