Development of an Autonomous, Compact, Broadband Acoustic Backscattering System for Remote Characterization of Zooplankton Variability (PART II)

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LONG-TERM GOALS

The long term goal of this research is to develop autonomous, high-frequency broadband acoustic scattering techniques, appropriate for use on a variety of platforms, including towed, profiled, moored, and mobile platforms that enable the remote characterization of zooplankton distributions on ecologically relevant spatial and temporal scales.

OBJECTIVES

The primary objective of the proposed research is to develop, calibrate, and test an autonomous, compact, low-power, high-frequency broadband acoustic backscattering system for remote characterization of zooplankton distributions. Specific objectives for this proposal include: 1) complete the development of second-generation sonar boards, 2) complete the integration of new transducers with the second-generation boards, 3) address remaining noise concerns, 4) develop real - time data downloading and visualization capabilities, and 5) addition of a 2 MHz sonar board and transducer.

APPROACH

Over the last 40 years, there has been significant research effort directed towards the use of high-frequency narrowband acoustic scattering techniques to remotely investigate the distribution, abundance, and size of zooplankton on multiple spatial and temporal scales (e.g. Holliday and Pieper, 1980, 1995; Pieper et al., 1990; Napp et al., 1993; Wiebe et al., 1996; Benfield et al., 1998; Brierley et al., 1998; Korneliussen and Ona, 2002; Lawson et al., 2004; Mair et al., 2005; Trevorrow et al., 2005; Lavery et al., 2007). Acoustic scattering techniques provide a rapid, high-resolution, synoptic, remote sensing tool to compliment more traditional sampling strategies. In fact, some of the world's largest stocks of zooplankton, such as Antarctic Krill (Nicol and Endo, 1999), as well as large fish stocks, are assessed using single- or multi-frequency narrowband acoustic scattering techniques (Simmonds and

MacLennan, 2005). Yet reducing the ambiguities in the quantitative interpretation of the acoustic returns remains one of the outstanding challenges.

The development of high-frequency broadband acoustic scattering techniques, spanning multiple octaves of bandwidth, may in principle lead to decreases in the ambiguities associated with interpretation of acoustic scattering measurements of zooplankton. The goal is to capitalize on the different characteristic frequency-dependent spectra associated to different scattering sources. The advantages of using broadband versus narrowband acoustic scattering techniques are generally recognized, supported by laboratory measurements of broadband scattering from zooplankton (e.g. Stanton *et al.*, 1998; Roberts and Jaffe, 2008) and micronekton (e.g. Au and Benoit-Bird, 2008). The application of high-frequency broadband acoustic scattering techniques in the field has been limited. The few broadband systems that are available commercially are cabled, relatively bulky, and have a restricted frequency range (e.g. EdgeTech < 600 kHz, Lavery et al., 2010; ScanFish 85-155 kHz, Ross and Lawson, 2009). To the best of our knowledge, the only custom-built high-frequency broadband acoustic scattering system that has been built and successfully used for the purpose of investigating fish and zooplankton is a seven-octave-bandwidth hull-mounted system (Foote et al., 2005). In contrast, lower frequency broadband acoustic scattering systems (1-120 kHz) to remotely characterize fish have been used more prevalently (e.g. Holliday, 1972; Thompson and Love, 1996; Zakharia et al., 1996; Love et al., 2004; Stanton et al., 2010).

In addition, there are no published studies on the development of high-frequency broadband acoustic scattering systems suitable for use on autonomous vehicles, such as gliders and AUVs, which offer advantages in persistence and spatial coverage. Although many autonomous vehicles carry an ADCP, which provides a crude measure of backscatter at a single narrowband frequency, and some AUVs carry single-frequency sidescan sonars (and this technology has been adapted for gliders), the lack of suitable instrumentation has impeded the use of broadband techniques from these platforms.

The autonomous, compact broadband system currently under development at WHOI should be ideally suited for deployment on small mobile platforms (as well as moored, profiling, or towed applications). There are two key issues that have been addressed: miniaturization and bandwidth. The approach taken here is to develop a compact, fully-programmable, low-cost, low-power, autonomous, high-frequency broadband acoustic scattering system by adapting existing technology recently developed at WHOI for a monostatic Doppler sonar module. Key personnel for this project include: Andone Lavery as the PI for this project and who has overall responsibility for the successful development, testing, and calibration of the broadband system. Fred Jaffre is responsible for the “nuts and bolts” of the modifications to the sonar boards, integration of the broadband transducers, software development, and overall system performance.

WORK COMPLETED

A. System development: first-generation system

An autonomous high-frequency broadband acoustic backscattering system has been developed, based on a monostatic Doppler sonar module recently developed at WHOI for turbulence studies by E. Terray and T. Austin with NSF support. The system has the capability of spanning the frequency range from 100 kHz to 24 MHz. The original sonar module was not optimized for measurements of acoustic backscatter, as Doppler shift can be estimated without using the signal amplitude. However, the receiver is linear, and the received signal is digitized at 24 MHz, and both the transmitter and receiver electronics (downstream of the preamplifier) are fully digital. Relatively straightforward modifications were necessary to allow backscattering to be measured. These modified sonar boards (revision 1) constitute the core of the first-generation autonomous broadband acoustic backscattering system. Each rev 1 sonar module has 16 GB of on-board flash memory, and is low-power, using approximately 1.5 Watts. Each sonar board is 1.25 inches in width and 5.25 inches long. A compact underwater housing has been fabricated, measuring 4 inches in diameter and 9 inches in length to house three such boards, depth rated to 500 m. Initial laboratory testing, calibrations and field tests, have been performed with the first-generation WHOI autonomous broadband acoustic scattering system with rev 1 sonar boards.

B. System development: second-generation system

In parallel to the first-generation system development, a second-revision (rev 2) sonar board has also been development. These new rev 2 sonar boards are slightly larger, measuring 2 inches in width and 5.25 inches in length, resulting in the need for a new, slightly larger diameter underwater housing, measuring 5 inches in diameter and 9 inches in length, depth rated to 500 m. Benefits of the rev 2 boards include:

1) 2MB of RAM. The extra memory translates into longer signals, up to 43ms in length, corresponding to 145 times the maximum signal length of 300μs using the rev 1 boards. This capability results in improved signal-to-noise ratios, after pulse compression processing, which are approximately given by the product of the signal duration and bandwidth.
2) USB2.0 for faster data downloading. A USB extender has been added in order to have up to 20 m of data cable. In addition, it is possible to download the data from one SD card while pinging and logging new data on the other SD card.
3) Two 32GB SD cards for memory storage, versus one 16GB SD card. This allows longer deployments as well as real-time data downloading.
4) 4 independent receive channels versus 1 receive channel on the rev1 board. This capability is not currently being capitalized on, but future applications of this may include measurements of the angular dependence of scattering.
5) Embedded sensors (thermometer, accelerometer, input for external pressure sensor and compass).
6) A more robust transmitter with bigger transistors, resulting in more available energy to transmit longer and stronger signals.
7) Four rev 2 sonar boards have been integrated with new broadband transducers (see next section for description).

C. Broadband transducers

Initially, three rev 1 boards were modified and interfaced with three almost octave-bandwidth transducers with center frequencies at 200 kHz (Airmar, approx. 9 degrees beamwidth at center frequency), 500 kHz (Airmar, custom-made, approx. 3 degrees beamwidth at center frequency), and 1 MHz (Panametrics, approx. 3 degrees beamwidth at center frequency). During laboratory and field tests of the first-generation system it became apparent that the 200 kHz BB and 1 MHz BB channels suffered from excessive noise. The three main factors contributing to this noise were 1) the impedance mismatch between the transducers and the Doppler sonar board, which had not been optimized, 2) a poor quality transducer at 1 MHz, and 3) broad beamwidth for the 200 kHz BB transducer.

The 200 kHz BB transducer has been replaced by a custom-built almost-octave-bandwidth 160 kHz broadband transducer (Airmar, approx. 6 degrees beamwidth at center frequency). The 1 MHz BB transducer has been replaced with a custom-built almost-octave-bandwidth 1 MHz broadband transducer (Airmar, approx. 3 degrees beamwidth at center frequency). An additional transducer with center frequency at 2 MHz (Reson TC3021, approx. 2 degrees conical beamwidth at center frequency) has also been integrated into the system. The new transducers have been interfaced (impedance mismatch optimized) with the rev 2 boards and tested in the laboratory and the field.

D. Data analysis and software development

Compressed pulse processing techniques have been applied to the broadband data in order to improve the spatial resolution of the measurements as well as to increase the signal-to-noise ratio (Chu and Stanton, 1998; Stanton and Chu, 2008). Software has been developed to visualize the acoustic data, for performing multiple-standard target calibrations (Atkins *et al.*, 2008), pulse compression processing, and for spectral analysis of the broadband data.

E. System calibration

The first- and second-generation autonomous broadband acoustic scattering systems have been calibrated using a 20mm diameter spherical tungsten carbide standard target, and the second-generation system has also been calibrated with an 8.9mm standard target, which is more appropriate for the very high frequency transducers as it has less structure in the frequency domain. Power linearity on both the transmit and receive signals has been verified.

F. Field demonstration

The basic function of the first-generation WHOI broadband backscattering system using the rev 1 boards has been tested in the field with the original transducers. The system was deployed from the RV Tioga in the Connecticut River in November 2008, with coincident measurements of turbulence and salinity microstructure. This system was deployed from Rocky Geyer's MAST (Measurement Array for Sensing Turbulence) in a completely autonomous mode of operation. This field test was heavily leveraged on an existing ONR-funded project. Similarly, the second generation system was tested in the field with the new transducers, again in the CT River, in November 2009, with coincident measurements of turbulence and salinity microstructure, and zooplankton and sediment sampling.

RESULTS

A first-generation autonomous, compact, high-frequency broadband acoustic scattering system has been developed that employs three broadband transducers spanning the frequency range from 150 kHz to 1250 kHz with some gaps. This system has been calibrated using standard target techniques. Reasonable agreement between the theoretical modal series solution for an elastic sphere and the measured broadband scattering has been obtained in the laboratory (see results in the 2009 progress report). The basic functionality of the system has been demonstrated in the field. It was found that the 500 kHz BB channel of the first-generation system provided good measurements of acoustic backscattering which were highly correlated to salinity microstructure in the CT River. Measurements of acoustic scattering from salinity microstructure using the first-generation WHOI broadband backscattering system agreed favorably to the broadband measurements obtained with the commercial Edgetech system.

High noise levels on two channels of the first-generation system have resulted in the development of a second-generation broadband system as well as the integration of new custom-built broadband transducers, spanning the expanded frequency range from 120 kHz to 2.4 MHz, with some gaps. This second-generation system has been tested and calibrated (Figure 1) in the laboratory, and the performance of the second-generation system has been tested in the field (Figure 2), in the CT River in November 2009, by collecting coincident acoustic scattering data, direct microstructure data, and zooplankton and sediment data. The second-generation system deployed in 2009 outperformed the first-generation system deployed in 2008 in a few key aspects, including improved noise characteristics (achieved through a combination of improvements described above), the ability to visualize data real-time, and increased persistence. Unfortunately, the 2 MHz transducer did not perform well, and a custom-made Airmar transducer is being developed to replace it. Future work must include the testing, calibration, and assessment of this 2 MHz transducer (the sonar board has already been developed and is part of the system).

IMPACT/APPLICATIONS

A compact, autonomous, high-frequency broadband acoustic backscattering system suitable for use on small mobile platforms, has been developed, providing a new and unique capability for the acoustic sensing of zooplankton distributions. This system:

1. Provides the zooplankton bioacoustics community with access to a low-cost, autonomous, compact, broadband, high-frequency, acoustic backscattering system that has the potential to significantly reduce the well-known ambiguities in estimating biologically meaningful parameters associated to the interpretation of traditional single-frequency acoustic backscattering measurements. (A single sonar module, including rev 2 sonar board and with transducer, can be fabricated for approximately $2k.)
2. Has the potential to significantly enhance the capabilities of gliders and small AUVs for mapping zooplankton distributions on ecologically relevant scales, with, for example, direct application to mapping the prey field of zooplanktivorous whales. In addition, this system could easily be used as a surface or bottom tracking device. The second-generation system is currently being integrated onto a REMUS-100, with a small internal WHOI grant. This integration should be complete by November 2010.

RELATED PROJECTS

"Continued Analysis of High-Frequency Broadband Acoustic Scattering from Non-Linear Internal Waves during SW06," Lavery, A.C. Funded by ONR Ocean Acoustics. Analysis of data collected with a cabled, high-frequency (150-600 kHz) broadband acoustic scattering system developed by Edgetech during SW06.

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STUDENTS ASSOCIATED TO THIS PROJECT

Wu-Jung Lee, Ph.D. Student, WHOI/MIT Joint Program, field participation.
Jon Fincke, WHOI Summer Student Fellow, University of New Hampshire, system calibration.

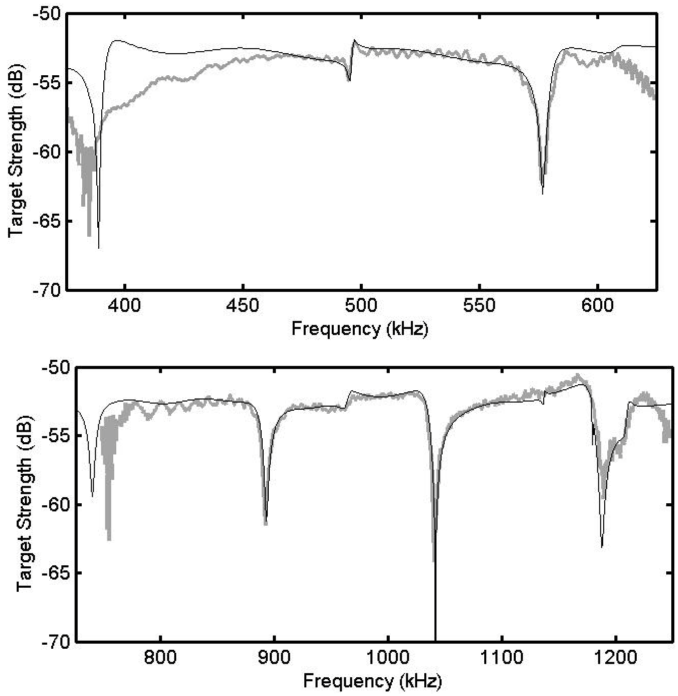

Figure 1. Comparison of the theoretical scattering prediction for an 8.9 mm diameter spherical tungsten carbide standard target, based on the exact modal series solution, to the measured scattering(gray lines) using the second-generation WHOI autonomous broadband acoustic scattering system for the custom-built 500 kHz (upper panel), and 1 MHz (lower panel) almost-octave-bandwidth Airmar broadband transducers.

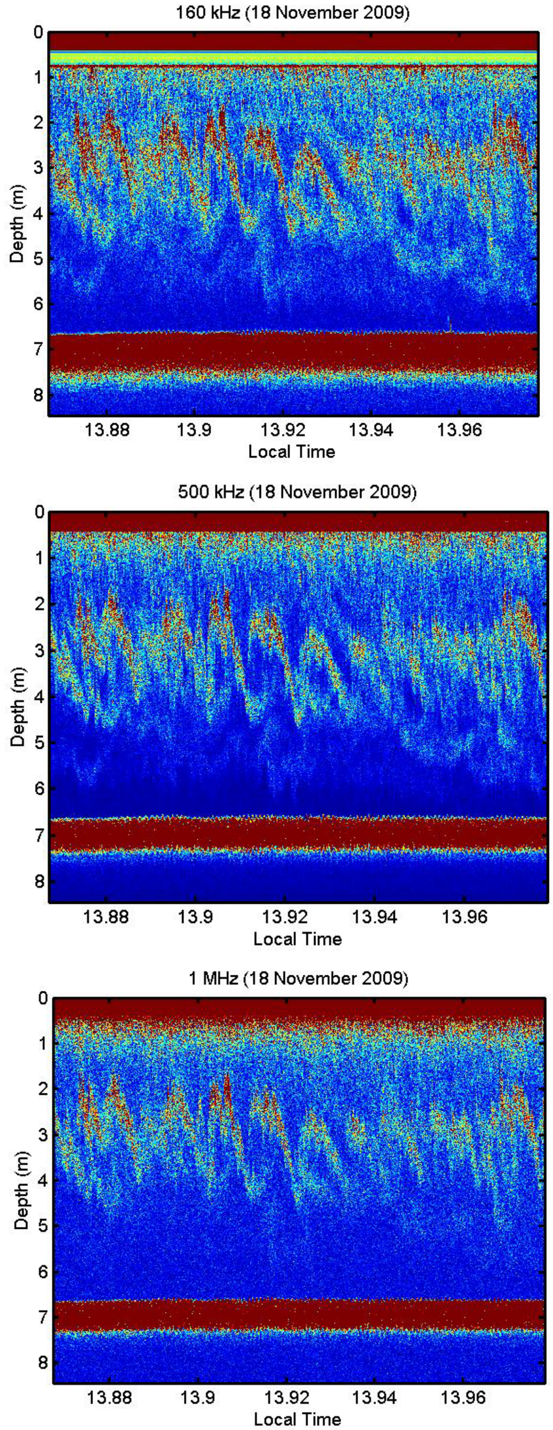

Figure 2. Broadband acoustic backscattering from salinity microstructure in the CT River in November 2009 using the a) 160 kHz BB, b) 500 kHz BB, and c) 1 MHz BB channels of the second-generation WHOI broadband acoustic backscattering system. Kelvin-Helmholtz shear instabilities are apparent in the data. It can be seen that the scattering from the shear instabilities is qualitatively similar at all frequencies.