Development of an Autonomous Broadband Acoustic Scattering System for Remote Characterization of Zooplankton

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LONG-TERM GOALS

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, high-frequency broadband acoustic backscattering system for remote characterization of zooplankton distributions.

APPROACH

The use of high-frequency narrowband acoustic scattering techniques have become relatively routine for synoptic studies of zooplankton populations from centimeter to kilometer scales and across seasonal time-scales (Wiebe et al., 1996, 1997; Benfield et al., 1998; Brierley et al., 1998; Pieper et al., 2001; Lawson et al., 2004). Although traditional single-narrowband-frequency echosounders are frequently used for visualizing zooplankton populations, there remain inherent difficulties associated with the interpretation of the acoustic scattering returns even when direct and coincident measurements of the scattering sources are available. The use of multiple-narrowband-frequency echosounders can expand the range of conditions under which it is possible to interpret the acoustic

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data in terms of relevant biological parameters, such as animal size or abundance (Holliday and Pieper, 1980, 1995; Costello et al., 1989; Pieper et al., 1990; Napp et al., 1993; Wiebe et al., 1997; Korneliussen and Ona, 2002; Warren et al., 2003; Mair et al., 2005; Trevorrow et al., 2005; Lawson et al., 2006; Lavery et al., 2007). Generally though, an insufficient number narrowband frequencies are used to accurately map the scattered spectrum for all zooplankton taxa present in heterogeneous zooplankton populations (Lavery et al., 2007). In order to increase the circumstances when acoustic scattering data can be interpreted in terms of abundance and size of zooplankton it is necessary to increase the bandwidth over which acoustic scattering measurements are obtained. Broadband acoustic scattering techniques, over a sufficiently broad frequency range, allow the spectrum of volume scattering to be accurately mapped.

The advantages of using broadband versus narrowband acoustic scattering systems to remotely characterize zooplankton are generally recognized, though the application of such 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, ScanFish 100-200 kHz). To the best of our knowledge, the only custom-built high-frequency broadband acoustic scattering system that has been used 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 to high-frequency broadband systems designed to remotely characterize zooplankton, lower-frequency broadband acoustic scattering systems (1-120 kHz) to remotely characterize fish have been used more prevalently (e.g. Thompson and Love, 1996; Love et al., 2004; Stanton et al., submitted).

In addition, to date, there have been no published studies in the literature on the development or use of an autonomous, compact, high-frequency, broadband acoustic scattering systems suitable for use on a glider or small powered AUV. Autonomous vehicles, such as gliders and AUVs, offer advantages in persistence and spatial coverage that can improve our ability to synoptically understand important ecological systems, such as thin layers and baleen whale habitats. Although many autonomous vehicles carry an ADCP, which provides a crude measure of a 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 more sophisticated broadband techniques from these vehicles. The autonomous 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), thus significantly enhancing their utility for studying zooplankton distribution and abundance.

Thus, there are two key issues to address: 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 that has been recently developed at WHOI for a monostatic Doppler sonar module (Figure 1). Though the system will have the capability of spanning the frequency range from 100 kHz to 20 MHz, for the purpose of this application, three approximately octave-bandwidth broadband transducers spanning the frequency range from 150 kHz to 1250 kHz, with some gaps, are being used.

Compressed pulse processing techniques will be 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). The autonomous high-frequency broadband acoustic scattering system currently under development is being tested in controlled environments, including a laboratory tank and in the

WHOI seawell. An existing multiple-standard-target calibration technique will be used to calibrate the system in order to eliminate calibration uncertainty inherent in single-target calibrations in the frequency bands close to the resonances of the standard targets. The performance of the system will be demonstrated in the field by collecting coincident acoustic scattering data, optical video plankton images of zooplankton, through the deployment of a combined CTD/VR/OPC instrument package, and net samples.

WORK COMPLETED

There are three tasks involved in the complete development of the autonomous, compact, high-frequency broadband acoustic backscattering system: 1) Modifications to the monostatic Doppler sonar module, recently developed at WHOI for turbulence studies by E. Terray and T. Austin, for the purpose of performing broadband intensity measurements, 2) testing and calibrating the system in a controlled laboratory environment, and 3) demonstration of capabilities in the field.

The primary effort to date has involved modifications to the Doppler module to incorporate the broadband transducers (task 1). Because the Doppler shift can be estimated without using the signal amplitude, the original sonar module was not designed to optimize the measurement of backscatter intensity. However, the receiver is linear and the received signal is digitized at 20 MHz, giving an effective dynamic range for digitization of around 100 dB, in the absence of other noise sources. Both the transmitter and receiver electronics (downstream of the preamplifier) are fully digital, and have currently been interfaced to three broadband transducers (Table 1, Figure 2), which together span the frequency range from 150 kHz to 1250 kHz, with some gaps. This frequency ranges ensure that the Rayleigh-to-geometric scattering transition is spanned for many common zooplankton, which is important for enabling robust acoustic discrimination and to determine zooplankton size. Each transducer has been interfaced to a separate board, an underwater housing fabricated, and the boards stacked within the underwater housing (Figure 3) and run from a common clock, to ensure fully coherent and synchronous operation. Each module has 32 GB of on-board flash memory, which with an appropriate sampling strategy will allow for long-duration deployments. To date, two of the channels (LOW and MID – Table 1) have been used to measure acoustic backscattering from a 20 mm diameter Tungsten Carbide calibration sphere. The system is in the final stages of development before it can be thoroughly tested and calibrated in controlled laboratory measurements. Demonstration of field capabilities will involve two deployments in the Connecticut River (November 2008 and March 2009- funded by ONR PO), and a field deployment in late spring 2009, in which the broadband system will collect data simultaneously with a combined CTD/VR/OPC instrument package, as well as net samples collected to directly characterize zooplankton.

Table 1: Transducers for WHOI compact autonomous broadband acoustic backscattering system.

Source Frequency (kHz)	Ceramic Diameter (mm)	Half angle beamwidth (degrees) at center frequency	Pulse Length (μs)	Pulses per Second	Duty Cycle (%)	Transducer manufacturer
LOW: 150-260	51	4.3	200/500	2	0.04-0.1	Airmar:Custom-Made
MID:375-625	60	1.5	200/500	2	0.04-0.1	Airmar: Custom-Made
HIGH:750-1250	25.4	1.7	200/500	2	0.04-0.1	Panametrics: V302-SU

RESULTS

The primary results to date involve the on-going development of a 3-channel, compact, autonomous high-frequency broadband acoustic backscattering system. Initial testing in a laboratory tank has been performed, more details are given in the section above.

IMPACT/APPLICATIONS

The goal of this project is to produce a compact autonomous broadband acoustic backscattering system suitable for use on small mobile platforms, thus providing a new and unique capability for the acoustic sensing of zooplankton distributions.

RELATED PROJECTS

"High-Frequency Broadband Acoustic Scattering from Temperature and Salinity Microstructure: From Non-Linear Internal Waves to Estuarine Plumes," Lavery, A.C. Funded by ONR Ocean Acoustics. A broadband acoustic scattering system developed by Edgetech was used to measure acoustic scattering from nonlinear internal waves. This system is cabled, relatively bulky, and has a restricted frequency range relative to the system being developed here.

"Remote Sensing of Temperature and Salinity Microstructure in Rovers and Estuaries Using Broadband Acoustic Scattering Techniques," Lavery, A.C., Terray, E., and Gallager, S. Funded by ONR Physical Oceanography. This project is in its infancy. The objectives are to use the system under development here to measure scattering from temperature and salinity microstructure in the Connecticut River.

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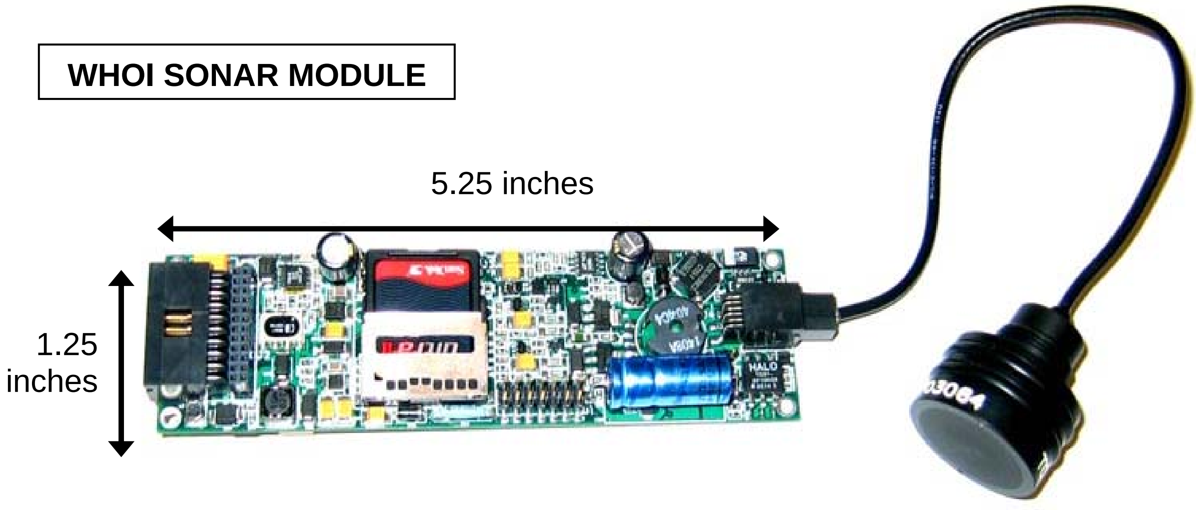

Figure 1: Doppler sonar module developed by Gene Terray and Tom Austin at WHOI, shown interfaced with a 2 MHz transducer. The board measures 5.25 $\times$ 1.25 inches. Minor modifications to this module allow quantitative measurements of broadband acoustic backscattering.

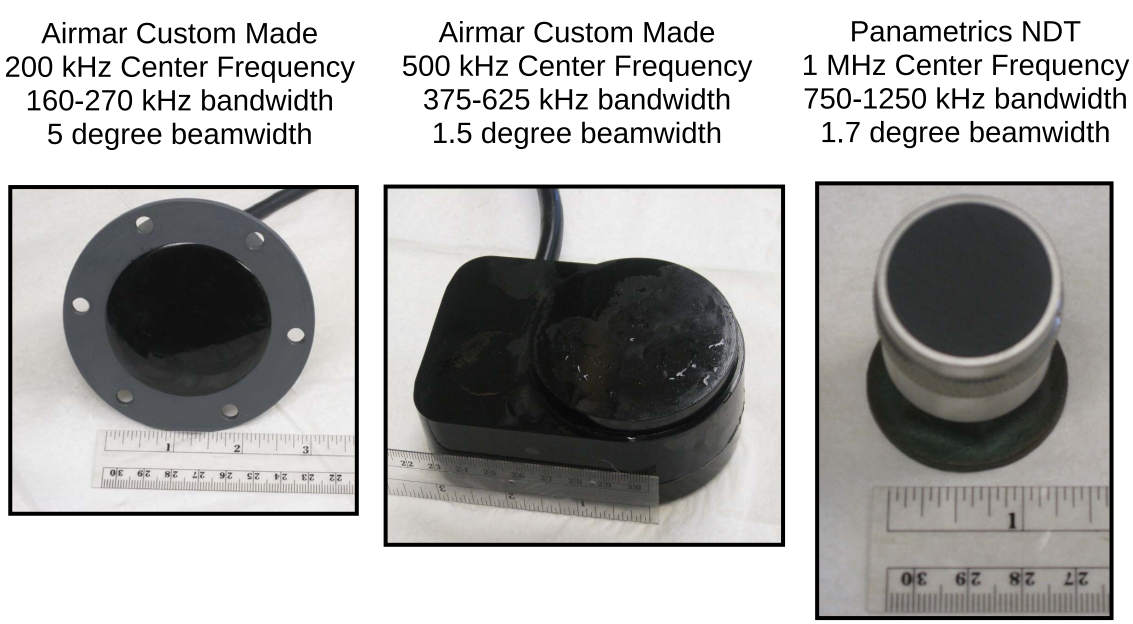

Figure 2: Three octave bandwidth broadband transducers, with center frequencies at 200 kHz, 500 kHz, and 1 MHz, that have been interfaced with the sonar boards.

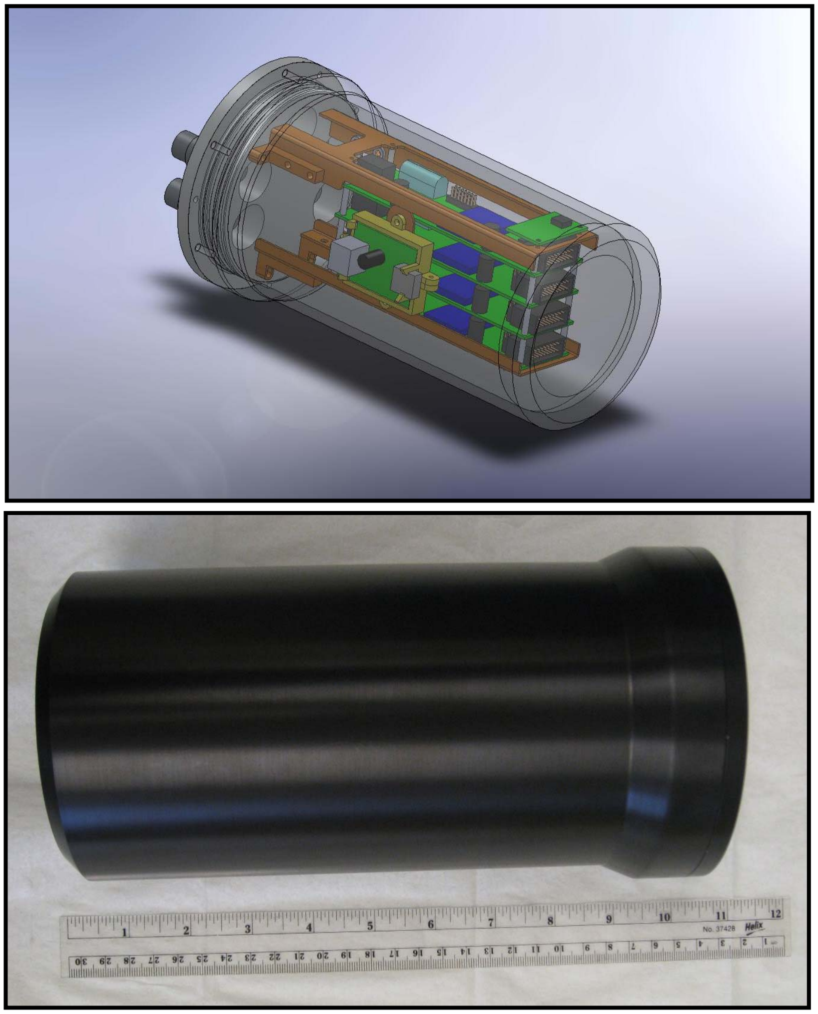

Figure 3: The underwater housing, constructed of aluminum, and depth rated to 300 m, is 9 inches long and 4.5 inches in diameter.