# Forward Scan & 3-D Forward Look Sonars
# for Ocean Explorer AUV's

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## LONG-TERM GOALS

The long-term goals of this research are to develop Forward Looking Sonar Systems (FLSS) for the Ocean Explorer and mini classes of AUV's, with specific emphasis on operation in a shallow water environment. Two types of sonar are being investigated that generate different seafloor images, one is a Forward Scan Sonar, (FSS) that generates a scan image and the second is a 3-D Forward Look Sonar (3-D FLS) that generates a 3-D rendition of the sea floor terrain.  The FSS acquires a complete beamformed image of the seafloor ahead of the AUV at a very fast frame rate (4 to 5 full forward sector frames per second) providing the information needed for obstacle avoidance, navigation, mine recognition and terrain mapping.  The 3-D FLS generates images at a slower rate but can be very effective in target recognition.  For the FLSS, different versions are developed to operate from low frequency (250 kHz) to high frequency (600 kHz or more).

## OBJECTIVES

The scientific objectives of this work are to develop the technology and the systems for high resolution, highly capable forward looking sonar systems to be used as payload on Ocean Explorer class and mini class AUV's, for use in the shallow water environment.  The technology requirements includes the development of the underlying signal processing approaches, data acquisition hardware, data acquisition and processing software implementation, sonar transducer development and power management approaches to facilitate the use of the forward look sonars on battery powered AUV's.  Other objectives include the development of image processing techniques for target identification, classification, and recognition, and for feature based navigation.

## APPROACH

The approach being used in the development of these sonars is based on matched field processing and simultaneous multiple beam forming to achieve high resolution images within a forward sector of view at a fast rame rate.  The current development systems are based on a 10% to 20% bandwidth projector that insonifies the whole sector of view.  The receive hydrophone is a 64 element array where each element of the array is individually received and sampled.  This is required for the simultaneous beamforming.

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Because of the need for the 64 channels of data acquisition, custom data acquisition cards with a PCI interface have been developed. These cards have 16 channels of data acquisition with direct digital filtering and decimation to minimize data bandwidth requirements. Using the PCI interface these cards have potential for other applications since this interface makes them readily integrated with standard PC systems. The rest of the acquisition and processing hardware consist of off the shelf components. The developed hardware interfaces to the power and control (through a Lontalk interface) of the OEX class and mini class AUV's.

For the FS sonar (FSS) two versions are being developed, one based on a 250 kHz center frequency and the other based on a 600 kHz center frequency. The 3-D FL sonar (FLS) is based on the 250 kHz center frequency. The sonars use the same underlying design for the data acquisition and processing hardware. For the transducer hardware, a new transducer has been designed and built for the low frequency FLSS. This new transducer uses standard piezoelectric materials and is conformal to the nose of the OEX AUV. A feature which has been included in the design of this transducer which will be implemented and used in future years is that the transducer has three rows of elements, with each row having 64 elements. Data from the three rows can be used to generate bathymetric FL images. The transducer for the 600 kHz FLSS has been design using piezocomposites which can be more easily conformed to the shape of the AUV. This transducer is being developed in collaboration with MSI. A faster data acquisition system is also required for the 600 kHz FLSS.

An additional component of the work in this project is the development of a lower cost version of the forward look sonar that can be used by Morpheus class AUV for basic navigation and obstacle avoidance.

**WORK COMPLETED**

This last year was mostly dedicated to new hardware design. Following the multiple successful missions of last year, one of which was over mine like targets, it became apparent that the 250 kHz FLSS was ready to be transitioned into a standard OEX AUV payload. Thus, a new revision of the data acquisition hardware has been completed (built and tested) together with the design of an OEX AUV nose conformal transducer. The revised complete system is ready for sea-trials, which would be taking place before the end of this current project year. The new transducer has three rows of 64 elements arrays in close proximity, separated by a half wavelength. Using the three rows simultaneous will provide FL bathymetric scan images. However this is the topic of future work once version 3 of the data acquisition is completed. This is required (version 3) because with three rows of 64 channels, the number of data acquisition channels has to be increased. Due to the lack of physical space a higher channel density data acquisition board needs to be designed and built. This is the version 3 board.Version 2 of the data acquisition board that can handle up to 600 kHz on all 64 channels has now been completed. This new data acquisition has been used with a new transducer designed using piezocomposites and built by MSI. The underlying design of these higher frequency data acquisition boards is very similar to the low frequency (250 kHz) design, except for the higher speed ADC's and DSP's. Tank tests for this new transducer and hardware have been completed and an image is included in the Results section.

As part of this year's work, a numerical model of the FLSS has been developed to better understand the parameters that control the quality of the generated FLSS images. The model data has been compared to data from the missions performed last year and some areas of improvement have been identified.

The numerical model helped in modifying the processing software to take into account the shape of the array since now it is conformal to the nose of the OEX AUV.

**RESULTS**

The results for the past year can be summarized as follows:

- Revision C of the 250 kHz data acquisition hardware has been completed and implemented.

- A new projector/receiver has been design and built for the 250 kHz sonar to be used with the OEX class AUV.  The transducer has the capability to generate bathymetric forward scan images in the future.

- Version 2 of the data acquisition hardware that can operates at a maximum frequency of 600 kHz has been completed and built.

- A piezocomposite array has been built by MSI (figure 1) and integrated with the 600 kHz data acquisition system.  The complete system has been tank tested (figure 2) and is being prepared for at sea trials.

- A design feasibility of the version 3 data acquisition hardware has been completed.
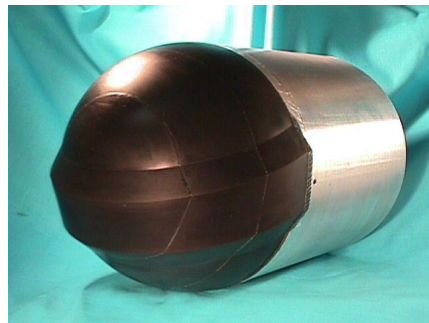


*1.  High Frequency (600 kHz) transducer head.*

During the feasibility study of the new data acquisition hardware, three key areas were investigated and a number of design issues resolved. These areas include:

1. The front-end acquisition amplifiers and mixer interface to the transducer elements

2. The connection method for interconnecting the front-end conditioning amplifiers and mixers to the acquisition card and the analog to digital converters.

3. A complete digital signal processing solution on a card for a 64 channel system.
More details on these issues are provided in the following sections.
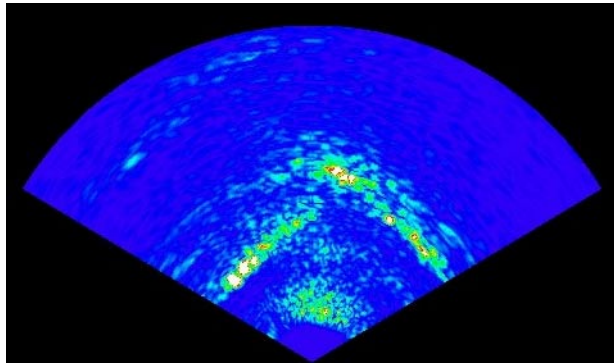
***2.   Tank test image from the 600 kHz MSI transducer and
version 2 data acquisition hardware.***

### Front-end acquisition amplifiers and mixers

The function of this hardware component provides the interface between the transducer elements and the data acquisition electronic hardware.  This function was difficult to define since there were a number of issues with packaging, functional breakdown and power.  A number of solutions have been identified that will work well.  The connection between the transducer elements and the acquisition hardware has to provide impedance matching and gain and frequency base banding.  The conditioning hardware will include both the pre-amplifier and a mixer for each transducer channel.

The pre-amplifier stage provides the high impedance required for impedance matching to the transducer elements.  The solution is an instrumentation amplifier but a single package with a frequency response of at least 2 MHz could not be identified.  Two alternate solutions are available:

1.  A custom designed instrumentation amplifier using Burr Brown 1NA137 or National LM6144 devices.

2.  Using the LNA (Low Noise Amplifier) in the mixer as the differential stage and connecting the transducer element to the mixer with a non-inverting follower OP-Amp.  This solution provides a low cost with a low number of components per channel, but it will potentially have higher noise than solution 1.

A prototype is expected to be completed in the coming weeks.

The mixer stage will provide the base banding function, shifting the acoustic signal to audio frequencies. The Phillips SA612A will be used because it has both an LNA and a double-balanced mixer in the same package.  The mixer provides gain but it has to be carefully matched to both the pre-amplifier and the front-end output stage. At this time testing is being performed on a prototype board.  Tests that will include both the mixer function with a local oscillator running at different frequencies and the interface to the pre-amplifier and the output stage will be performed in the next few weeks.

**Interconnection to the ADCs:**

The connection of the front-end hardware to the acquisition hardware is a complex task because of the large number of wires that must be interconnected between the front-end hardware and the ADC's. A Very High Density Cable Interconnect (VHDCI) connector has been identified as a solution which will provide the necessary number of pins in an acceptable small footprint and the correct package layout. This connector is reliable and available from different manufacturers.

For the analog to digital converters, an audio ADC sampling at up to 48 kS/s (Burr-Brown PCM1800) has been selected. These ADCs will sample the base banded signal from the front-end function. These ADCs also have a 95dB dynamic range, which eliminate the need for variable gain amplifiers. With this large dynamic range, TVG can be implemented in the software. These ADCs are widely used in the audio industry.

Samples of the connector and prototype ADC cards have been acquired and are undergoing tests.

**Complete Signal Processing Solution**

The version 3 data acquisition hardware design has the objective of concentrating 64 data acquisition channels on one single PCI or compact PCI card. This is possible since all the base banding functions will be performed on the conditioning hardware. Thus space is available to add multiple DSP's for beamforming and target identification processing. Multiple TMS320C6xxx Digital Signal Processor ICs from Texas Instruments are being considered to perform the beamforming. Evaluation hardware for current DSP's have been acquired and new processing software is being tested.

The new bathymetric FLSS system has three rows of transducer elements, where each row has 64 elements. The higher channel density design of the version 3 will allow for simultaneous acquisition of all 192 channels (3 rows @ 64 channels per row) which will enable bathymetric forward scan images.

At this time a number of benchmark tests on development boards have been run to determine the number of DSP's needed to perform the required tasks. Some consideration needs to be given on how to package the DSP's on one card. The DSP's being considered are available only in BGA (Ball Grid Array) technology, which requires some new considerations to fabricate the cards. The final analysis to determine the number of DSP's and configuration to use will be done in the next couple of months.

**TRANSITIONS**

The FLSS is still in the process of being transitioned to a commercial company to produce a low cost forward look sonar systems for use in low cost AUV's and small to medium recreational boats. All the development for this transition has been performed and it is estimated that a low-resolution (8 element transducer) system can be developed for under $1,000. Interphase Technologies, Inc. is currently interested in this technology transition and are pursuing a licensing agreement with the University.

**RELATED PROJECTS**

This project is connected with a number of other ongoing projects.  The hardware for the data acquisition and processing developed for these forward look sonars is the same hardware being used for the coherent path beamformer acoustic communication project.  The project uses the capabilities of the hardware developed here to identify the strongest coherent path for the acoustic communication data.  Another project closely connected with this project is an SBIR project with MSI using a piezocomposite transducer.  There is also a project with SACLANT (Italy to use the data acquisition hardware in a low frequency synthetic aperture sonar for buried mine hunting.  This project will also support a pending project for an organic design for the mine-hunting mini AUV that integrates FLSS, with side scan sonar, with acoustic communication and with transponder navigation.