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# RECEIVING AND TRANSMITTING ACOUSTIC SYSTEMS FOR AUV/GLIDERS

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**Abstract:** *NURC in the past years have focused its research on the use of AUV and more recently on gliders and is now developing littoral autonomous sensing networks based on those sensors to perform missions such as mine warfare, anti-submarine warfare, marine mammals risk mitigation and Rapid Environmental Assessment. For the different missions, new acoustic sensors, much smaller in size and having lower cost and lower power consumption are needed to be developed. The purpose of this paper is to present the work NURC started to do in that field since 2007. For example, in August 2007, NURC began to design and build a new thin High-frequency (up to 20 kHz) nested towed array (31 mm diameter) for ASW purposes. Array data analysis of at sea experiments will be shown to demonstrate that both AUV self noise as well as flow noise were not an issue whatever the tow speed and did not alter with the performance of the array. Based on those results, NURC decided in 2008 to investigate the use of thinner diameter arrays, very thin line arrays, which could be used with small size AUVs and/or gliders as with reduced weight and drag. A very thin line 12 mm diameter array prototype has been built in order to assess flow noise performance and also for exploring Linear Noise Power Averaging as a technique for suppressing flow noise on small diameter towed arrays. Then, the paper will describe the current development of a very high frequency (up to 160 kHz) tetrahedral array for a glider that will allow detection and accurate localization of marine mammals. Eventually, the paper will describe the current development and the first results of a towed transmitter that will be towed by a NURC AUV to perform both bottom characterization and ASW missions.*

**Keywords:** AUV, glider, Acoustics, Transmitter, Receiver, towed array, tetrahedral array

## 1. INTRODUCTION

NURC in the past years has focused its research on the use of AUV and more recently on gliders and is now developing littoral autonomous sensing networks based on those sensors to perform missions such as mine warfare, anti-submarine warfare, marine mammals risk mitigation and Rapid Environmental Assessment. For the different missions, new acoustic sensors, much smaller in size and having lower cost and lower consumption are needed. The purpose of this paper is to present the work NURC started in that field in 2007. Both receiving and transmitting systems are described.

## 2. ACOUSTIC RECEIVING SYSTEMS FOR AUV/GLIDER

This section will present different systems already developed or under development at NURC for acoustic measurements to be performed from both AUV and glider. The first paragraph will described two different diameters arrays that have been developed for ASW applications while the third paragraph of this section will present a very small acoustic system under development for the detection and more importantly localization of marine mammals.

### 2.1. 31MM DIAMETER THIN LINE ARRAY (SLITA)

In August 2007, NURC began to design and build a new thin diameter (31 mm) High-frequency (up to 20 kHz) nested towed array for ASW purposes. An Engineering at-sea trial of the array towed by the 21” OEX-C Explorer AUV was performed beginning of November 07. The flow noise level of the array while towed and the potential influence of the AUV self noise on the acoustic array were also measured. Since that, a new 4 octaves 31mm array (called BENS) has been recently (beginning 2009) built at the Centre. This array includes as well 3 compass units.

#### 2.1.1. Specifications

The SLIm Towed Array SLITA (see Fig.1) is a towed array derived from the SLIVA Vertical Line Array developed at NURC.

*Figure 1- SLITA Array deployment and OEX-C*

It features:

- 48 hydrophones in total
- 2 x 32 hydrophones
    - o octaves spacing 0.211 and 0.422 m
    - o array apertures are named Octave 2 (3550 Hz), and Octave 3 (1780 Hz)
    - o cylindrical hydrophones (sensitivity -201 dB ref. to 1 Volt per µPa)
    - o total gain 33.8 dB

The analog to digital acquisition board is a General Standards PCI-24DSI32 with 24 bits resolution. The used Benthos AQ-4 hydrophones (Sh=-201 *dBV re 1 µPa ±1dB)* are designed to compensate for noise generated from array movement, commonly known as acceleration noise. Noise is substantially reduced by symmetrically supporting the active element inside the mounting structure.

The mechanical design is shown below on Fig. 2.

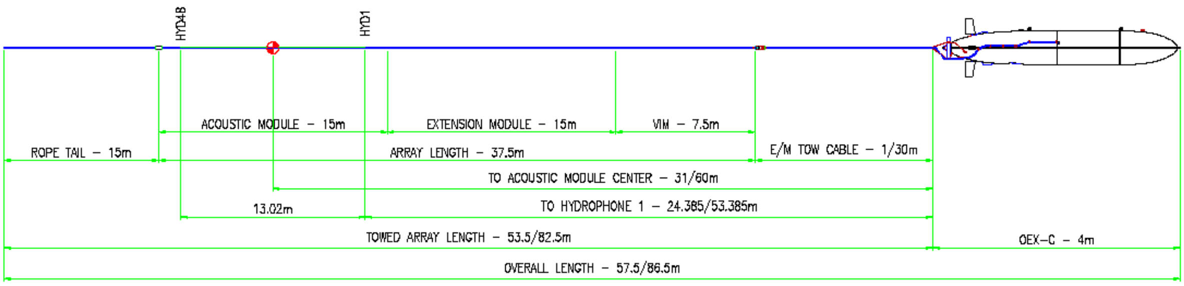


*Figure 2 - SLITA array mechanical drawings*

#### 2.1.2. Performance evaluation at sea

Two trials of the SLITA array have been carried out during November 2007 and February 2008 in an area in front of the Palmaria Island, in around 30 m water depth.

*Mechanical noise considerations*

In order to differentiate between acoustic and non-acoustic noise, e.g., mechanical noise, one tool is provided by the wave-number-frequency diagrams (also called k-ω transform). These diagrams allow the identification of the speed of the pressure waves measured by the array.

Wave-number-frequency diagrams for real data do not show significant artifacts which could be produced by mechanical vibrations or array distortions. Figure 3 shows the k-f diagrams obtained during AUV navigation. The V-shape is well characterized, and the array gain is around 30 dB as expected. The residual energy outside the V-area is due to sidelobes effects (above roughly 3500 Hz and 1750 Hz for MF and LF aperture respectively)

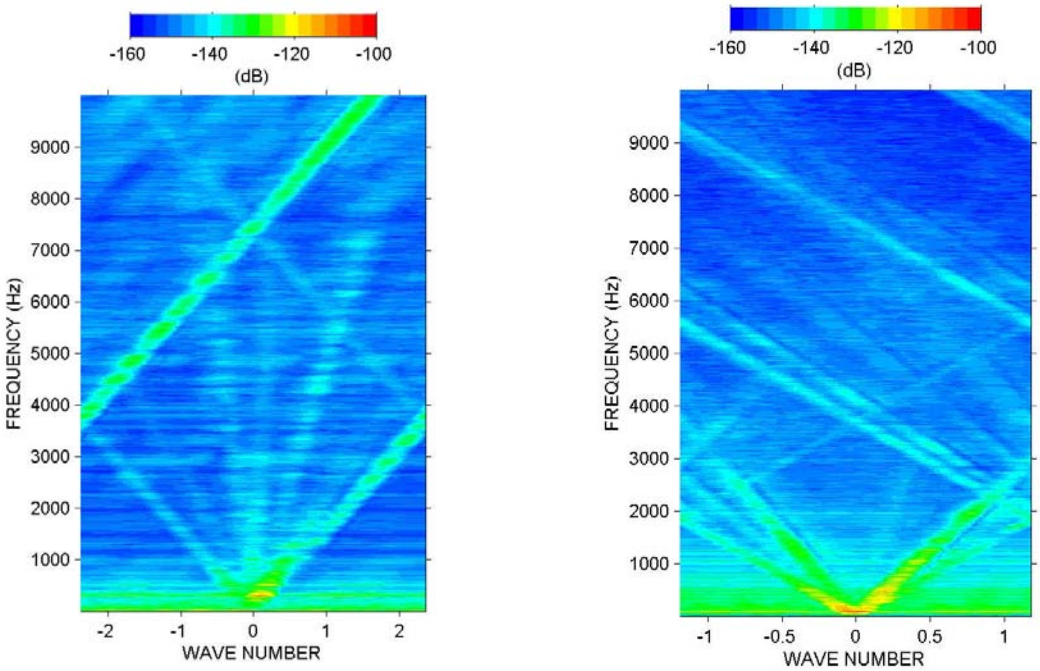


*Figure 3 – k-f diagrams during navigation; duration 4 seconds*
*(a) MF aperture, 211 mm, (b) LF aperture 422 mm*

*AUV propeller noise*

During the experiment carried on in February 2008, a tone generated by the AUV propeller can be seen when the AUV was on the surface on the SLITA array. The same noise however is not measurable while the AUV is underwater.

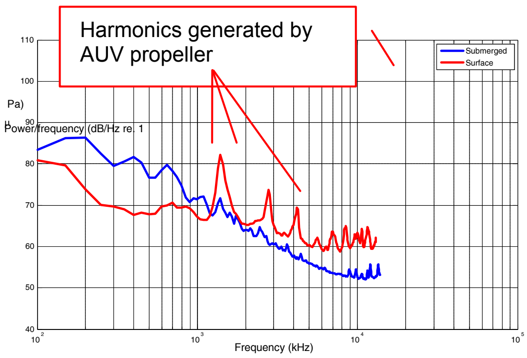


*Figure 4 – Noise comparison between submerged and surface navigation*

*Array shape*

An analysis of the array shape during a 90 degrees turn of the AUV was performed using acoustic means. It was observed that the array is coming straight behind the AUV after less than 80 seconds which is operationally very interesting.

### 2.2. 12MM DIAMETER VERY THIN LINE ARRAY (Micro-SLITA)

Based on the previous very promising results, NURC decided in 2008 to investigate the use of thinner diameter arrays, micro thin line arrays, which could be used with small size AUVs and/or gliders as with reduced weight and drag. A very thin line 12 mm diameter experimental array has been built in order to assess flow noise performance and also for exploring Linear Noise Power Averaging as a technique for suppressing flow noise on small diameter towed arrays.

#### 2.2.1. Specifications

The prototype built is made of 20 hydrophones and has one depth sensor and one tilt sensor. The array total length is 14 meters. The array has an interface to the SLITA data acquisition system. The micro-SLITA has been designed to be towed from the OEX-C explorer.

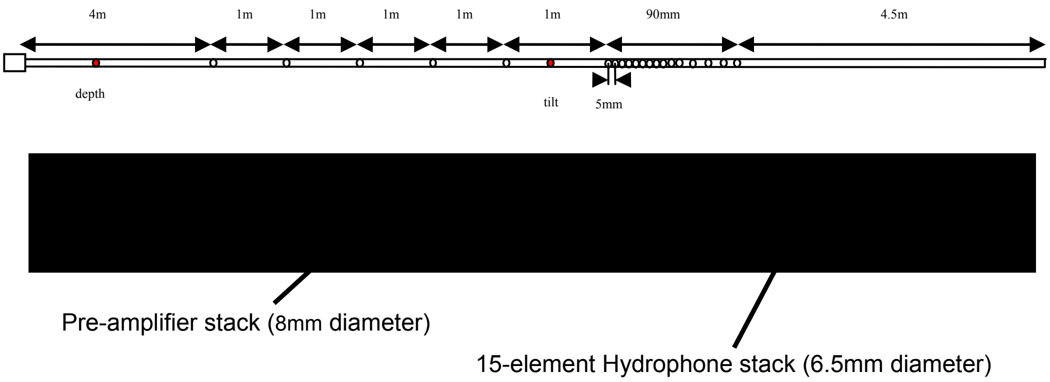


*Figure 5 – Very thin 12mm diameter Line Array (Micro-SLITA)*

#### 2.2.2. First at-sea results

The trials consisted of towing from the R/V Leonardo the micro-SLITA at various speeds from 3-7 knots along straight paths approximately parallel to the Italian coast adjacent to Tellaro, just SE of NURC. By design unfortunately, the towing cable length was not long enough to get rid of the R/V Leonardo noise. This was a limitation that is shown later in the data analysis results but this trial served as a first initial test for this array in water.

There were a number of issues that limited the quality of the acoustic data from the micro-SLITA. Briefly, these were:

- As the tows progressed, there were more drop-outs, spikes and other signal breakdowns in the hydrophone channels, most likely due to mechanical stressing of the array under tow. This was particularly noticeable on higher-speed tows.

- The R/V Leonardo generates substantial mechanical noise below 6 kHz, making analysis of acoustic data for other sources in this frequency band impossible.

- At 14 kHz and above there are substantial quasi-tonals, apparently generated electronically by the R/V Leonardo. The lack of phase lag along the array suggests that these are injected into the hydrophone data stream via electromagnetic pickup rather than by an acoustic propagation path.

Fig. 6 shows the characteristic R/V Leonardo mechanical acoustic noise prevalent to 6 kHz, the 9 kHz pinger event (about 1/3 of the way through this record) and the 14 kHz R/V Leonardo electromagnetic tonal. Towards the latter part of the spectrogram one of the episodic vortex shedding events can be seen, interpreted as R/V Leonardo hull wake turbulence.

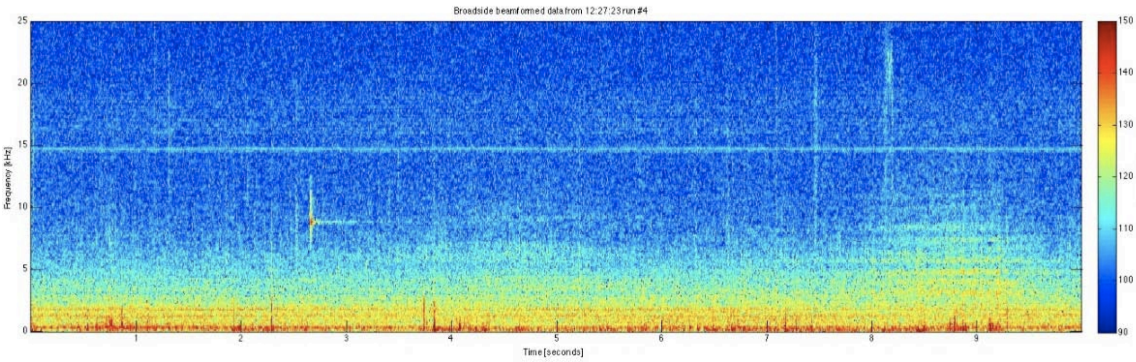


*Figure 6. Broadside beamformed acoustic data from run 4.*

The acoustic data were bandpass filtered with an Butterworth IIR filter, passing 6 kHz - 13.5 kHz with a 1 dB passband ripple and -20 dB stop band ripple, the filter being passed twice through the data (once forward and once in reverse) to obtain a zero time-shifted output. Time-frequency transients were then removed by a bi-orthogonal Debauchies QMF wavelet decomposition, thresholded filtering and re-synthesis to suppress the impact of noisy transients on the subsequent processing. Having finally obtained an acoustic dataset cleaned of R/V Leonardo mechanical and electromagnetic noise and time-frequency transients, and excluding faulty channels, it is possible to examine the cross-correlation between channels to explore if there are turbulence signals that are advected along the array at or near the tow speed. For each separation from the minimum available (5 mm) to the maximum (70 mm) all possible pairs of hydrophones were cross-correlated and the average normalised amplitude plotted as a function of temporal and spatial separation. An example output is shown in Fig. 7.

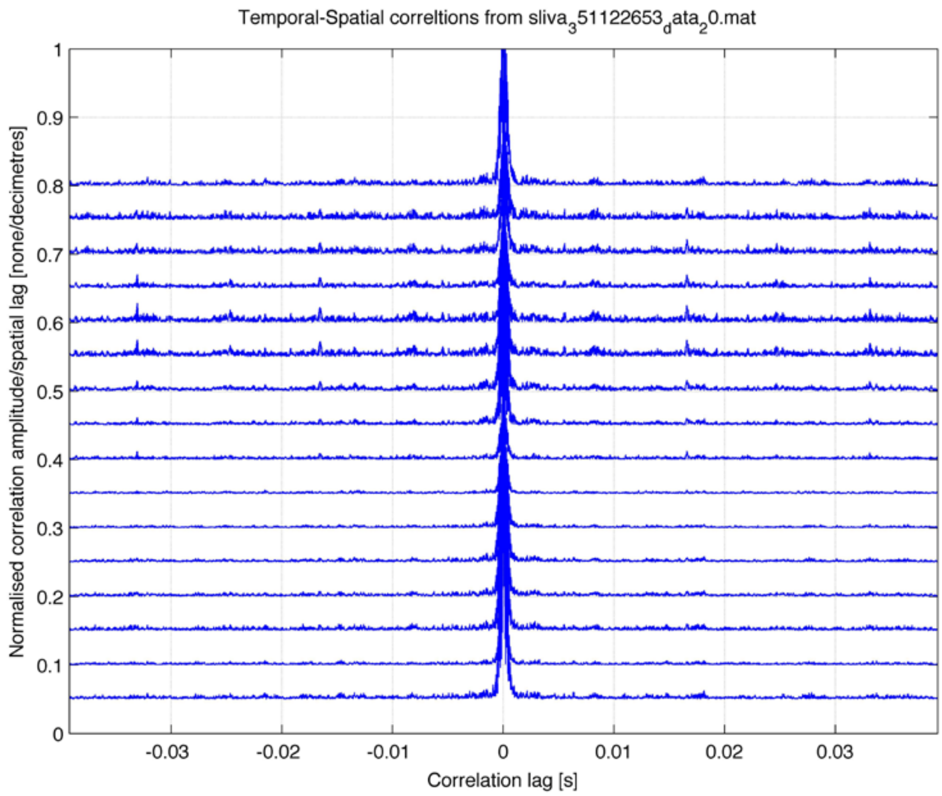


*Figure 7. Example temporal cross-correlations as a function of linear spatial separation for 'good' hydrophone channels after data cleaning.*

The high cross-correlation coefficients at near zero time lag are due to the propagating acoustic energy received by the hydrophones. That there are negligible cross-correlation amplitudes at lags outside the narrow acoustic propagation angles in space-time indicates that there is no discernible passive turbulence signal in this acoustic data.

As a summary of the data analysis, the following things were observed:

- While the artefacts due to the mechanical and electromagnetic noises from R/V Leonardo are significant, they are not the only sources of noise in the acoustic data.
- The tilt and pressure sensors worked well, and the data shows much of interest that can be understood in terms of the towing environment. Most of the acoustic energy observed in these data is in some way generated by the R/V Leonardo.
- No apparent turbulence energy is found in the frequency range 6-13.5 kHz. Below this band the acoustic energy is dominated by R/V Leonardo mechanical noise. Above this band the hydrophone data is dominated by R/V Leonardo electromagnetic noise.

An other trial with the micro-SLITA towed from the OEX-C Explorer will be conducted in June 2009.

## 2.3. TETRAHEDRAL ARRAY FOR MARINE MAMMALS "TAMM" DETECTION AND LOCALIZATION

### 2.3.1. Background

It is now widely accepted that sound-generating anthropogenic activities may have a negative impact on marine live. This impact will not only depend on the type of sound, but will also depend on the species and their behavioural activity. Expected hazards range from temporal behavioural disruption, over permanent displacement to potential fatal stranding.

To mitigate the risk of anthropogenic sound, it is critical not only to uncover the causal effects of the sound and to establish criteria for the onset of negative effects, but also to develop risk mitigation methods aimed to minimize sound exposure. An important approach for the development of mitigation measures is to develop the capability to monitor for the presence of marine mammals in an area prior to, and during anthropogenic activity.

One approach for reducing the risk of exposing cetaceans to unacceptable sound levels is to avoid areas with their presence. This strategy would require build up of confidence that, with a given probability, no cetacean is within the area that is impacted by a certain sound pressure level from the sound source. For this it is important to be able to quantify the probability of cetacean presence in a given area. Acoustic detection of cetacean sounds is a viable way to detect their presence also at depth and may be an efficient complement to visual sightings of surfacing animals. When integrated in autonomous systems like buoys/gliders passive acoustic is an efficient alternative to expensive ship based systems. The range over which whale sound can be heard is usually greater than the range they can be detected during surfacing, and acoustic detection remain effective at night and, especially using autonomous systems, in poor weather.

### 2.3.2. Specifications

The TAMM (Tetrahedral Array for Marine Mammals) is a self-contained underwater sound recording and detecting device capable of acquiring wide bandwidth sound continuously, processing the sound, and then storing extracts of sound to non-volatile memory. The device can be used as a stand-alone recorder or with an external GPS and radio telemetry as part of a monitoring installation.

The data collected by the TAMM can be offloaded, after the device is recovered, via USB to a personal computer. The internal battery in the TAMM is recharged at the same time (either from the USB connector at a low rate or from an external power supply at the full rate). The amount of time required to offload and recharge the device will depend on use but should be less than 5 hours (charging with an external power supply).

The system under design and development will have 4 hydrophone inputs sampled at

500 kHz 18 bit and will use home-made low noise pre-amplifiers. Digital compasses, pressure sensors and temperature sensors will be also included in the TAMM system. A TAMM comprises 2 circuit boards. The main board contains a digital signal processor (DSP), memory, power supply, and interface circuits. The sensor board contains audio acquisition circuits and depth and (possibly) orientation sensors.

The design will leverage on the recent development of the NURC CPAM (Compact Passive Acoustic Monitor) as shown on the figure below:

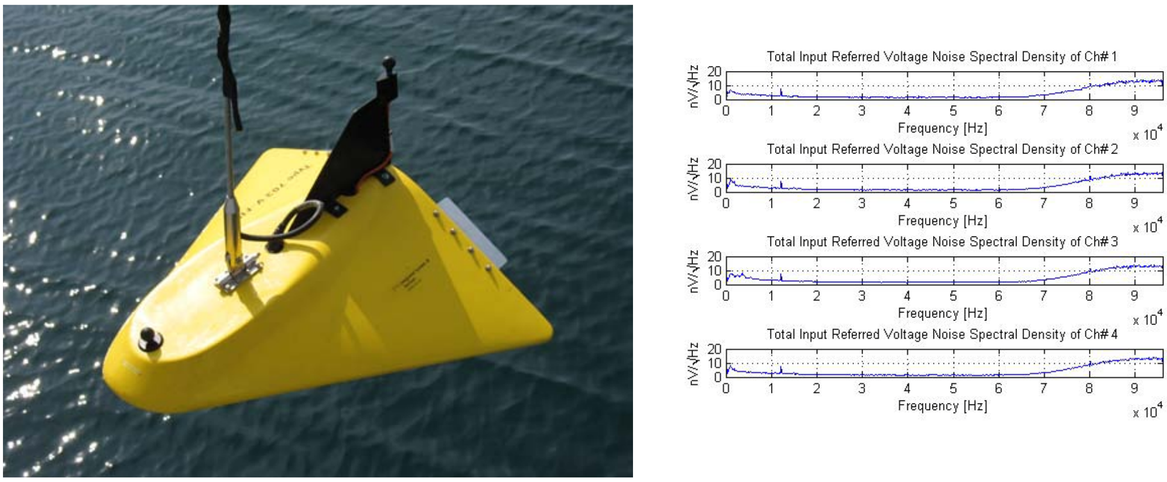


*Figure 8 – Compact Passive Acoustic Monitor (CPAM) tow body and acoustic channel electronic noise*

This system is equipped with four hydrophones positioned in tetrahedral mode and with low pre-amplifier (< 2 nV/√Hz in the 30-60 KHz bandwidth) and can be deployed at a depth up to 750 meters and towed up to 5 knots speed. New A/D technology will be used within the TAMM to decrease the noise floor in the upper band of the frequency band of interest.

## 3. ACOUSTIC TRANSMITTING SYSTEM FOR AUV

In addition to the previously described acoustic receiving systems, NURC has decided in late 2008 to develop as well a transmitting sound source to be towed by AUV for both bottom characterization and ASW missions.

For the bottom characterization mission, the objective is to characterize the geoacoustics properties (sound speed, density, attenuation and stratification) of the clutter features as well as the seabed surrounding the clutter features. Both characterizations are needed for sonar performance modelling. The broadband spherical reflection coefficient contains significant information about the seabed geoacoustic properties at spatial scales relevant to the clutter problem. The method uses an AUV with a towed source and horizontal array, and a moored vertical array as a receiver along previously conducted tracks using a boomer source. The boomer source runs are considered as "ground truth" to the AUV runs. The method requires CTD and XBT measurements to properly characterize the water column. The system described below will be used at-sea in May 2009.

### 3.1. DESIGN SPECIFICATIONS

The TOwed Sound Source for Auv (TOSSA) is described on Fig.9 . The transmitter bandwidth covers from 800 Hz to 3400 Hz and is using Ultra MPS transducers. The required bandwidth is achieved in two separate bands using both the MPS 6-35 and the MPS 2-100. The achieved Source levels are given on the figure below.

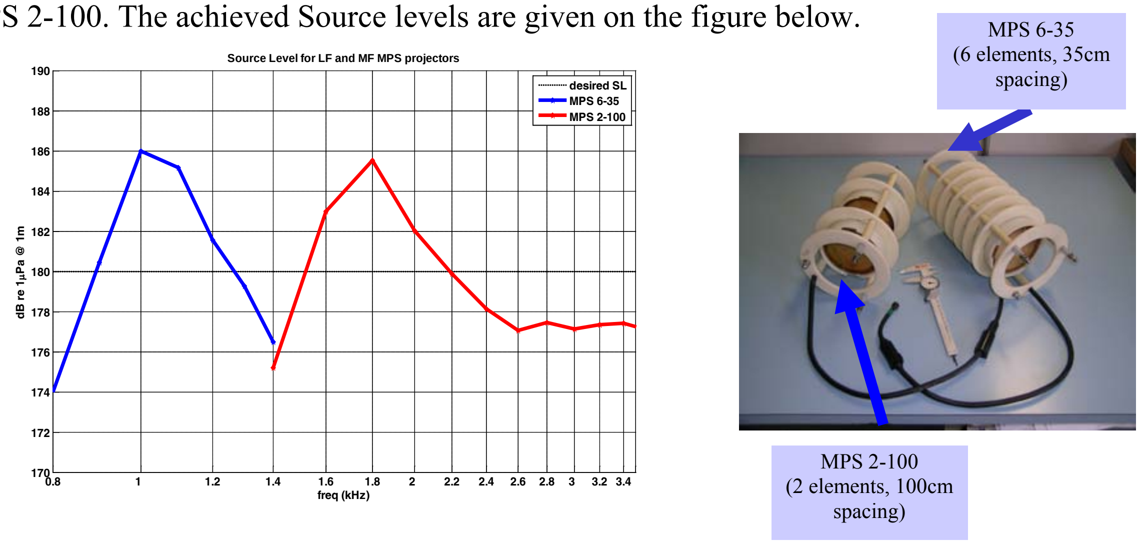


*Figure 9 – Acoustic transducers characteristics*

Greater Sound Pressure Level (SPL) (5 to 10 dB more) will be easily achieved soon in changing the amplifier modules.

The power amplifier container is described below:

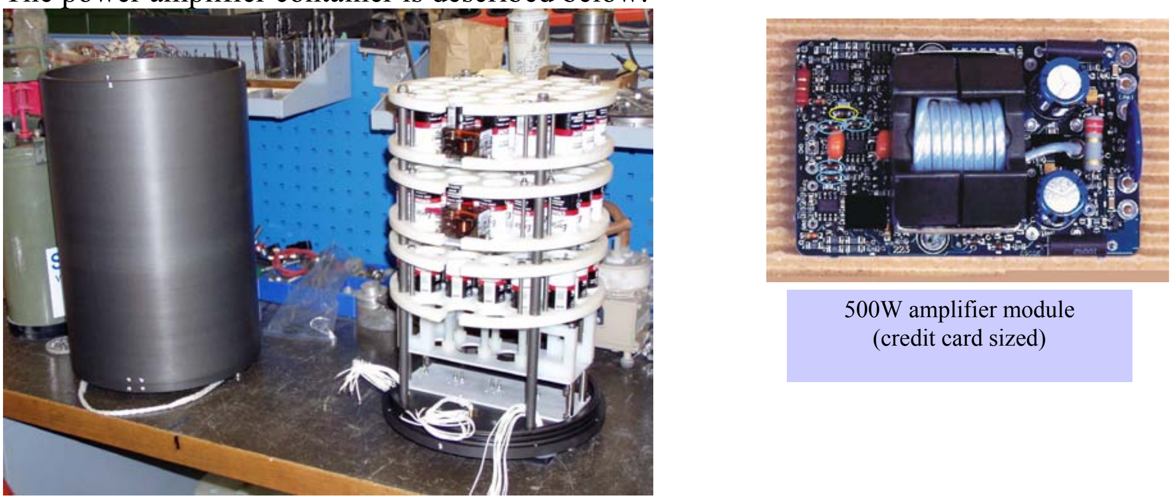


*Figure 10 – Acoustic transducers amplifier*

The mechanical design is shown on Fig. 11.

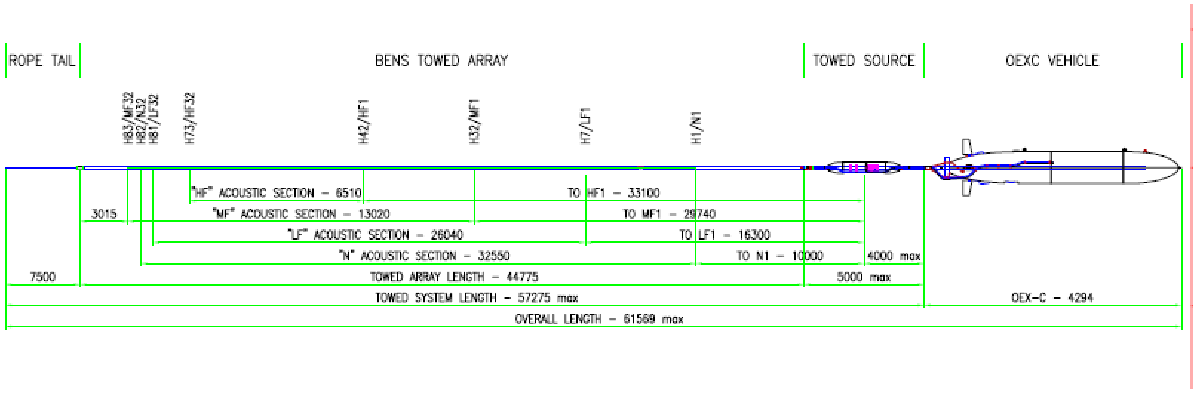


*Figure 11 – Towed Sound Source AUV (TOSSA)*

The following figure shows the tow body that has been specifically designed for implementing the transducers and providing the best towing capability:

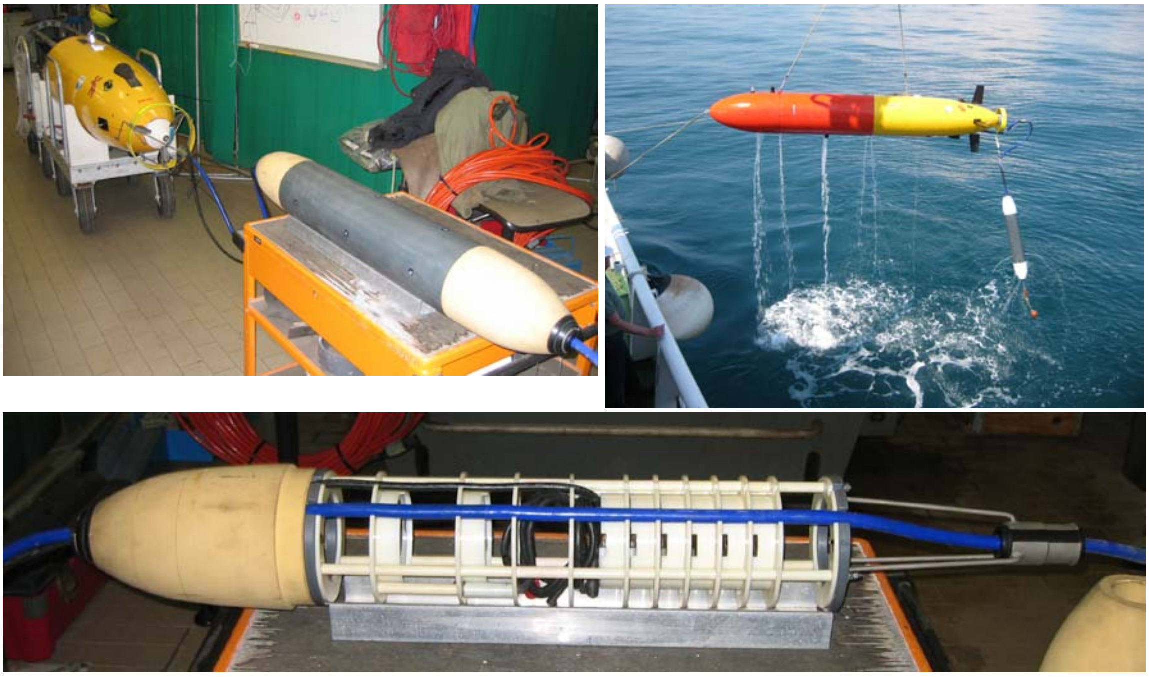

*Figure 12 – OEX-C AUV+ TOSSA*

First at-sea experiments of this system were conducted beginning of April. It was shown that the OEX-C explorer was able to tow the Source at around 2 knots. The at-sea behaviour of the AUV was not affected at all by the towed transmitter. During the experiment, one of the 31mm towed array (BENS) described above were towed also from the AUV while attached to the transmitter.

Fully monostatic sonar operation on an AUV was fully demonstrated as shown by the beams figure below. An echo repeater was used to simulate a submarine and a clear detection was seen on the processing display.

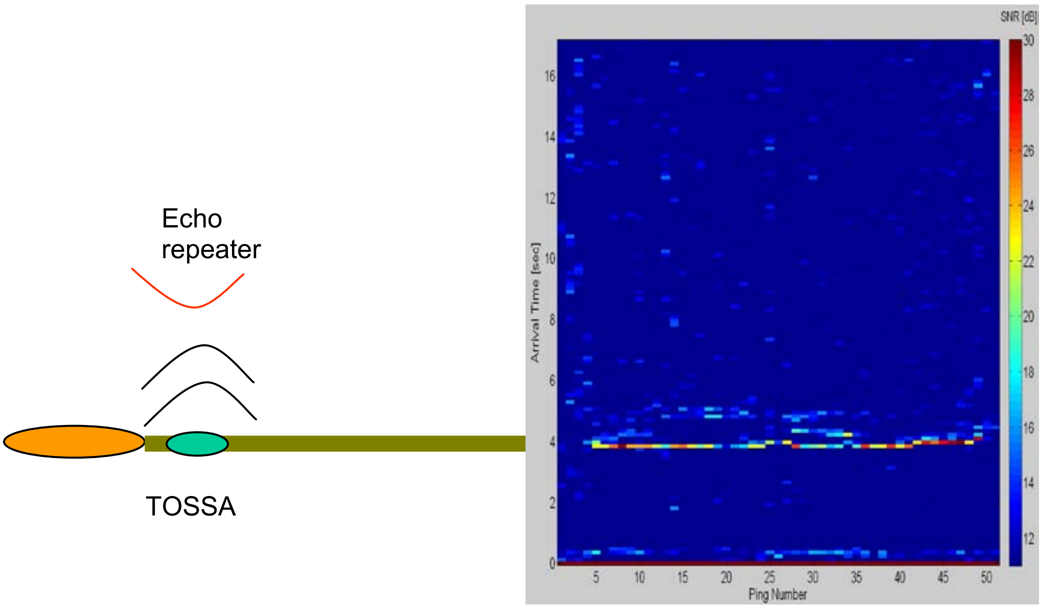


*Figure 13 – OEX-C AUV+ Sound source + echo repeater: beam display from towed array*

## 4. CONCLUSION

This paper has described very promising new acoustic equipments developed or under development at NURC for both Autonomous underwater vehicles and gliders. The results obtained so far are very good and open new ways for performing bottom characterization anti-submarine warfare and marine mammals risk mitigation.

## 5. ACKNOWLEDGEMENTS

The authors would like to thank the Leonardo crew for their dedication to the successful test of all the described equipments. A special thanks to Marco Mazzi and Stefano Biagini, without whom, any test with the OEX-C explorer could not have been made with such a great success.

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