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An Embedded Passive Acoustic Device for Real-Time Hydroacoustic Surveys

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***Abstract* – In this paper, we provide a comprehensive description of cost-efficient, innovative and interoperable ocean passive acoustics sensors systems, developed within the European FP7 project NeXOS (Next generation Low-Cost Multifunctional Web Enabled Ocean Sensor Systems Empowering Marine, Maritime and Fisheries Management), which can be deployed both on fixed and mobile platforms. Within this context, we designed and developed two passive acoustic sensors, A1 and A2, as new embedded passive acoustic device, low power and innovative digital hydrophone systems. An important part of the effort is focus on the need for greater dynamic range and the integration on autonomous platforms, such as gliders and profilers. A1 is a standalone small, compact, low power, low consumption digital hydrophone with embedded pre-processing of acoustic data, suitable for mobile platforms with limited autonomy and communication capability. A2 consists of four A1 digital hydrophones with Ethernet interface and one master unit for data processing, enabling real-time measurement of underwater noise and of several soundscape sources.**

Keywords – underwater acoustics, digital hydrophone, interoperability, marine observations, smart interface, embedded processing

I. INTRODUCTION

More than 70% of the earth's surface is covered by water, and the majority of the underwater areas are still unexplored, and in-situ observation of oceans is generally difficult and costly in resources and time.With this in mind, the main objective of NeXOS project is to develop innovative, cost-effective, and compact multifunctional sensor systems in ocean passive acoustics, ocean optics and for an Ecosystem Approach to Fisheries (EAF). These systems are envisioned to be deployed both from mobile and fixed platforms, with data services contributing to the GEOSS, the Marine Strategy Framework Directive (MSFD) and the Common Fisheries Policy of the European Union. This paper focuses on the passive acoustic development objectives of NeXOS project and provides a comprehensive description of these developments [1].

NeXOS moves beyond just sensors, as observations can be better served through functionalities that simultaneously address multiple objectives and applications. Thus NeXOS takes a perspective of both sensors and sensor systems with significant advantages over existing observing capabilities. These range from more precise monitoring of the marine environment to an improved management of fisheries applications. From a technical perspective, the focus is on improved life cycle cost-efficiency via the implementation of innovations, such as multiplatform integration, greater reliability through better antifouling management and greater sensor and data interoperability. Requirements for the sensors have been refined from this perspective through surveys and discussions with science and industry users. The feedback has then been folded into the engineering design process.

Within the context of NeXOS project, we developed a new kind of small dimension, low power and innovative digital hydrophone in different configurations: single, multi-channel or array. In particular, we design and development two passive acoustic sensors, named A1 and A2, whose features and functionalities are described in this paper.

II. PASSIVE ACOUSTIC SENSORS SYSTEM

A. A1 sensor system

A1 consists of one hydrophone and two A/D converters, simultaneously sampled, with different gain, to detect acoustic source levels from 50 dB to 180 dB re 1μPa in the frequency range from 1Hz to 50kHz.

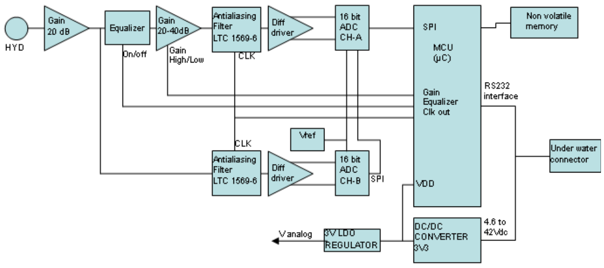

Fig 1. A1 sensor block diagram

As illustrate in Figure 1, as first step, the hydrophone signal is pre-amplified with an input stage with a gain of 20 dB. The first channel (CHA) consists of a high pass filter “equalizer”, connected before the high gain stage in order to optimize the Signal to Sea noise ratio at low frequency. The equalizer circuit is a one-pole filter with a cut-off frequency of 3200 Hz and it can be enabled or disabled through the MCU. Furthermore, the equalizer ensures also high dynamic range at high frequency where the noise level is lower. The post gain amplifier of CHA can be set to 20 dB or 40 dB through the MCU. The second channel (CHB) does not make changes to the hydrophone pre-amplified signal. Therefore, the two channels are different by the gain:

- CHA “Hi” Gain: 40 dB or 60 dB
- CHB “Low” Gain: 20 dB

Both channels have a low pass antialiasing filter: to avoid aliasing problems a switched capacitor filter digitally controlled by the MCU has been added in both the chains after the amplifier stage. The operator, through the MCU, can set the cut off frequency of the anti-aliasing filter, changing its control clock frequency (CLK), depending on the application and on the sampling frequency. The hydrophone signal is sampled by two 16-bit SAR converters controlled by an ARM microcontroller, that takes care of proper data processing (mathematical operations). The working sampling frequency SF should be 100 ksps and it is controlled by the MCU timer. Fig. 2 shows the top and bottom sides of the PCB.The MCU processes the sampled data and transmits the results on a EIA RS-232 serial port. A1 is equipped with a real time clock useful to tag temporally sampled data, but it is also equipped with a Pulse Per Second (PPS) input for the GPS link. The frequency response requirement is a frequency range of 1Hz to 50 kHz. The selected ADC can run up to 100 ksps (50kHz of bandwith). Any frequency range may be selected by the MCU changing the frequency clock (“fclock”) to the Antialiasing filter.

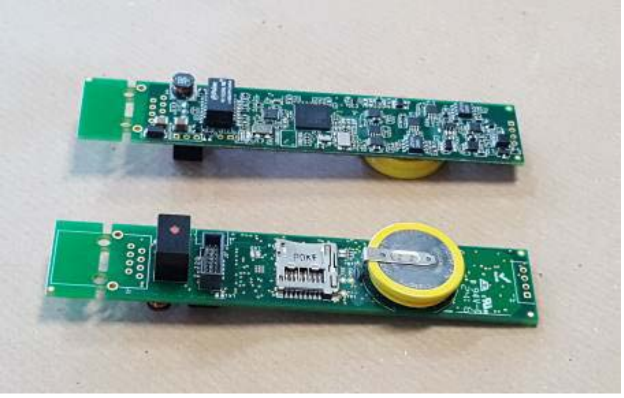

Fig 2. A1 sensor printed circuit board

B. A2 sensor system

A2 is a digital passive acoustic transducer array whose output (raw signal) is pre-processed by a master unit.

The acoustic array consists of four acoustic devices, called A2hyd. These devices have the same characteristics as the A1 sensor regarding the Signal Conditioning Unit (SCU), the A/D Converter (ADC) and the Micro Controller Unit (MCU), with the difference of a smaller internal memory (32 GB) and the absence of the battery. Regarding the transducer stage, the hydrophone JS-B100 has been selected for high depth underwater application.

The time synchronization of the master unit and the slave units (A2 Hydrophones) is done using the IEEE1588 Precision Time Protocol (PTP) standard [2], which defines a network protocol enabling accurate and precise synchronization of the real-time clocks of devices in networked distributed systems.

Therefore, A2 array is composed of four hydrophones A2hyd, a PTP Grandmaster Clock plus one Master Unit; Figure3 shows the A2 block diagram.

The acoustic array A2 can be equipped with positioning sensors (pan, tilt and compass) to allow the measurement of its geo-referenced position. The device can also receive relevant oceanographic parameters (sound velocity, temperature, depth, time) via Ethernet, in order to optimize the algorithms. Therefore, the main capability of A2 is to provide directional sound source information for hydroacoustic surveys.

In Fig. 4 is illustrated one of the four A2 sensors deployed at OBSEA observatory.

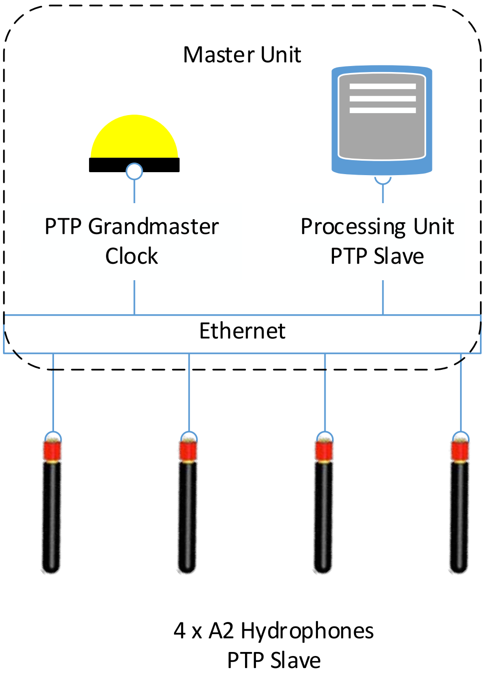

Fig. 2. A2 Block Diagram with Master Unit Components

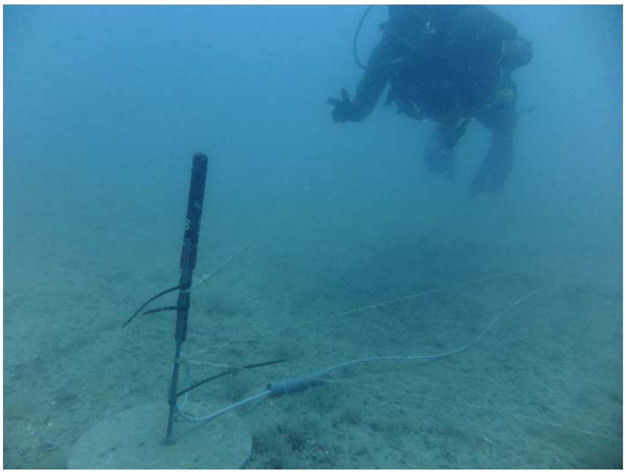

Fig. 3. A2 sensor deployed for validation at OBSEA observatory

C. Hydrophone transducers

Within the NeXOS project context, three types of transducers suitable for A1 and A2 sensor system requirements have been identified. Differences consist in sensitivity, shape, maximum operating depth and cost, as indicated in Table 1. A prototype of A1 was manufactured for each of these transducers and a prototype of A2 was manufactured for JS-B100 transducer.

D. Gain and Frequency measurements

Fig. 5 shows the transfer function of CHB (20dB gain) with Antialiasing filter F_{cutoff}=50kHz.The marker at 5kHz measures 19.69dB gain that meets the expected tolerance.

Table 1. Characteristics of acoustic transducers used for A1 and A2

	Technology Limited mod. SQ26-01	Neptune Sonar mod. D/70	JS-B100-C4DP Acoustic Sensor
Sensitivity CHA	-133.5/-153.5 dBV re 1µPa	-138/-158 dBV re 1µPa	-141/-161 dBV re 1µPa
Sensitivity CHB	-173 dBV re 1µPa	-178 dBV re 1µPa	-181 dBV re 1µPa
Frequency range (±1.5dB)	From .151 Hz to 28 kHz	From 1 Hz to 50 kHz	From 1 Hz to 50 kHz
Sea noise equalizer	HP filter one pole 3.2 kHz	HP filter one pole 3.2 kHz	HP filter one pole 3.2 kHz
Beam pattern	Omni-directional	Omni-directional	Omni-directional
Input equivalent noise (@5kHz G=60dB	22.5 dB re 1µPa/√Hz	27 dB re 1µPa/√Hz	30 dB re 1µPa/√Hz
Working depth	Up to 2000 m	Up to 1500 m	Up to 3600 m

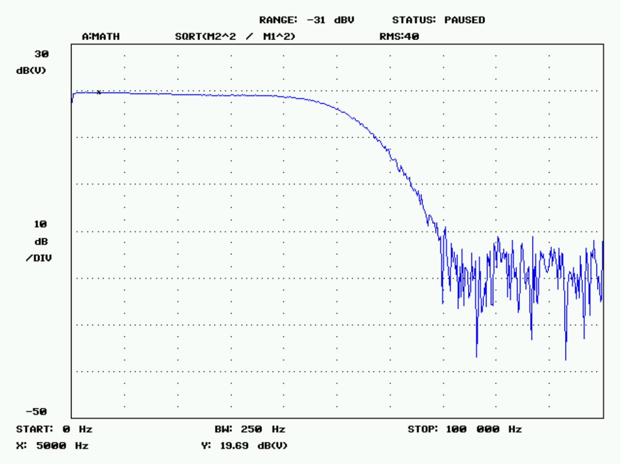

Fig. 4. Output - CHB 20dB gain - fclock = 3.2MHz – fcutoff = 50kHz

Fig. 6 shows the transfer function of CHB (20dB gain) with Antialiasing filter F_{cutoff}=22.05 kHz. The marker at 5 kHz measures 19.51 dB gain that meets the expected tolerance.

Fig. 7 shows the transfer function of CHA with selected 60dB gain with Antialiasing filter F_{cutoff}=50kHz.The marker at 5kHz measures 59.90dB gain that meets the expected tolerance.

Fig. 8 shows the transfer function of CHA with selected 60dB gain with Antialiasing filter F_{cutoff}=22.05 kHz.The marker at 5 kHz measures 59.69 dB gain that meets the expected tolerance.

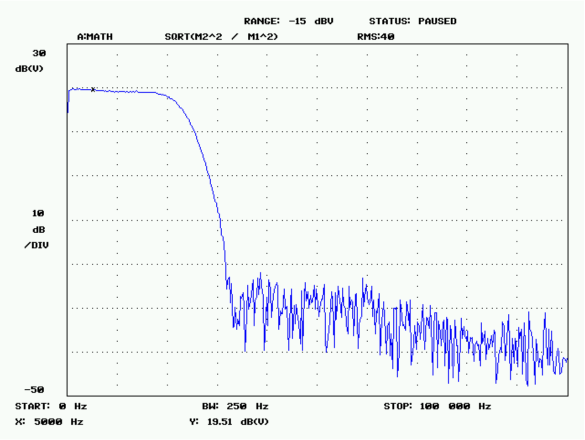

Fig. 5. Output - CHB 20dB gain - fclock = 1.4MHz – fcutoff = 22.05 kHz

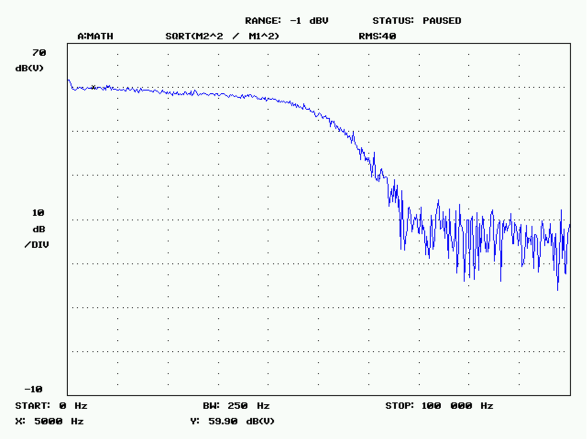

Fig. 6. Output - CHA 60dB gain - fclock = 3.2MHz – fcutoff = 50kHz

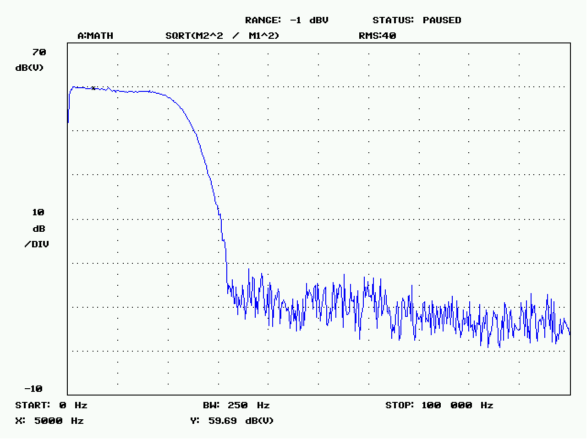

Fig. 7. Output - CHA 60dB gain - fclock = 1.4MHz – fcutoff = 22.05 kHz

Fig. 9 shows the transfer function of CHA with selected 40dB gain with Antialiasing filter F_{cutoff}=50kHz.The marker at 5 kHz measures 40.52 dB gain that meets the expected tolerance.

Fig. 10 shows the transfer function of CHA with selected 40dB gain with Antialiasing filter F_{cutoff}=22.05kHz.The marker at 5 kHz measures 40.36 dB gain that meets the expected tolerance.

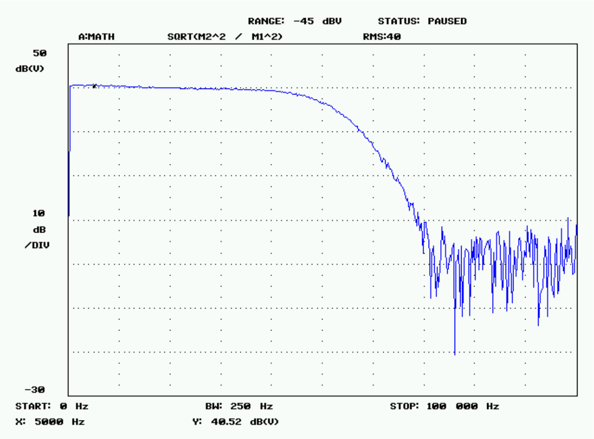

Fig. 8. Output - CHA 40dB gain - fclock = 3.2MHz – fcutoff = 50 kHz

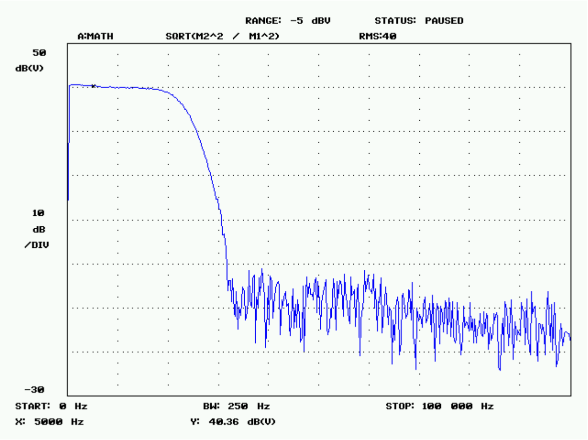

Fig. 9. Output - CHA 40dB gain - fclock = 1.4MHz – fclock = 22.05kHz

III. MUTLIPLATFORM INTEROPERABILITY

A1 and A2 integrate OGC-PUCK with SensorML metadata embedding interface command description, enabling sensor status traceability and plug and play capability for PUCK capable platforms [3,4]. OGC PUCK protocol will be used to retrieve this information from the instrument and also to save selected information to the instruments. This information will be saved in the PUCK payload, and will be based on a SensorML template. Each sensor, platform and actuator developed in NeXOS will have his own SensorML description [5]. The SensorML will be provided inside each system in the PUCK payload as shown in Fig. 10, which can be reconfigured for each new deployment, in any scenarios, by the observatory operator or by the scientist [6].

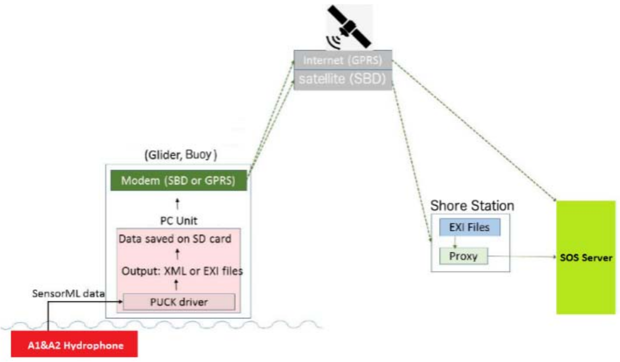

Fig. 10. Standard processes between Marine Sensor Web architecture and components and the A1 and A2 hydrophones

The SensorML documents the sensor system descriptions and provide the configuration for the platforms where A1 or A2 hydrophones are deployed. The host can then use the information from the SensorML inside the PUCK payload to auto configure his operation mode such as: sampling period, auto-manage new sensors connected to his input interfaces, enable output interface (Ethernet, Serial), IP filters, etc.

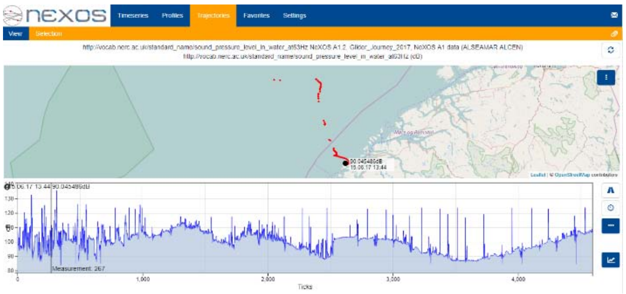

Fig. 11. Real time noise measurements at 63Hz done with the A1 installed on the ALSEAMAR glider at the cost of Norway (June 2017)

At the web side, a driving factor behind the design of the Sensor Web architecture for NeXOS is the provision of a cost-efficient solution that allows data providers to integrate their sensors and sensor data easily into a web-based infrastructure. This aim of a cost-efficient approach is achieved through several characteristics of the architecture: Re-Usability, Interoperability (through the use of international standards) and Open Source. In Figure 12 is depicted an OGC SOS client showing real time noise measurements done with an A1 sensor attached to a glider communicating through Iridium satellite link.

IV. CONCLUSIONS

Two compact low power, low noise digital hydrophone systems with embedded processing, A1 and A2, were developed by the NeXOS project team.

The embedded functions developed for these innovative sensors are: Noise statistics (including EU MSFD indicators), Mammal detection (PAMGUARD), Directional sound source information, Relevant raw data storage in internal memory.

The NeXOS A1 and A2 acoustic systems are designed for mobile platforms such as Gliders / AUVs and can also equip larger platforms such as deep fixed observing systems.

The two acoustic systems allow both industrial and research application for the following environmental measurements: noise from human activities (air guns, shipping noise, etc.), ambient noise and bioacoustics, seismic events.

V. ACKNOWLEDGMENT

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