A new approach to real-time acoustic oceanographic measurements:

Digital hydrophones integrated with oceanographic sensor

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Abstract— **A line of highly innovative products is presented, which particularly addresses acoustical oceanographic measurements, and includes digital hydrophones and digital acoustic arrays. Major features are very low self-noise, wide dynamic range, wide bandwidth, possibly very high working depth, simultaneous non-acoustic data integration (possible options: CTD data, sound velocity and depth, orientation, GPS time and position, etc.), portability and ease of use, and high cost effectiveness. The systems being digital, the digitizer is very close to the hydrophones, which prevents from any electromagnetic interference and signal weakening along cable, even at high frequency. The systems are particularly suitable for ambient noise measurements. The wide bandwidth from 4 Hz to 90 kHz is particularly appropriate for marine mammal survey. Orientation and positioning data are fundamental for array applications aimed to noise source localization. The integration of acoustic data with data from a CTD or from a sound velocity profiler is particularly innovative, and is of major interest to who needs to have both noise and oceanographic survey simultaneously and in real time, along the same deployment, with significant time saving and better knowledge of the environment.**

Keywords—acoustical oceanographic measurements; passive acoustic monitoring; digital underwater measurement system

I. INTRODUCTION

Monitoring the ocean with the aim of protecting and preserving the marine environment in all its aspects is becoming a high-priority objective. One of major issues is to protect wild life against man-made activities. Among the different kinds of pollution produced by mankind and particularly dangerous for marine life there is acoustic noise [1][2][3][4], which at sea can be generated by ship traffic [1][5], but also by the installation of an offshore platform or of a wind farm [6][7][8], as well as by standard, daily activities of a regasification ship or, again, of a wind farm [9]. For such applications, AGUAtech proposes digital hydrophones, which are characterized by very low self noise, immunity from electromagnetic interferences and wideband response.

In many applications the only acoustic measurements are not sufficient for a proper ocean monitoring, and it can be useful to simultaneously measure non-acoustic parameters such as hydrophone depth, water sound velocity, GPS positioning, etc. In order to meet these requirements, AGUAtech presents highly innovative digital integrated measurement systems, which allow real-time acoustic monitoring of the ocean at known depths, by means of one or more hydrophones, possibly along with the simultaneous measurement of oceanographic parameters. The simplest solution is a digital hydrophone equipped only with a depth sensor. One of the most complete solutions, particularly devoted to ship noise measurement, includes three digital hydrophones (each equipped with depth sensor and possibly with sound speed sensor), which can be deployed in a vertical array configuration with variable spacing and variable total length, in order to properly measure noise radiated by ships of different lengths) [2]. Furthermore, a maximum of four synchronous hydrophones can be arranged in a volumetric array configuration for 3D localization of a noise source; in that case pan-tilt-compass sensors can be integrated as well, in order to provide the array orientation.

In this work, a digital hydrophone is proposed which is integrated with a CTD sensor. It was tested in the acoustic and oceanographic measurement facilities of NATO STO-CMRE. It was also used during a sea campaign in August 2012 in the Tirrenian Sea in a 100m-deep water area in front of Livorno; in that case the aim was to collect ambient noise data, as no noise source was present.

II. TYPICAL ACOUSTIC OCEANOGRAPHIC MEASUREMENTS

Generally, before, during and/or after the installation of: wind farms offshore platforms, offshore regasification ships, etc. underwater acoustic noise monitoring is requested. The upmost purposes of this acoustic noise data collection and analysis are the following [9][10]:

- Determine the background noise level in the absence of the major selected noise source(s) to monitor
- Determine noise levels caused by these anthropogenic noise sources,
- Estimate noise frequency composition
- Predict sound propagation in the area on the basis of the data collected
- Predict possible impact on local species of marine mammals.

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These objectives require the simultaneous measurement of oceanographic parameters, such as temperature, salinity, sound speed in water along the water column, along with the geographical position of the underwater measurement system. A typical procedure of noise monitoring [11] consists in the measurements on a dense grid of points around the noise source of:

1) CTD measurement along the whole water column (generally conducted in self-recording mode)
2) Once recovered the CTD, estimate of the SVP curve from CTD data, in order to determine the depth and extension of the main thermocline
3) Finally, deployment of a hydrophone for acoustic noise measurements at a number of fixed depths, generally selected below and above the thermocline. These are data generally used to match with sound propagation simulations in order to estimate noise source levels at the origin and as range varies.

These three actions are conducted in temporal sequence, with the following major consequences (drawbacks):

(a) oceanographic and acoustic data acquisitions are not simultaneous, and when acoustic data are taken, once decided at which depths conduct the measurements, on the basis of the measured SVP, in the meantime the environmental conditions may have changed;

(b) the hydrophone would need a depth sensor transferring its data to a monitor onboard in real time, in order to be sure at what depth acoustic noise is recorded, while hydrophones are generally not equipped with a depth sensor;

(c) making periodic maps of noise generally takes a lot of time in this way, especially if the spatial resolution of the grid of measurement points has to be dense.

III. DIGITAL ACOUSTIC OCEANOGRAPHIC MEASUREMENT SYSTEMS

The main components of the proposed systems (see Fig. 1) consist of: an omnidirectional spherical hydrophone, two low-noise preamplifiers having different gain values, and a digitizer with a 2-channel, ΣΔ, 24-bit A/D converter (192 kHz sampling frequency). The simultaneous acquisition of two channels with different gains allows the user to have a wider dynamic range, and, hence, to collect at the same time either very weak or very strong signals without saturation. The system is equipped with a serial port to which it is possible to connect a non-acoustic device; in this way the acoustic and non-acoustic data are integrated in the same digital data flow towards the dry-end receiver. The receiver can work in stand-alone mode as it is equipped with two D/A converters for analog outputs of acoustic data, and a serial port for the non-acoustic data output. At the same time, the whole data flow can be transferred to a PC through an Ethernet interface for data storage and analysis. The modularity of the system allows the integration of any multi-parameter device or sound velocity profiler with serial output.

In particular the proposed system (Fig. 2) integrates a digital hydrophone with a CTD. It is characterized by the following upmost features:

- Real-time selection of measurement points re. actual thermocline
- Precise hydrophone positioning in the water column
- Continuous data reception through slip-ring on winch.

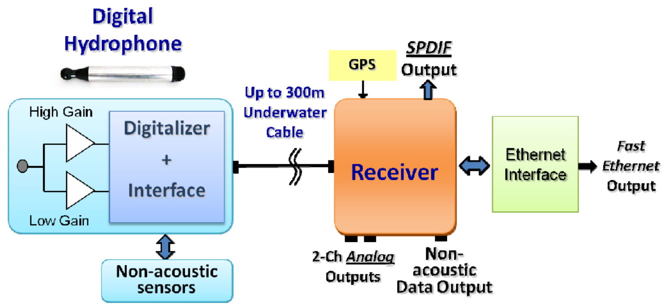

Fig. 1. General block diagram of a digital acoustic oceanographic measurement system, as designed and proposed by AGUAtech.

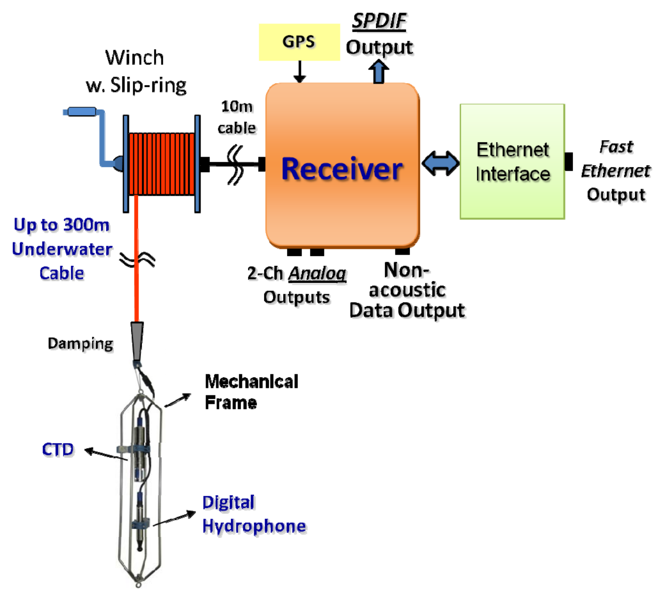

Fig. 2. Block diagram of the integrated CTD-hydrophone digital measurement system.

The new, faster and more accurate measurement procedure, which this system allows the user to apply for mapping ambient noise in a grid of points may become the following:

a) Deploy the system along the water column for SVP estimation (going down)

b) Stop the system close to the seabed

c) From SVP real-time display and analysis during deployment, decide where to conduct acoustic measurement on the way back, for example selecting one depth (D1) above and one depth (D2) below the main thermocline

d) On the way back, stop the system at depth D2 and collect acoustic measurements along a selected number of minutes

e) Then, stop the system at depth D1 and do the same data collection procedure as in *d)*

f) Recover the system.

IV. Results of Tests Conducted in Water Tank and at Sea.

The equivalent input noise of the digital hydrophone was measured in lab. Its curve as frequency varies is shown in Fig. 3 (blue curve) and is the same for the two simultaneous channels. The curves of "0" sea state ambient noise and shipping noise (in the optimistic case of light traffic) are superimposed as a reference (from Wenz): the hydrophone's noise is lower than underwater ambient noise in the whole bandwidth of interest, which means that the hydrophone can sense any kind of underwater noise which may occur at sea.

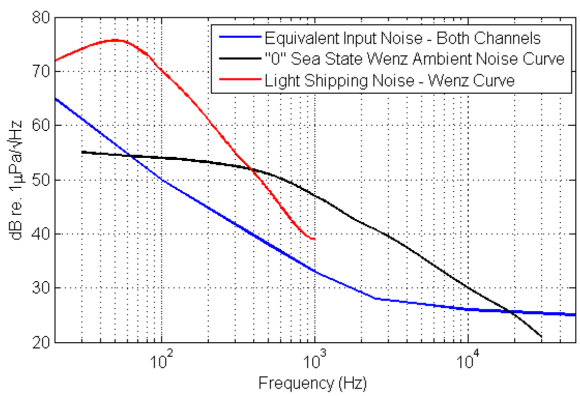

Fig. 3. Equivalent input noise of AGUAtech digital hydrophone, as measured in lab. Representative Wenz curves of sea ambient noise are superimpose as a reference .

The digital hydrophone of the integrated system was calibrated in terms of its receiving sensitivity at CMRE in a water tank. Sensitivity curves were computed for both low gain and high gain channels of the hydrophone. Calibration was performed by comparison method by using a calibrated reference analog hydrophone (RESON TC4034); the digital hydrophone was acquired through the analog outputs of its digital receiver, after D/A conversion, in order to collect data with a common acquisition system.

The hydrophone calibration results are shown in Figs. 4 and 5. The curves in Fig. 4 refer to the high-gain channel of the hydrophone. At high gain the hydrophone sensitivity is compared when the hydrophone is deployed in water without its frame while the CTD was on and off (top plot), and when it is inside its protective frame along with the CTD (mid plot), again while the CTD was on and off. There is no influence at all by the CTD in the measured bandwidth. Comparison of the sensitivity curve when the hydrophone is alone or within the frame along with the CTD is shown in the bottom plot of Fig. 4. This aims at quantifying the influence of the frame and of the CTD case on the hydrophone response. As expected, there is a certain influence (reflections from the mechanical structures) which causes a deviation from the reference curve (hydrophone alone) of a maximum of 4 dB. This may slightly vary with the aspect of the frame with respect to the a major noise source.

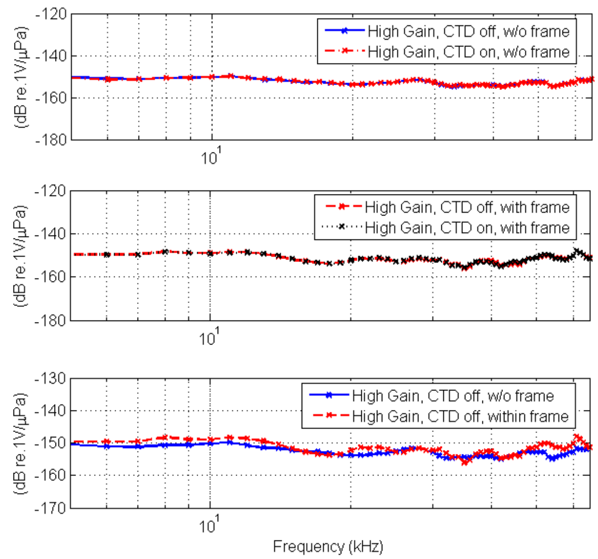

Fig. 4. Sensitivity curve of hydrophone (high-gain) measured under various conditions.

Figure 5 shows the sensitivity curves of the hydrophone's low and high gains, when the hydrophone was suspended within the whole integrated system, with the CTD off. The two curves are identical, apart from the sensitivity shift (constant with frequency), corresponding to the difference between the two gain values (36 dB).

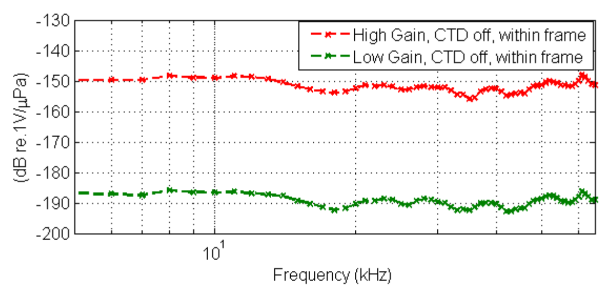

Fig. 5. Measured sensitivity curve of the hydrophone high-gain and low gain while the hydrophone is within the mechanical frame.

The possible influence of the mechanical frame and of the hydrophone on the CTD measurements (conductivity in particular) was verified in the oceanographic calibration tank of CMRE. First the CTD was tested in stand-alone mode within the calibration tank. Later it was tested as connected to the whole system and included in its frame along with the hydrophone. Hence, in this latter case, CTD data were integrated with the acoustic data and sent to the system receiver in a digital data flow. A slight influence in conductivity can be outlined in Fig. 6, which causes a slight different value of the sound speed in water between the two conditions. In the test the water temperature was 23.44o and the water was salted (salinity=38.8 ppt). Table 1 shows the mean and standard deviation of the measurements shown in Fig. 6. The variability is within the sensor accuracy. The effects of the presence of the frame on conductivity is such that the sound speed change can be considered negligible from acoustic point of view.

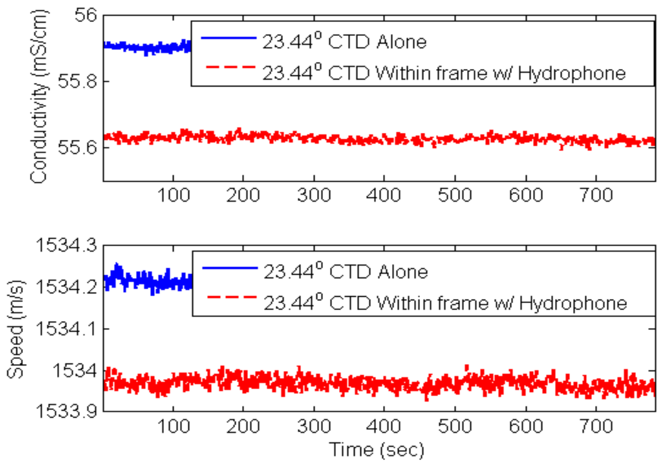

Fig. 6. Electrical conductivity (top plot) measured in the oceanographic calibration facility at CMRE under different conditions (stand-alone and along with the whole system). Estimate of the sound speed in water (bottom plot).

TABLE I. MEAN AND STANDARD DEVIATION OF CONDUCTIVITY AND SOUND SPEED MEASUREMENTS SHOWN IN FIG. 6.

Variable	**Mean value**		**Standard deviation Alone**	
	Alone	*w/ whole system*	*Alone*	*w/ whole system*
Conductivity (mS/cm)	55.90	55.626	0.009	0.01
Sound Speed (m/s)	1534.21	1533.97	0.014	0.015

The system was also tested at sea from CETUS catamaran (August 2012, Livorno area, Italy) in an area with water depth varying between 70 and 200 m. The measurement procedure proposed in Section 2 was adopted on that occasion. As an example, the measured SVP and the PSD function of noise recorded at two depths (one below and one above the thermocline) in one of the measurement locations are shown in Fig. 7.

V. DISCUSSION

Laboratory test results show that the presence of the protective frame around the sensors causes a change in the measured conductivity which can be considered negligible from an acoustic point of view. In any case if the sensor calibration is conducted with the sensor inside the cage, in the same operational conditions adopted at sea, even this small influence could be taken into account and would not affect the final result.

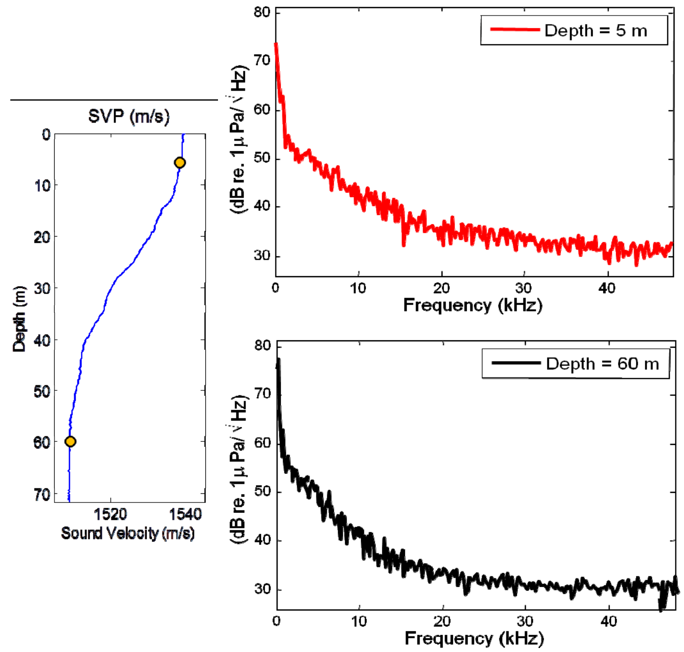

Fig. 7. Measured SVP (left side), and curves of power spectral density function in the frequency range (0, 50] kHz computed on 2 minutes long recordings of ambient noise, collected at two depths (right side). The weather was good and sea state around 1.5.

As expected the hydrophone response is influenced by the presence of the protection frame at high frequency (mainly above 50 kHz, where the acoustic wavelength starts to be comparable to the cross-section diameter of the frame bars). Such influence may slightly depend on the frame orientation with respect to the source-hydrophone axis. It should be either reduced as much as possible in the bar dimensions, or changed with a more compact design of the digital measurement system including both the hydrophone and the oceanographic sensors, clamped to a rope to which a final ballast can be hung.

Among the major features emphasized during at-sea experiments, there is the system portability: the device resulted very easy to use and deploy at sea from a relatively small boat with one or two operators. The operations were straightforward and fast, so that many measurement points in the map grid could be completed in short time (less than half an hour per measurement point, including deployment, 6 minute-long environmental/acoustic measurements at three different depths, and recovery).

Real-time data display of both acoustic and non acoustic data was very useful in order to immediately check the quality of the whole set of data, and to log possible crossings of boats or other acoustic events in the surroundings.

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REFERENCES

[1] Richardson, W.J., Greene, C.R.J., Malme, C.I., Thomson, D.H., Marine Mammals and Noise, Academic Press, San Diego, 1995.

[2] Van der Graaf, A.J., Ainslie, M.A., André, M., Brensing, K., Dalen, J., Dekeling, R.P.A., Robinson, S., Tasker, M.L., Thomsen, F., Werner, S., European Marine Strategy Framework Directive-Good Environmental Status (MSFD GES), Report of the EU Technical Subgroup on Underwater Noise and Other Forms of Energy, 2012.

[3] Carey, W., Sound sources and levels in the ocean, WHOI Report.

[4] Popper, A.N., Fewtrell, J., Smith, M.E., McCauley, R.D., Anthropogenic Sound: Effects on the Behavior and Physiology of Fishes, Marine Technology Society Journal, 37 (4), pp. 35-40, 2003.

[5] National Oceanic and Atmospheric Administration (NOAA), Shipping Noise and Marine Mammals: A Forum for Science, Management, and Technology, International Symposium, Arlington, Virginia, 2004.

[6] Bailey, H., Senior, B., Simmons, D., Rusinb, J., Pickenc, G., Thompson, P.M., Assessing underwater noise levels during pile-driving at an offshore windfarm and its potential effects on marine mammals, Marine Pollution Bulletin 60, pp. 888–897, 2010.

[7] De Jong, C.A.F., Ainslie, M.A., Underwater radiated noise due to the piling for the Q7 offshore wind park, Acoustics'08, 2008.

[8] Nedwell, J., Langworthy J., Howell, D., Assessment of sub-sea acoustic noise and vibration from offshore wind turbines and its impact on marine wildlife; initial measurements of underwater noise during construction of offshore windfarms, and comparison with background noise, COWRIE Report, 544 R 0424, 2003.

[9] Nedwell, J., Howell, D., A review of offshore windfarm related underwater noise sources. Cowrie Report, 544 R 0308, 2004.

[10] Robinson, S.P., Lepper, P.A., Theobald, P.D., Ablitt, J., Hayman, G., Beamiss G.,A., and Dible S., A methodology for the measurement of radiated noise from marine piling, In UAM Int. Conf., Greece, 2009.

[11] Pavan, G., Fossati, C., Caltavuturo, G., Linee guida per la riduzione dell'impatto del rumore di origine antropica sull'ambiente marino e sui mammiferi marini in particolare, CIBRA-UniPavia Report, 2011.