A NOVEL LOW-POWER HIGH SPEED ACCURATE AND PRECISE DAQ WITH EMBEDDED ARTIFICIAL INTELLIGENCE FOR LONG TERM BIODIVERSITY SURVEY

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ABSTRACT

Acoustic monitoring is a key feature for studying biodiversity. Recent works on very high frequency animal sounds open new insights and challenges on biodiversity survey. In order to set a scaled monitoring, and to cover most of the frequencies of the present species, a novel multi-channel ultra high velocity recorder has been designed, called Qualilife HighBlue. This paper presents its architecture and characteristics. One of its most innovative features is an always-on ultra-low power wake-up, triggering recordings when temporal and/or spectral interesting events are detected. For this task, shallow neural networks are embedded for advanced pattern detection, as well as mixed signal features extractors. Several communications devices are implemented, and the system can be customised. Multiple deployments of this monitoring system over the world are presented in this paper to demonstrate its robustness, versatility and efficiency.

1. INTRODUCTION

Acoustic monitoring is a key feature for studying biodiversity. Recent works on very high frequency animal sounds (such as those emitted by dolphins *Inia g.*), coupled with fast movements (such as bats) are a real challenges for non disturbing passive monitoring with advanced features.

In order to set a scaled monitoring, and to cover most of the frequencies of the species, a novel multi-channel ultra high velocity recorder, called Qualilife HighBlue (QHB) has been designed, composed of a motherboard coupled with daughter-boards (Fig.1).

During long-term bio-acoustic survey (Fig.2), a regular time interval recording for soundscape analysis is required, plus the recording of some specific events, as some animals that are sparsely present. Therefore, we developed, for reducing data storage size and power consumption, the innovative feature always-on ultra-low power wake-up. It triggers recordings when temporal and/or spectral patterns of interest are detected. It makes the most of 3 types of circuits that can be used for embedded Artificial Intelligence (AI) implementation, each one having a different magnitude of power consumption (Fig.3).

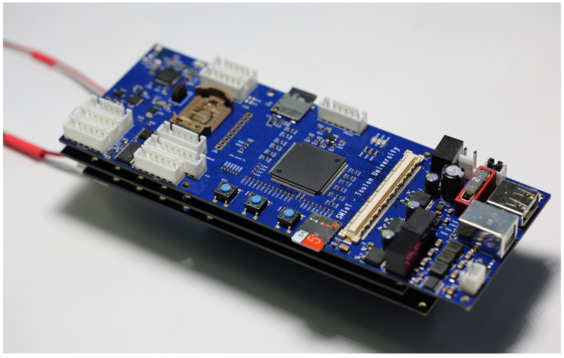

Figure 1. QHB plugged to 2 daughter-boards.

This ultra-low power always-on detector allows the high performance acoustic recorder to enter an ultra-low power mode with a power consumption lower than 100 μW. It significantly extends battery life, as well as storage capacity, as only useful data is stored.

This QHB DAQ, with different sensor combinations, is being used in several projects across the world as described below. Some applications are running for 3 years (we called its prototype 'QHB1' or JASON).

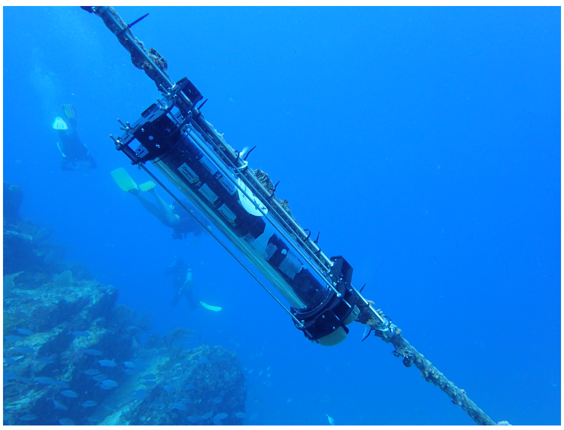

Figure 2. QHB tube, Caribbeans (Photo J. Bernus).

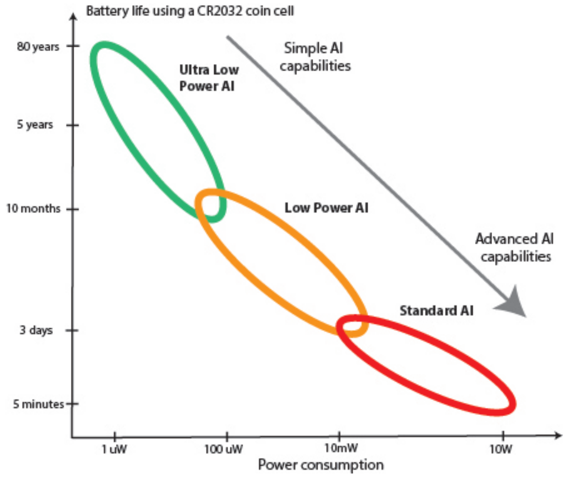

Figure 3. Different types of embedded AI according to their power consumption.

2. SYSTEM ARCHITECTURE

QHB electronics block diagram (Fig.4) is based on 3 independent systems connected between them using serial interfaces. They can be used for implementing different levels of AI on the edge, each one having different applications and power consumption (Fig.3):

a) an Ultra-low power detector, always-on acoustic wake-up system, power consumption of 40 μW. It aims at detecting abnormal or target acoustic events to wake-up and start high frequency recorder. It is an ultra low-power wake-up [1–3]. However, unlike [4] where only analog parts are used, or [5] where only a digital microcontroller is used without external analog circuitry, it makes the most of the combination between ultra-low power analog circuits and the *sensor controller* [6] of an ultra-low power system on chip (SoC) (Section 4).

b) a Recording Manager middle stage of power consumption, based on *TI CC2652R1* SoC [7], which interfaces two sensors integrated on the board: an Inertial Measurement Unit (IMU), and a Real Time Clock Calendar (RTCC) by SPI. It stores data on a SD card, and communicates by *Bluetooth Low Energy* (BLE). It is in charge of managing records, enabling the High Frequency Recorder system. It can be configured to record in time intervals, or when defined time-frequency patterns are detected. These methods allow a global ultra-low power consumption without relevant data loss.

c) a High frequency recorder, higher power, 24 bits 5-channels recorder, based on a *Microchip PIC32* microcontroller [8]. It ables to compute deep-learning signal analysis using an embedded GPU. Recordings have an excellent quality with high Sampling Rate (SR) in several channels, however, power consumption is higher than 1.8 W. Its high temporal resolution (*512 ksps*), precise channels synchronisation, and multiple sensors (such as IMU), has a maximum jitter of one sample, that means less than 2 μs at $f_s = 512\ kHz$. This allows accurate further processing of the signal and is a key for locating animal in the wild, and for identifying them reliably. This recorder is controlled by the Recording Manager system, reducing drastically its average power consumption compared to an always-on recorder. Active less than 0.05% of the time in real conditions, it extends the battery life of the recorder by a factor 2000 reducing it average power consumption to less than 1 mW. This allows a drastic battery and overall size reduction, easing its installation and maintenance while reducing its cost (Section 3).

3. HIGH PERFORMANCE RECORDER

QHB high frequency recorder features up to five 24 bits channels operating at 512 ksps each. They are implemented on daughter-boards (Fig.6), each one having 2 channels. It is possible to use several daughter-boards at the same time. Each channel input is compliant with :

- Differential input for lowering transmission noise from the microphone to the recording system, especially in harsh electromagnetic environment.
- Single 3.3 V inputs for standard hydrophones or microphones such as $CR55, 57, 75, 305$ (Cetacean Research Tech. (CRT)).
- Input superposed on power supply for specific microphones or hydrophones such as *SQ26* (Sensor Tech.).
- A high quality charge amplifier can be added for connecting passive piezo-electric sensors such as *CR3* (CRT).

Each channel features a high pass filter having a cut-off frequency of $f_C = 0.5\ Hz$, for centring signal. They can also include an amplification that can be adjusted upon request in hardware. Using ultra low noise differential amplifiers, analog front end has a very high signal noise ratio equal to 104 dB (tested with a full scale 10 kHz sine wave in input). Total harmonic distortion is equal to $-106\ dB$ at half-scale signal amplitude.

Each channel also includes an anti-aliasing filter. The Fig.5 shows a chirp test signal from 1 *Hz* to 1 *MHz*, recorded at 512 $ksps$. Recorded signal has a constant amplitude on all the bandwidth. This one is limited to $fc = 256\ kHz$ by the anti-aliasing filter. Anti-aliasing filter is a high performance switch capacitors one, more efficient than a 5^{th} order low pass filter. This filter is automatically tuned according to sampling frequency.

Signals from each channels are synchronised with a precision equal to the sampling period. These signals can also be synchronised with sensors controlled by the Recording Manager (such as Inertial Measurement Unit) with a time precision of one sample of any type of sensor thanks to a novel synchronisation mechanism based on comparative arrival time detection on each microcontroller. This paves the way towards high precision tracking of animals, even

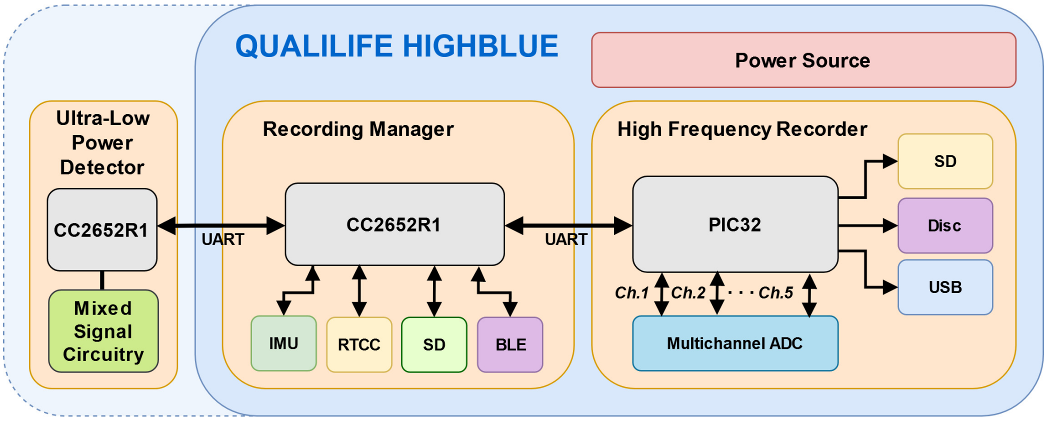

Figure 4. QHB electronics blocks diagram.

	Sampling Frequency							
	64 ksps		128 ksps		256 ksps		512 ksps	
	Data Rate [GB/h]	Power [W]	Data Rate [GB/h]	Power [W]	Data Rate [GB/h]	Power [W]	Data Rate [GB/h]	Power [W]
1 Channel SD Card	0.69	1.8	1.38	1.9	2.76	2.1	5.52	2.5
2 Channels SD Card	1.38	1.9	2.76	2.2	5.52	2.5	11.04 (lossy)	2.8
4 Channels SD Card	2.76	2.5	5.52	2.8	11.04 (lossy)	3.0	22.05 (lossy)	3.1
5 Channels SD Card	3.45	2.7	6.91	3.0	13.82 (lossy)	3.2	27.64 (lossy)	3.2
1 Channel USB Drive	0.69	4.1	1.38	4.0	2.76	3.8	5.52	4.0
2 Channels USB Drive	1.38	4.0	2.76	3.8	5.52	3.9	11.04	4.2
4 Channels USB Drive	2.76	3.9	5.52	4.1	11.04	4.4	22.05	4.6
5 Channels USB Drive	3.45	4.0	6.91	4.3	13.82	4.6	27.64	4.8

Table 1. Data rates and measured power consumption for 24-bits operation of QHB recorder on a HDD or SD Card storage.

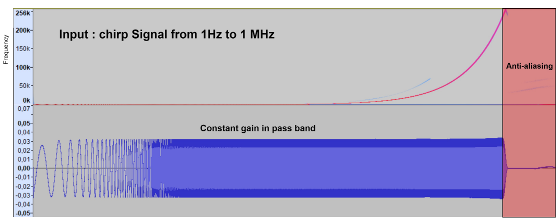

Figure 5. Spectrogram and signal of a chirp test from 1 Hz to 1 MHz recorded on QHB.

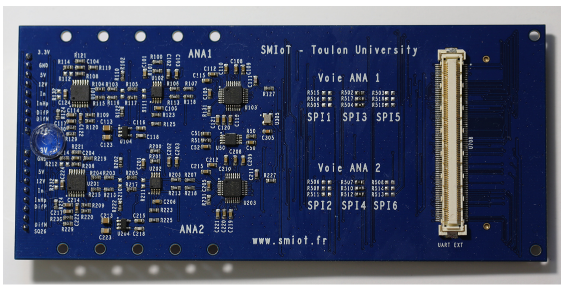

Figure 6. Qualilife HighBlue daughter-board.

in difficult conditions such as recordings from a buoy or a boat in swell.

Power consumption and data rate in recording mode depends on the number of channel used and on the recording media. The Tab.1 shows power consumption including storage medium one. This explains why power consumption is smaller using (μ)SD cards than with hard drive disks (HDD). Using SD cards for data storage have also a drawback : some data losses can occur at data rates higher than 10 GB per hour. Using HDD allows to reach higher data rates, going up to 27 GB per hour with 5 24-bits channels at 512 ksps per channel (Tab.1). For higher frequency applications, more than 1 *Msps* with 16-bit resolution can be achieved using a special daughter-board (Section 5.2).

There is a trade-off between power consumption and maximum data rate: depending on application, one of both solution can be chosen by the user.

QHB can be scheduled, allowing to put the system in sleep mode in order to extend battery life and long term storage. However, this extension is not a real one because system doesn't record nor detect anything during sleep mode. In order to cope with this problem, an additional ultra low power (less than 100 μW) always-on smart wake-up module based on mix analog and digital feature extraction and analysis can been added as an option (Section 4).

4. ULTRA-LOW POWER ALWAYS-ON SMART WAKE-UP FOR LONG-TERM SURVEYS

As in most bio-environmental surveys animals are rarely present, it in not always energy aware to record acoustic signal all the time. Doing scheduled recordings can be an improvement with some species, for example for nocturnal animals, but the best would be to record data when animals are present or suspected to be there. This is the purpose of the ultra-low power mixed signal always-on wake-up electronics, proposed as an option, for triggering high power recordings (Section 3). Its architecture (Fig.8) makes the most of the combination of ultra-low power analog circuits and the peripherals of the SoC *CC2652R1* from *Texas Instruments*. In particular, we use the *sensor controller* integrated in this chip, able to perform synchronous tasks with an ultra-low power consumption.

Prototype circuit board (Fig.7) consists of a set of ultra-low power analog primitives connected between themselves and to the inputs and outputs of the sensor-controller embedded in the CC2652 chip. Among the analog primitives implemented are :
- Charge amplifiers for amplifying piezo-electric sensors and hydrophones,
- Ultra-low power configurable filters that can be used as a filter bank allowing to detect several species in parallel,
- Peak detectors,
- Comparators.

These analog primitives, coupled with the sensor controller are used for extracting features from the signal.

In addition to the sensor controller, CC2652R1 SoC also embeds an ARM M4F microcontroller, allowing to implement expert rules state machines using extracted features, such as pulse duration, spectrum, noise level, signal level etc.

Both these detection stages allow an efficient always-on pattern identification with ultra-low power consumption. ARM M4F microcontroller is in sleep mode until a feature has been extracted and identified as characteristic of a given species. The mixed-signal circuitry and the sensor controller are always-on, allowing continuous pattern detection with a power consumption of less than 100 μW.

This system is essential for extending battery life, as most of the time recording targets are not present. Furthermore, the size of storage medium is not negligible when

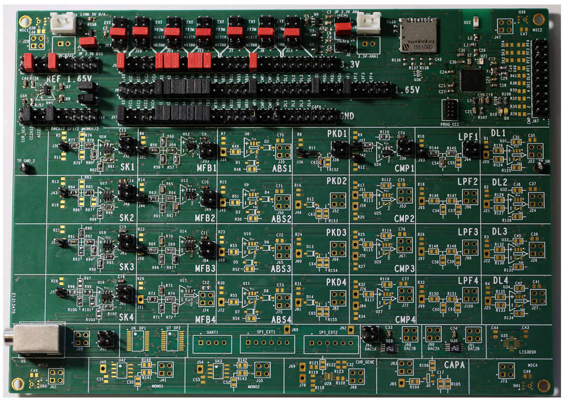

Figure 7. Ultra-low power detector prototype board.

SR is 512 *ksps* for five channels with a resolution of 24-bits. The storage medium, a SSD disk or (μ)SD card, may run out of storage space rapidly with useless data if the ultra-low power detector is not used. For these reasons this system is integrated in QHB.

5. APPLICATIONS

These improvements open the road for advanced bio-acoustic long term studies, and have been adopted by many bio-environmental agencies throughout the world presented in the next subsections. Some presented sound samples are available at `http://sabiod.org/qhb`.

5.1 Bat recordings

Bat calls can range form 10 to more than 100 *kHz*. Fig.9 shows a recording made with QHB with chirps of up to 100 kHz. High sampling of QHB allows bat 3D tracking over 20 m range by small antenna [9].

5.2 QHB reveals details of ultra high frequency biosonar in Amazon River

QHB1 is used in Amazon for research on river dolphins, like Pink Dolphin *Inia geoffrensis, (I.g.)* since 2016. They emit a very high frequency sonar for localisation into the dark water of the Amazon river. Our recordings at 1 MHz SR by QHB in the wild demonstrate that *I.g.* emits biosonar up to 450 kHz [10, 11]. The previous observations were limited at 500 kHz SR [12], thus at half of the *I.g.* bandwidth.

5.3 Surveys of marine traffic or orca communication

The QHB1 has been successfully deployed in Scandola UNESCO reserve in 2017 to monitor boat traffic and birds, but also cetaceans (Fig.11, [13]).

A similar application in 2019 has been conducted at OrcaLab, Canada, to segregate calls from Orcas with 4 small aperture hydrophone array (Fig.11, [14]).

5.4 QHB portable antenna for near field observation

Based on QHB1s we developed methods to localise and segregate nearly all the clicks emitted by a group of Sperm

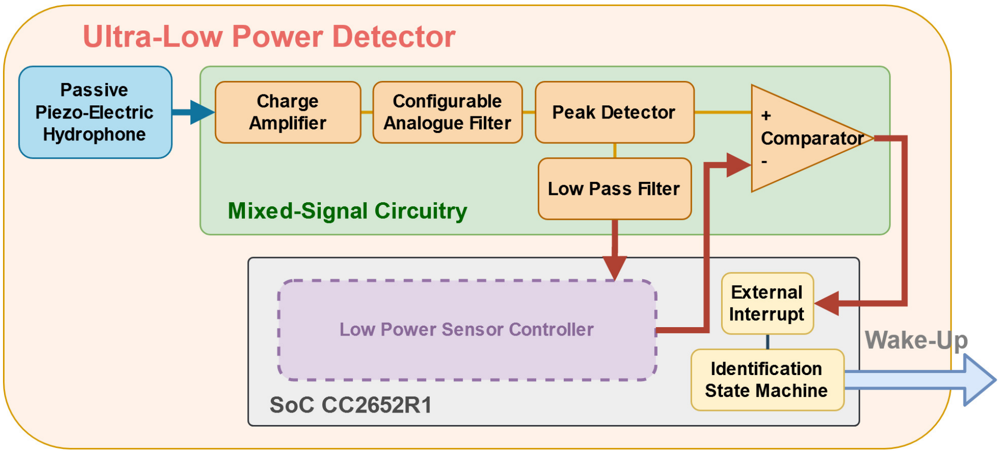

Figure 8. Ultra-low power mixed signal always-on smart wake-up blocks diagram.

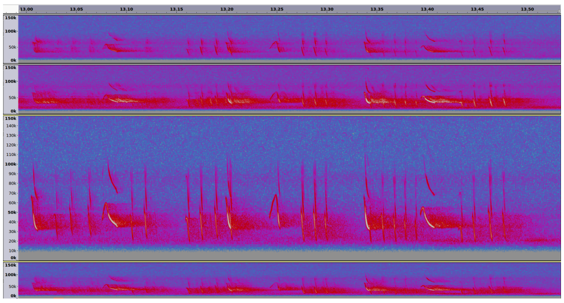

Figure 9. QHB1 record of Chiroptera in 4 channels at 512 ksps 16 bits using SMIoT microphones. It shows chirps up to 100 kHz (H.G., Bananes Vertes Ecolodges, Guadeloupe, 20181231).

whales ([15]), recorded by a portable hydrophone array (Fig.13). This method yields to the first characterization of the growth curves of this biggest toothed cetacean and opens avenues to look for acoustic individual signature.

5.5 Caribbeans large scale survey

A fourth of the world's 80 cetacean species have been observed in the waters of the Caribbean islands and the AGOA Sanctuary. There are huge issues at stake across the Caribbean and internationally, to reconcile their protection. Thus, we answered and have been selected by the EU Interreg Feder CARIMAM project (`https://www.interreg-caraibes.com/carimam`), to design and build twenty low cost robust QHB tubes (Fig.2) deployed in 2020 in this network for marine mammal conservation in the Wider Caribbean region and beyond. It results in the largest international bioacoustic observatory along 6000 km over several a dozen of nations, instrumented homogeneously, allowing joint studies. The project after its first year will yield to 100 TB of high definition biodiversity recordings, from the lowest frequency (Blue whale, 20 Hz), to the highest (*Kogia b.*, higher than 100 kHz).

5.6 Autonomous Laboratory Vehicle

The Sphyrna Odyssey 2018-2020 was composed of 2 Autonomous Laboratory Vehicles (ALV) (Fig.15), each instrumented with QHB1 and a small aperture 5-hydrophone array fixed under the keel. Thus we recorded during months the megafauna of Med. Sea, 384 kHz SR x 5. The ALV's hydrodynamic quality joint to QHB high velocity allow detailed acoustic observations and individual diarization for the study of free range animals communications (Fig.16). One major result [16] is the 3D tracking by passive acoustics of cachalots (*Physeter m.*) and the first description of their group behaviour in the abyss, at more than 3 km range, one position per second, in groups up to 4 animals clicking together and for the first time shown to hunt together. We also observe correlation between temporal patterns of the predator's biosonar and the halocline [16].

6. CONCLUSION : TOWARDS EMBEDDED AI

We proposed, designed built and tested a novel 'smart', robust, low cost DAQ that may help biodiversity surveys. Current works are conducted towards edge embedded AI joint into QHB, as AI is increasingly applied to bioacoustics ([17] and after). One example is the 'intelligent' sonobuoy Bombyx-2 [18] designed to automatically detect endangered species and send 4G alert messages with direction and range of the animal. It aims to prevent whale-ship collision. It is based on long term survey and integrated AI in QHB. Other research programs are developed in terrestrial survey for Avian, Chiroptera and other monitoring within an IoT framework.

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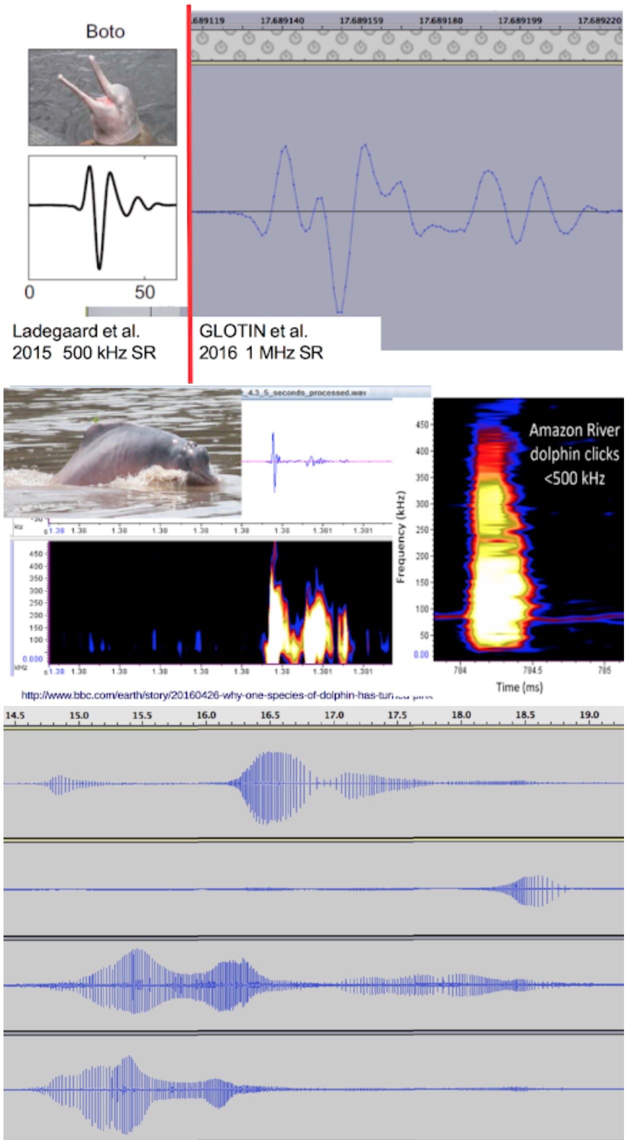

Figure 10. Recording of *I.g.* by QHB1 at 4 x 1 MHz 16 bits. This demonstrates for the first time their clicks higher than 450 kHz, and their precise wave form. The amplitude modulation difference across channels is due to the beam pattern of *I.g.* and the directivity of the hydrophones at the nodes of a regular tetrahedron of 2 m edge (H.G. et al, Amazon river, Iquitos, Peru 2016).

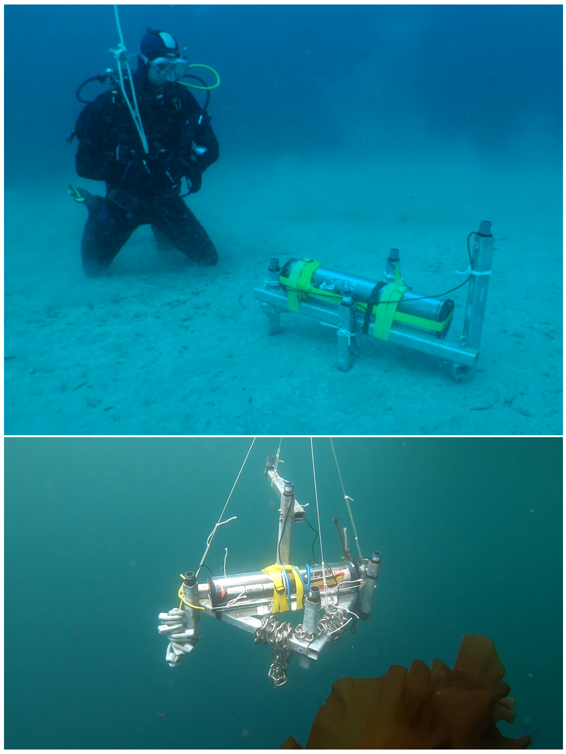

Figure 11. QHB portable array: small hydrophone aperture (max 77 cm) is enough to track boat traffic because the high velocity of QHB gives good Difference of Angle observability (design & real. H.G.). (Top) With 4 SQ26 and alkaline batteries, QHB fills up 1 TB HDD in few days (UNESCO World Reserve Scandola, 2017). (Bottom) QHB with 5 SQ26, later powered from shore by 75 m cable protected by a garden hose, for months of sparse recording and analyses of orcas cocktail parties at 4 x 192 kHz SR (M. Poupard & H.G., OrcaLab, Canada, 2019).

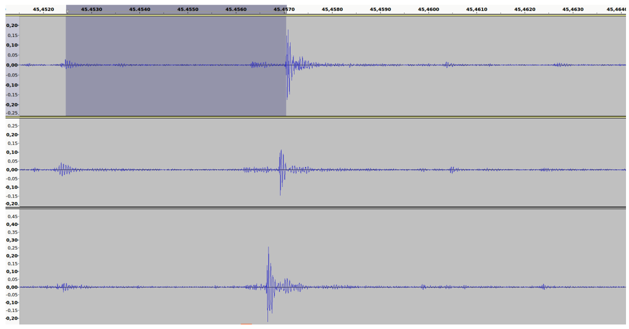

Figure 12. *Physeter m.* recorded from Scandola UNESCO World Heritage Reserve by QHB1, probably 5 km away into the Canyon of Girolata (H.G. 2018).

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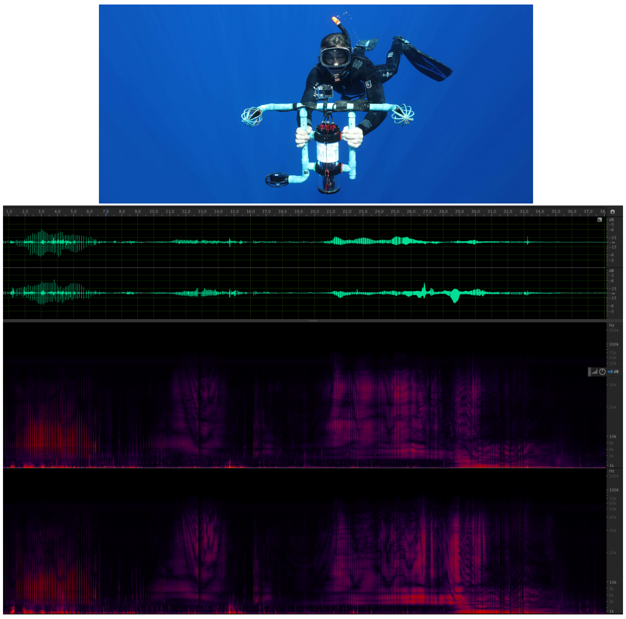

Figure 13. (Top) F. Sarano holding the QHB1 antenna, with 2 CR57 spaced by 60 cm, at the bottom a CR305 (design & real. H.G., Photo F. Guerin). (Bottom) Spectrogram of *Physeter m.* recorded by the 2 CR57 in near field with this antenna, 300 kHz SR 16 bits, showing clicks up to 50 kHz (Mauritius, 2018041, Image M. Mercier).

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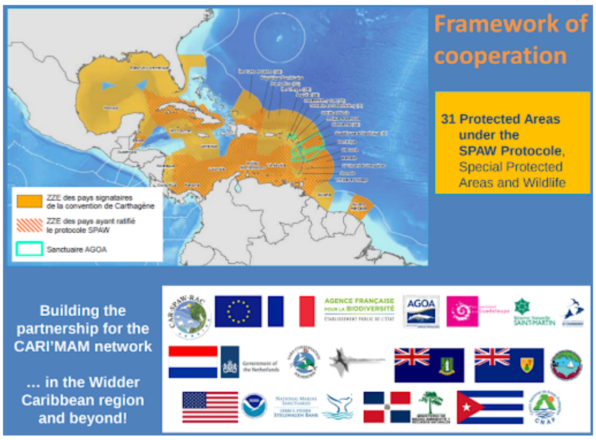

Figure 14. Deployment of 20 QHB tubes : the 1st international high definition large scale biodiversity observatory.

Figure 15. The ALV Sphyrna embedding QHB1 (Port-Cros nat. park, 2018.)

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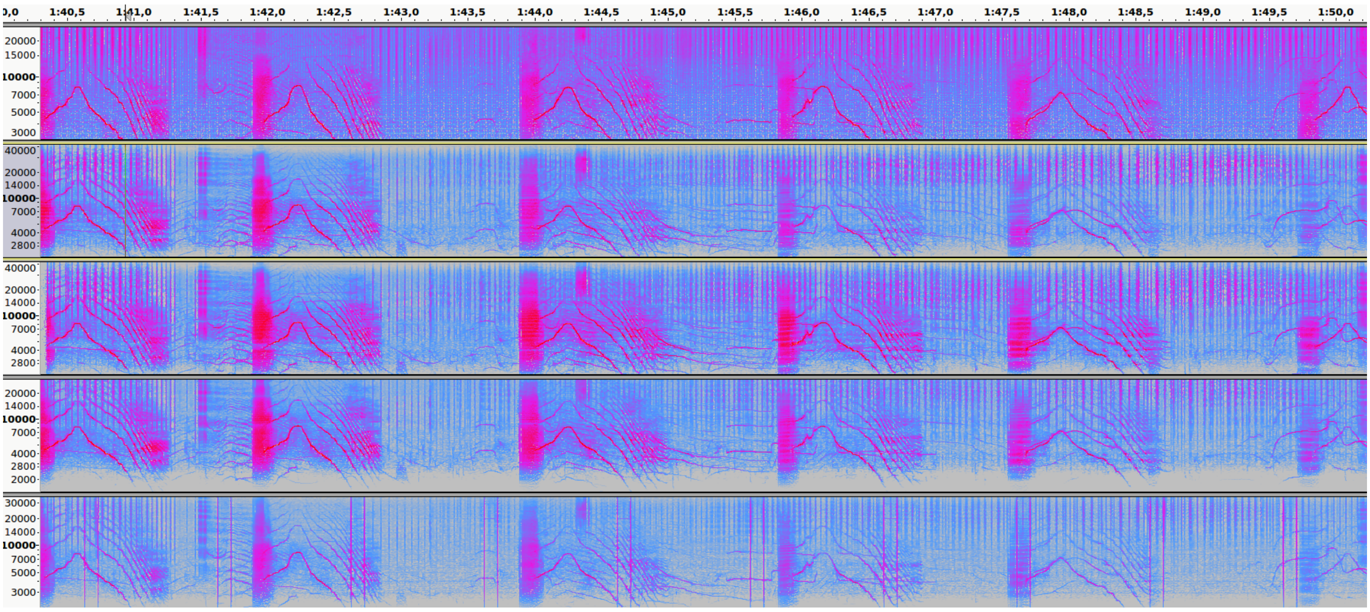

Figure 16. Example of recording of voicings and clicks of a group of Pilot whales (*Globicephala m.*) by QHB1, (4 CR57+ 1 CR75) x 384 kHz SR 16 bits, from ASV Sphyrna Odyssey (Med. Sea, Golf du Lion 2019, M. Poupard & H.G. et al [16]).

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