Passive and Active Sonar Applications for a Non-Uniform and Low Cost Linear Array

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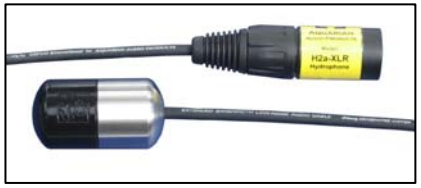
Outline

- Hydrophones:
  - Specifics
  - Acoustic characterization (air)
- Measurement system
  - Array of hydrophones
  - Audio equipment
- Array: acoustic characterization
- Array applications:
  - “Passive mode”: DOA estimation;
  - “Active mode”: Target research and identification
- Conclusion

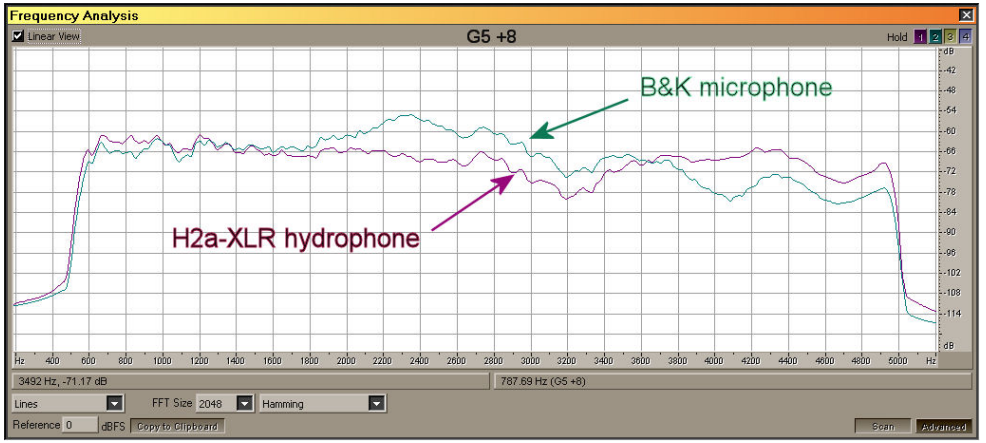
Hydrophones

- *Aquarian Audio H2a-XLR" hydrophone (www.aqaud.com):*



  - low-cost;
  - small dimension (25mm x 46mm);
  - wide range of employment (10 Hz ÷ 100 kHz);
  - easily interfaced with commercial audio devices (+48V phantom power required).

- *Acoustic characterization (air): B&K 4189 Vs H2a-XLR*:
  - Test signal: Linear sine sweep (0.5 ÷ 5 kHz);
  - H = H(Amplifier + Speaker + Medium + Transducer)
  - Frequency responses are comparable!



Array of receivers

- *"Aquarian Audio H2a-XLR" hydrophones array.*

- *10 low-cost omnidirectional hydrophones* were mounted on a 2m long aluminum frame;
- *increasing distance between receivers (NULA)* [*-0.875, -0.455, -0.250, -0.105, -0.035, +0.035, +0.105, +0.250, +0.455, +0.875 meter, w.r.t. the center*];
- *Flexible mounting system* that allows to change easily the transducers positions in according to different design strategies

Audio equipment

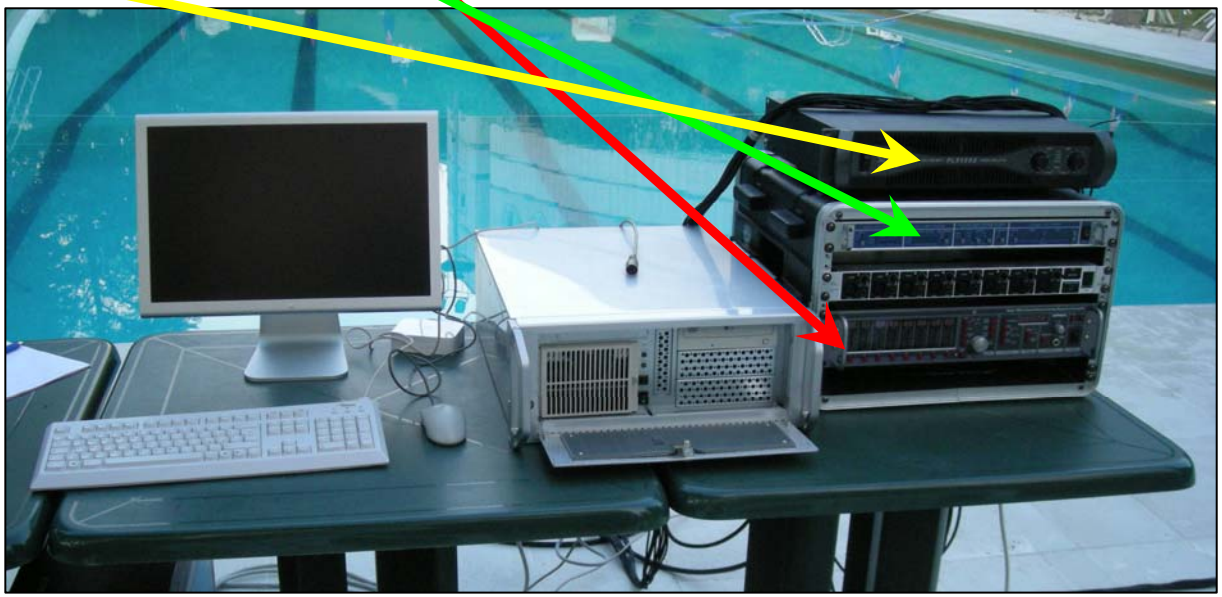
- *Measurement "chain" (8-channels): audio devices*

Receiving system:

- *APHEX 1788* high precision microphone preamplifier with ADAT outputs (8 channels, Fs = 96 kHz);
- *RME AD648* ADAT to MADI converter (max 64 channels);

Transmitting system:

- *QSC PLX-1202* power amplifier



Audio equipment

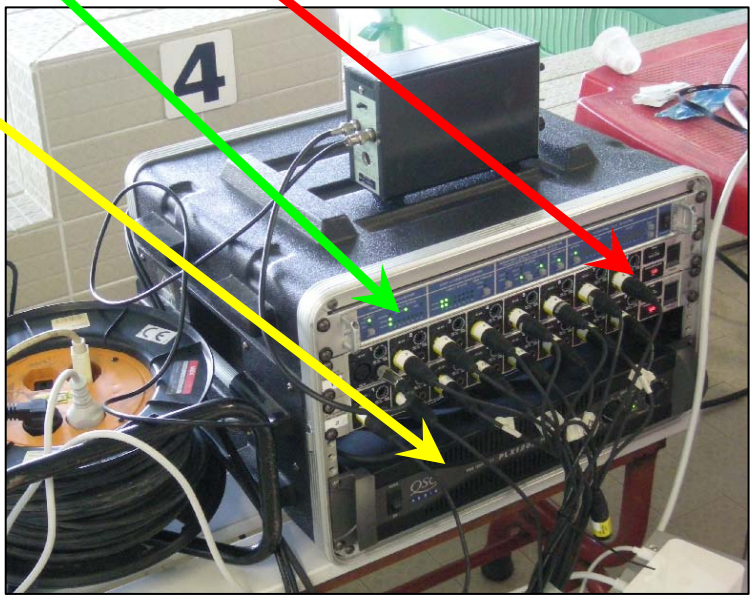
- *Measurement "chain" (16-channels): audio devices*

Receiving system:

- *N°2 Behringer Ultragain PRO-8 DIGITAL ADA8000* microphone preamplifier with ADAT outputs (8 channels, Fs = 48 kHz);
- *RME AD648* ADAT to MADI converter (max 64 channels);

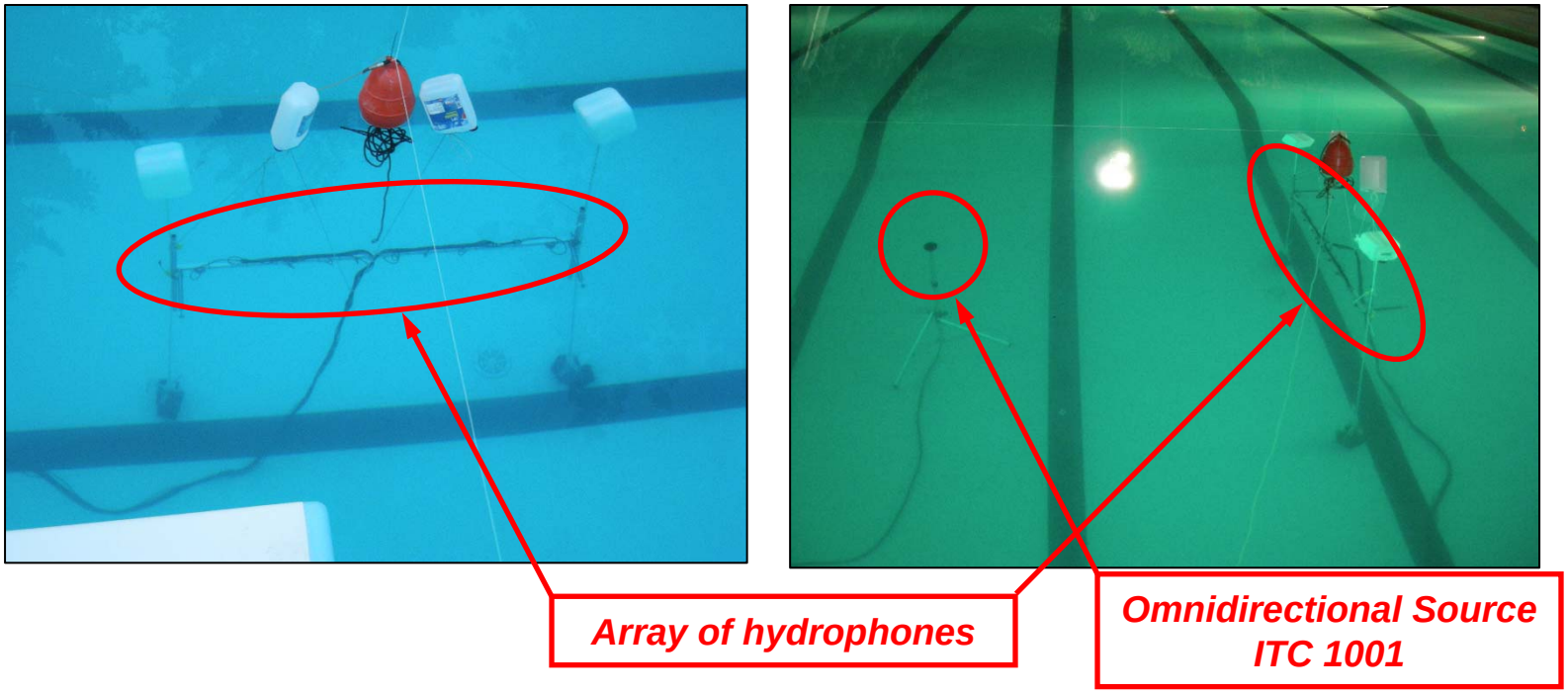
Transmitting system:

- *QSC PLX-1202* power amplifier



Acoustic characterization of the array

To characterize the acoustic behavior of the array of receivers, the equipment (omnidirectional source and array) was set on the flat bottom of a large and 3.8 m deep pool.



- Test signal: long linear sine sweep (1÷23 kHz).

Acoustic characterization of the array

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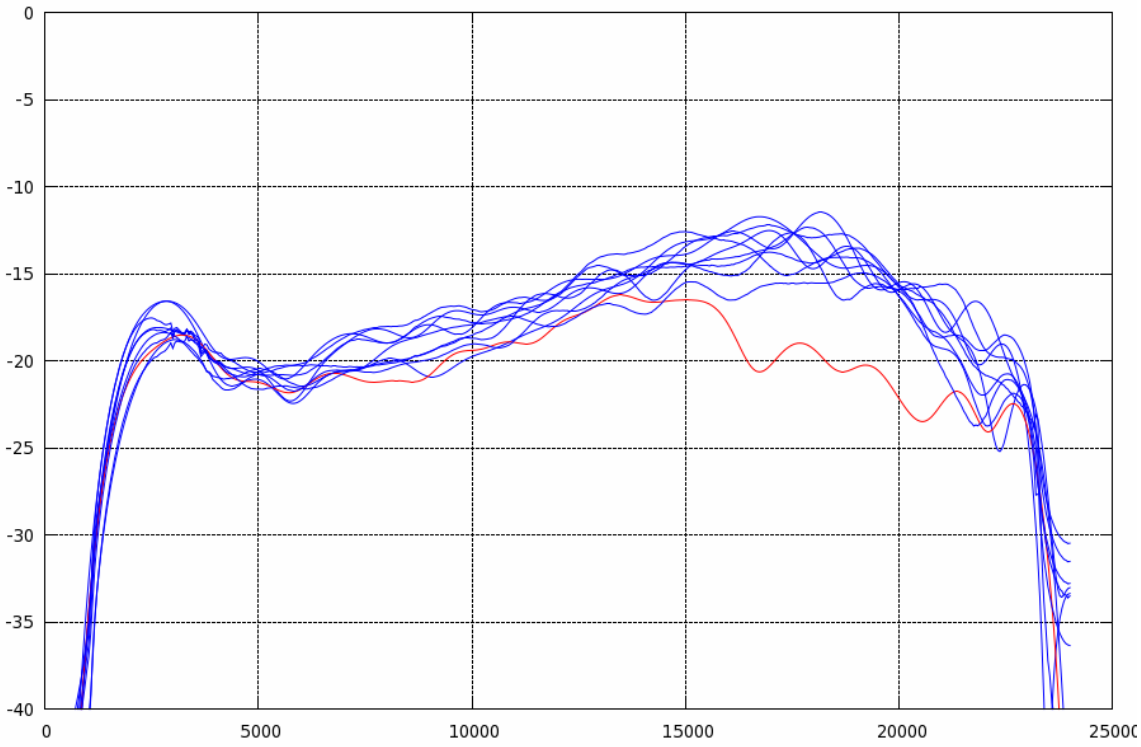
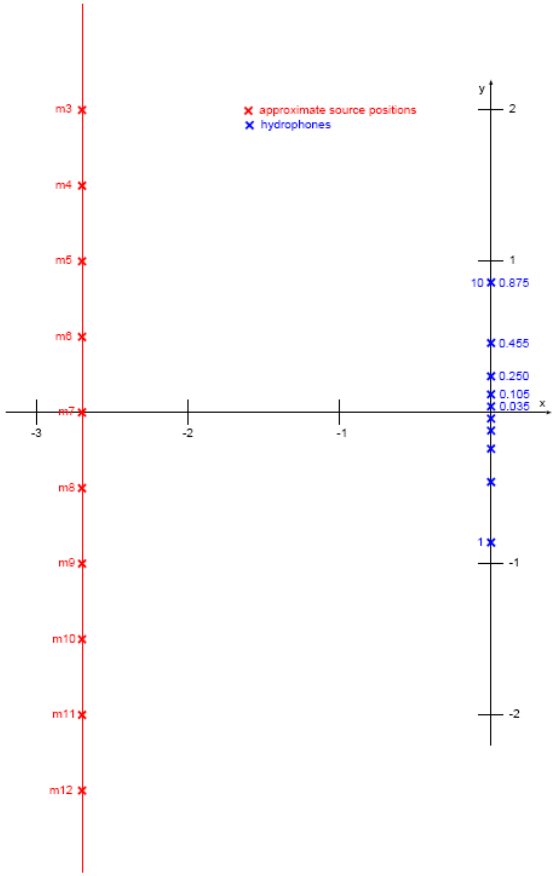
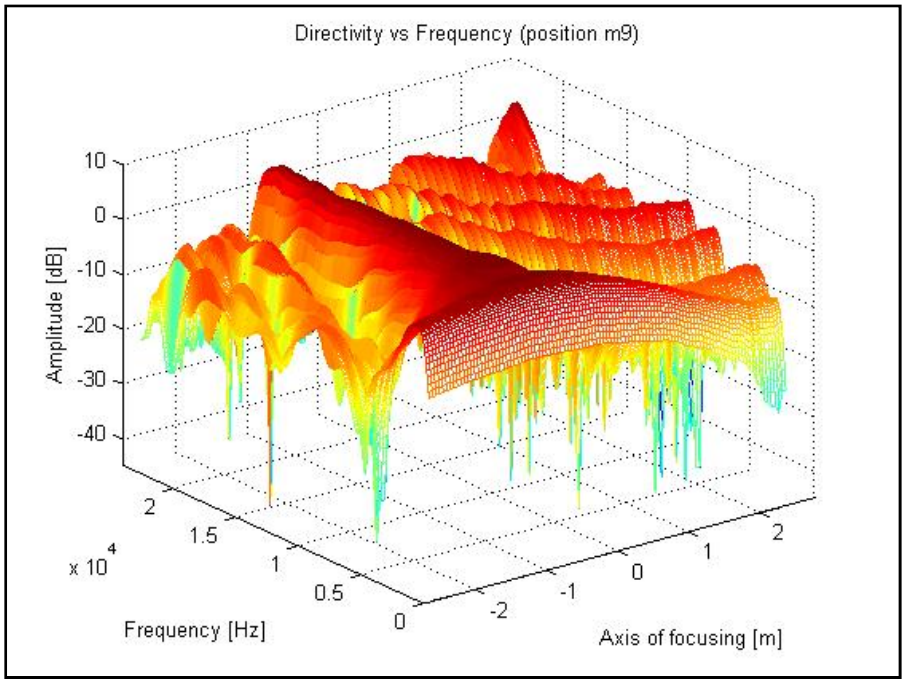


- Frequency responses of the ten hydrophones are very similar except for one transducer (shown in red) that has a higher attenuation at frequencies over 15 kHz

Acoustic characterization of the array

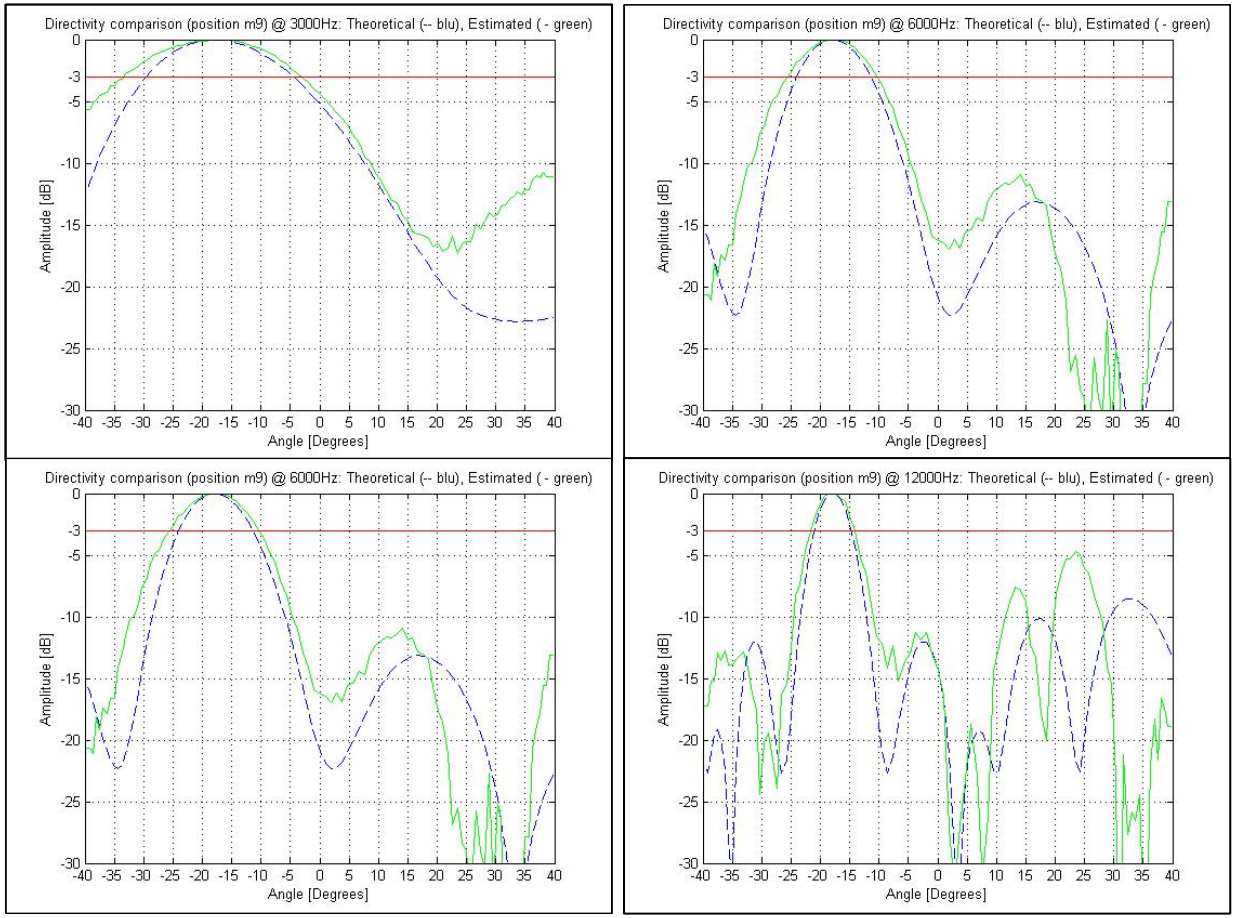
- Distance between planes containing source and array is equal to 3 m;
- source placed in 7 different positions (m4÷m10) in front, on left and on right of the array centre;
- estimated directivity using real measures and beamforming (step 5cm).





Acoustic characterization of the array

Comparison between theoretical (blu) and estimated (green) directivity, position m4, m7, m9 @ freq. 3, 6, 9 and 12 kHz.



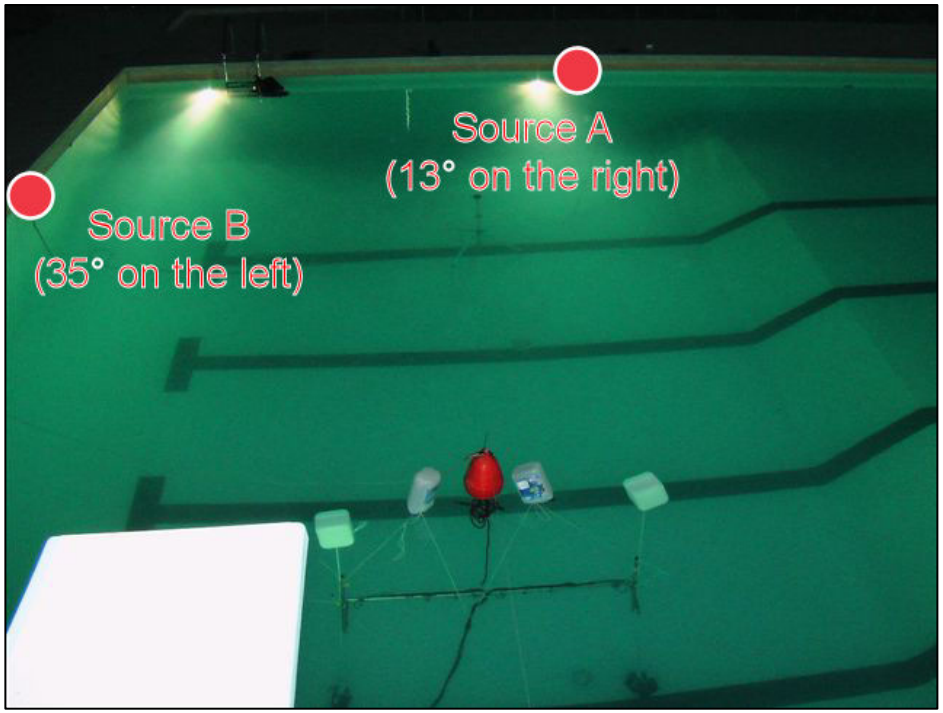
"Passive mode": DOA estimation

- Test oriented to estimate the capability of the system to find the direction of arrival of the sound (DOA).

Sound Source:
sound generated ramming simultaneously two iron plates in the water in two different positions:

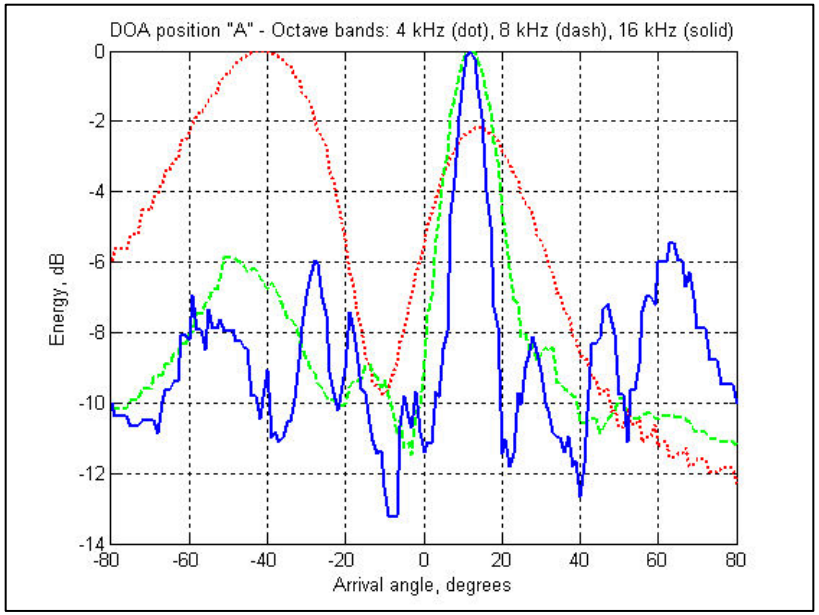
- *Position A* (13° on the right);
- *Position B* (35° on the left);

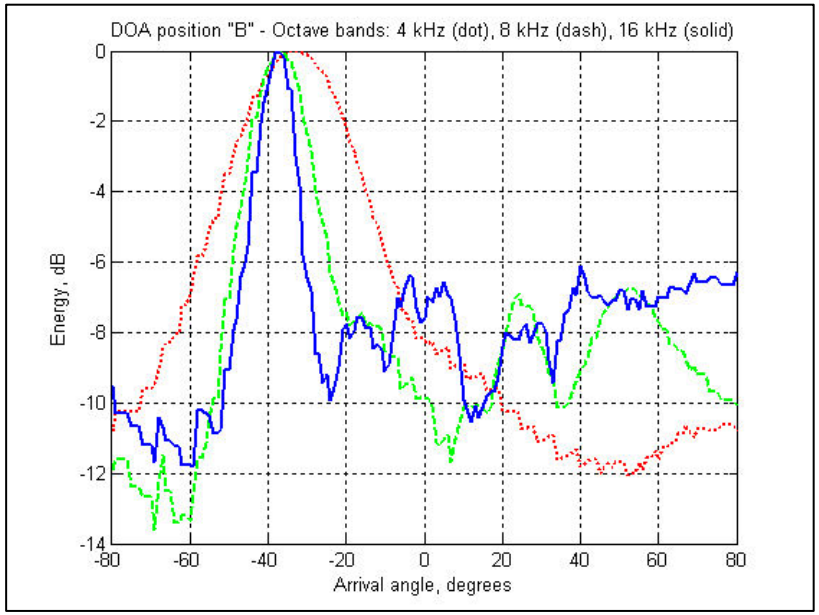
Post-processing based on:
- Inverse filtering
- Beamforming (step of 1°)



"Passive mode": DOA estimation

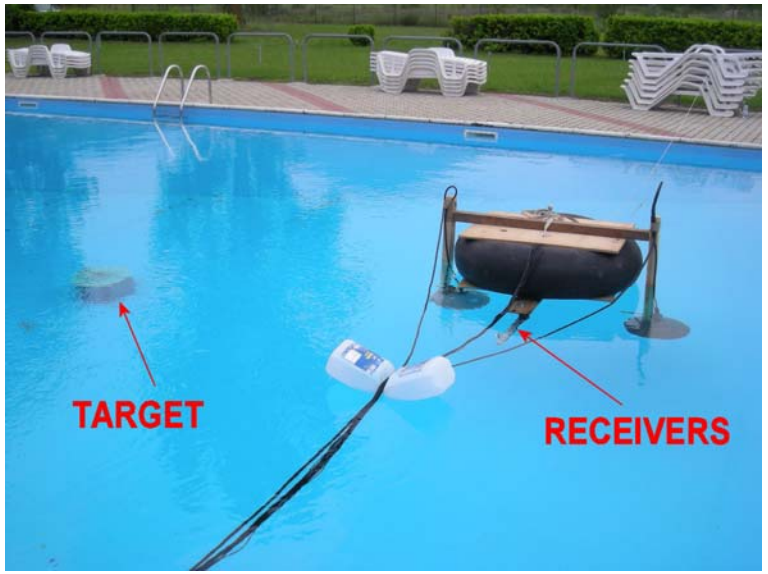
- Analysis was performed in octave bands and the most significant results were obtained in the 4, 8 and 16 kHz bands.
- Confined environment (swimming pool) ⇒ reflections on the walls.
  - *Position A:* effects noticeable at low frequencies (4 kHz band), a broad lobe is present at around -40°, caused by reflections on the lateral wall. This "false image" disappears with increasing frequency because it increases the array directivity.
  - *Position B:* it is apparent only direct sound, reflections are not appreciable.





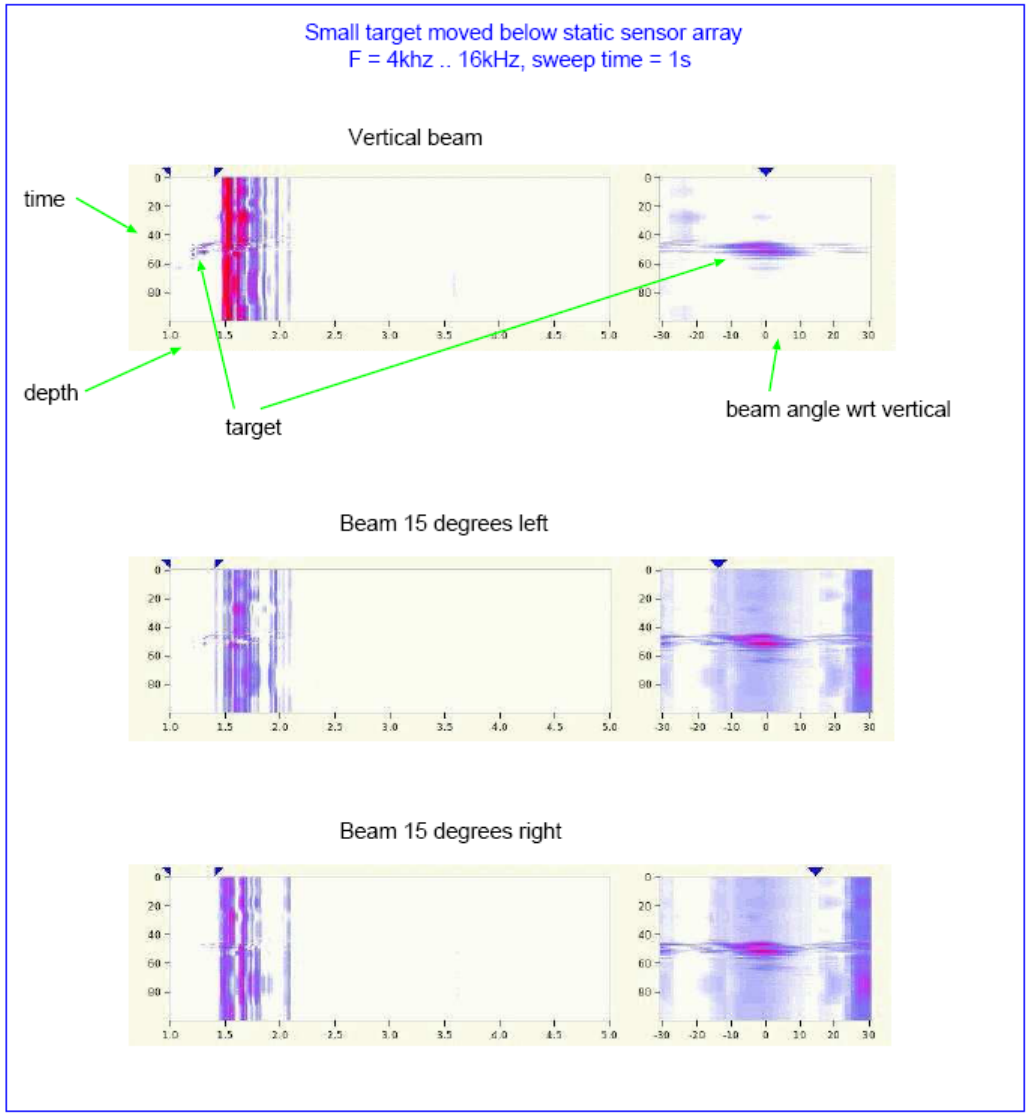
“Active mode”: target research

To discover submerged objects inside a large pool (2 m deep) and to test array and the new real-time software (by Fons Adriansen).



- Equipment (1 source and “array” of receivers) mounted on a special “raft” and object was pulled under the raft with uniform speed.
- Test signal: linear sine sweep.

“Active mode”: target research



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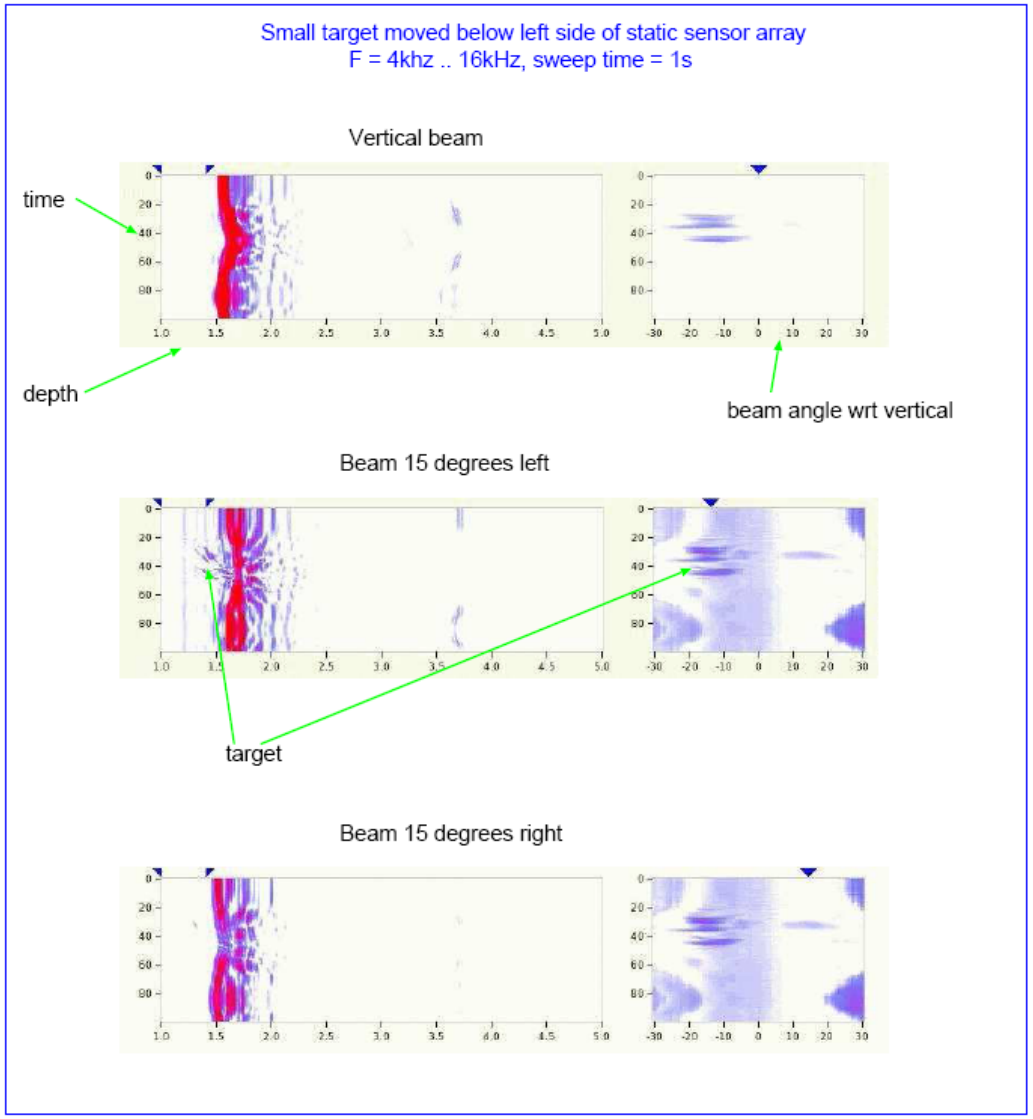

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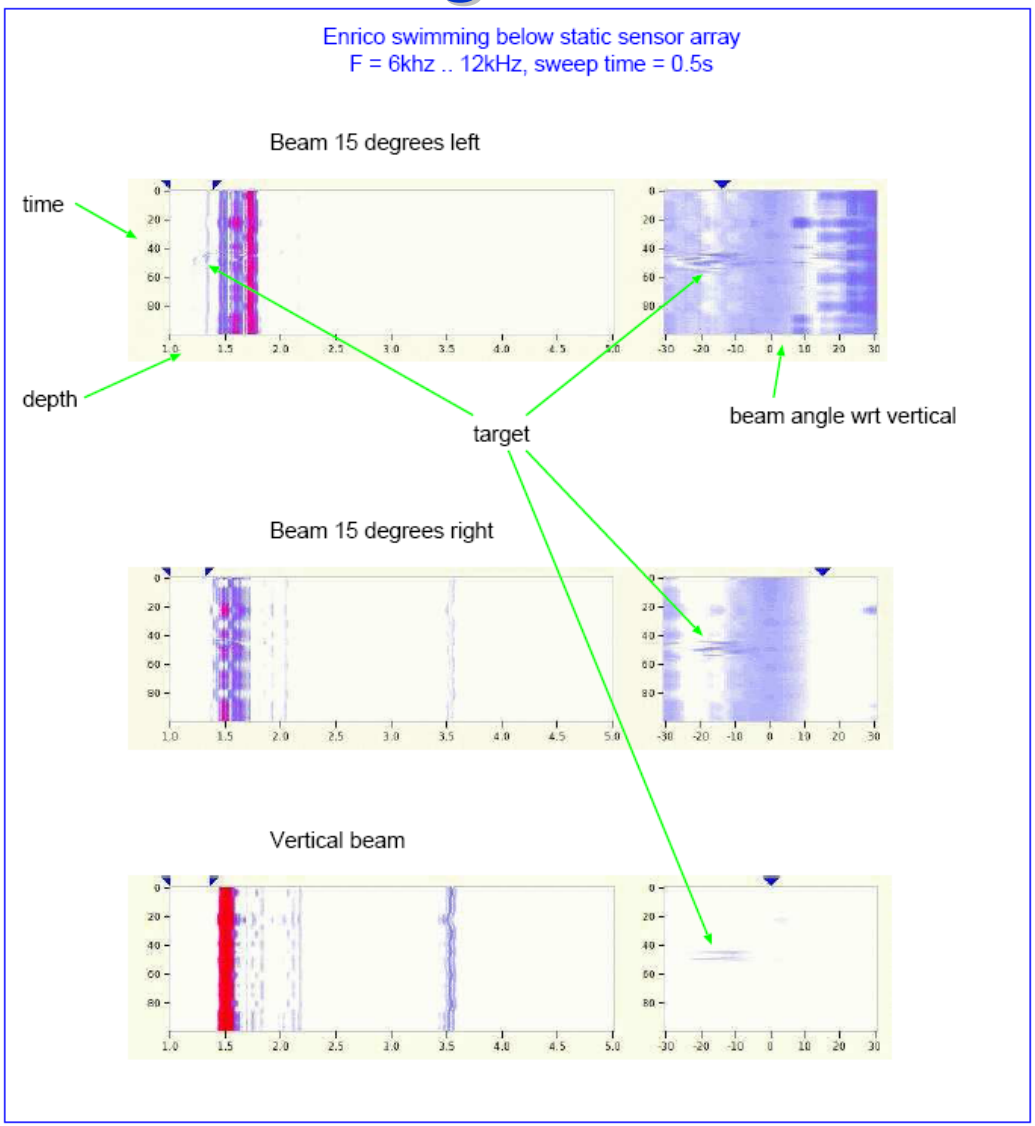
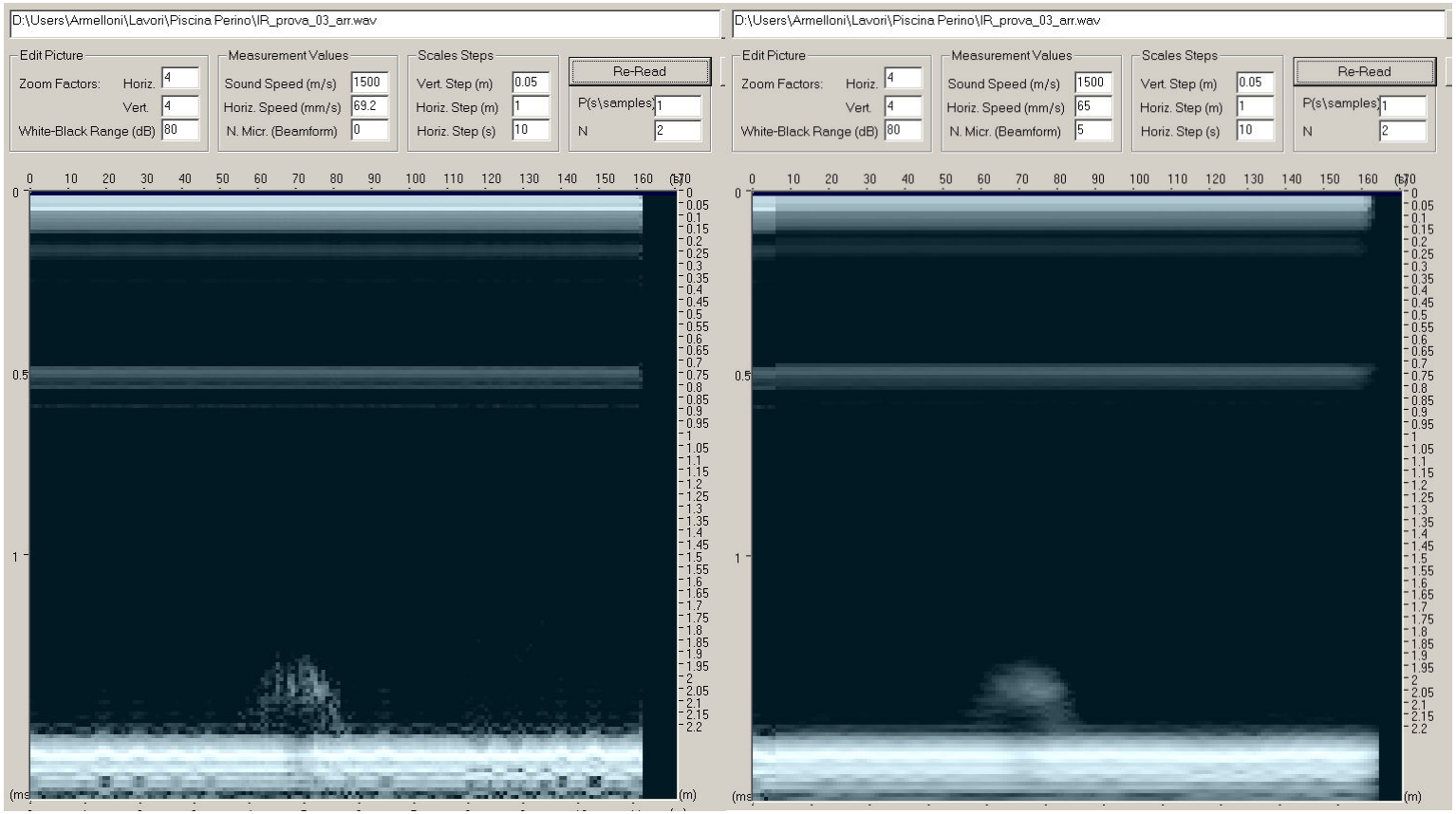


"Active mode": target research

"virtual" beamforming making use of a number of adjacent impulse responses (optimal results ⇔ virtual array of 5 mic.).



Measure *without* beamforming (left) and *with* fixed focalization at 2.0 m (right).

"Active mode": target research

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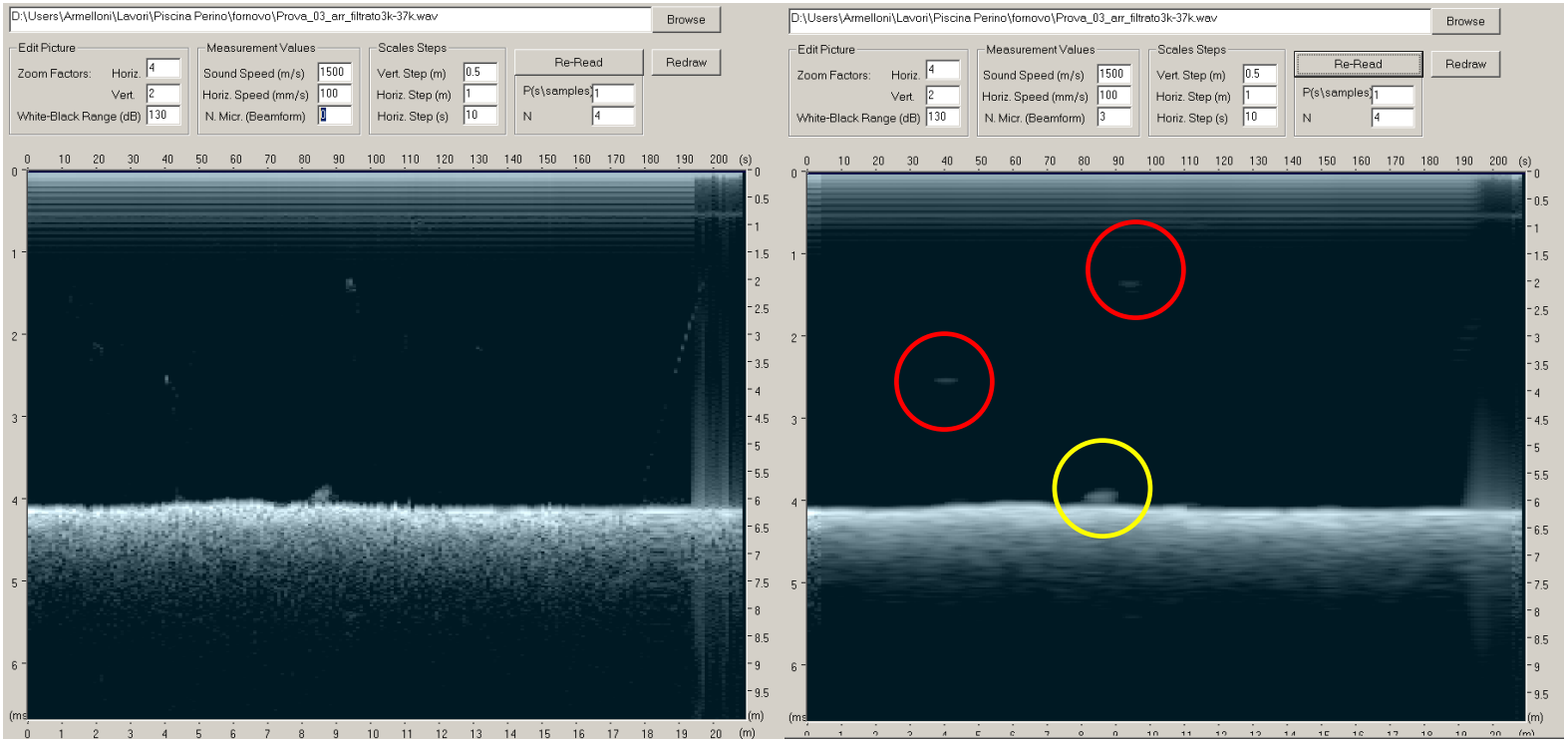
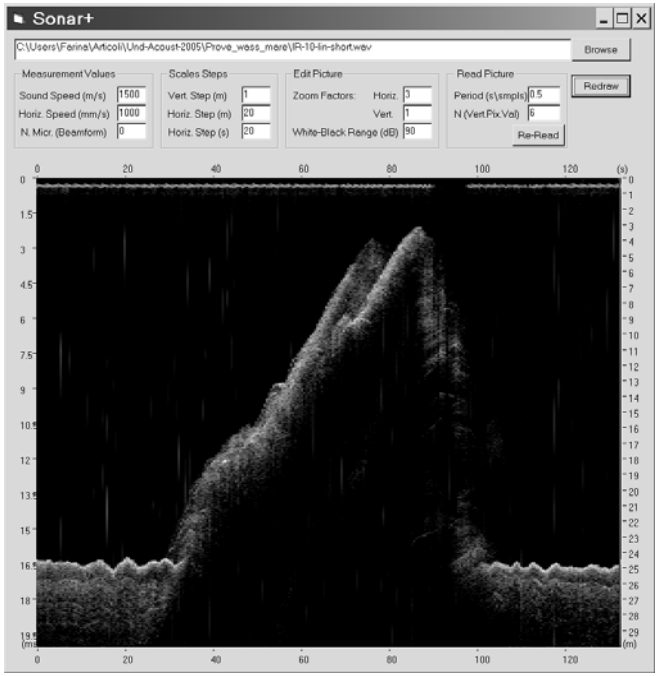


Lake depth = 6.20 m and *Target height* = 0.35 m.

“Active mode”: target research

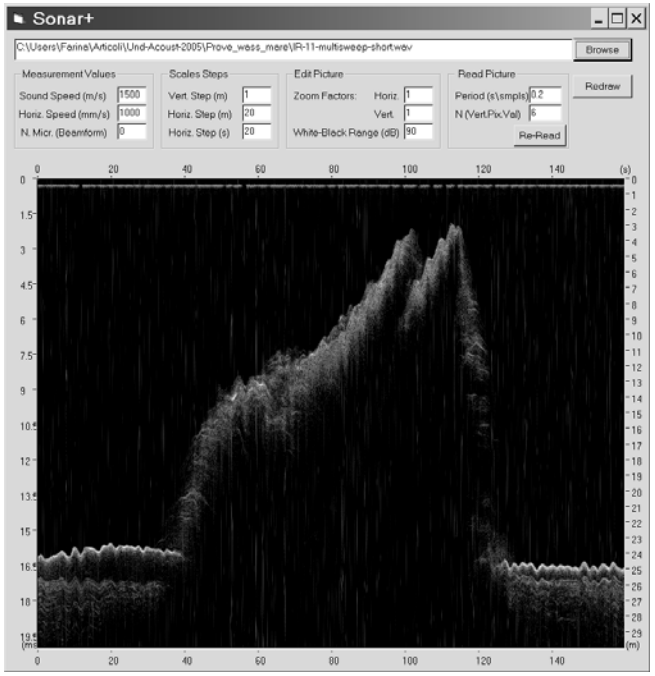
“Lin” sine sweep

2.4 to 45.0 kHz - duration = 0.5 s.



“Lin” sine multi-sweep

2.4 to 45.0 kHz



- Measurements performed in the open sea, in front of Tinetto cliff.
- Equipment (2 hydroph. ITC 5264) mounted on a WASS vessel.
- The micro ripple on the bottom profile is due to the boat pitching.
- Different bottom layer are well-defined.

Conclusion

- Implementation of a low-cost system and software, based on a “Not-Uniform Linear Array” is possible;
- Good agreement between the estimated and theoretical values of array directivity.
- Good capability of the system to detect real angle of incoming sound (DOA), especially at medium-high frequencies (greater directivity). (*Passive sonar*)
- Identification of submerged objects placed in a wide angle under the array is possible. (*Active sonar*)
- The linear sine sweep shows high SNR, high immunity to external noise and good capability to penetrate in the sediments.

Future Work

- Test of the penetration performance for the new array system.

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- **Dr. Michele Zanolin** (Embry-Riddle Aeronautical University – Prescott (AZ)), who attended some of the measures and provided the sound source used in the characterization of the array.