University of Parma

Industrial Engineering Department

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Experimental Evaluation Of The Performances Of A New Pressure-Velocity 3D Probe Based On The Ambisonics Theory

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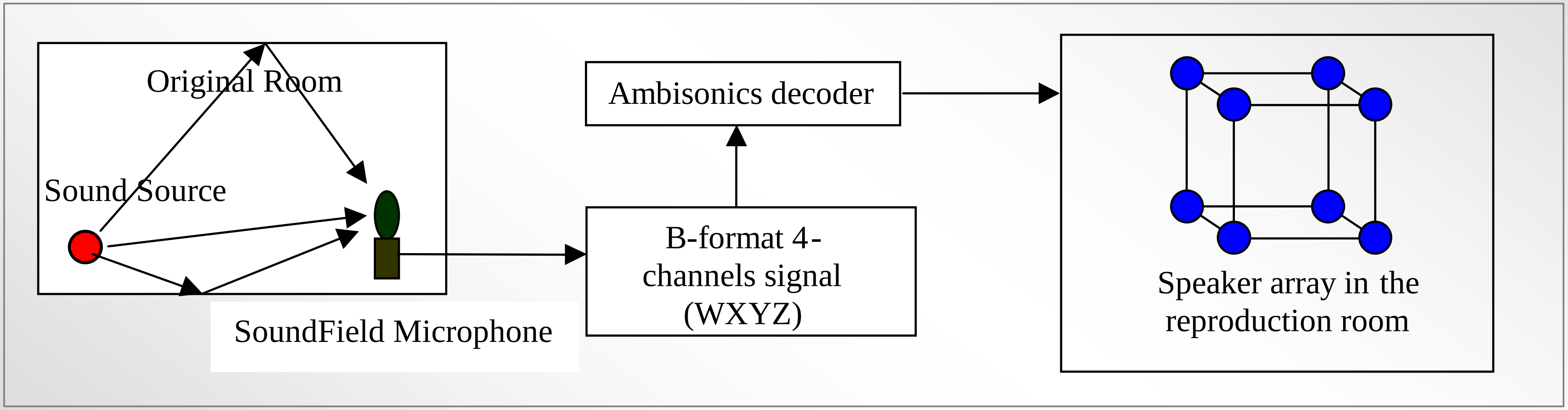
Goals

- Explanation of the Ambisonics technology, as currently employed in room acoustics
- Brahma: the first underwater 4-channels digital sound recorder
- A tetrahedrical hydrophone array for Brahma
- Sound source localization from Ambisonics (B-format) recordings
- Graphical mapping of boat trajectory

Ambisonics technology

- Ambisonics was invented in the seventies by Michael Gerzon (UK)
- It was initially a method for recording a 4-channel stream, which later was played back inside a special loudspeaker rig
- It is based on the pressure-velocity decomposition of the sound field at a point
- It makes it possible to capture the complete three-dimensional sound field, and to reproduce it quite faithfully

Ambisonics recording and playback



Reproduction occurs over an array of 8-24 loudspeakers, through an Ambisonics decoder

Ambisonics Technology

Recording

Processing

Decoding

Speaker-feeds

Encoding

B-Format

Playback

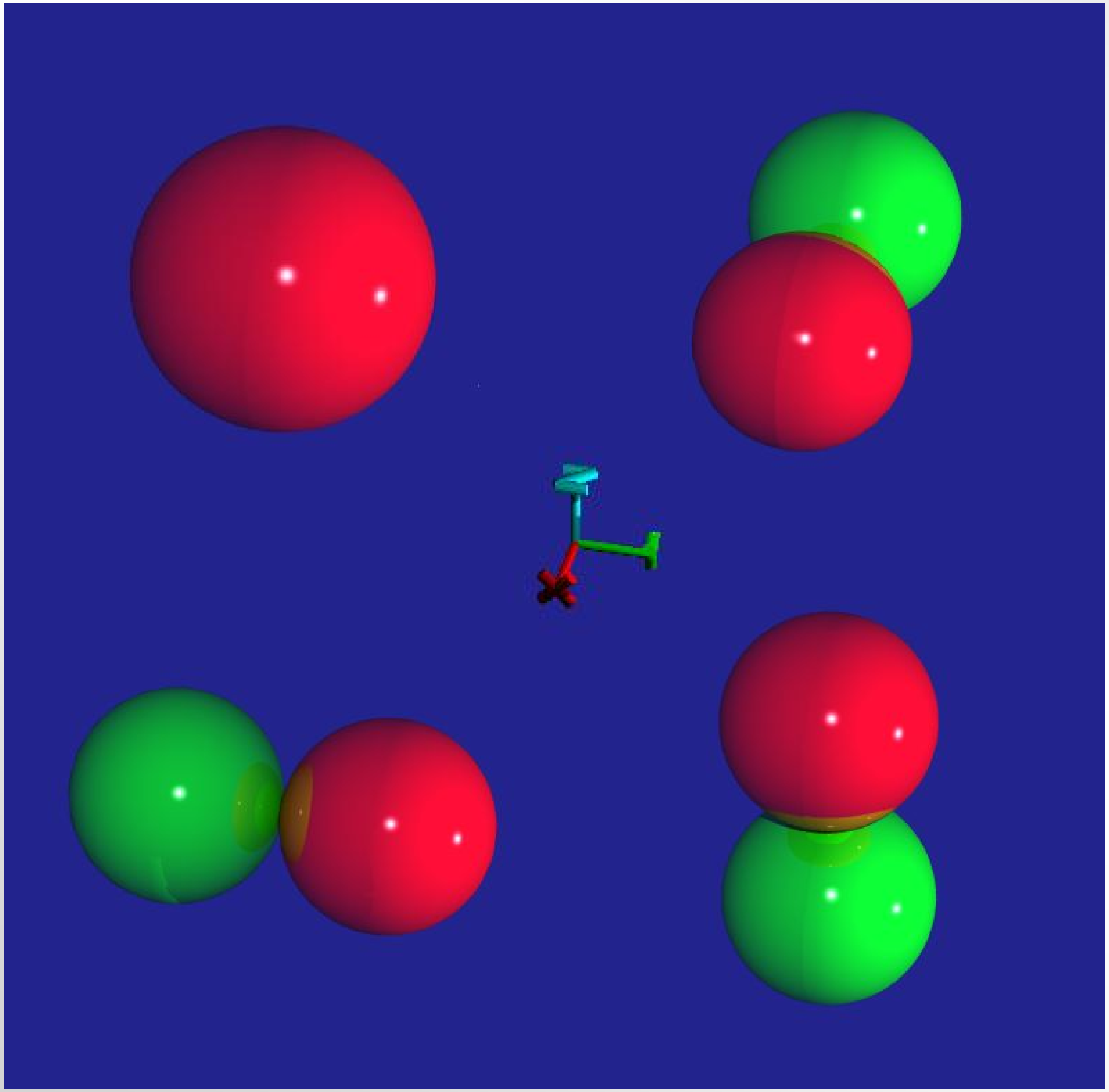
The Soundfield microphone

- This microphone is equipped with 4 subcardioid capsules, placed on the faces of a thetraedron
- The signal are analogically processed in its own special control box, which derives 4 “B-format” signals
- These signals are:
  - W : omnidirectional (sound pressure)
  - X,Y,Z : the three figure-of-eight microphones aligned with the ISO cartesian reference system – these signals are the cartesian components of the “particle velocity” vector

Other tetrahedrical microphones

- Trinnov, DPA, CoreSound, Brahma are other microphone systems which record natively the A-format signals, which later are digitally converted to B-format

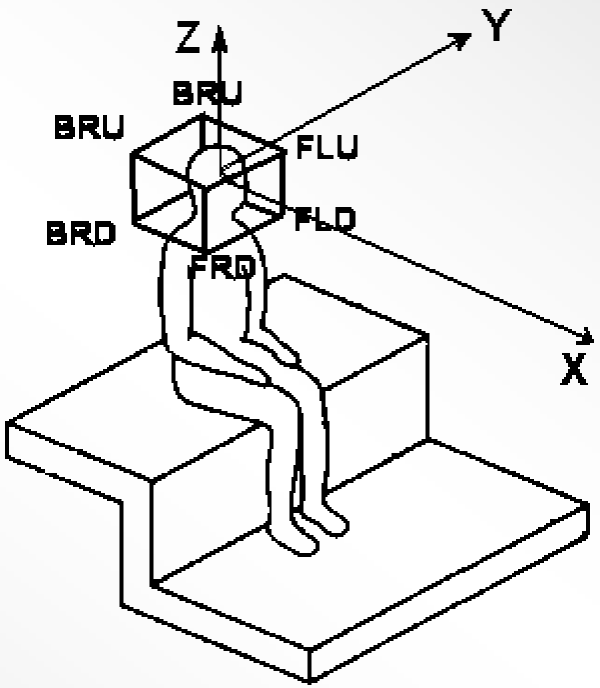
The B-format components



• Physically, W is a signal proportional to the pressure, XYZ are signals proportional to the three Cartesian components of the particle velocity

• when a sound wave impinges over the microphone from the “negative” direction of the x-axis, the signal on the X output will have polarity reversed with respect to the W signal

A-format to B-format



- The A-format signals are the “raw” signals coming from the 4 capsules, loated at 4 of the 8 vertexes of a cube, typically at locations FLU-FRD-BLD-BRU

A-format to B-format

- The A-format signals are converted to the B-format signals by matrixing:

$$W' = FLU+FRD+BLD+BRU$$

$$X' = FLU+FRD-BLD-BRU$$

$$Y' = FLU-FRD+BLD-BRU$$

$$Z' = FLU-FRD-BLD+BRU$$

- and then applying proper filtering:

$$F_W = \frac{1 + j\omega r / c - \frac{1}{3}(\omega r / c)^2}{1 + \frac{1}{3} j\omega r / c}$$

$$F_{XYZ} = \sqrt{6}\,\frac{1 + \frac{1}{3} j\omega r / c - \frac{1}{3}(\omega r / c)^2}{1 + \frac{1}{3} j\omega r / c}$$

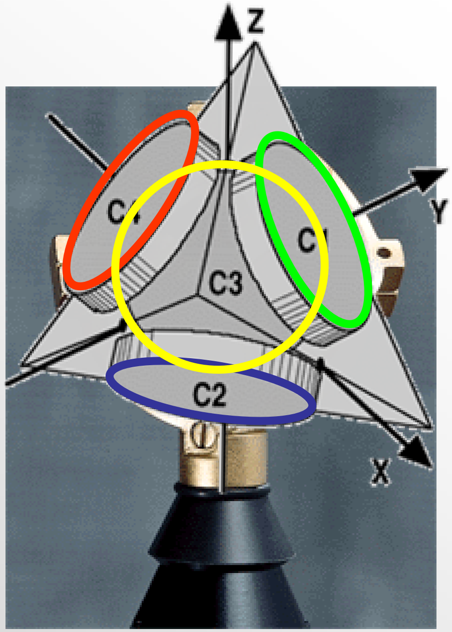
r = distance of each capsule from the center of the tetrahedron in m

ω = angular frequency in rad/s ($\omega = 2\pi f$)

c = speed of sound in m/s

Recording

Recording → Encoding → Processing → Decoding and Playback

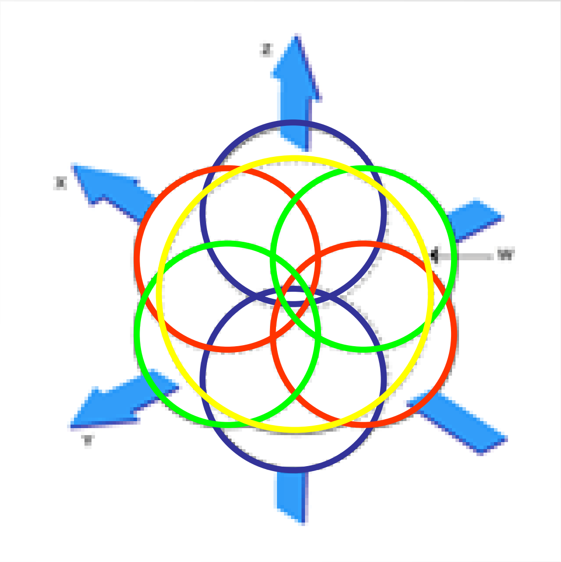


Soundfield Microphone

X Y Z – Directional components: *velocity*

W – Omnidirectional component: *pressure*

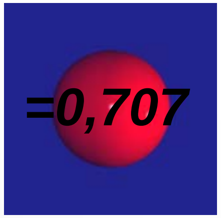
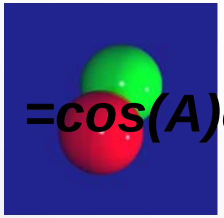
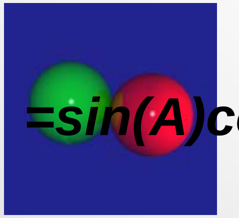
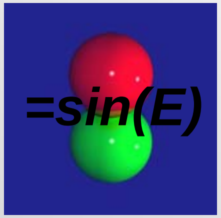
B-FORMAT

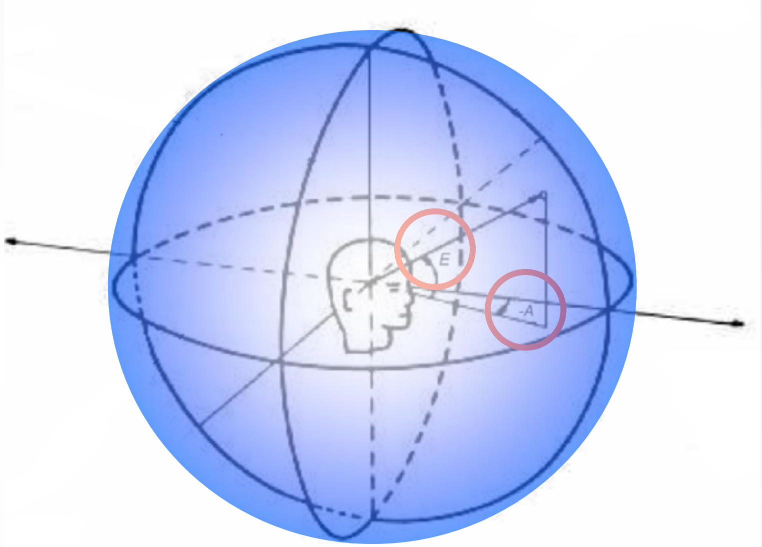


Polar Diagram

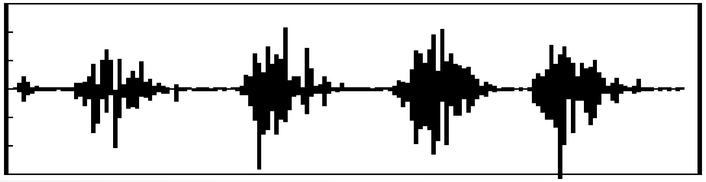
Encoding (synthetic B-format)

Recording → Encoding → Processing → Decoding and Playback

0	W		=0,707 *s(t)
1	X		=cos(A)cos(E)*s(t)
	Y		=sin(A)cos(E) *s(t)
	Z		=sin(E) *s(t)

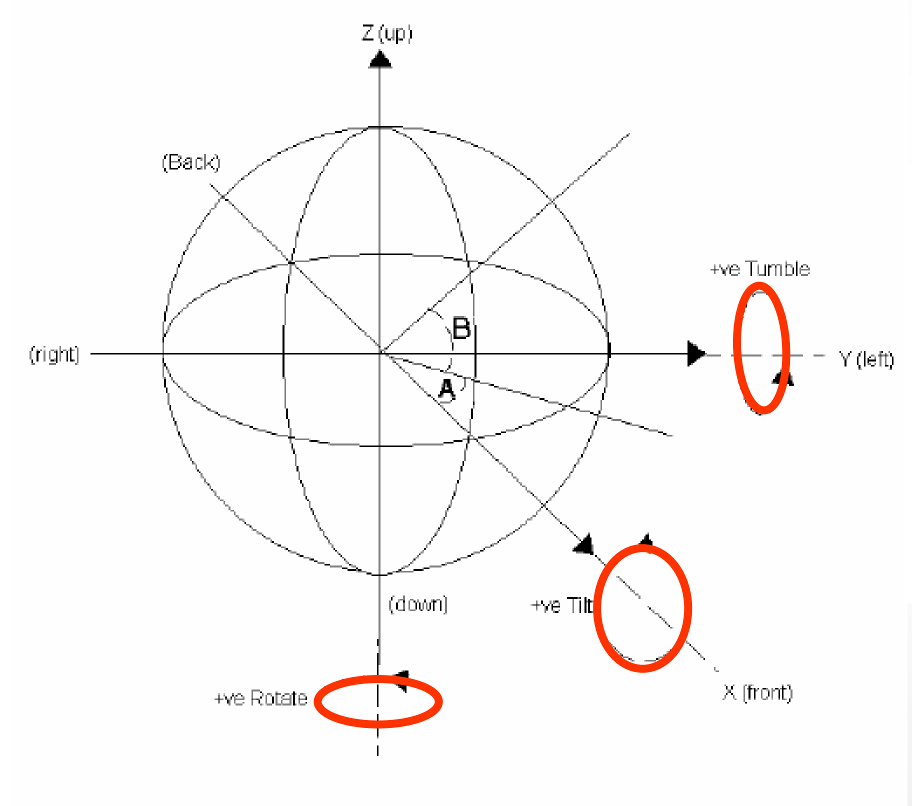


$$\sqrt{X^2 + Y^2 + Z^2} = 1$$

s(t)= 

Processing

Recording → Encoding → **Processing** → Decoding and Playback



$$w' = w$$
$$x' = x \cdot \cos(R) - y \cdot \sin(R)$$
$$y' = x \cdot \sin(R) + y \cdot \cos(R)$$
$$z' = z$$

Rotation

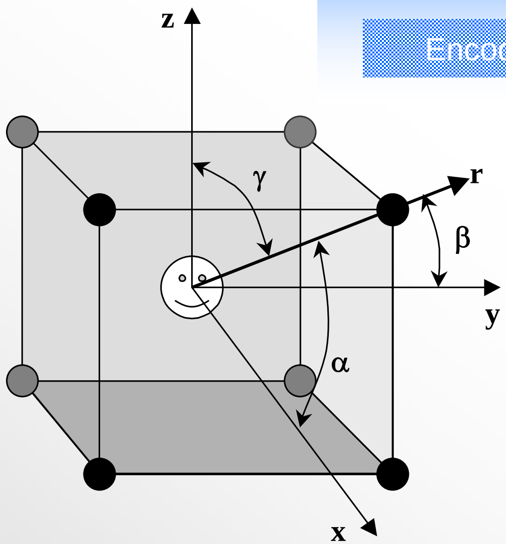
$$w' = w$$
$$x' = x$$
$$y' = y \cdot \cos(T) - z \cdot \sin(T)$$
$$z' = y \cdot \sin(T) + z \cdot \cos(T)$$

Tilt

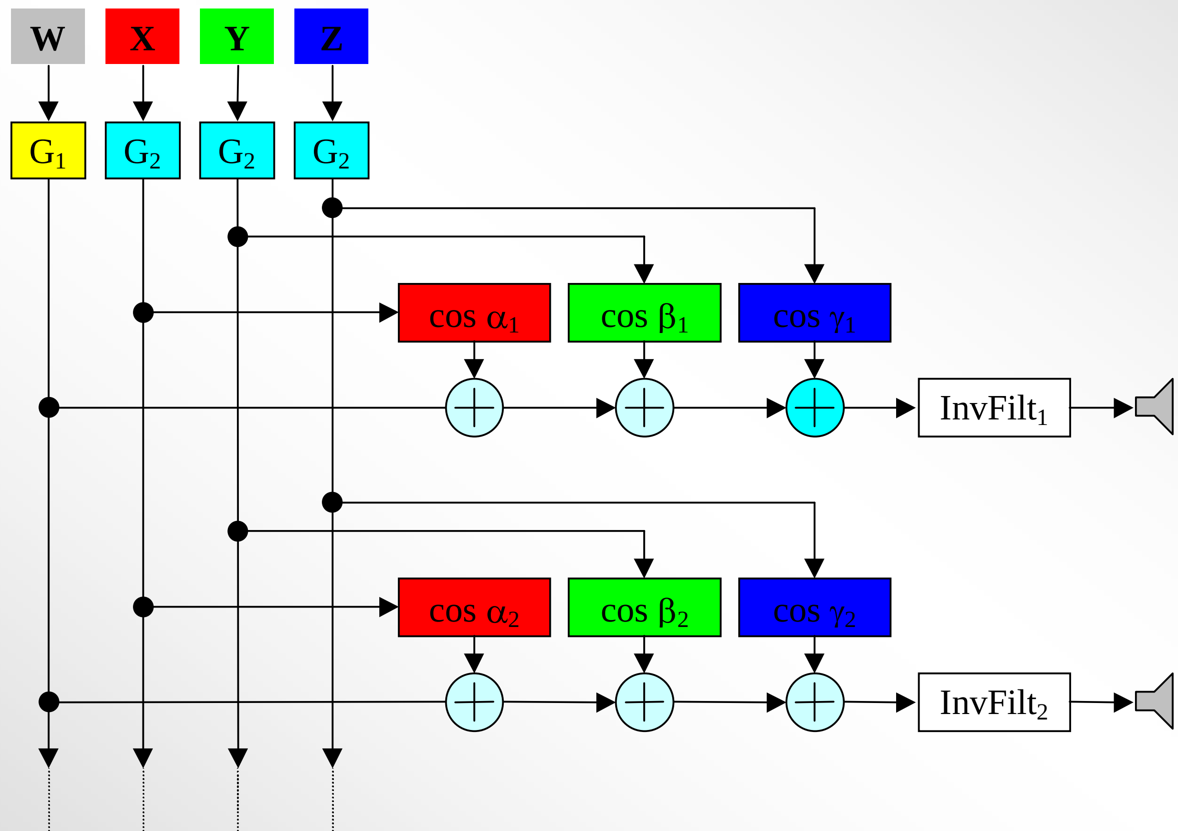
$$w' = w$$
$$x' = x \cdot \cos(T) - z \cdot \sin(T)$$
$$y' = y$$
$$z' = x \cdot \sin(T) + z \cdot \cos(T)$$

Tumble

Decoding & Playback



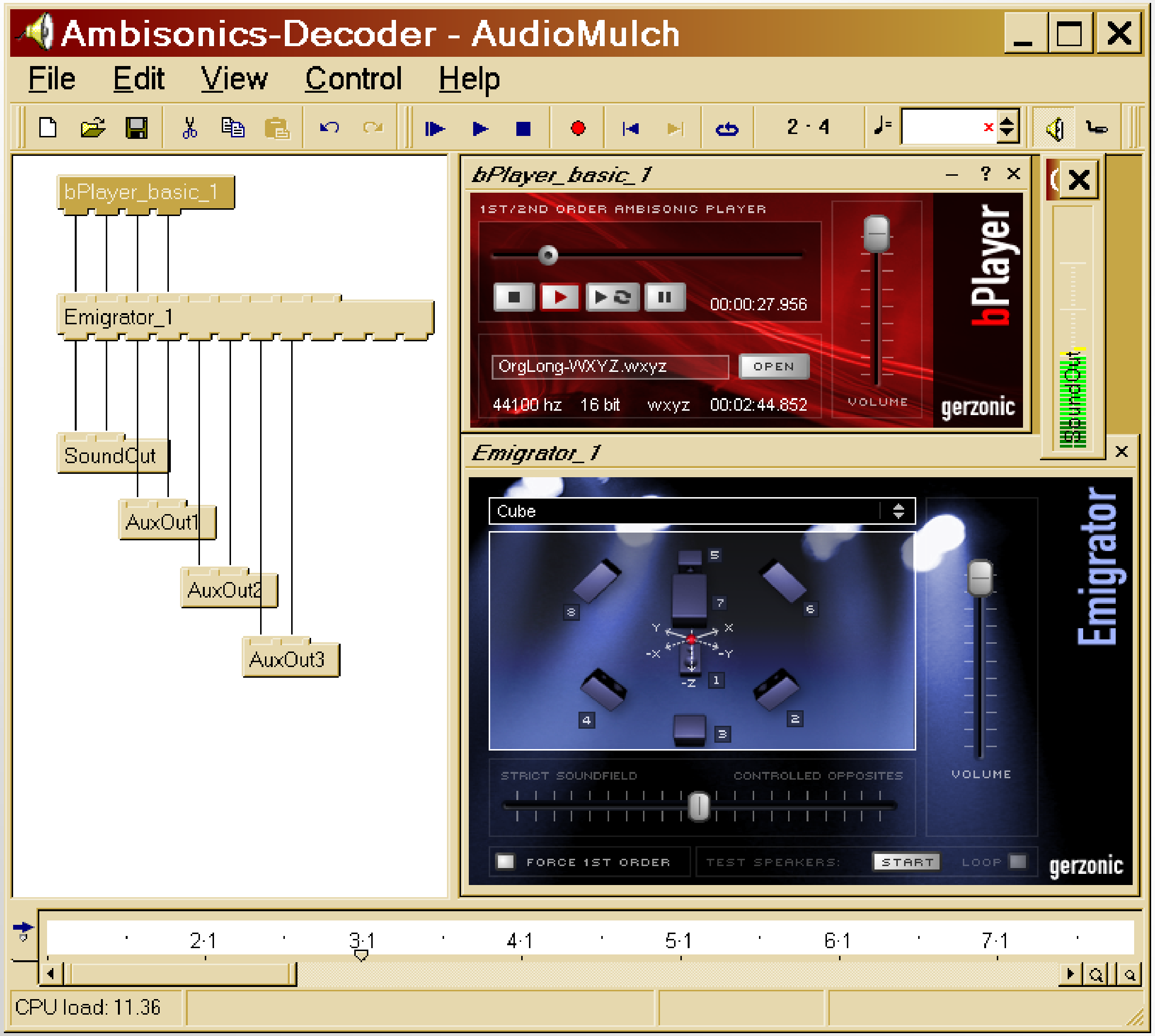
$$F_i = \frac{1}{2} \cdot \left[G_1 \cdot W + G_2 \cdot \left(X \cdot \cos(\alpha) + Y \cdot \cos(\beta) + Z \cdot \cos(\gamma)\right)\right]$$



Each speaker feed is simply a weighted sum of the 4 B-format signals.

The weighting coefficients are computed by the cosines of the angles between the loudspeaker and the three Cartesian axes

Software for Ambisonics decoding

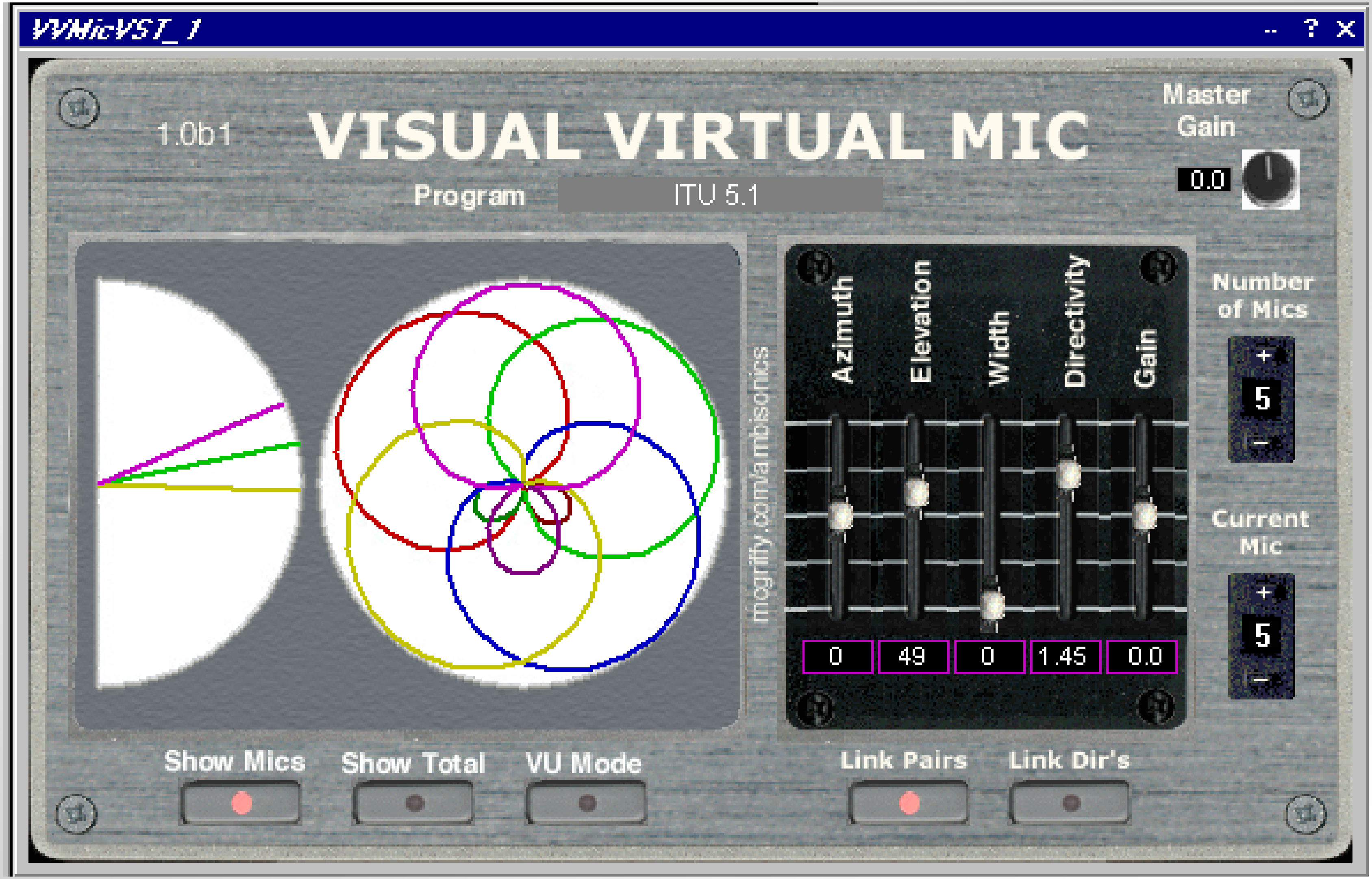


Audiomulch VST host

Gerzonic bPlayer

Gerzonic Emigrator

Software for Ambisonics processing



Visual Virtual Microphone by David McGriffy (freeware)

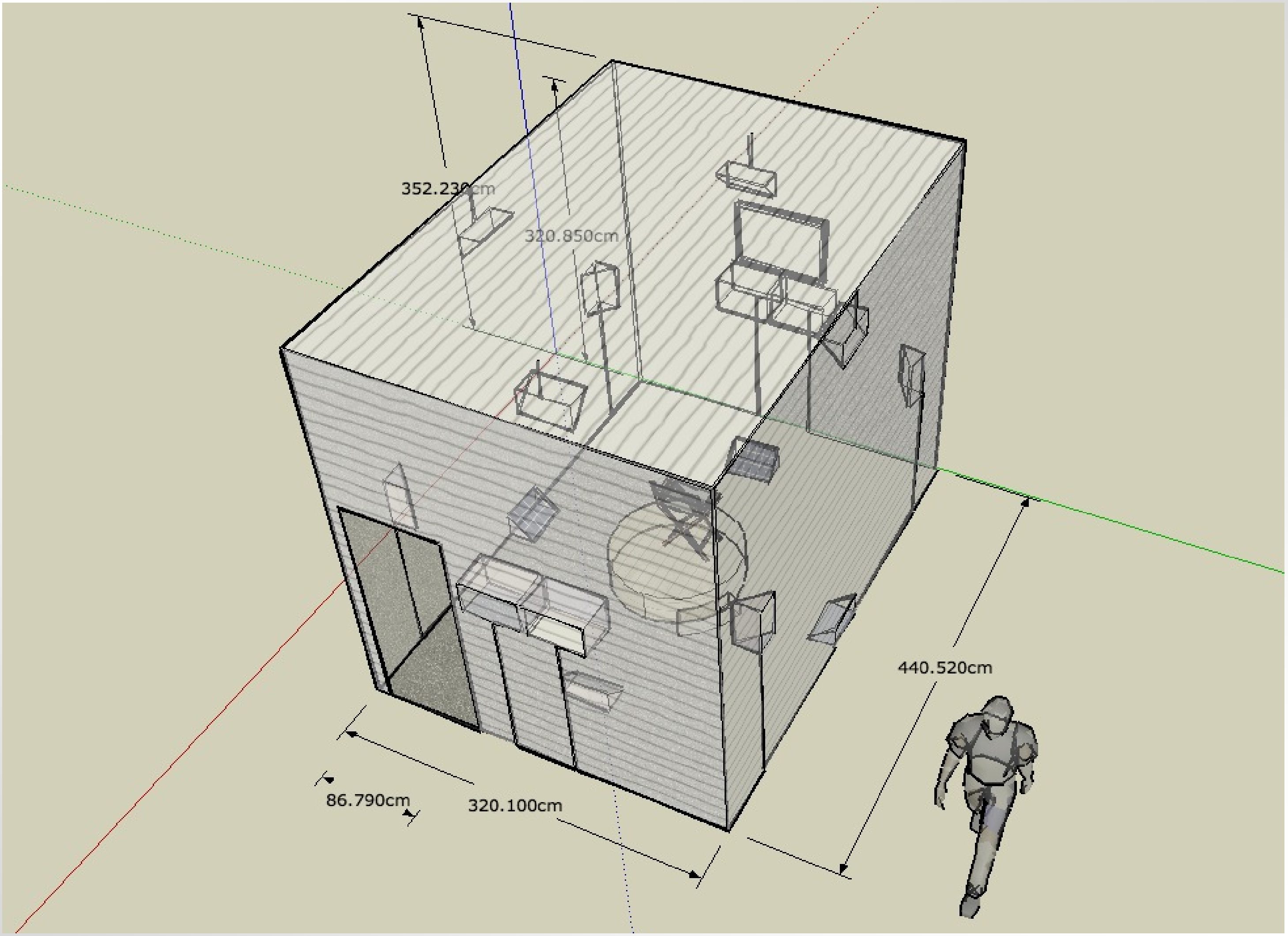
Rooms for Ambisonics playback


ASK (UNIPR) – Reggio Emilia


University of Ferrara


University of Bologna

Rooms for Ambisonics playback



University of Parma (Casa della Musica)

BRAHMA: 4-channels recorder

- A Zoom H2 digital sound recorder is modified in India, allowing 4 independent inputs with phantom power supply

BRAHMA: 4-channels recorder

- The standard microphone system is usually a terahedrical probe equipped with 4 cardioid electrect microphones

BRAHMA: 4-channels recorder

- However the recorder is equipped also with a split-out cable, allowing for the connection of other transducers, including microphones, accelerometers and hydrophones

Hydrophones for Brahma

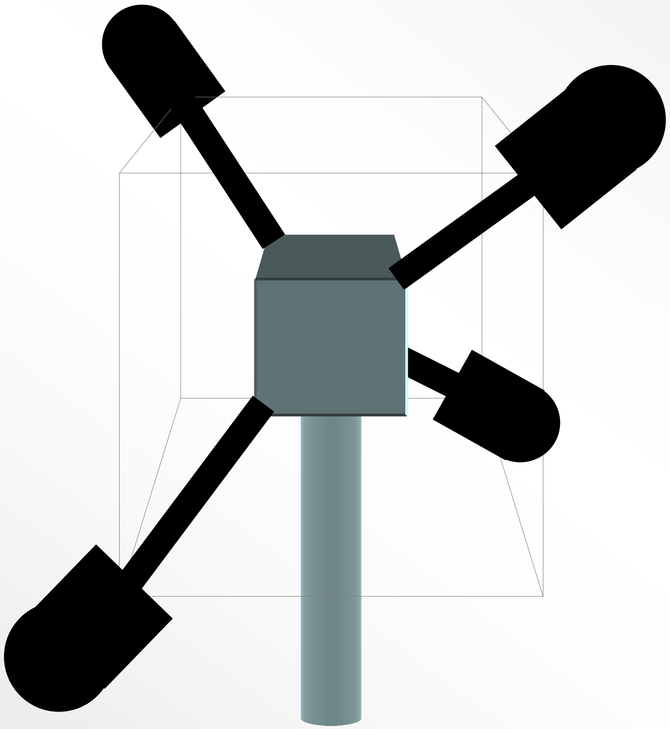
- Brahma provides phantom power (5V) for transducers equipped with integral electronics. Hence the ideal hydrophone is the Acquarian Audio H2A:

Aquarian Audio Products
A division of AFAB Enterprises
1004 Commercial Ave. #225 Anacortes, WA 98221 USA
(360) 299-0372 **www.AquarianAudio.com**

Sensitivity:	-180dB re: 1V/μPa	(+/-4dB 20Hz-4.5KHz)
Frequency range:	<10 Hz to >100KHz	(approximate sensitivity @100KHz = -220dB re: 1V/μPa)
Polar Response:	Omnidirectional	(horizontal)
Operating depth:	<80 meters	
Output impedance:	1 KΩ	(typical)
Power:	0.6 mA	(typical)
Physical:		(cable and output plug excluded)
Dimensions:	25mm x 46mm	
Mass:	105 grams	

Hydrophones for Brahma

- A tetrahedrical assembly can be built for underwater Ambisonics recording:



A regular tetrahedron is obtained placing the 4 hydrophones at 4 of the 8 vertexes of a cube measuring 80mm x 80mm x 80mm

Underwater probe for Brahma

- For underwater recordings, a special setup of 4 screw-mounted hydrophones is available:

Underwater case for Brahma

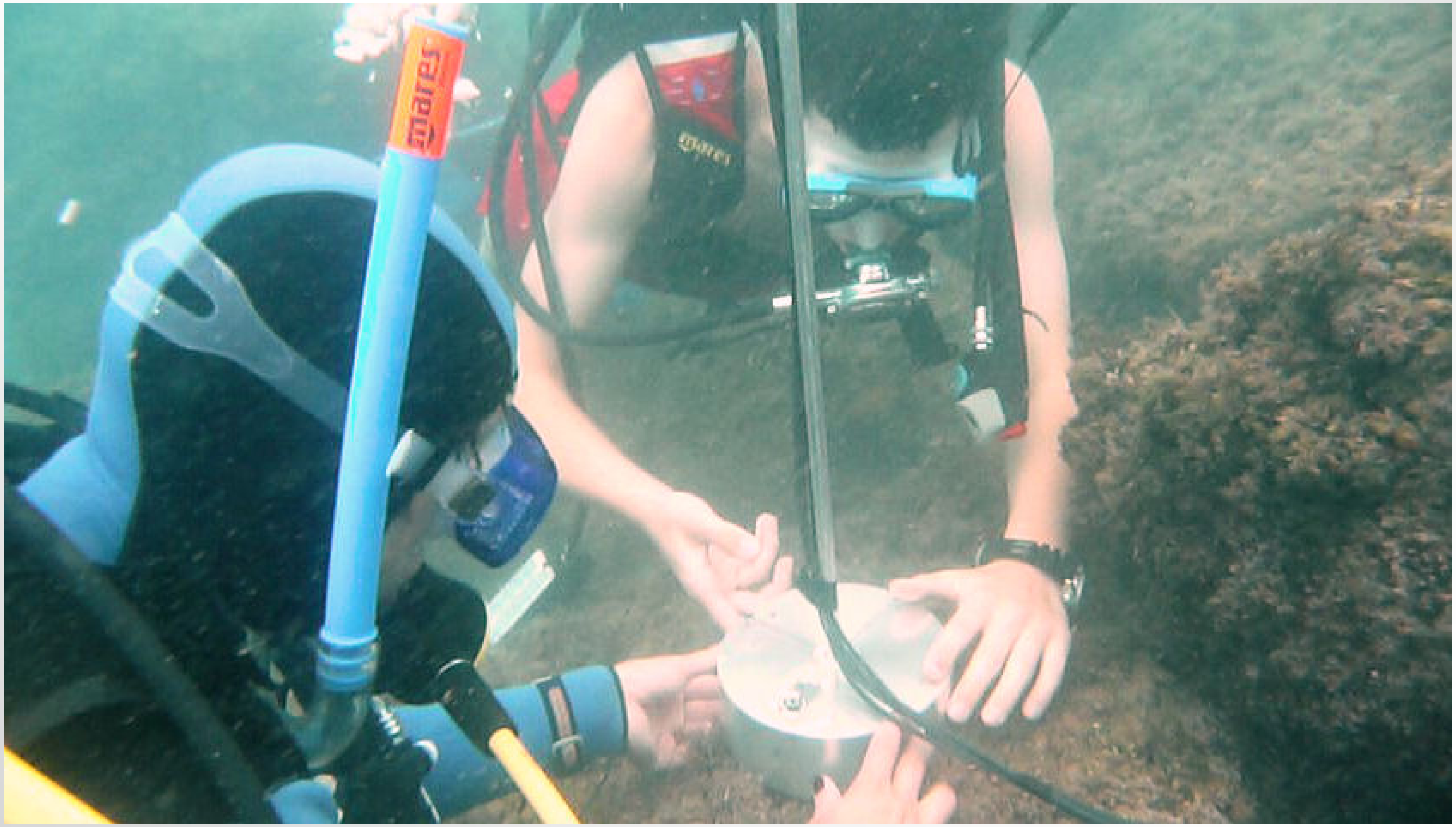
- Due to the small size (like a cigarette packet) it is easy to insert the Brahma inside a waterproof cylindrical container, sealed with O-rings
- An external lead-acid battery can be included for continuous operation up to one week (in level-activated recording mode)

Soundfish : 4-channels recorder

- The probe can be mounted on a weighted base, allowing for underwater placement of the recorded, inside a waterproof case. However, the cables are long enough (15m) also for keeping the recorder on the boat

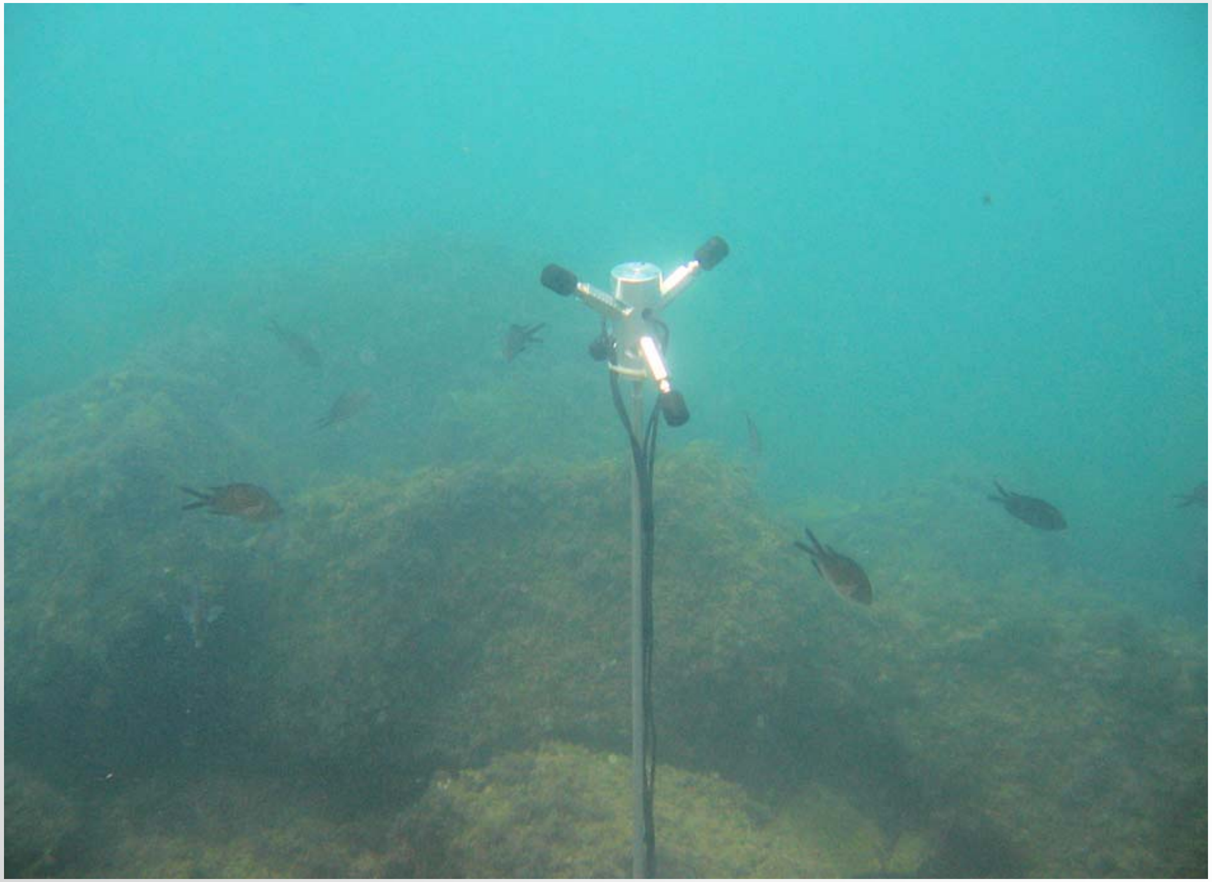
Soundfish: 4-channels underwater recorder

- The system is aligned vertically by means of a bubble scope, and horizontally by means of a magnetic compass:



Soundfish: 4-channels underwater recorder

- Once placed on the sea bed, the system is usually well accepted (and ignored) by the marine life:



Brahmavolver: the processing software

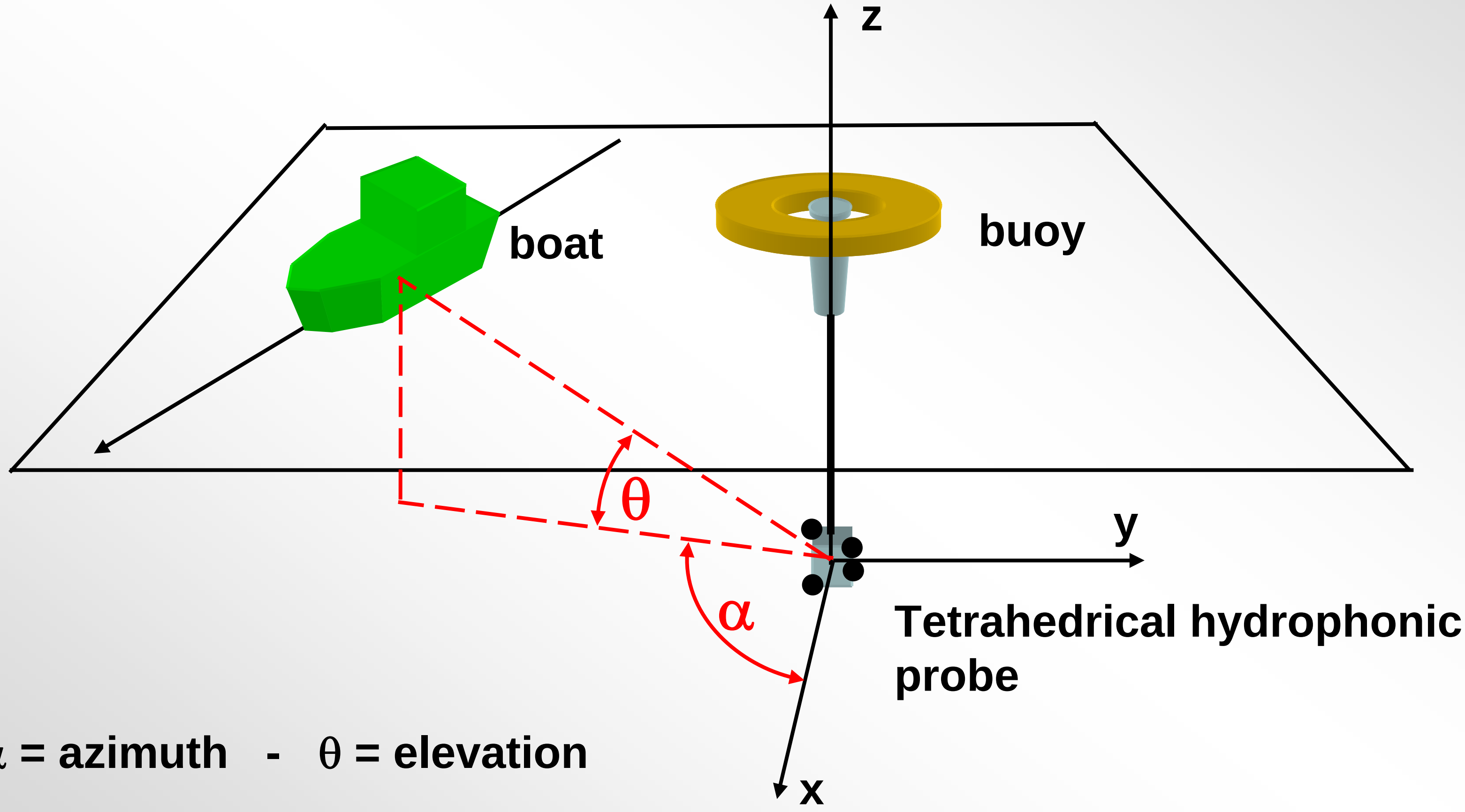
- Brahma records A-format signals. They can be converted to standard B-format by means of the Brahmavolver program, running on Linux / Windows / Mac-OSX

BRAHMA: technical specs

- Sampling rates: 44.1 kHz, 48 kHz, 96 kHz (2 ch. only)
- Recording format: 1 or 2 stereo WAV files on SD card
- Bit Resolution: 16 or 24 bits
- 3 fixed gain settings, with 20 dB steps (traceable)
- Memory usage: 1.9 Gbytes/h (@ 44.1 kHz, 24 bits, 4 ch.)
- Recording time: more than 16 hours (with 32 Gb SD card)
- Power Supply: 6 V DC, 200 mA max
- Automatic recording when programmable threshold is exceeded
- The SD card can be read and erased through the USB port

Source localization from B-format signals

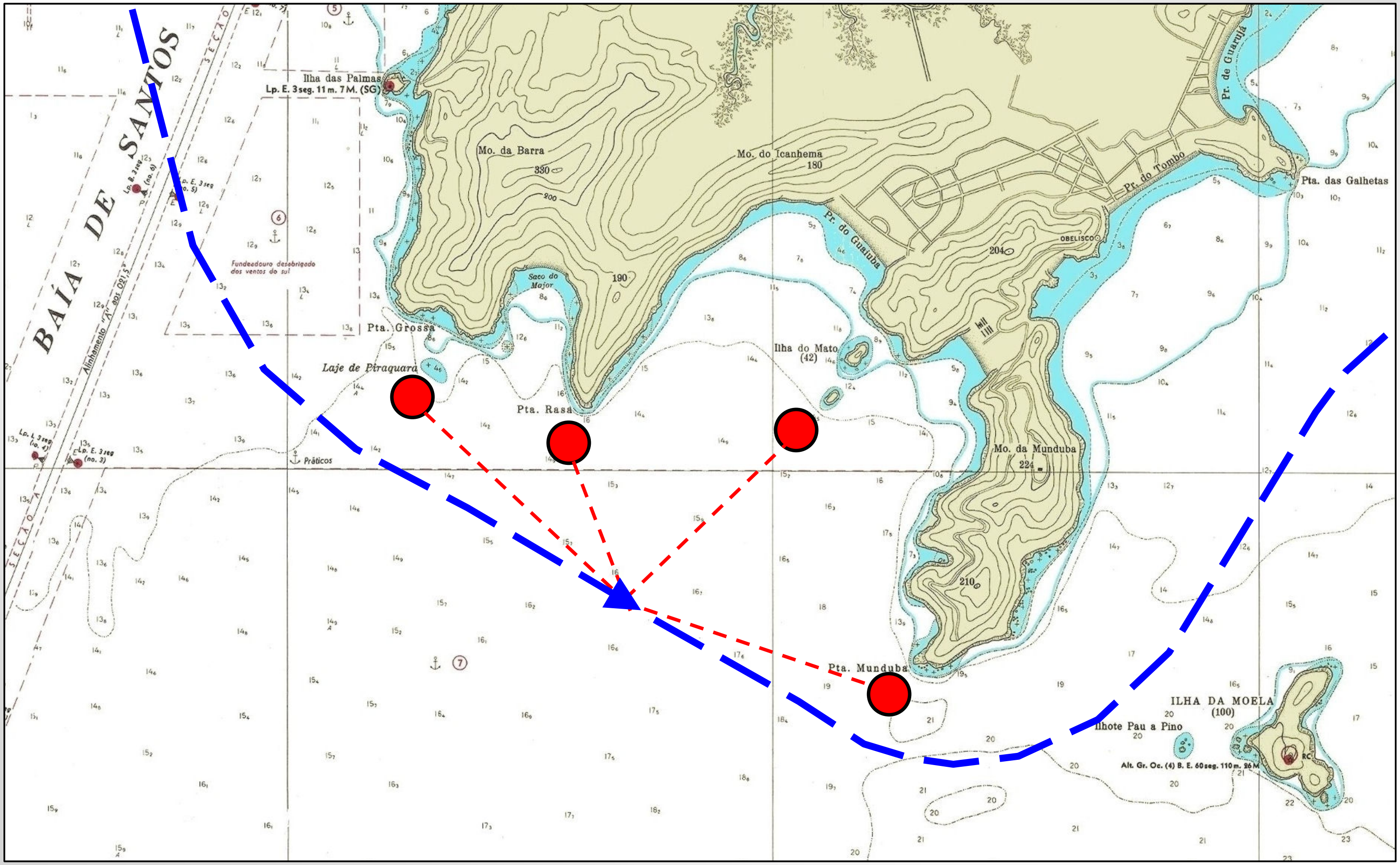
- At every instant, the source position is known in spherical coordinates by analyzing the B-format signal



α = azimuth - θ = elevation

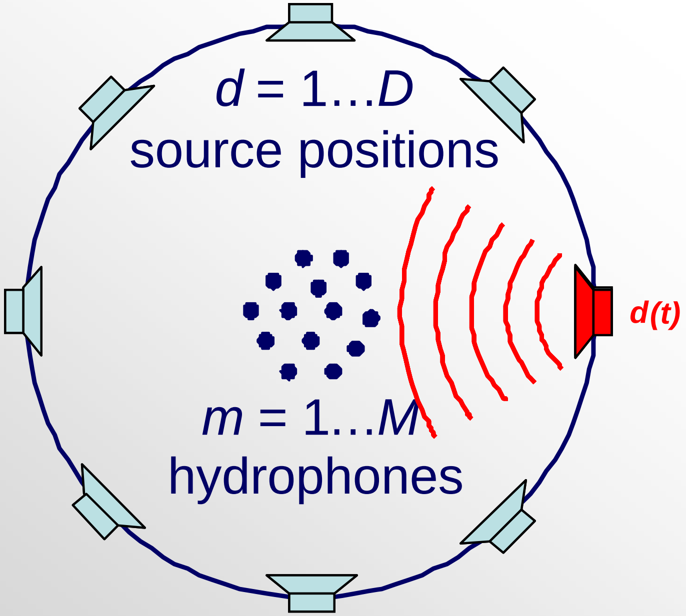
Trajectory from multiple recording buoys

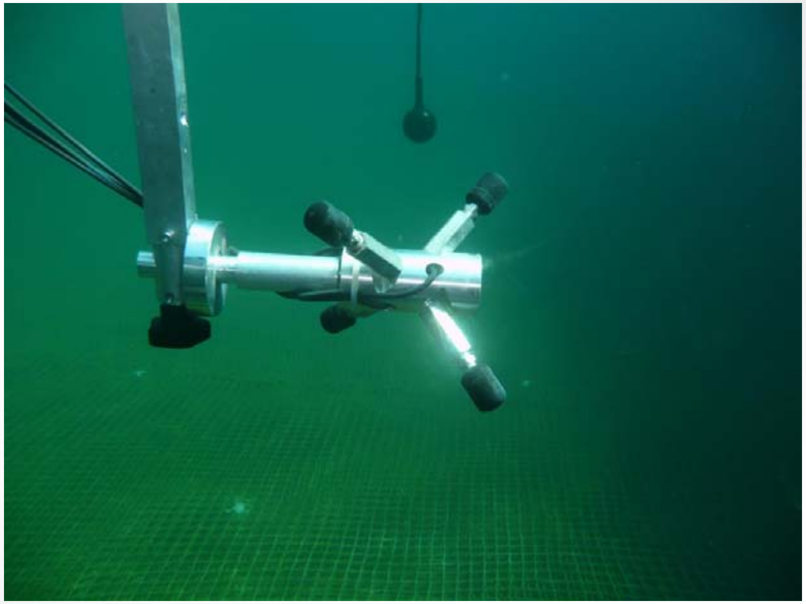
- Employing several buoys, the complete trajectory can be triangulated



Characterization of the probe

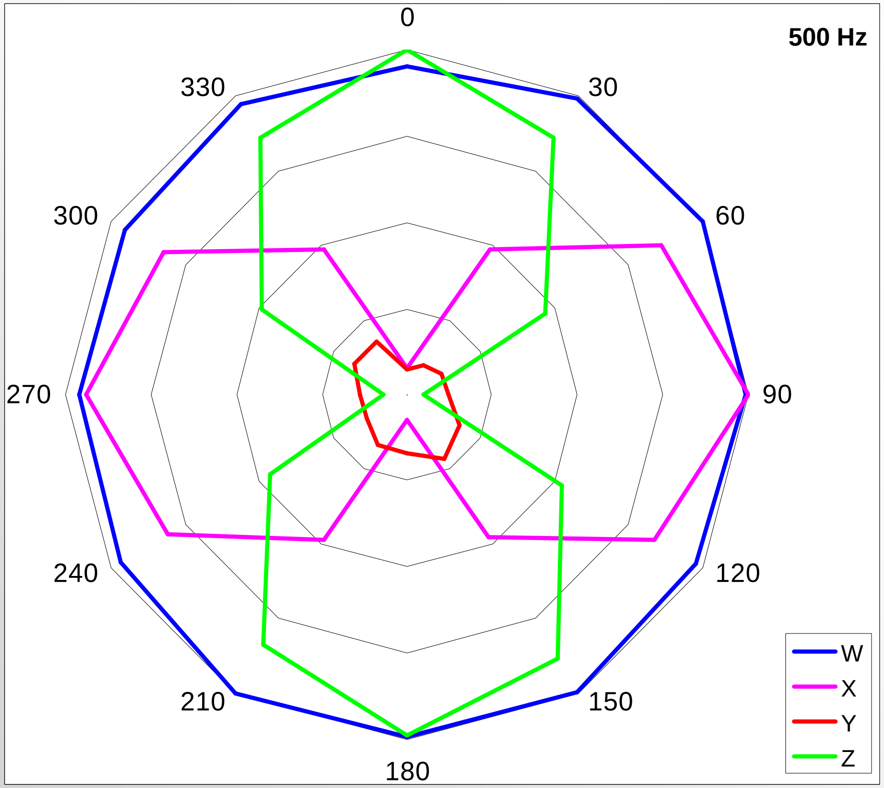
- Impulse response measurements inside a large pool

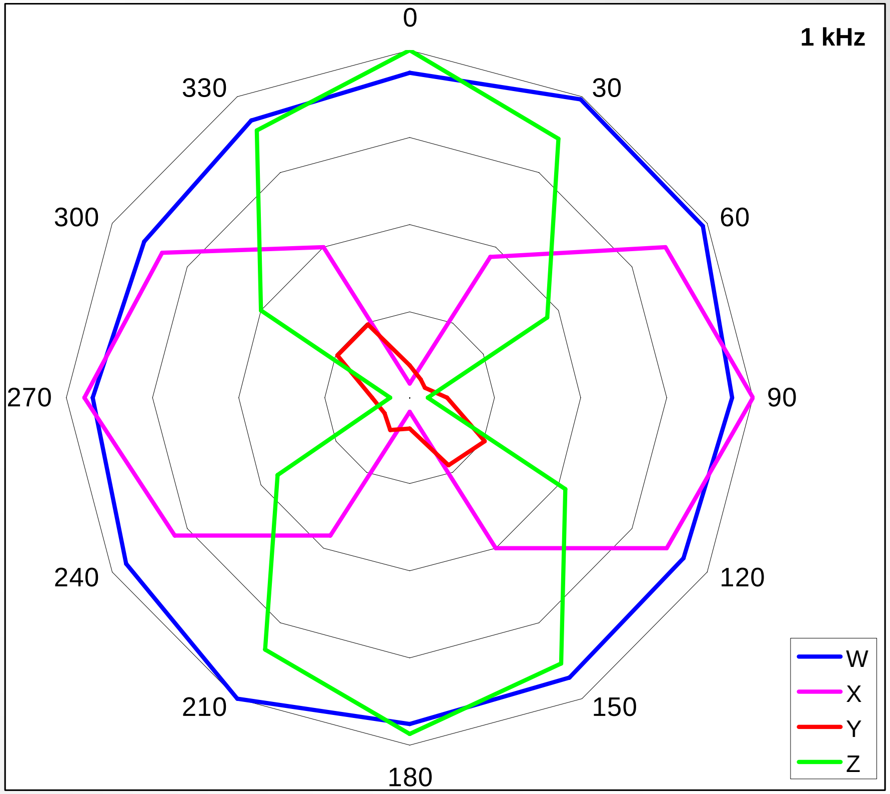




Characterization of the probe

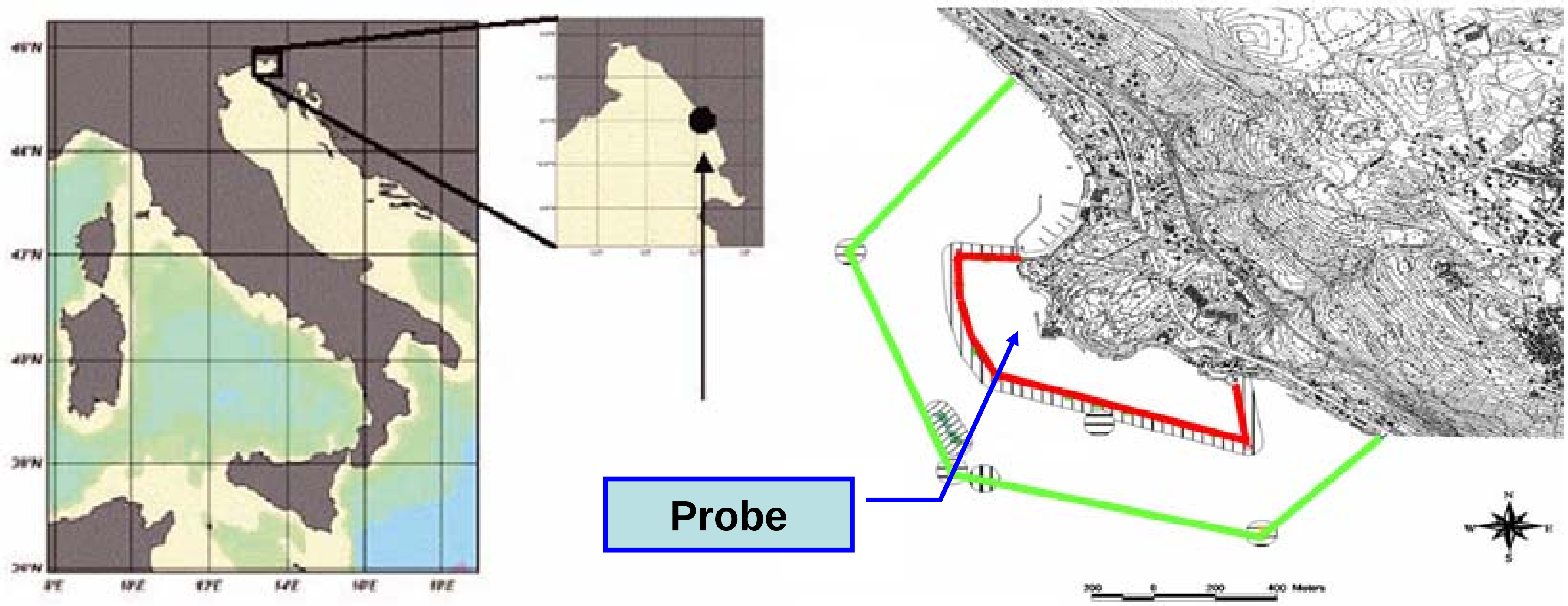
- Polar patterns at two frequencies





First experiment: M.P.A. Miramare

- The Marine Protected Area of Miramare (Trieste, Italy)

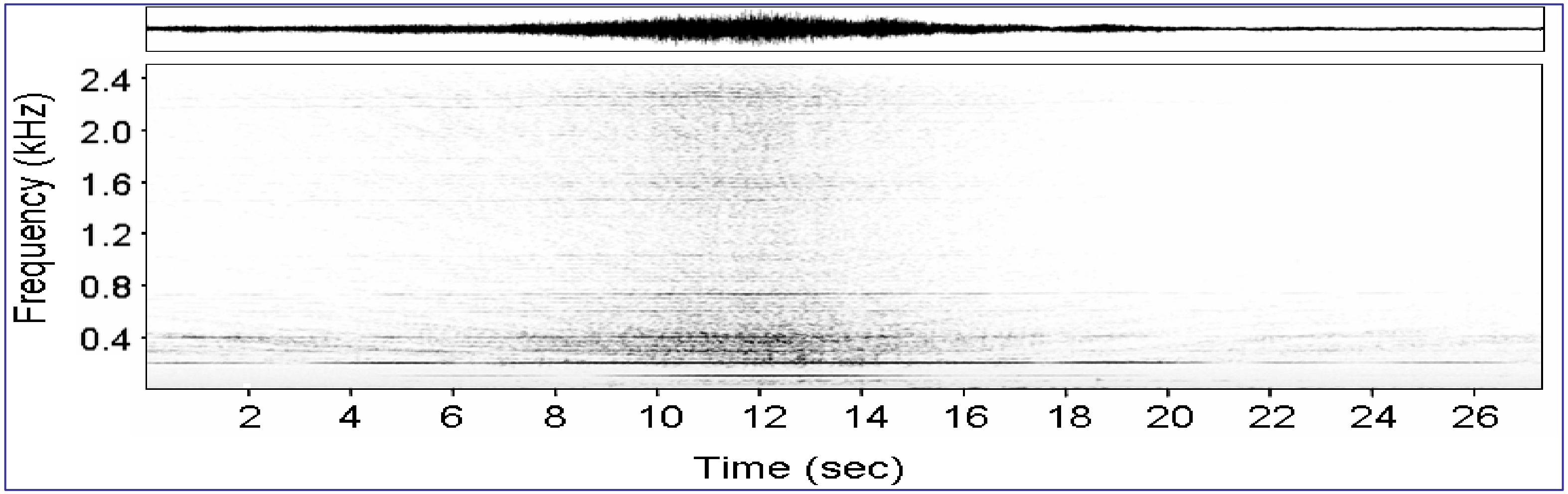


WWF-Natural Marine Reserve of Miramare

First experiment: M.P.A. Miramare

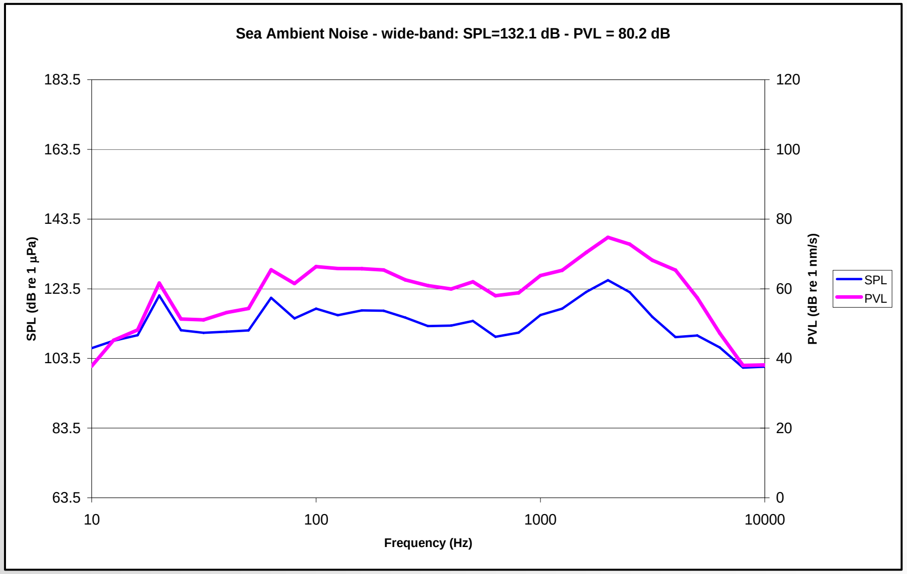
- Noise measurements

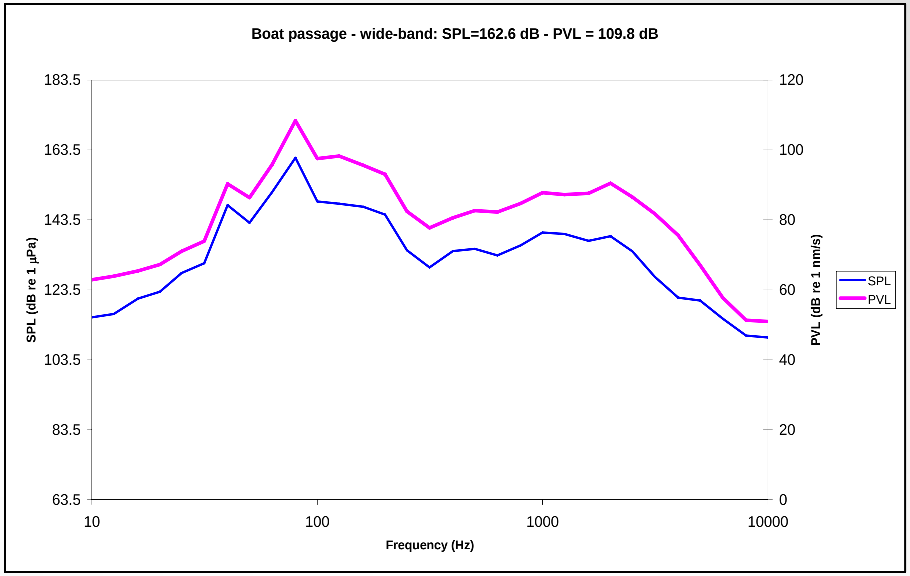
A boat was moving around the probe



First experiment: M.P.A. Miramare

- Noise spectra (SAN and boat passage)

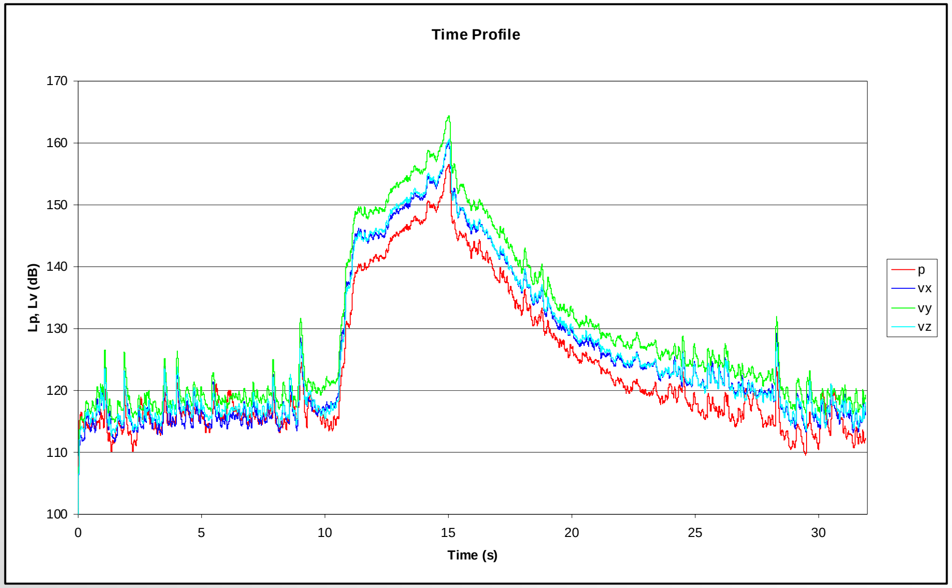


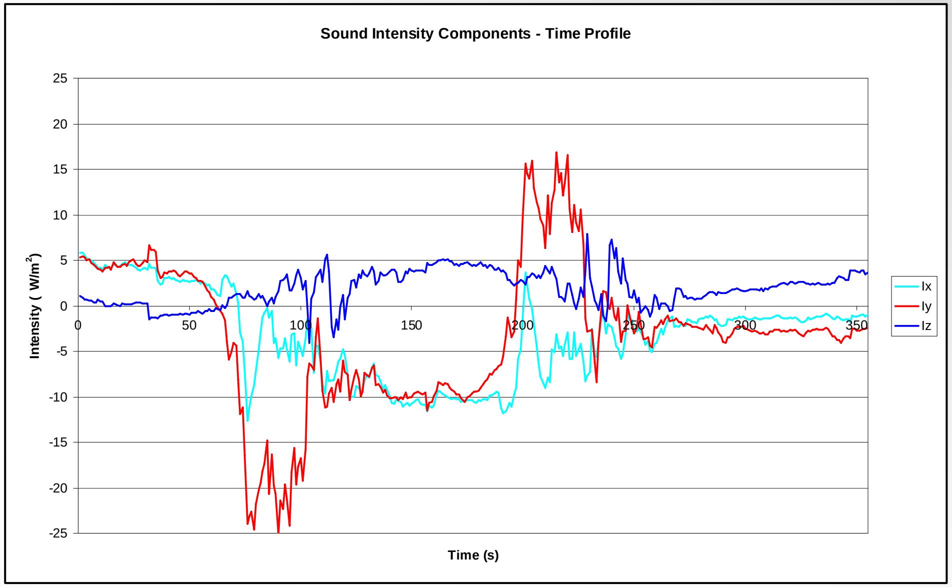


Note the difference between the sound pressure and particle velocity spectra

First experiment: M.P.A. Miramare

- Vectorial analysis of a boat passage

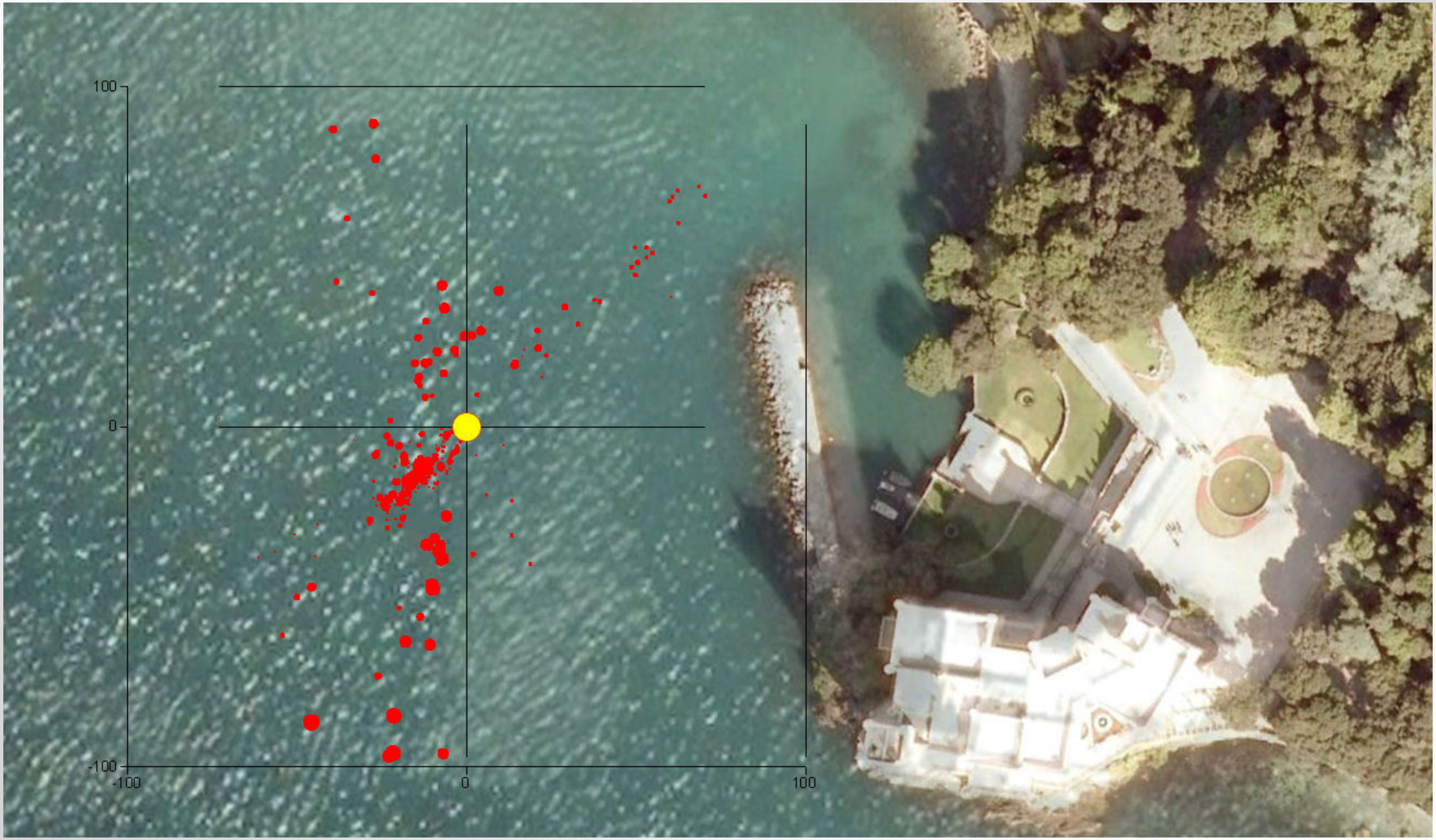




The B-format component magnitudes (left) and the corresponding Sound Intensity Cartesian components (right)

First experiment: M.P.A. Miramare

- Estimated boat trajectory



Internet resources

All the papers previously published by Angelo Farina can be downloaded from his personal web site:

www.angelofarina.it