360 degrees video and audio recording and broadcasting employing a parabolic mirror camera and a spherical 32-capsules microphone array

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Exhibition 9-13 September 2011

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The origin of a new multichannel shooting and recording system

- The project was started by Rai Research Centre and Advanced Industrial Design in Acoustic (A.I.D.A.), spin-off of the University of Parma, in 2009
- It resulted in the patent of an innovative system for live shooting and recording, called 3D Virtual Microphone System
- Starting from a sperical microphone probe, the system can synthesize up to 7 virtual microphones, which can be moved in realtime, with variable directivity (zooming) capability

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Previous experience

- At UNIPR-Aida we had 10 years of experience employing 1st-order Ambisonics microphones (Soundfield ^{TM}, DPA-4, Tetramic, Brahma)
- At RAI-CRIT, the Holophone HD was employed as the stanadard microphone system for surround recording
- Both systems were unsatisfactory in terms of spatial resolutiion and stability of the polar patterns with frequency

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Capturing Ambisonics signals

- A tetrahedrical microphone probe was developed by Gerzon and Craven, originating the Soundfield microphone

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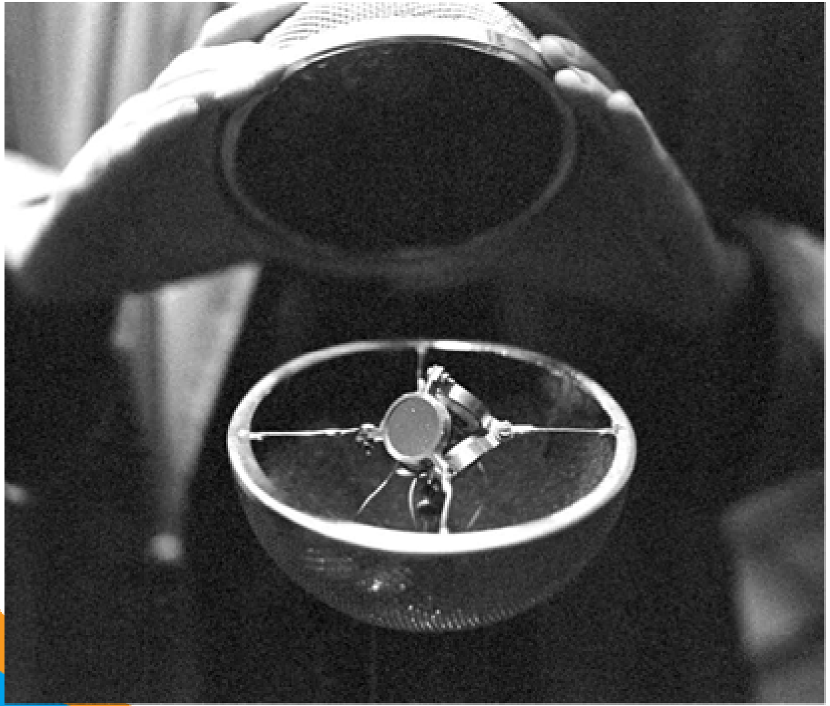
Soundfield microphones



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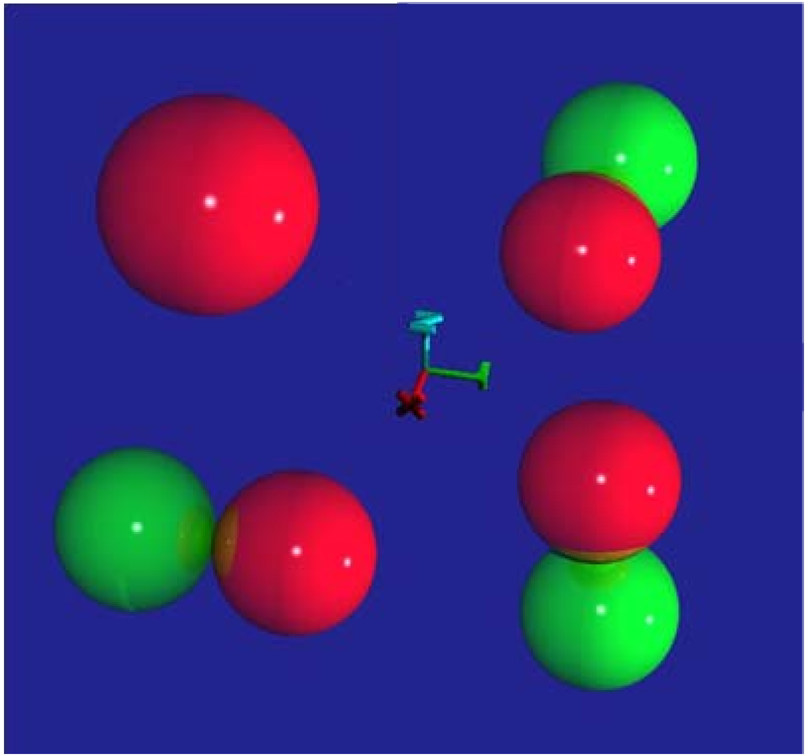
Soundfield Recordings

- The Soundfield (TM) microphone provides 4 signals:
  1 omnidirectional (pressure, W) and 3 figure-of-8 (velocity, X, Y, Z)



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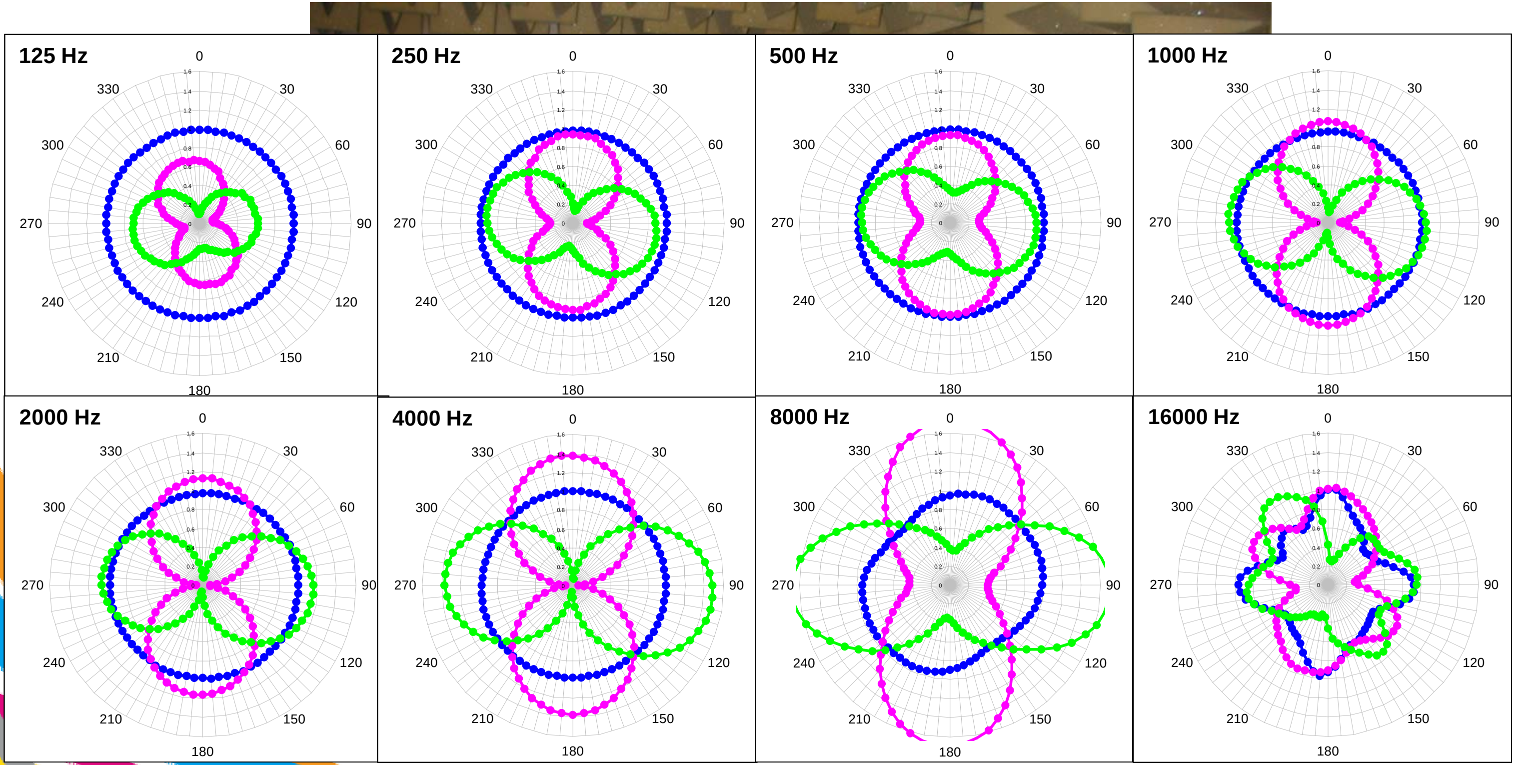
Directivity of transducers

Soundfield ST-250 microphone



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RAI – previous state of art

- The Holophone H2 Pro is a microphone system equipped with 8 capsules placed on a egg-shaped framework. The audio signals are delivered directly in G-format or using an audio mixer.

- The directivity of Holophone's capsules was measured in an Anechoic Room

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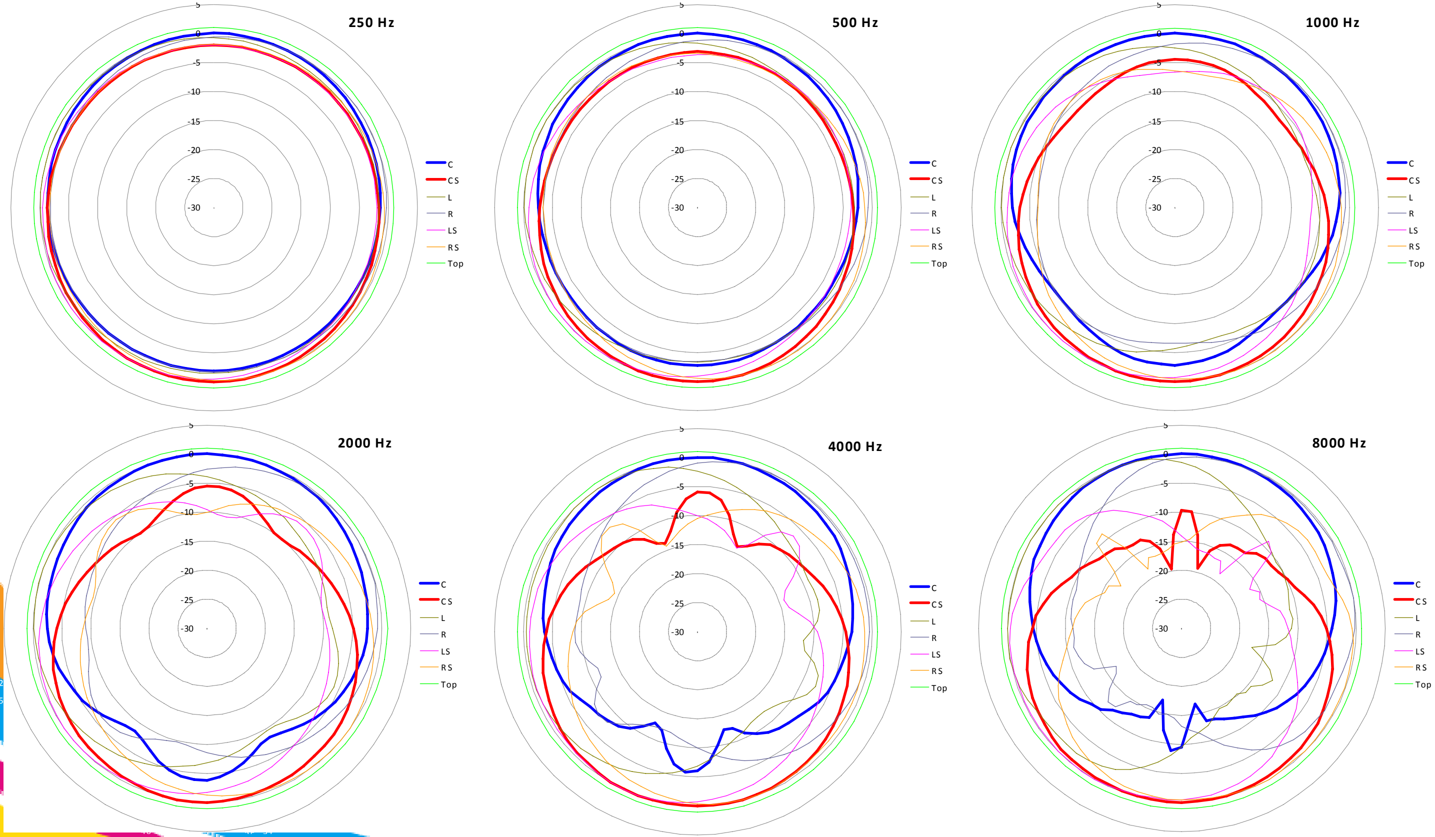
Holophone polar patterns



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HOLOPHONE PROBLEMS:

- Directivity and angles between single capsules are not changeable in post-processing.
- There isn't enough separation between sources because of the low directivity of the capsules. For this reason the probe should be placed very close to the scene that is object of recordings
- Surround imaging is in any case inaccurate, albeit the recording sounds spacious and with good frequency response (thanks to the DPA omnis)

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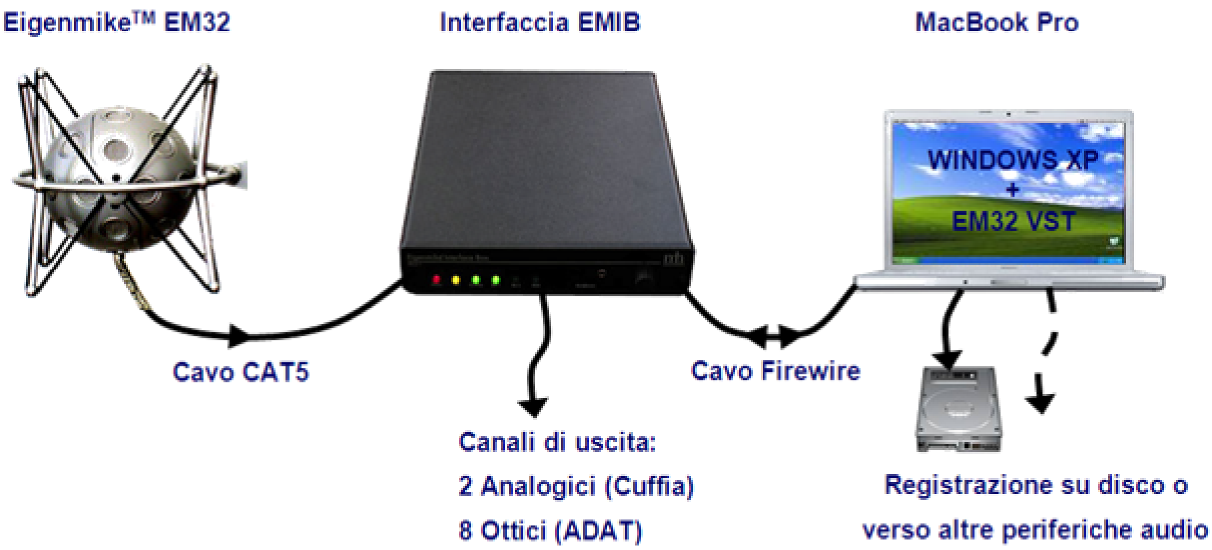
The EIGENMIKE™



- ✓ Array with 32 ½” capsules of good quality, frequency response up to 20 kHz
- ✓ Preamplifiers and A/D converters inside the sphere, with ethernet interface
- ✓ Processing on the PC thanks to a VST plugin (no GUI)

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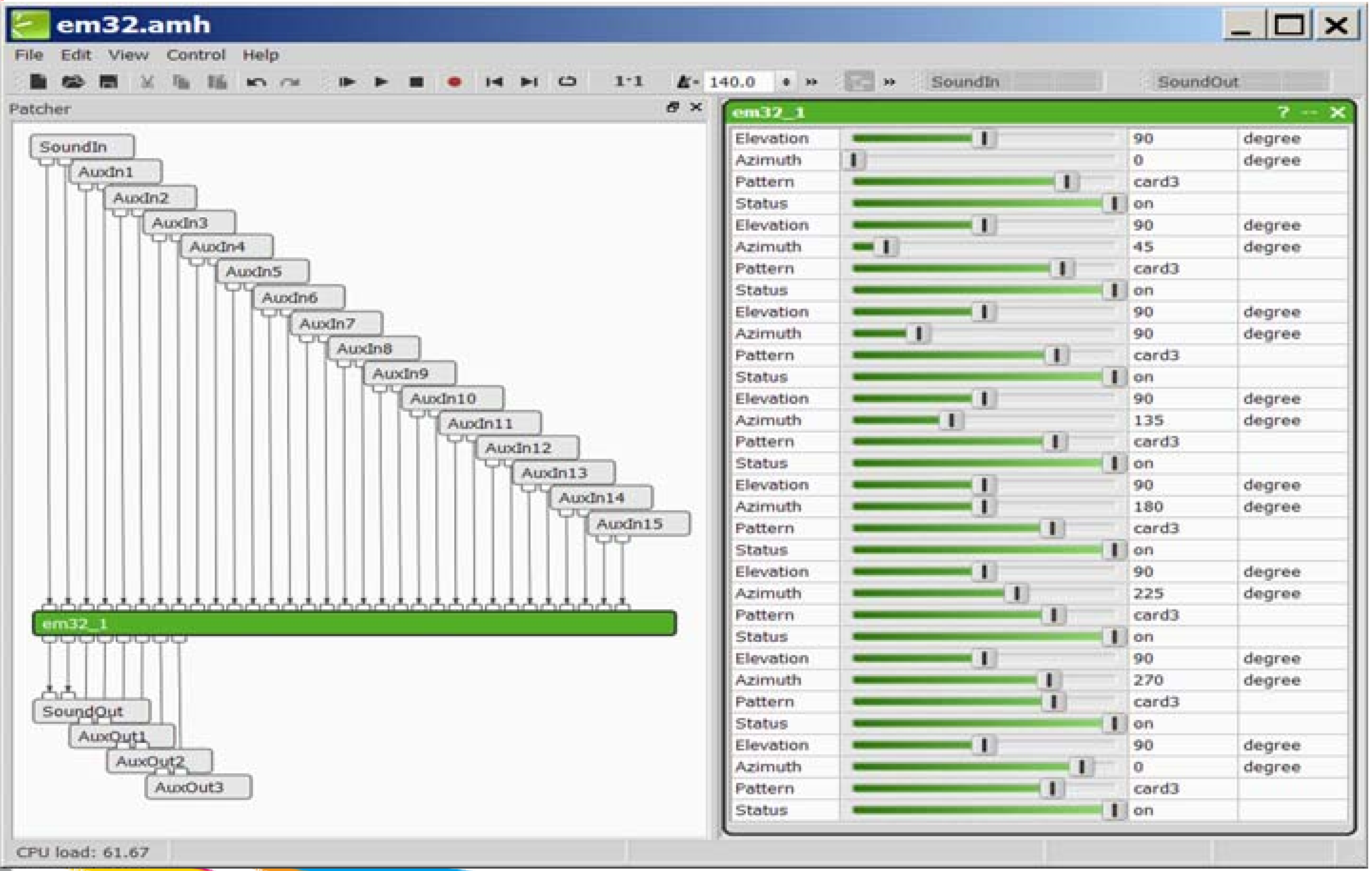
The EIGENMIKE™ software



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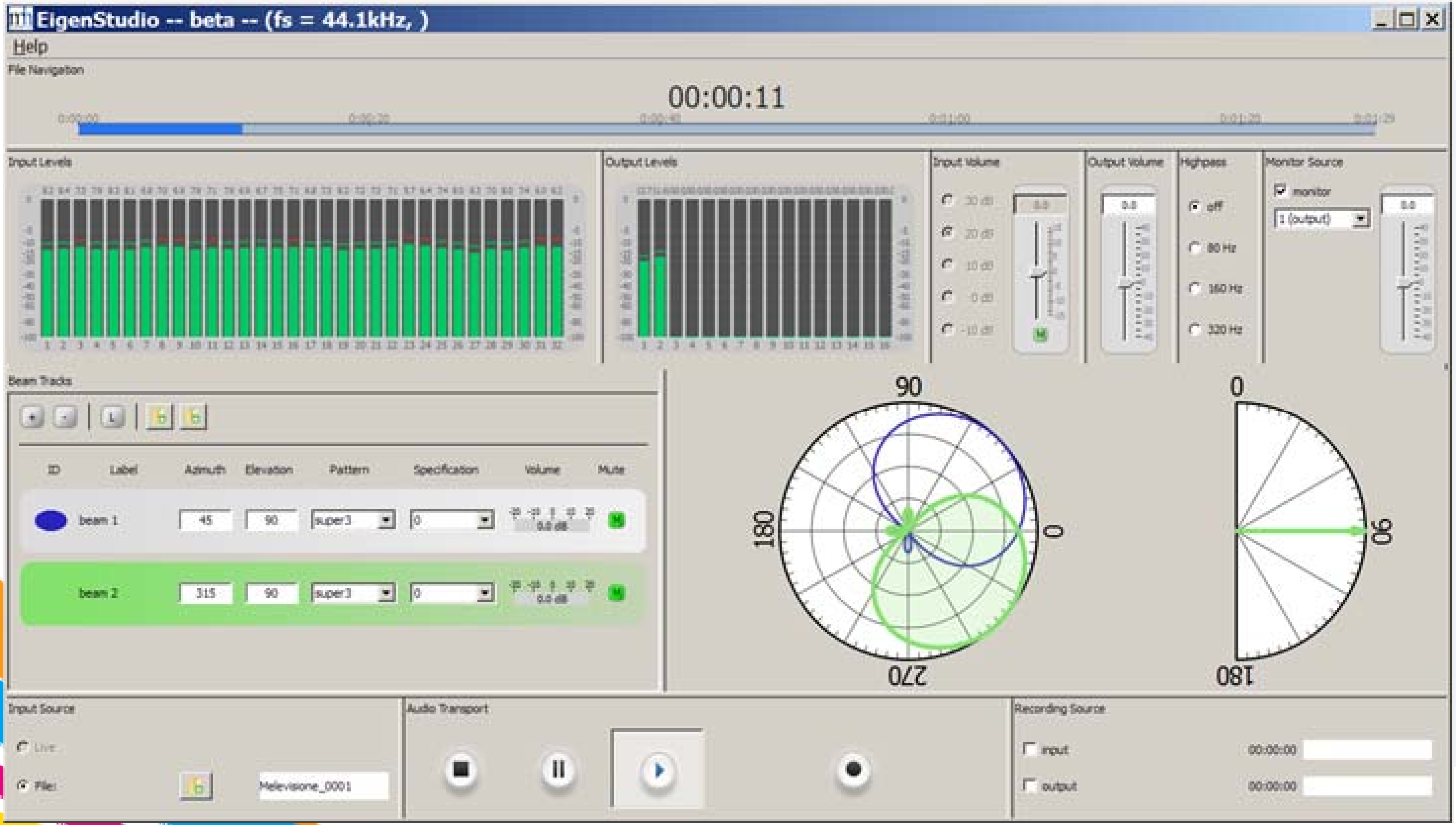
The EIGENMIKE™ software



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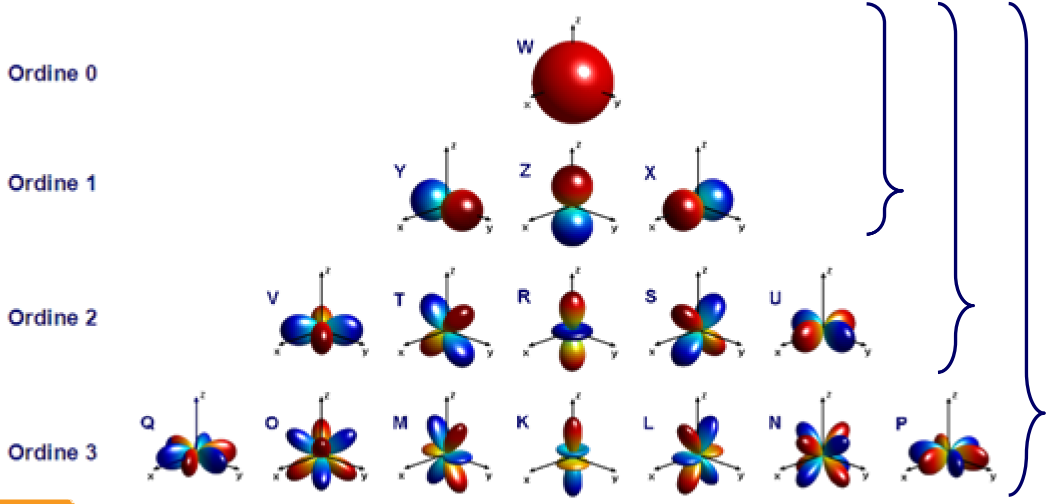
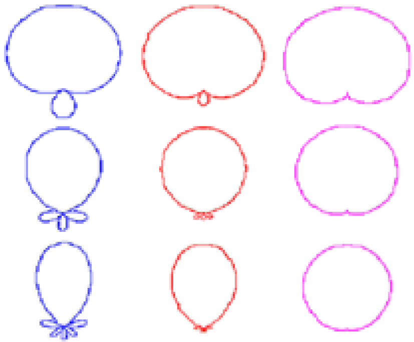
Traditional Spherical Harmonics approach

Spherical Harmonics (H.O.Ambisonics)



Virtual microphones



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A fixed number of “intermediate” virtual microphones is computed (B-format), then the dynamically-positioned virtual microphones are obtained by linear combination of these intermediate signals. This limits both dynamic range and frequency range.

The RAI-CRIT project

GOALS:

- "Virtual" microphones with high directivity, controlled by mouse/joystick in order to follow in realtime actors on the stage. They should be capable to modify their directivity in a sort of "acoustical zoom".
- Surround recordings with microphones that can be modified (directivity, angle, gain, ecc..) in post-production.
- Get rid of problems with Spherical Harmonics signals

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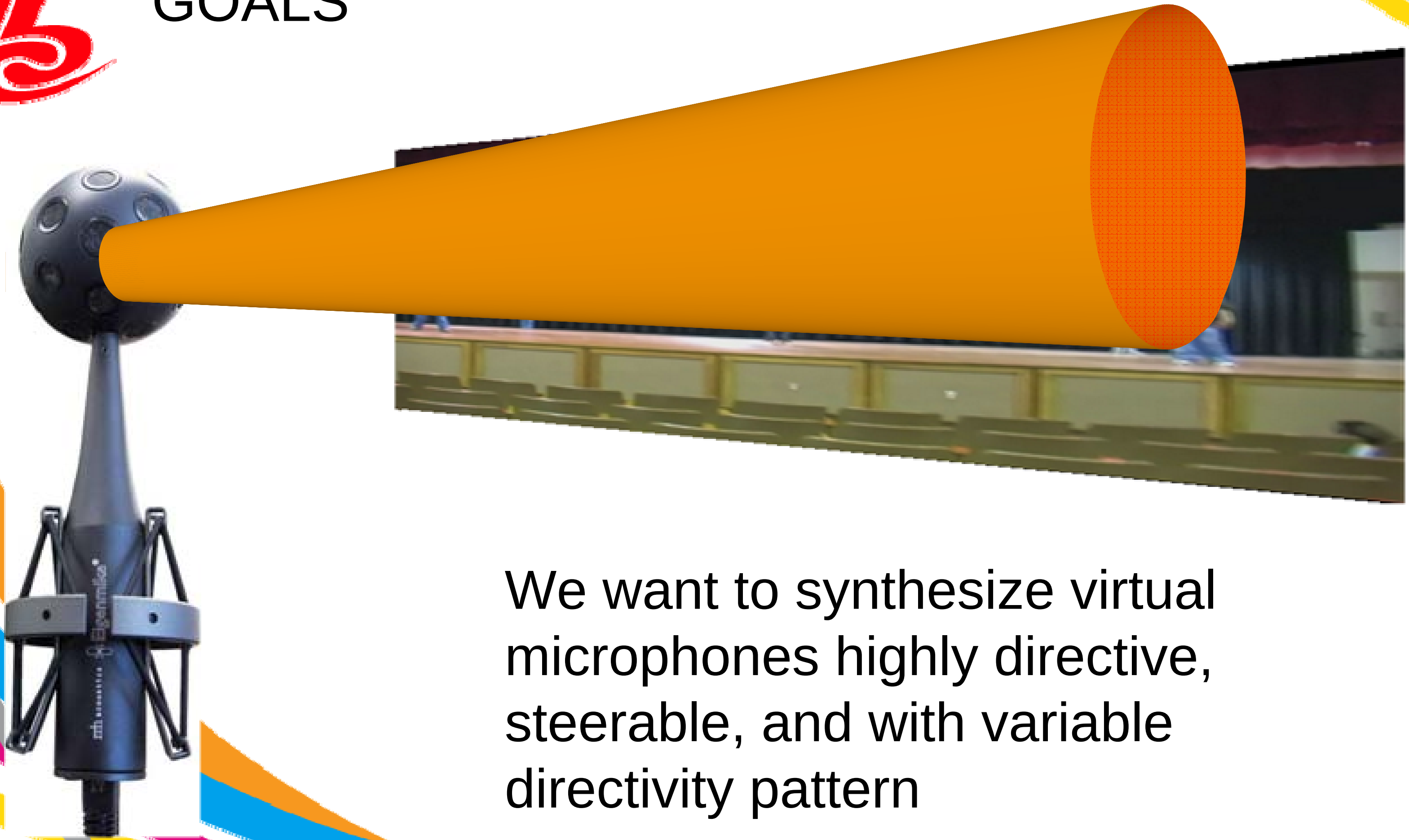
GOALS



We want to synthesize virtual microphones highly directive, steerable, and with variable directivity pattern

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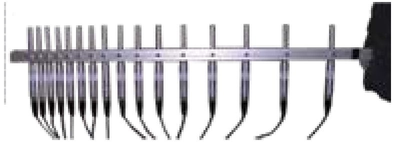
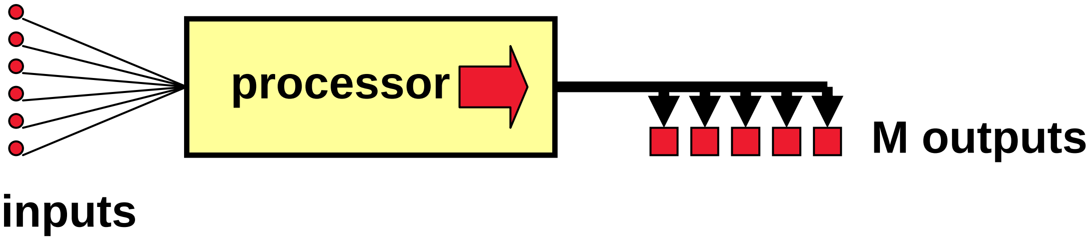
MICROPHONE ARRAYS: TYPES AND PROCESSING



Linear Array

Planar Array

Spherical Array



Processing Algorithm: $$y_j = \sum_{i=1}^{N} h_{ij} \otimes x_i$$

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Computation of filter coefficients

- No theory is assumed: the set of $h_{i,j}$ filters are derived directly from a set of impulse response measurements, designed according to a least-squares principle.
- In practice, a matrix of impulse responses is measured, and the matrix has to be numerically inverted (usually employing some regularization technique).
- This way, the outputs of the microphone array are maximally close to the ideal responses prescribed
- This method also inherently corrects for transducer deviations and acoustical artifacts (shielding, diffractions, reflections, etc.)

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Computation of filter coefficients

- No theory is assumed: the set of $h_{i,j}$ filters are derived directly from a set of impulse response measurements, designed according to a least-squares principle.
- **STEP1**: a matrix **C** of impulse responses is measured,
- **STEP2**: the target polar pattern **P** of the virtual microphone is defined
- **STEP3**: the processing filters **H** are found by imposing that

$$[C] \cdot \{H\} = \{P\}$$

and inverting the matrix.

- This way, the outputs of the microphone array are maximally close to the ideal responses prescribed
- This method also inherently corrects for transducer deviations and acoustical artifacts (shielding, diffractions, reflections, etc.)

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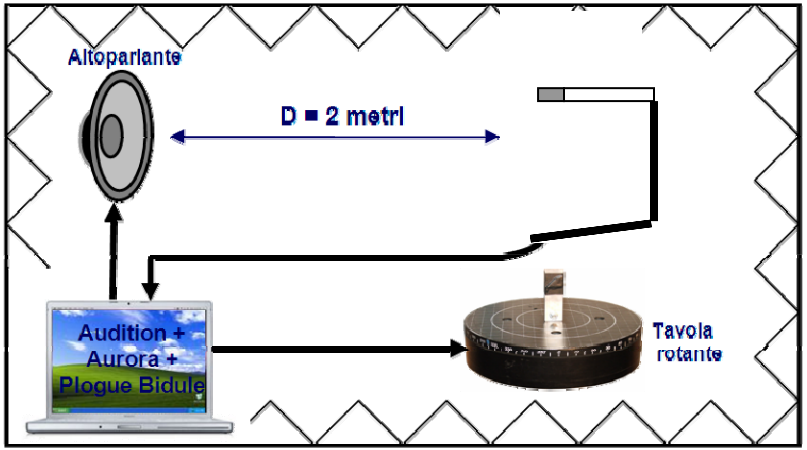
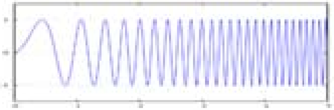
STEP1: Anechoic measurements

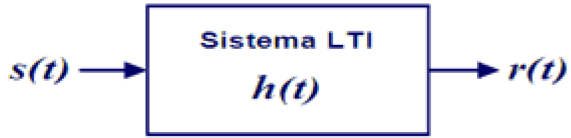
- A large anechoic room was employed for full-range measurements
- A computer-controlled turntable was employed for rotation at fixed angular steps
- The AURORA software was employed for generating the test signals and the control pulses for the turntable
- ESS (Exponential Sine Sweep) test signal
- The loudspeaker response was measured with a class-0 B&K microphone, and a suitable inverse filter applied to the test signal



$s(t) =$



$$s(t) * s^{inv}(t) = \delta(t)$$



$$h(t) = r(t) * s^{inv}(t)$$

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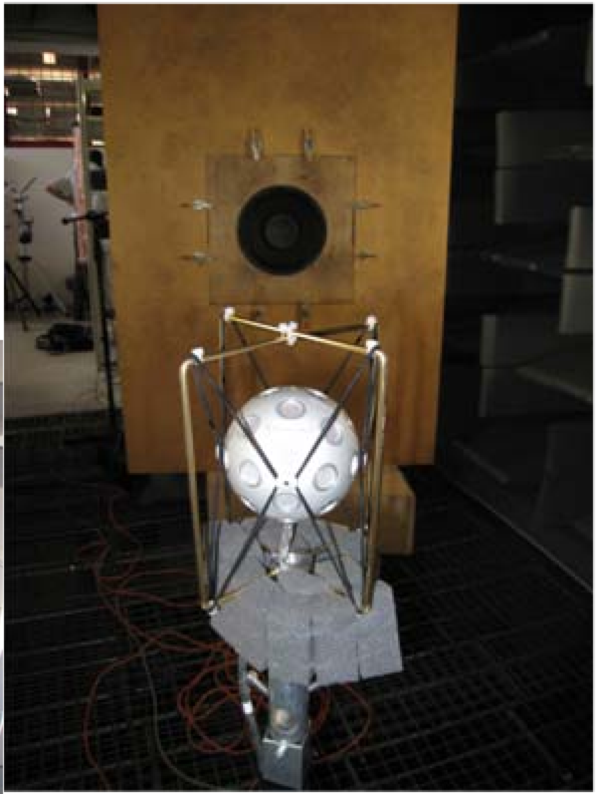
STEP1: Measurements in the horizontal plane

- Small angular steps

- These are the verification measurements, employed for checking the polar responses of the virtual microphones

Angular step:	5°
N. of measurements:	72
ESS signal duration:	10 seconds
Total measurement time:	18 min



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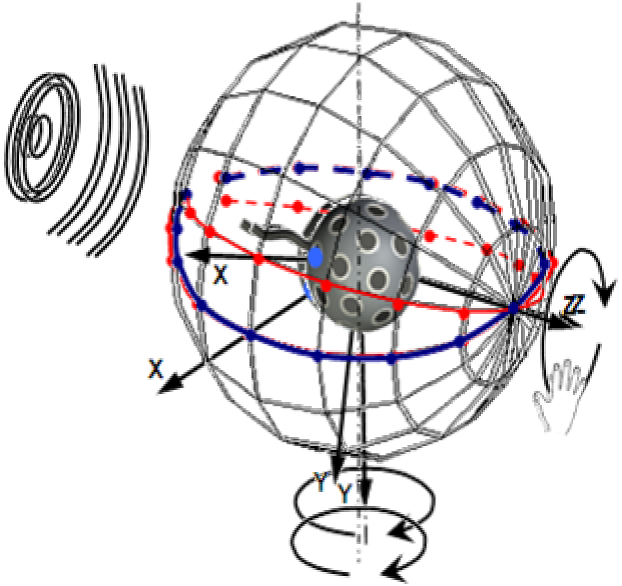
STEP1: Measurements on the whole sphere

Support for rotating the probe

2-axes rotations (meridians and parallels)



- Reduced angular resolution for shortening measurement times

Angular step: 10° x 10°
N. of measurements: 684 (36 meridians x 19 parallels, including the poles)
ESS signal duration: 10 sec
Total measurmenet time: approximately 3 hours

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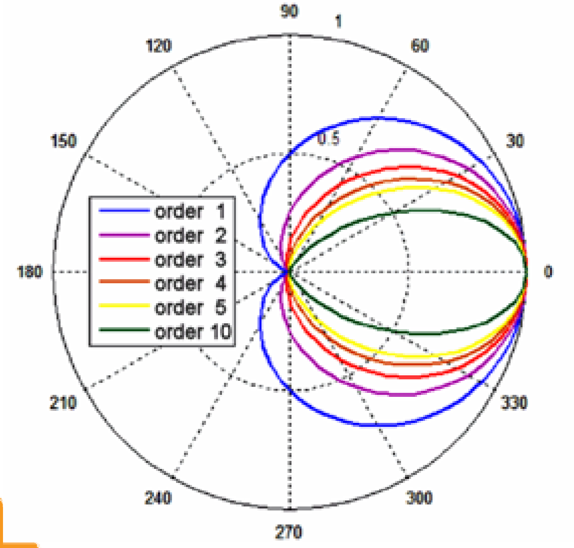
STEP2: Target Directivity



Our synthetic, “virtual” microphone is chosen among a family of cardioid microphones of various orders:

$$Q_n(\vartheta, \varphi) = [0.5 + 0.5 \cdot \cos(\vartheta) \cdot \cos(\varphi)]^n$$

Where ***n*** is the directivity order of the microphone – normal microphones are just 1st-order…

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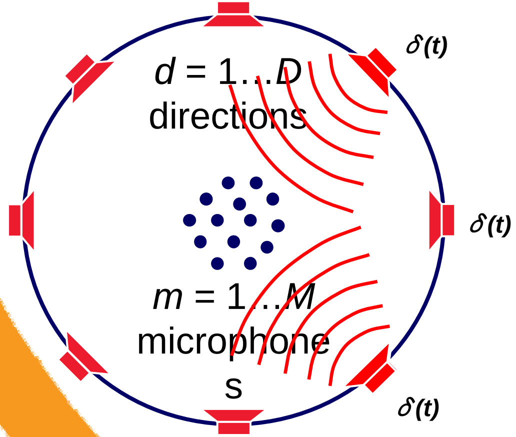
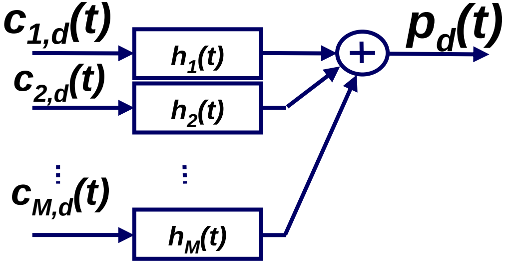
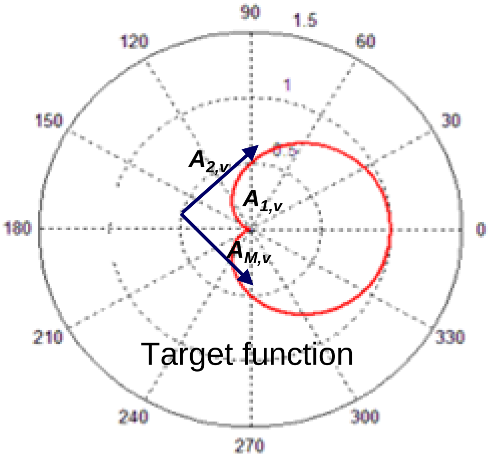
STEP3 – solution of linear equation system

Applying the filter matrix H to the measured impulse responses C, the system should behave as a virtual microphone with wanted directivity







$$\sum_{m=1}^{M} c_{m,d} * h_m \Rightarrow p_d \qquad d = 1..D$$

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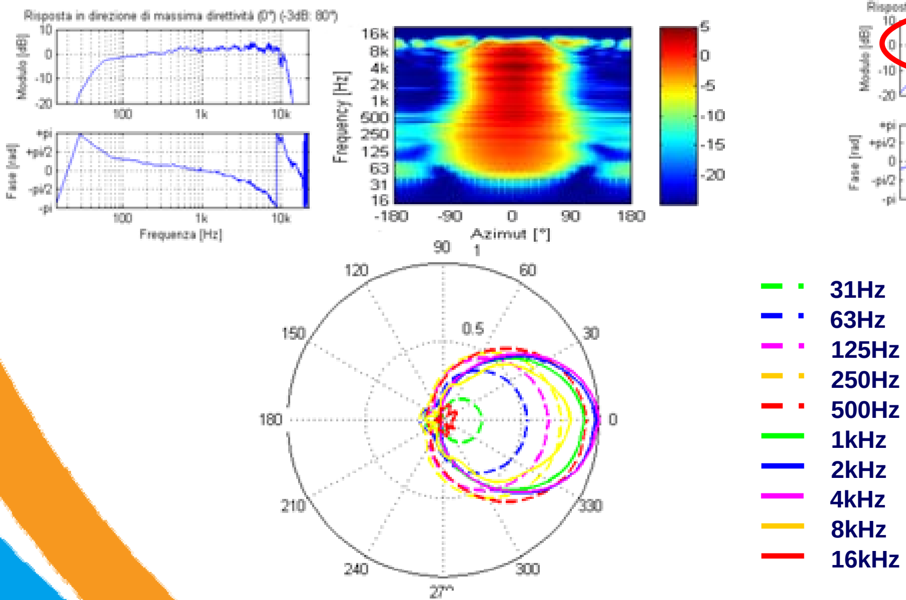
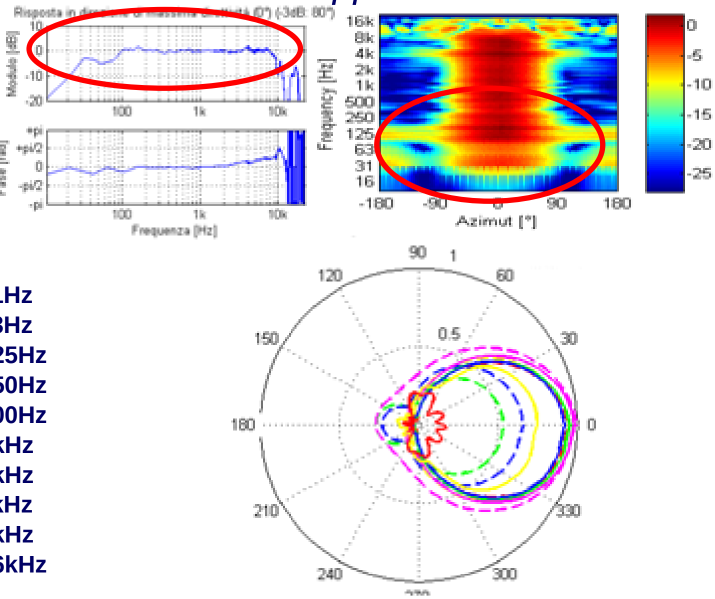
Comparison with H.O.A.

Eigenmike™ software(HOA)



Novel approach

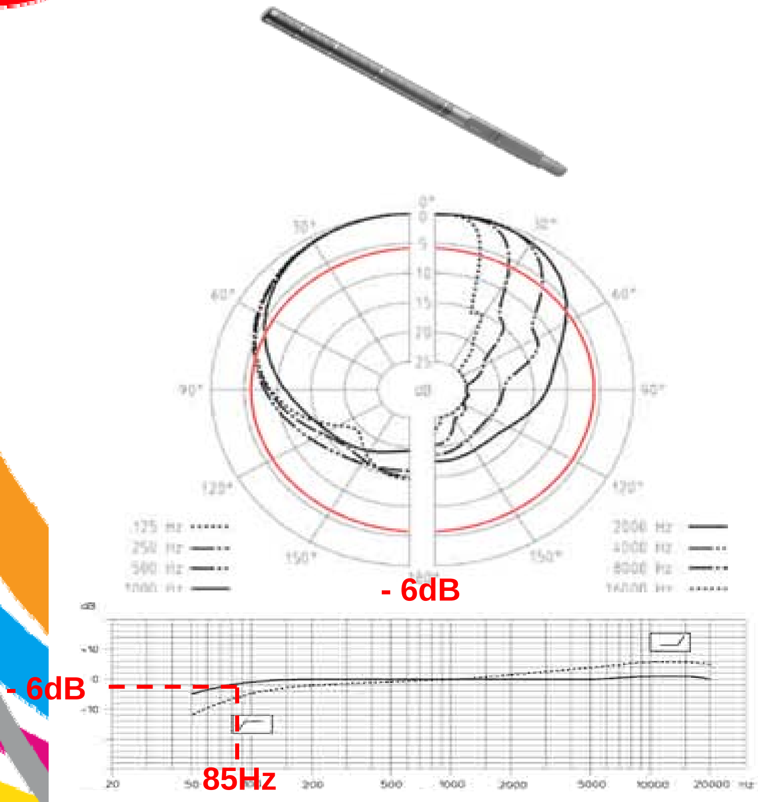


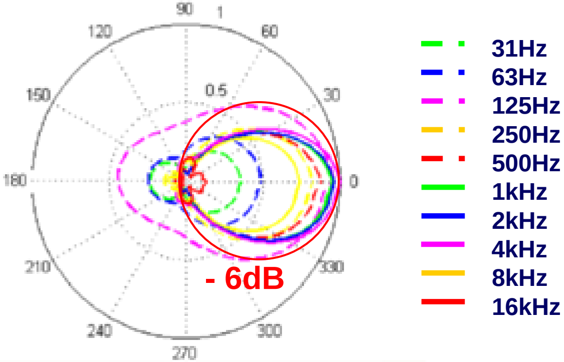
- ➢ Better frequency response
- ➢ Better directivity control at low frequency
- ➢ Increased upper frequency limit

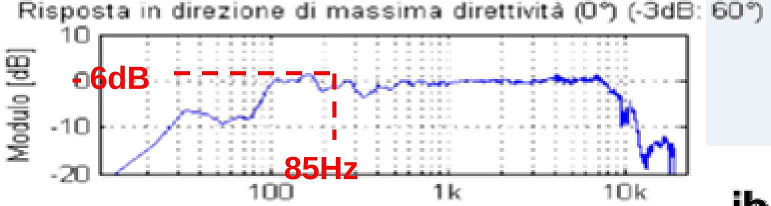
In any case, the novel approach is always better than traditional HOA

Comparison with a Sennheiser shotgun

- Similar beam width (≅ 60° at -3dB)
- Constant directivity with frequency: no colouring outside the beam
- Comparable frequency bandwidth







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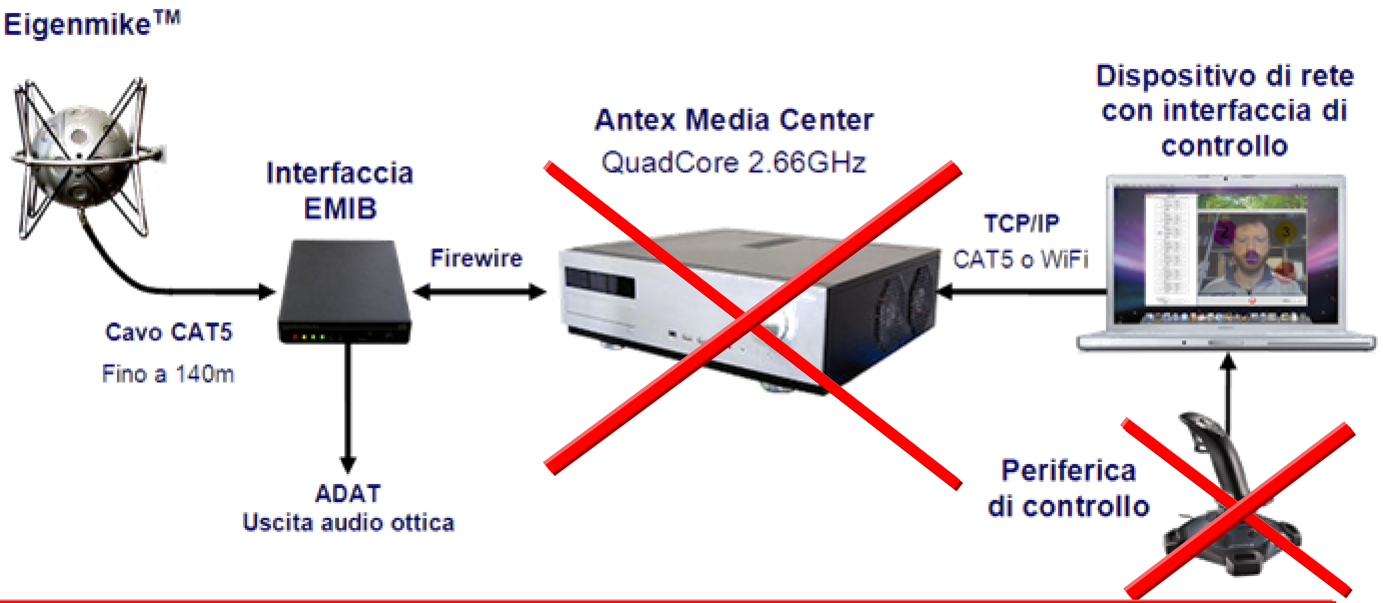
The real-time microphone system



But nowadays all the processing is performed on a powerful MacBook Pro with Core i7 processor and mouse control

- Realtime synthesis of processing filters with our novel algorithm
- Aiming and directivity of the virtual microphones can be changed in realtime under control of a joystick or with the mouse

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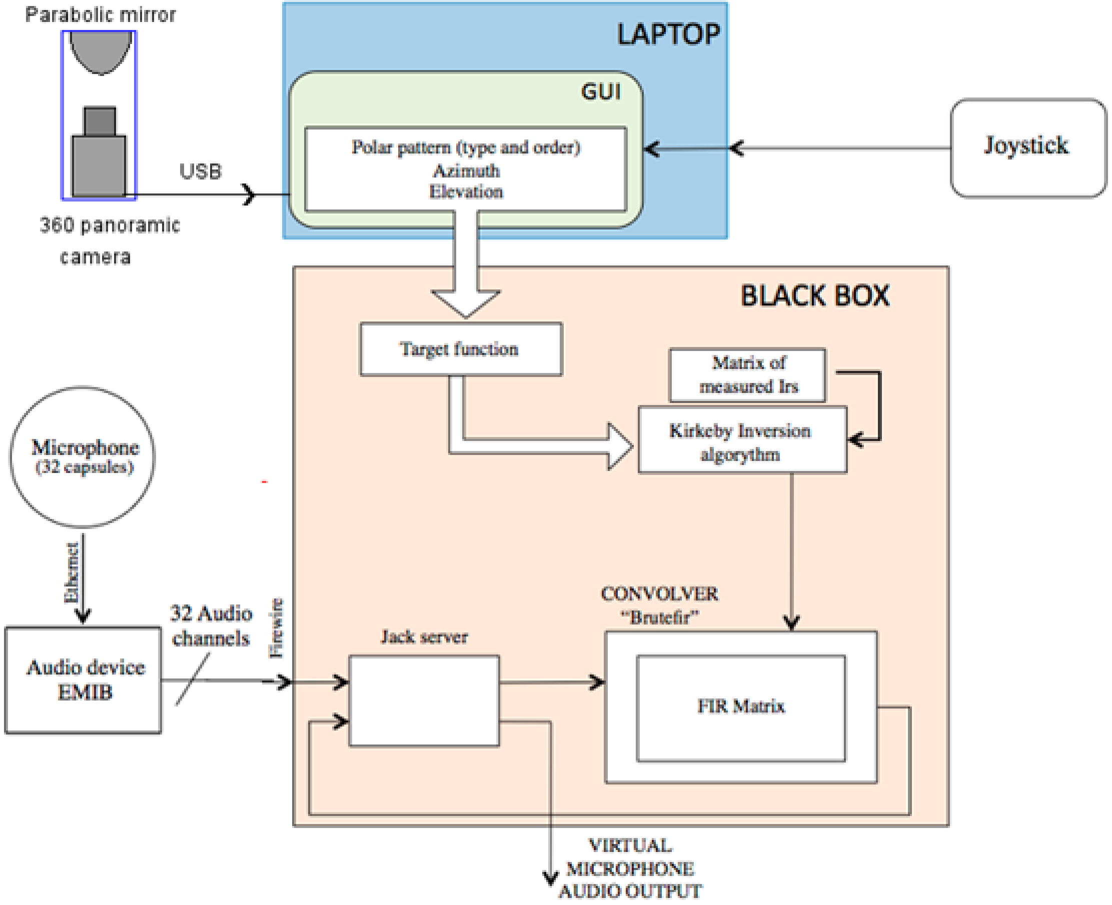
The real-time microphone system

- A panoramic camera provides the background live video imaging
- The Laptop operates with a GUI written in Python, and controlled with a mouse or a joystick
- The "Black box" runs a special version of Linux, optimized for low latency and multitasking on multicore processors, and the open-source convolution engine BruteFIR



Hardware for 360° video

- A 2 Mp hires Logitech webcam is mounted under a parabolic mirror, inside a Perspex tube
- The video stream from the Logitech webcam is processed with a realtime video-unwrapping software, written by Adriano Farina in “Processing”, a Java-based programming language and environment
- It is possible to record the unwrapped video stream to a standard MOV file

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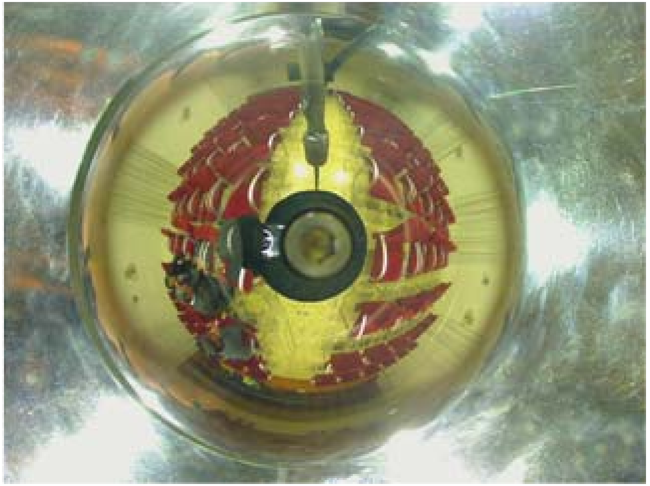
Video unwrapping



Original image

Unwrapped image

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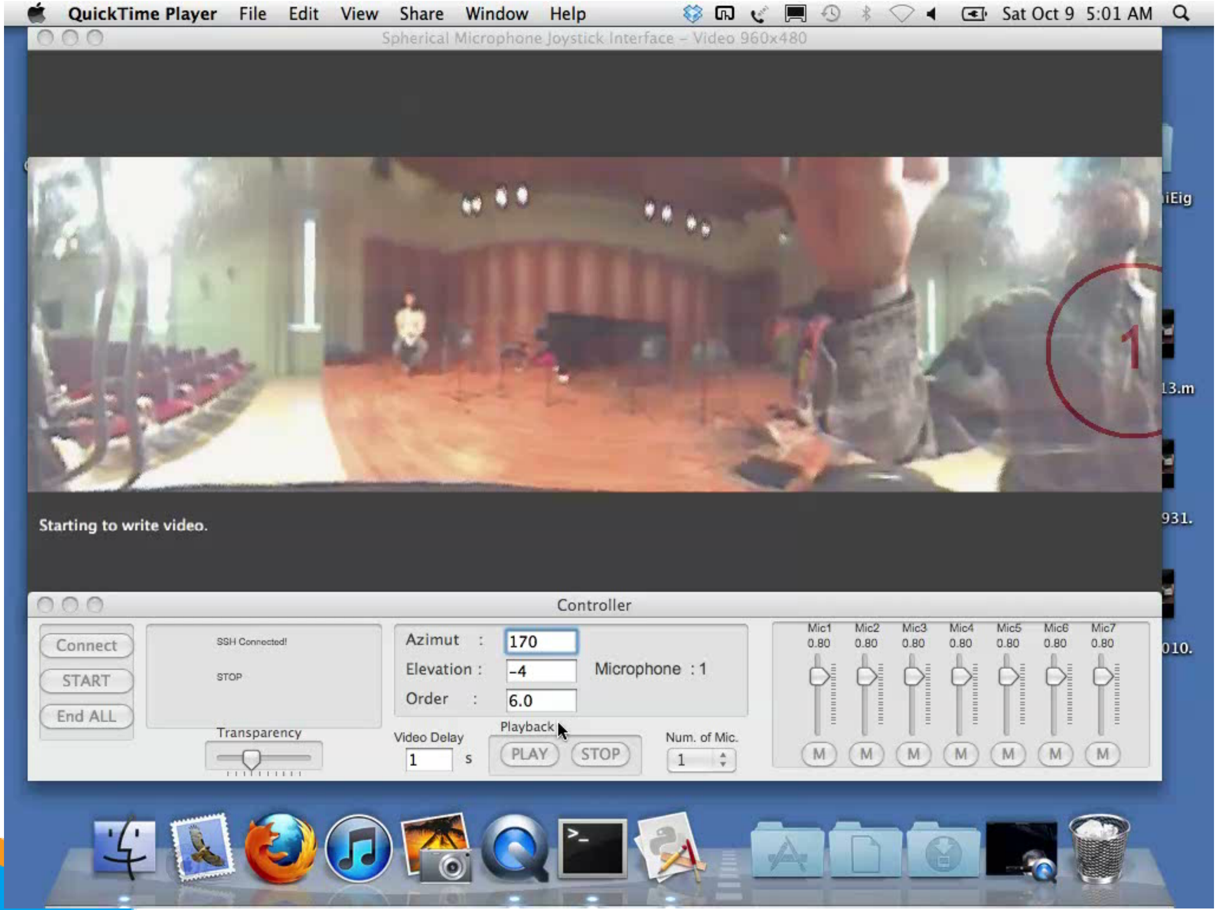
Video Sample: ScreenRecording



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Example with multiple speakers and a single, movable virtual microphone inside a Reverberant room (post processing)

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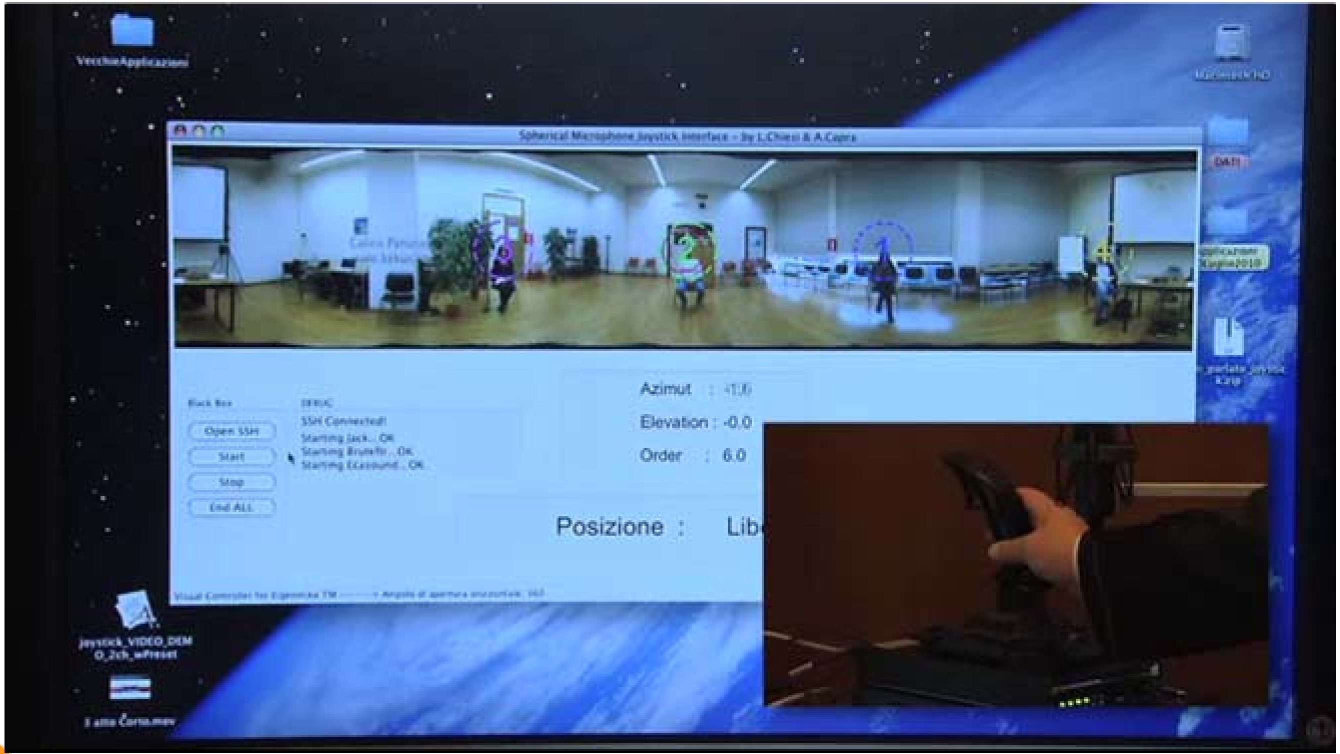
Video Sample: Parlato



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Example of operation from a very unfavourable shooting position

Arlecchino servo di due padroni

"Piccolo Teatro", Milan

20 october 2010

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5 fixed virtual microphones in post-production

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Video Sample: Arlecchino

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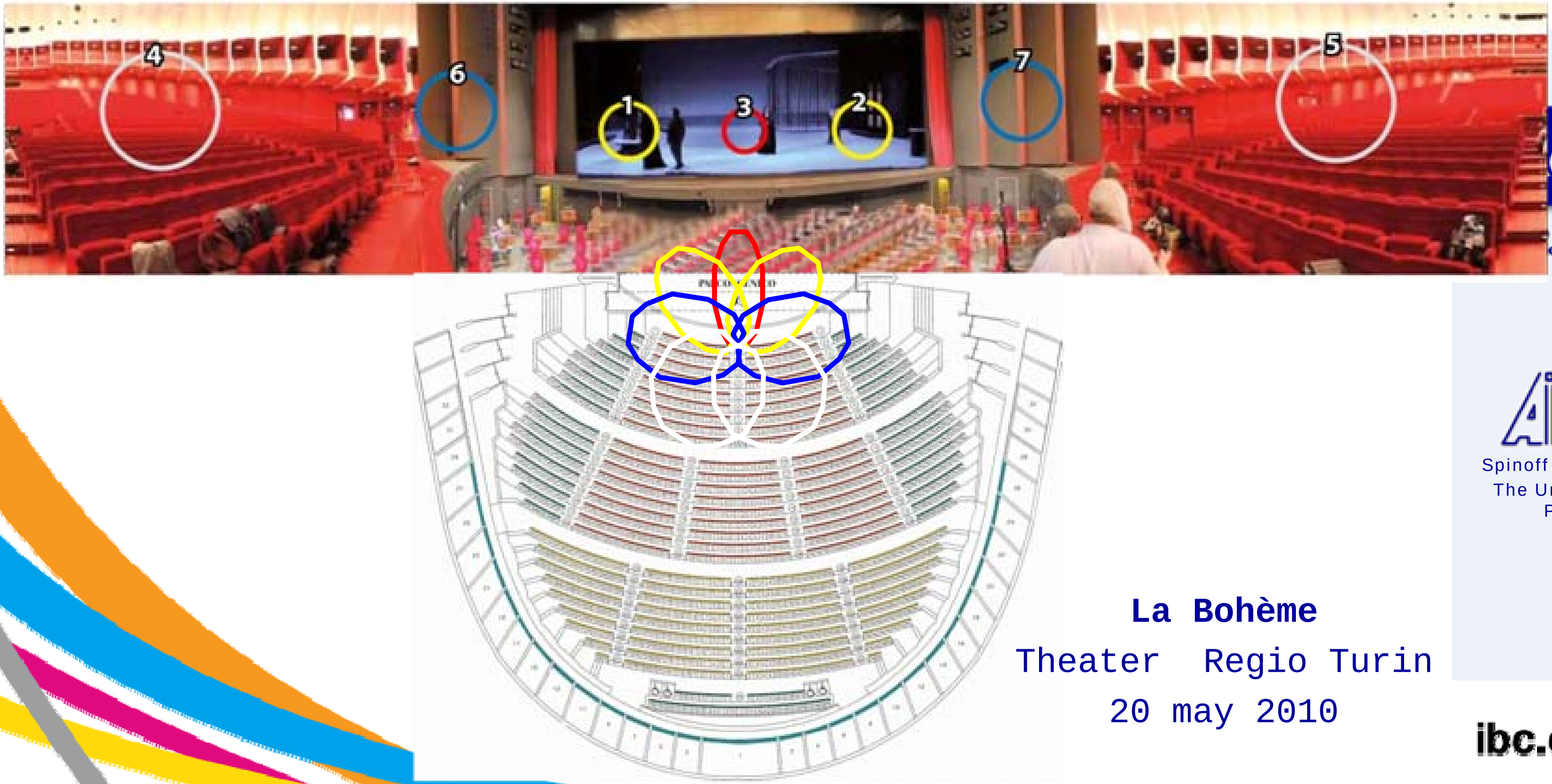
Example of post-processing with 7 fixed microphones



La Bohème

Theater Regio Turin

20 may 2010

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Video Sample: Boheme

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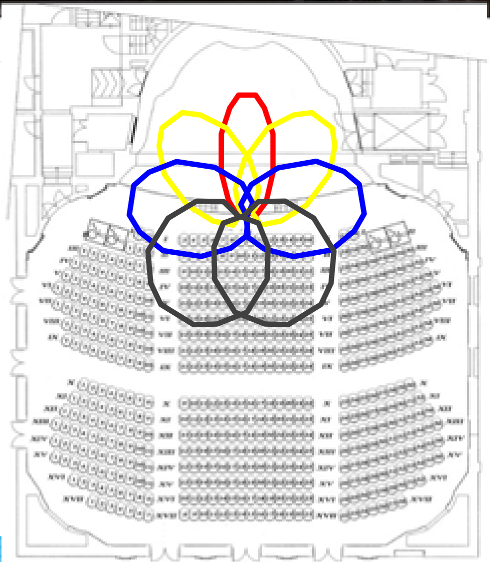
7.1 recording of symphonic music



Concerto in re maggiore op. 35 per violino e orchestra P. I. Tchaikovsky

Conservatory of Turin

22 november 2010

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Video Sample: Tchaikovsky

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First realtime broadcasting: 21 june 2011

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Lucia di Lammermoor

Teatro Regio, Martedì 21 Giugno 2011 - Domenica 3 Luglio 2011

Comunicato stampa

eni italgas

Il capolavoro di Donizetti diretto da Campanella, per la regia di Vick

Teatro Regio, martedì 21 giugno 2011 ore 20
Trasmissione in diretta 21 giugno ore 20 su Rai-Radio3

Lucia di Lammermoor di Gaetano Donizetti va in scena al Teatro Regio **dal 21 giugno al 3 luglio** nel bellissimo allestimento creato da **Graham Vick**. Sul podio dell'**Orchestra** e del **Coro del Teatro Regio** il maestro **Bruno Campanella**, tra i massimi interpreti dell'opera preromantica italiana.

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Lucia di Lammermoor

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Audio/Video Samples download

- The audio/video samples employed during the presentation can be downloaded from

HTTP://pcfarina.eng.unipr.it/Public/EBU-2011