Spatial analysis of room impulse responses captured with a 32-capsules microphone array

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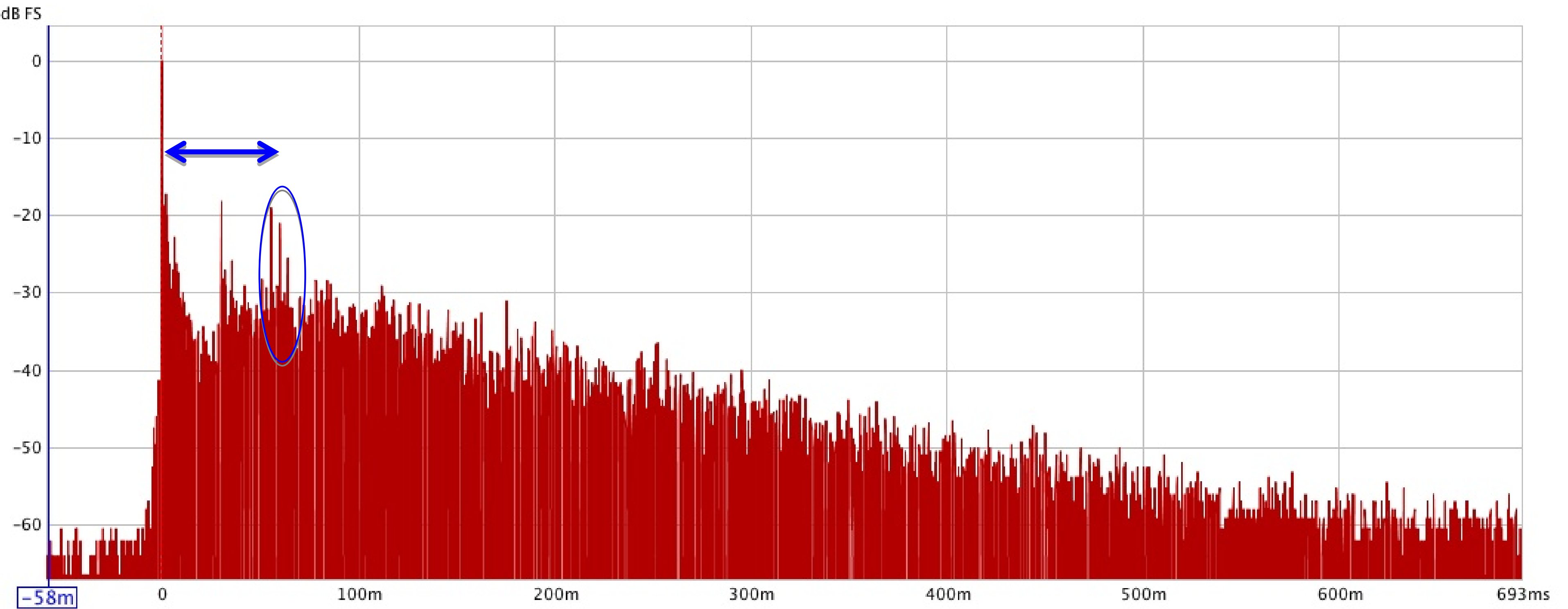
Introduction

Most of the acoustical measurements in theatres, concert halls and musical spaces are performed by using a single omnidirectional pressure microphone.

Used for reverberation time and other monophonic parameters

NO information about the arrival direction of the sound



Having at disposal directive microphones and aiming them in different directions it should be possible to obtain a chart of the behaviour of the sound in time and in frequency

Aim of the research: visual and dynamic representation of the acoustical behaviour of the room under test (theatres, concert halls, etc.).

The dynamic vision of this behaviour could be useful for :

- Finding unwanted reflections (echoes)
- Evaluating the spectral content of those reflections
- Checking if the sound reinforcement loudspeakers are correctly located and aimed

First attempt: a rotating shotgun microphone

2008 - two similar opera houses chosen for the measurements:

Teatro Sociale di Como

Teatro Comunale di Modena

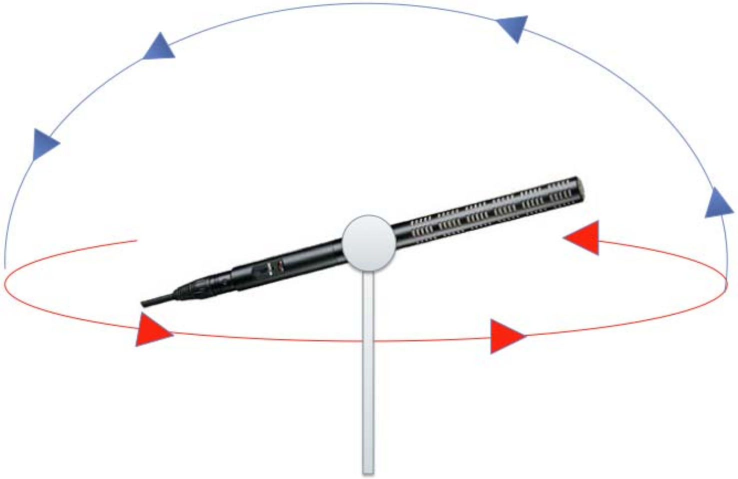
Measurements equipment:

- Omnidirectional source

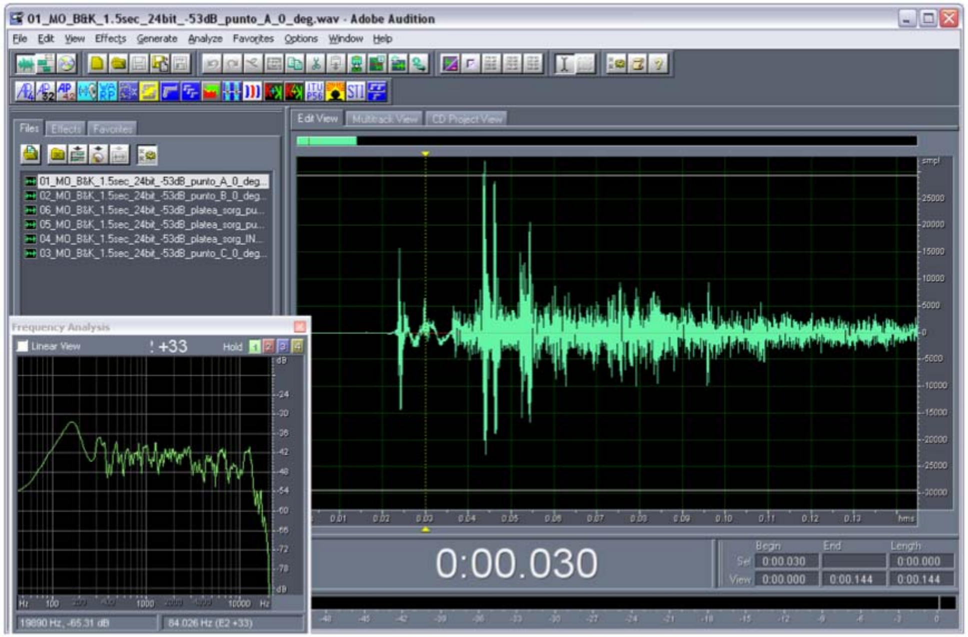
- Sennheiser ME66 directive microphone mounted on a Outline rotating table

- Edirol FA-101 sound card and a laptop for the recording of the sine-sweep test signal

- Azimuth: 18 steps (20°)
- Elevation: 8 steps (22.5°)



- Impulse responses derived from sweeps by using Adobe Audition 1.5 and Aurora plug-ins

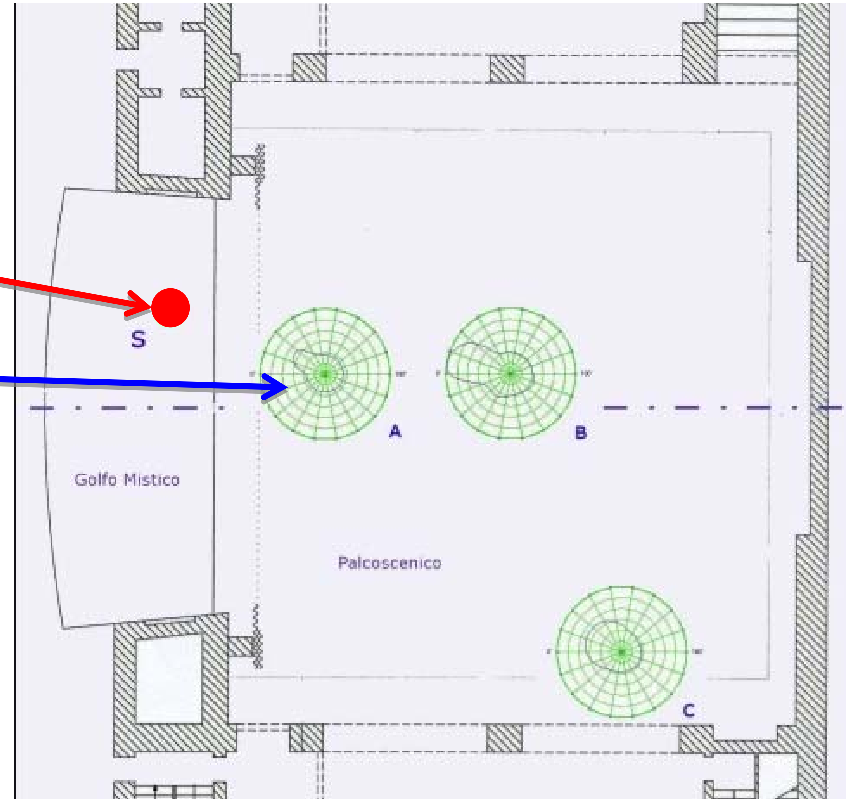


Some results

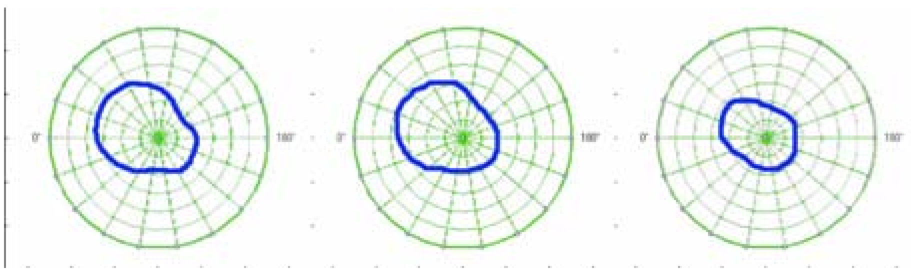
Teatro Comunale di Modena

Source in orchestral pit

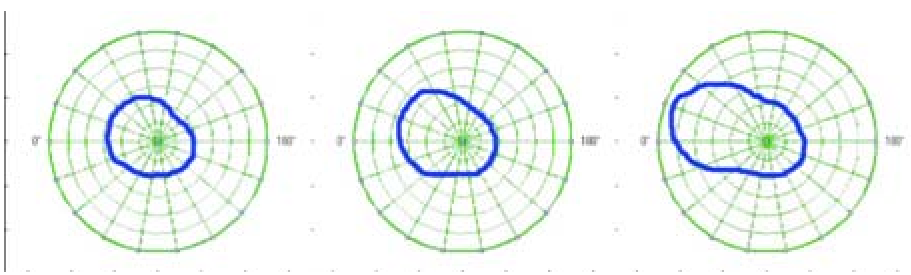
Point A



125 Hz 1000 Hz 4000 Hz



24 ms (direct sound)



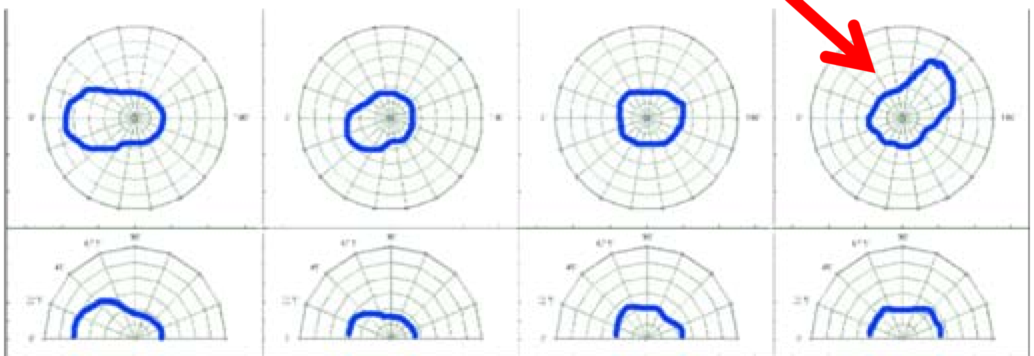
40 ms (first reflection)

The direct sound is rich of low frequencies for the diffraction of the pit

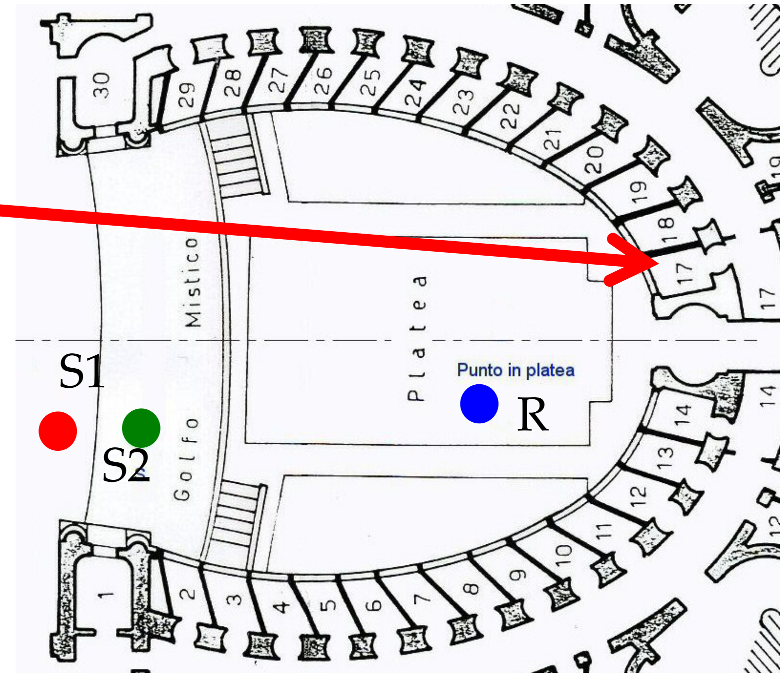
The high frequencies arrive to the performer 16 ms after the direct sound

Teatro Sociale di Como

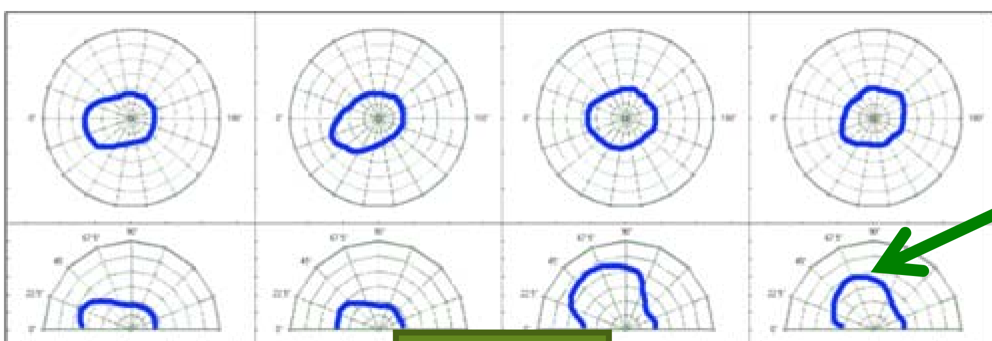
Source S1: the first reflection arrives from the back wall of the theatre after 40 ms



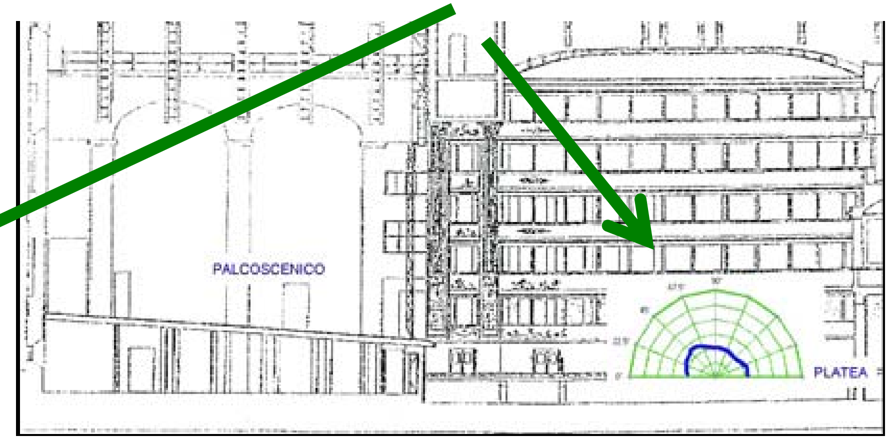
4000 Hz



Source S2: direct sound at high frequencies is weaker than the first reflection coming after 56 ms from the proscenium arch

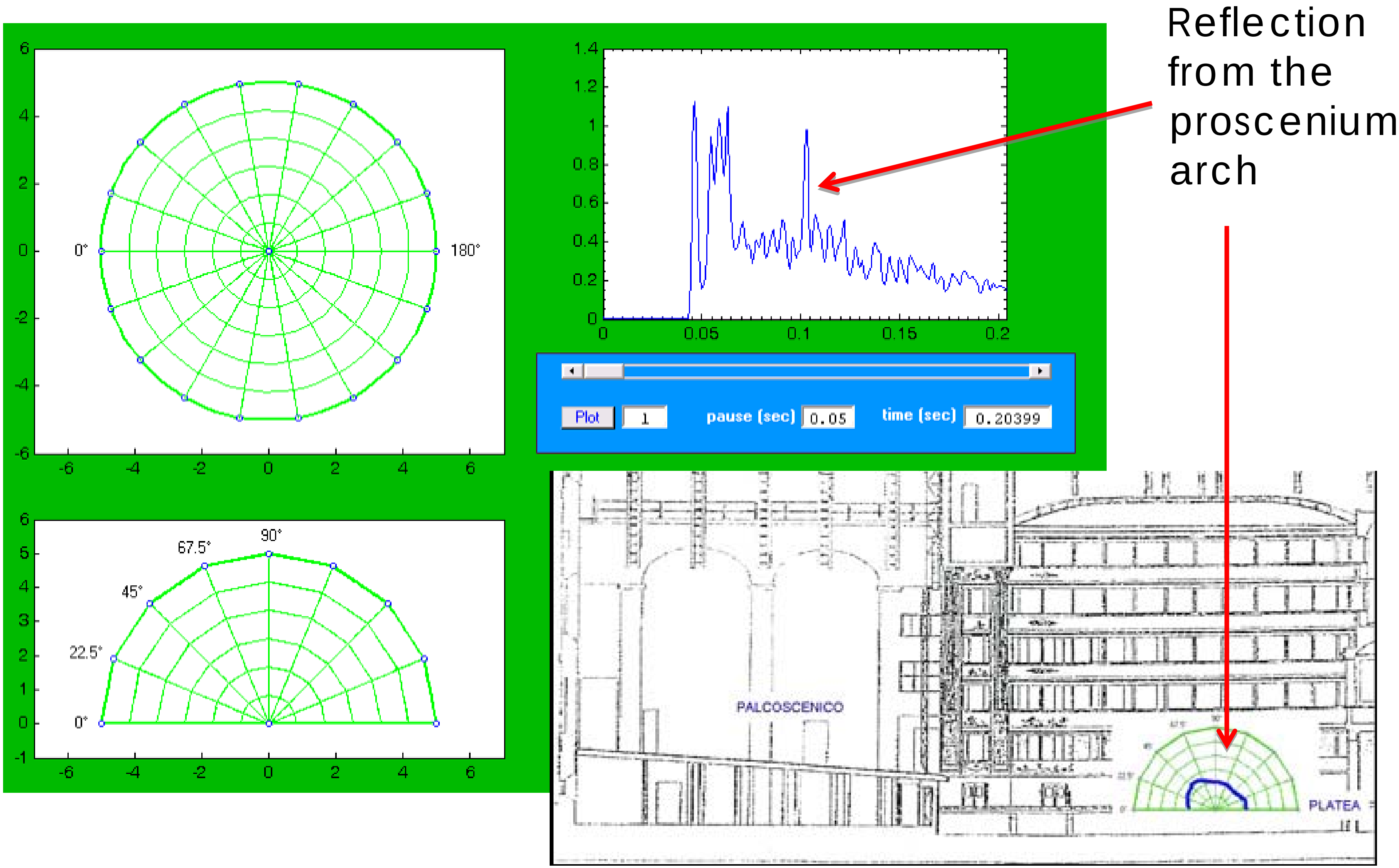


4000 Hz



Dynamic polar plot in vertical and horizontal plane.

Teatro Sociale di Como – 4000 Hz



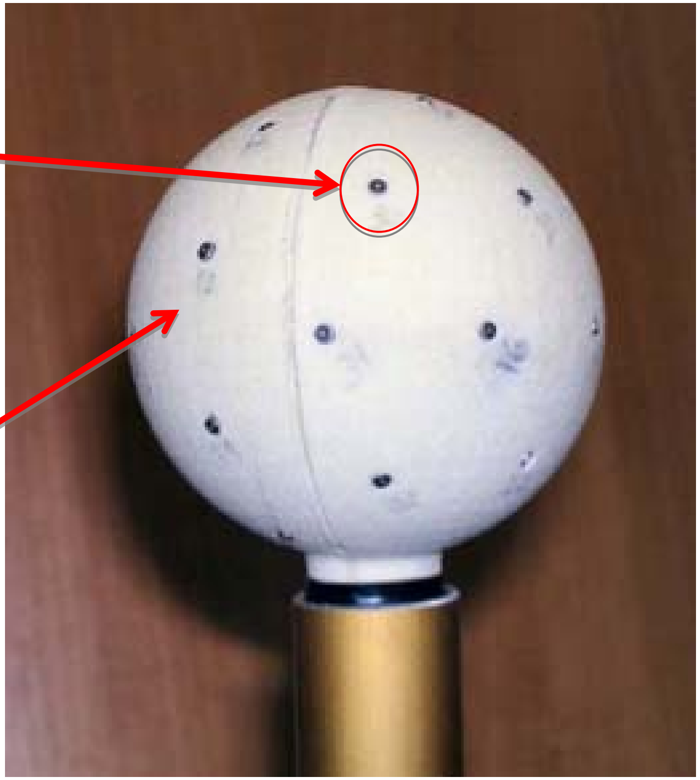
The new approach

How can we obtain lots of directive microphones with only one probe? Using an array of capsules!

2009: first prototype of a spherical array (32 capsules)

32 capsules for earing-aid (poor quality)

Expanded polyurethane (too much delicate for handling!)



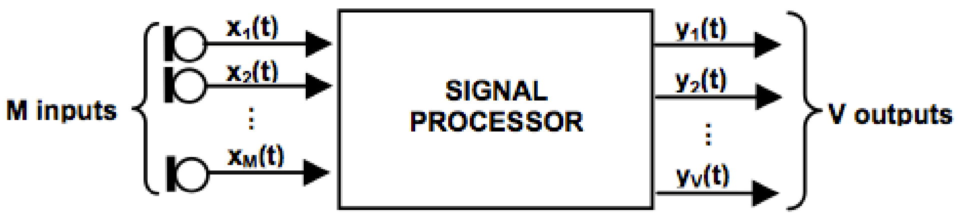
…in the meantime …

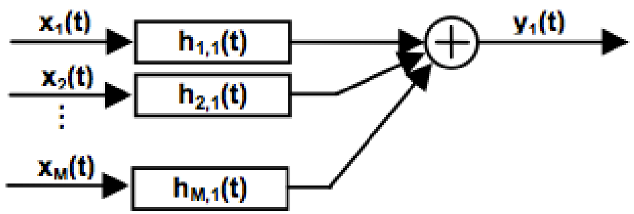
Eigenmike® by mhAcoustics

- 32 high quality capsules
- Pre-amplifiers and A/D converters packed inside the sphere
- All the signals are delivered to the audio interface through a digital CAT-6 cable
- The audio interface is an EMIB Firewire interface based on TCAT DICE chip:
  - supported by any OS
  - 8 digital output(ADAT) + 2 analogue output
  - Wordclock
- The pre-amplifier gain control is operated by MIDI control

The signal processing

The idea → Synthesis of 32 directive virtual microphones in the direction of the capsules employing a set of digital filters





M = 32 signals coming from the capsules
V = 32 signals yielding the desired virtual microphones

↓

Bank of MxV FIR filters

$$y_v(t) = \sum_{m=1}^{M} x_m(t) * h_{m.v}(t)$$

Output signal of V mic.

Input signal from the m-capsule

Matrix of filters

Traditional design of the filters

The processing filters h_{mv} are usually computed following one of several, complex mathematical theories, based on the solution of the wave equation (often under certain simplifications), and assuming that the microphones are ideal and identical

In some implementations, the signal of each microphone is processed through a digital filter for compensating its deviation, at the expense of heavier computational load

Novel approach

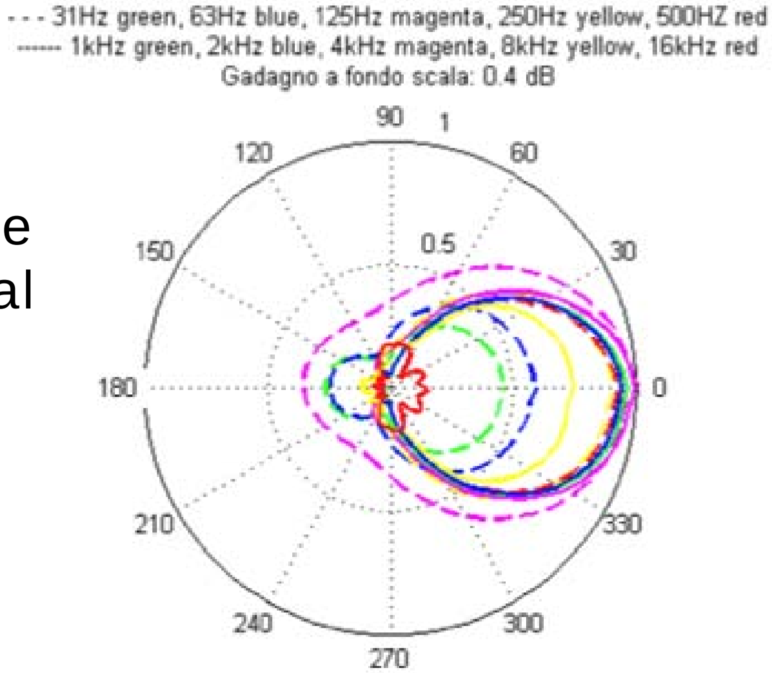
No theory is assumed: the set of h_{mv} filters is derived directly from a set of impulse response measurements, designed according to a least-squares principle.

This method also inherently corrects for transducer deviations and acoustical artefacts (shielding, diffractions, reflections, etc.)

outputs of the microphone array are maximally close to the prescribed ideal responses

Matlab script

- Inputs:
  - ✓ 2048 samples of each IR
  - ✓ The number of virtual microphones
  - ✓ Directivity of each virtual microphone
  - ✓ Azimuth and elevation of each virtual microphone



IRs Matrix inversion

Output: FIR filters matrix

FIRs matrix ⊗ Capsules' signals = Virtual mics

Virtual microphones synthesized for this research:

4th ORDER CARDIOIDS

The new session of measurements

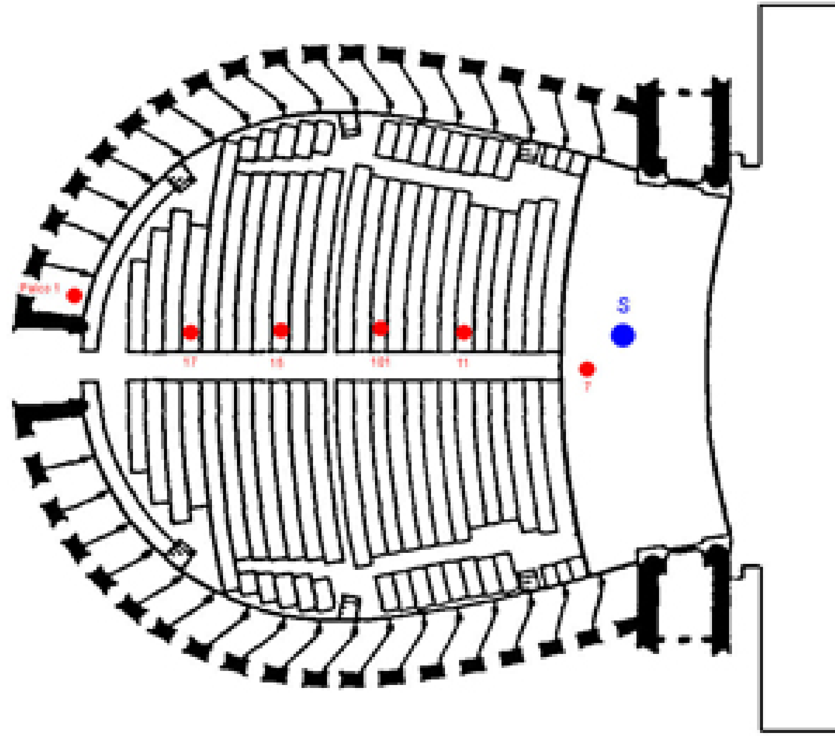
Two different kind of musical space:

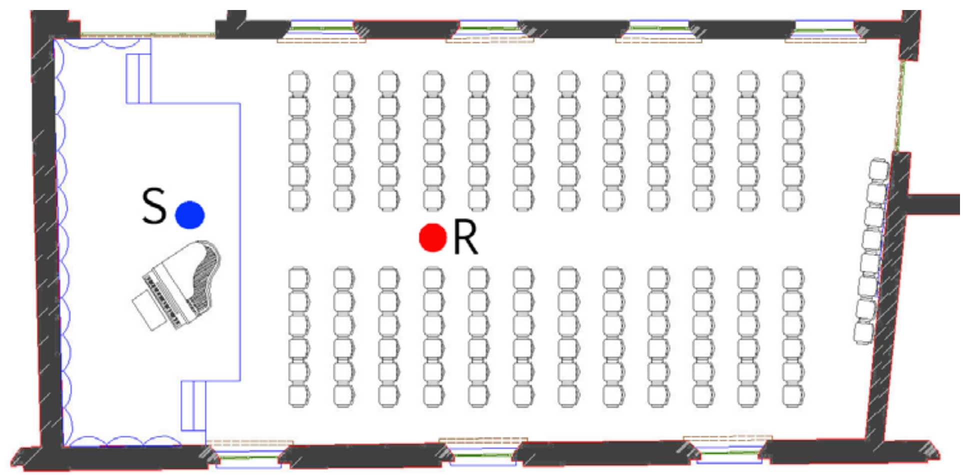
Sala dei Concerti
(Casa della Musica - Parma)

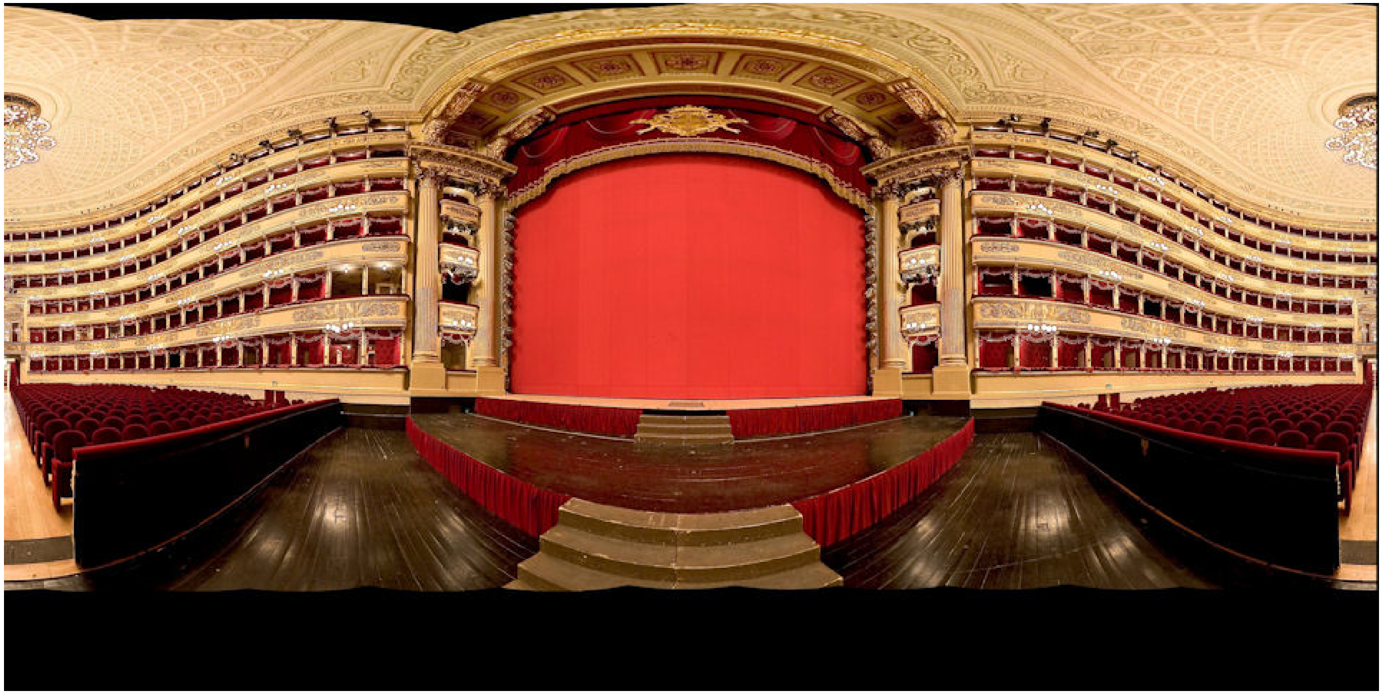
Teatro “La Scala”
(Milano)

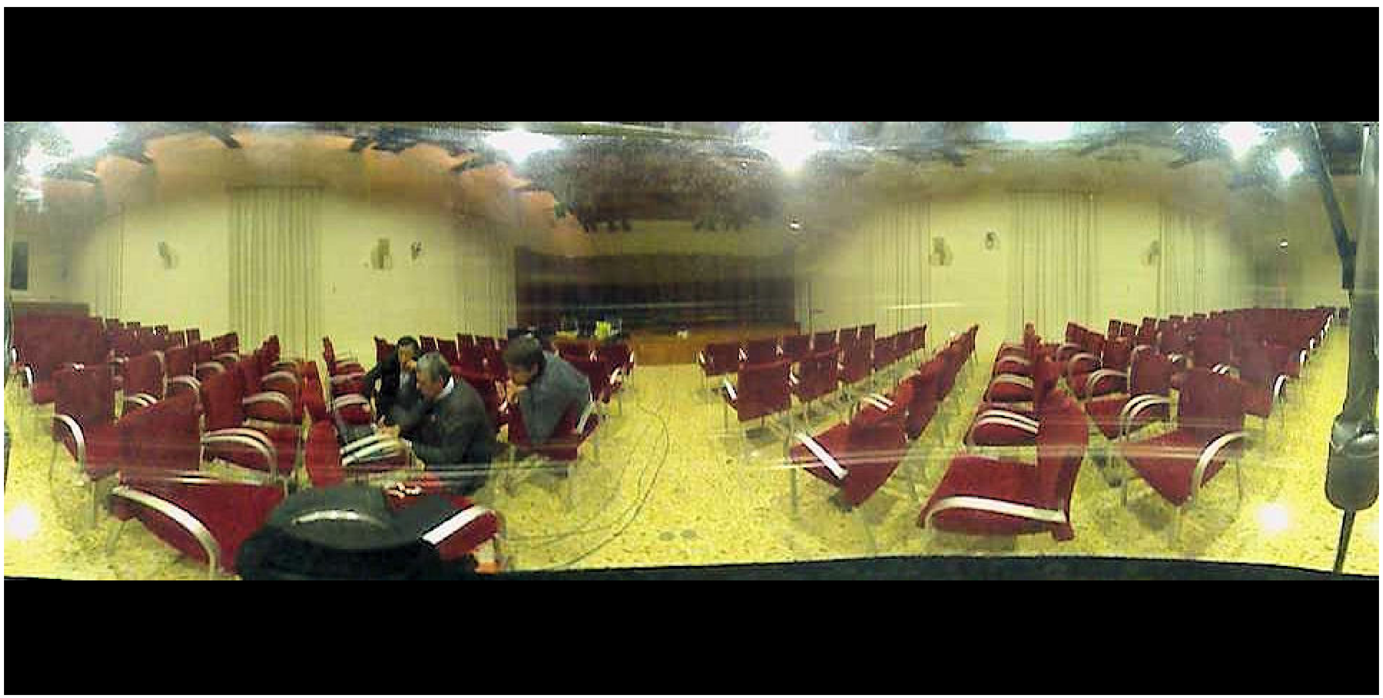
Equipment:

- Eigenmike® probe as receiver
- Laptop as recorder
- "Lookline" Dodecahedron as omni-direcitonal source
- Sine sweep as test signal









The post processing software

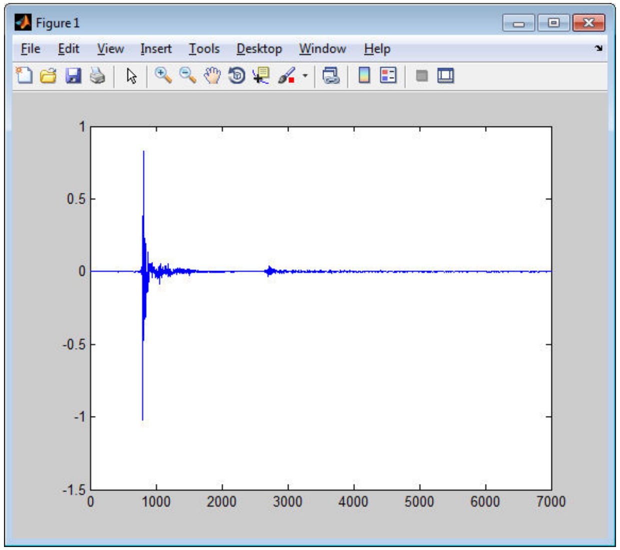
MATLAB script → Polar plot of the sound levels in the horizontal plane

MATLAB script → Mesh map of the levels on a 360° x180° picture of the room

Dynamic plots

1st step

Import of WAV files containing the IRs obtained from the 32 virtual microphones

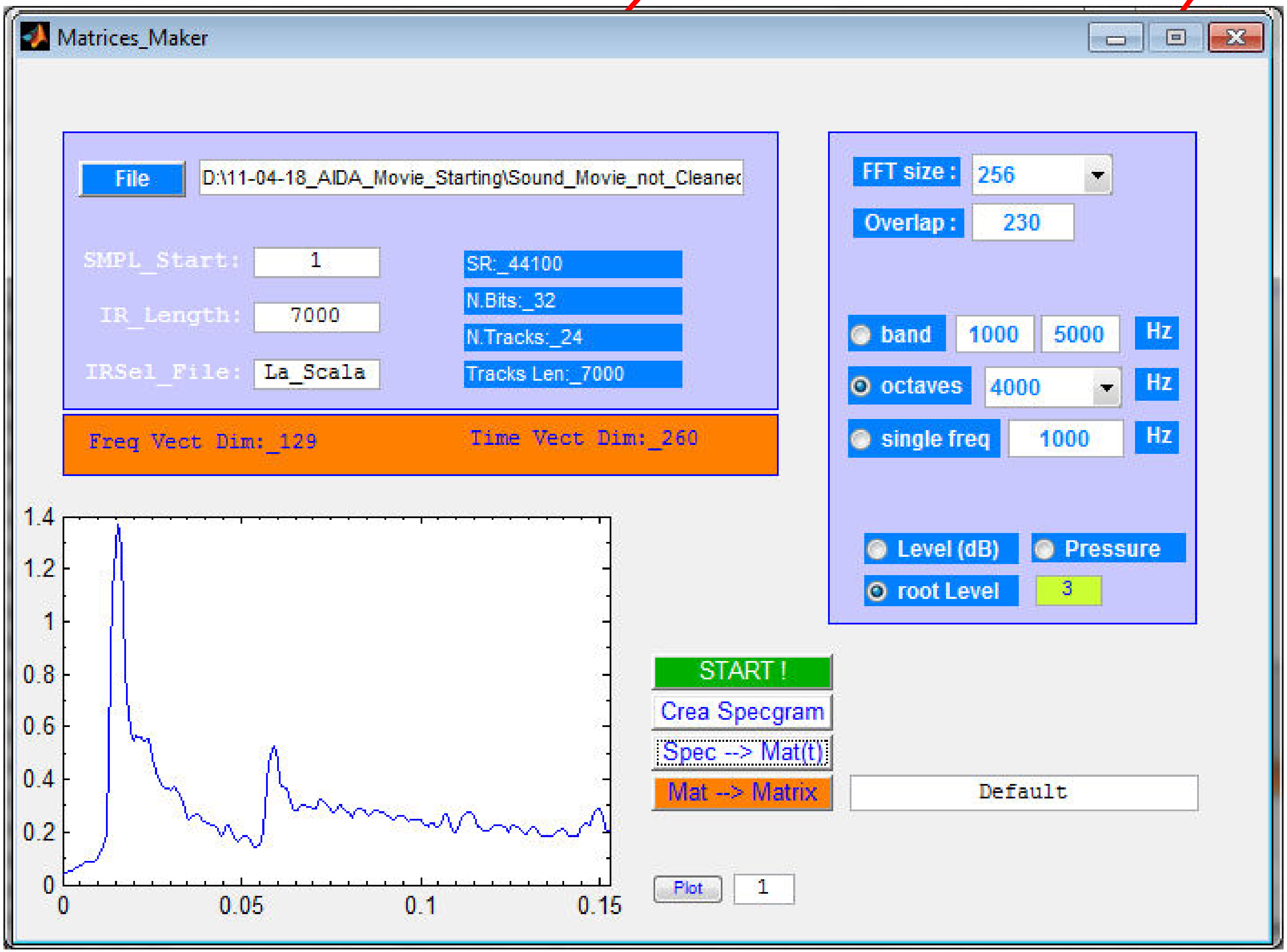


2nd step

FFT processing

Impulse Response length

Frequency bands of analysis



Pressure

Level (dB)

Root 2

Root 3

The results

The probe is not calibrated with an absolute level: every point of measure has its own level normalization and colour scale.

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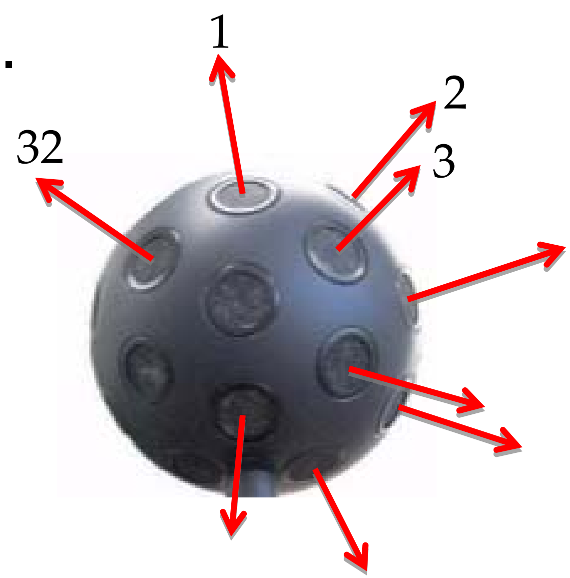
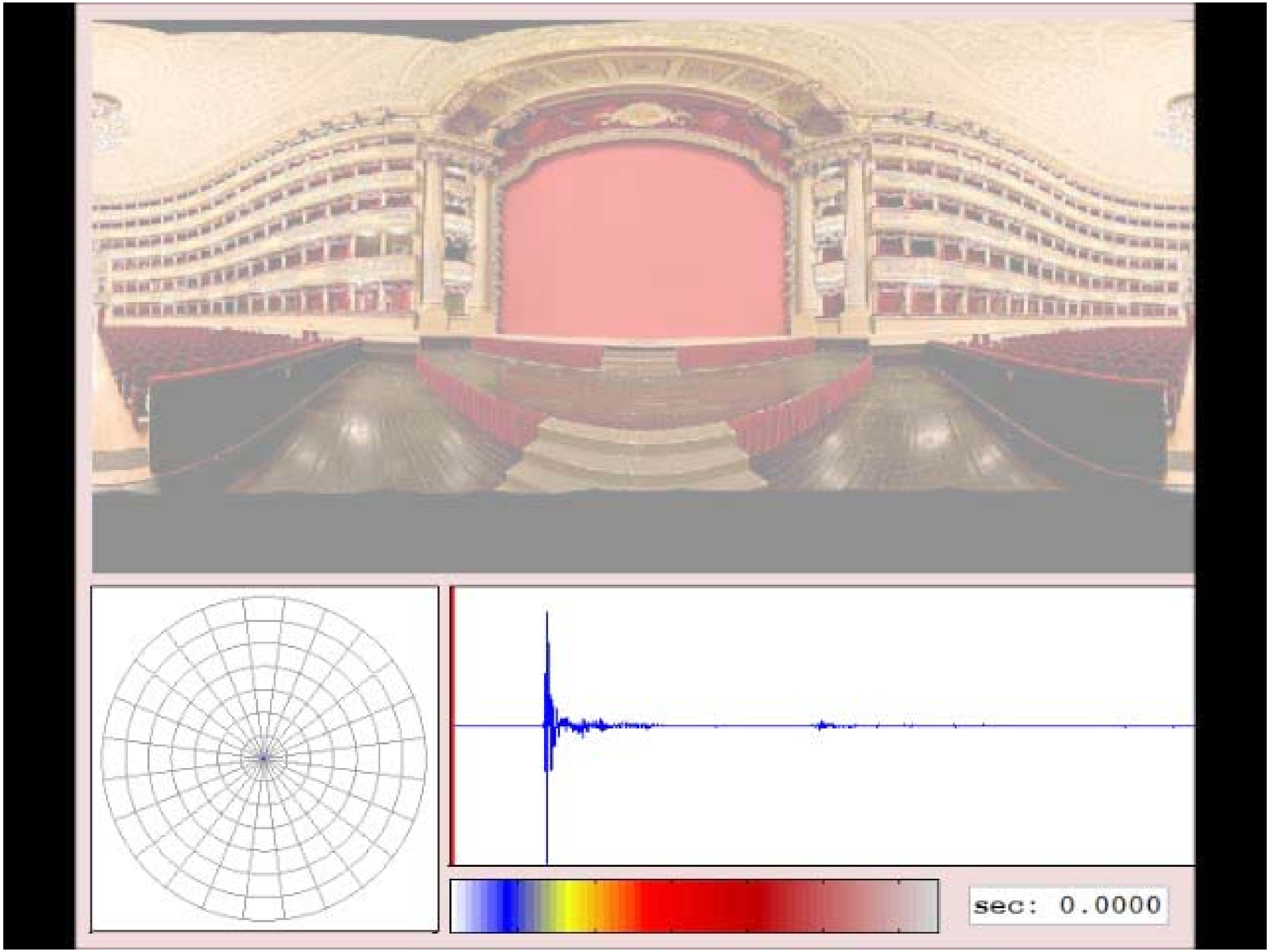
Growing the distance between source and receiver the lobe of the reflections becomes more relevant in comparison with the direct sound.

24 virtual microphones for horizontal polar



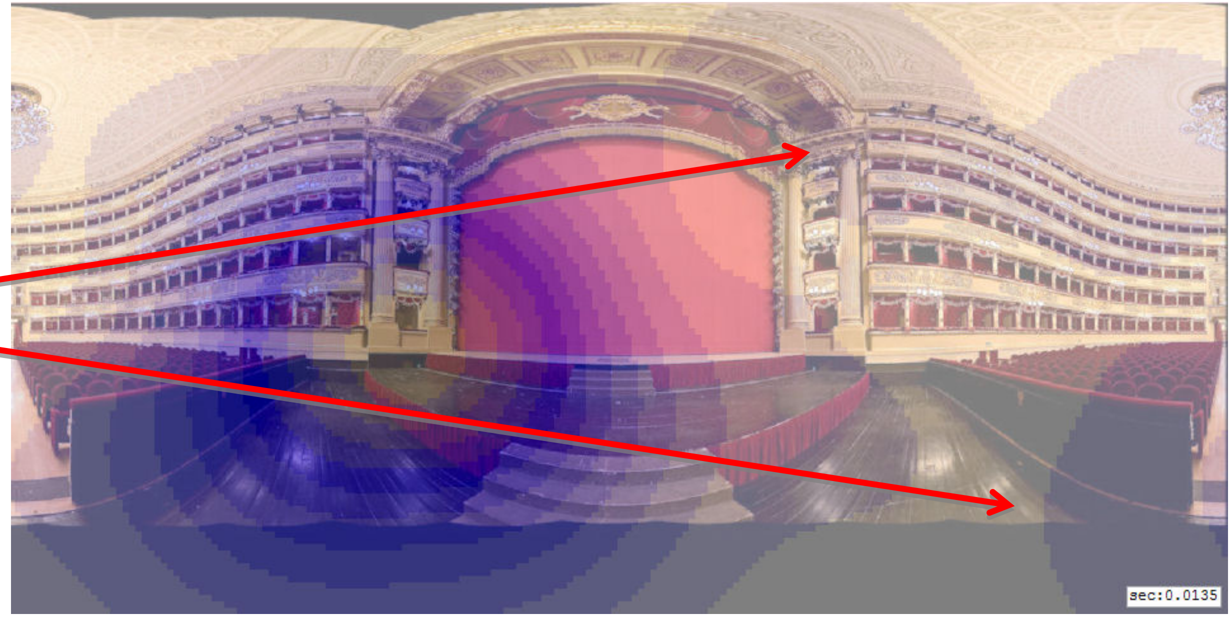
32 virtual microphones for 3D map

Teatro "La Scala": 4 kHz – root 2 – 8000 samples



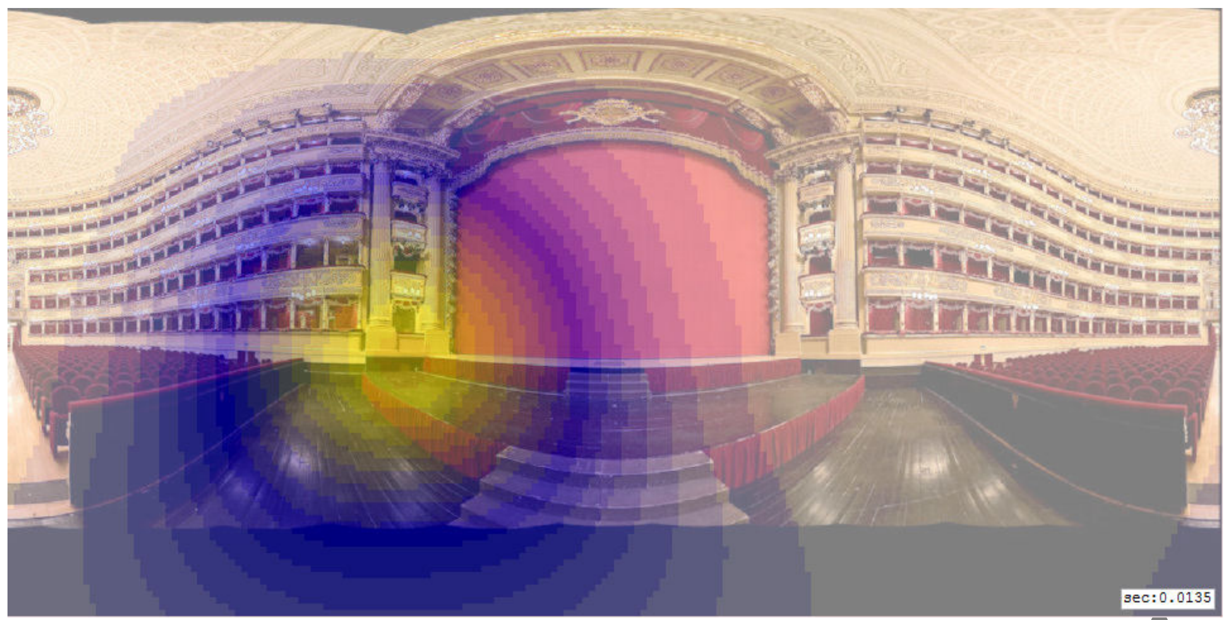
The direct sound

500 Hz



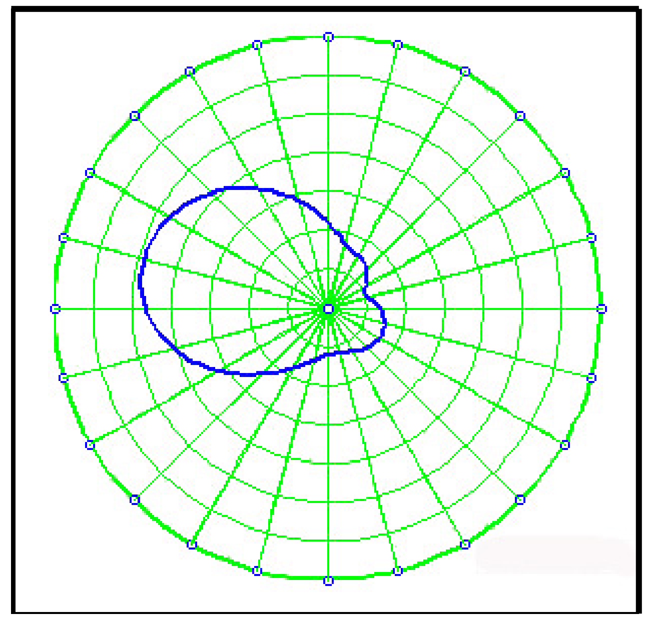
Radiation of the wooden stage

1000 Hz



The source is close to the receiver

The direct sound masks on the map the first reflection on the floor



The reflections

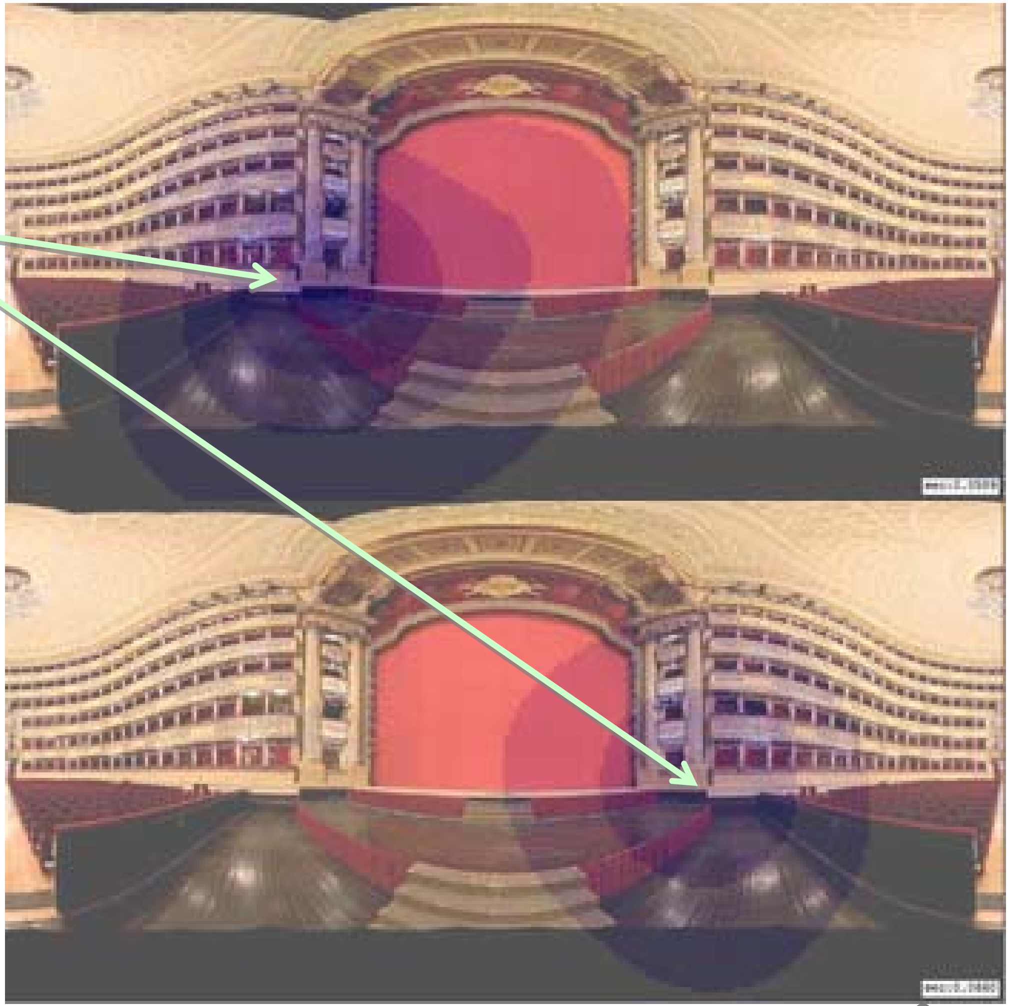
4 ms

The first visible reflection comes from the column behind the source, followed by a reflection on the floor and by a reflection coming from the opposite direction of the first one.

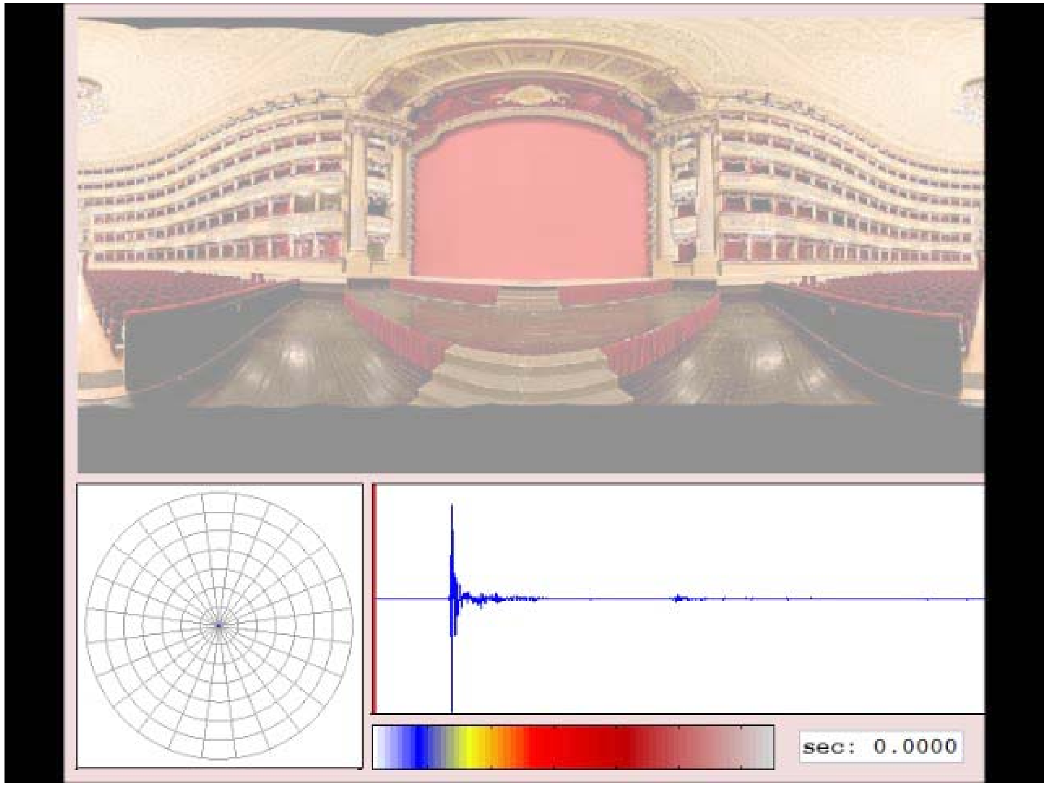
57 ms

The sound bounces between the columns of the proscenium arch…

… and then arrives the ceiling reflection.

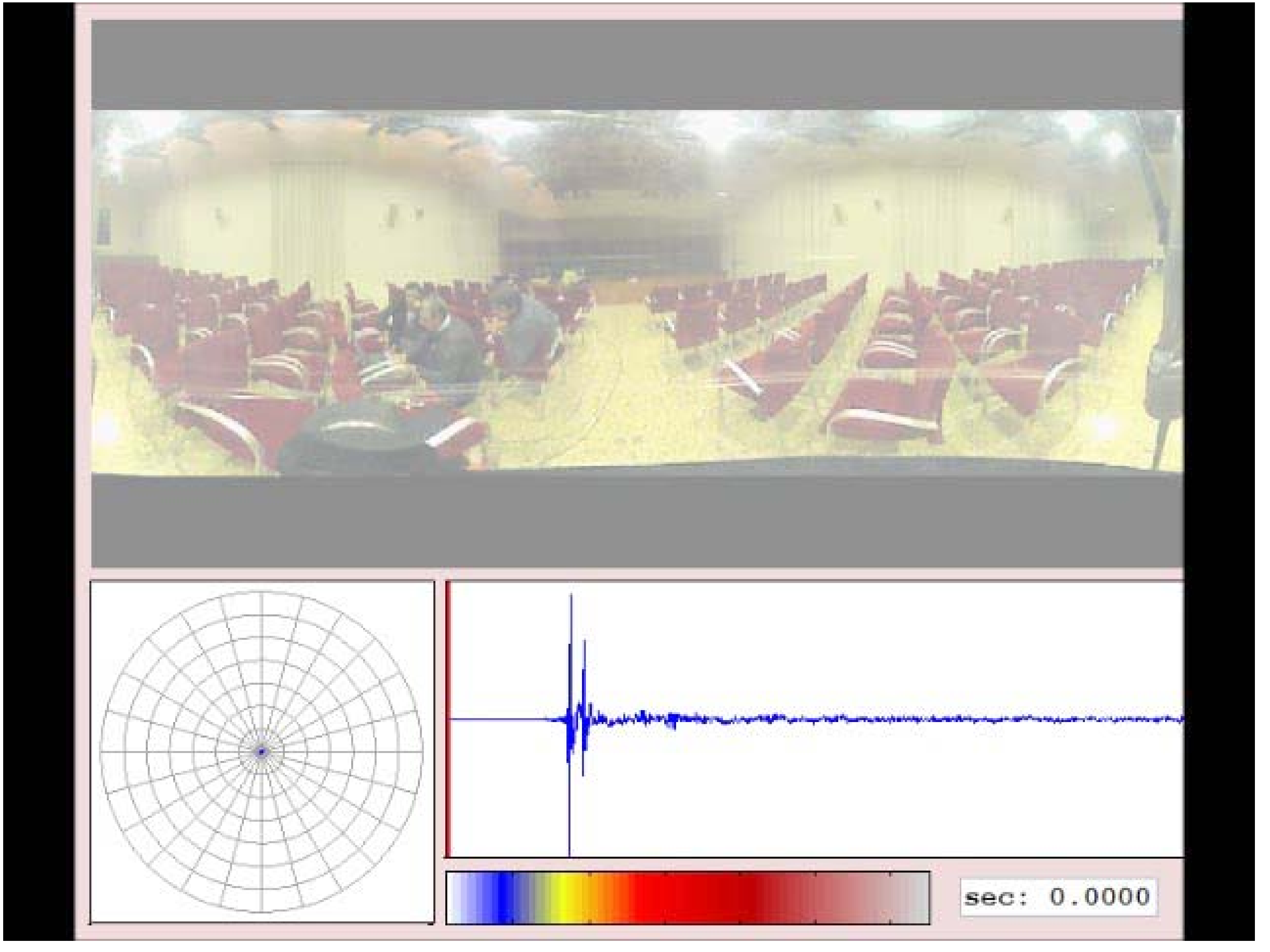


Some notes



- The shape of the theatre refocuses the sound in the point of provenience
- Lobes in the 500 Hz band: they are effect of the diffraction
- The reflections coming from the walls are displayed with cold colours: big amount of absorption

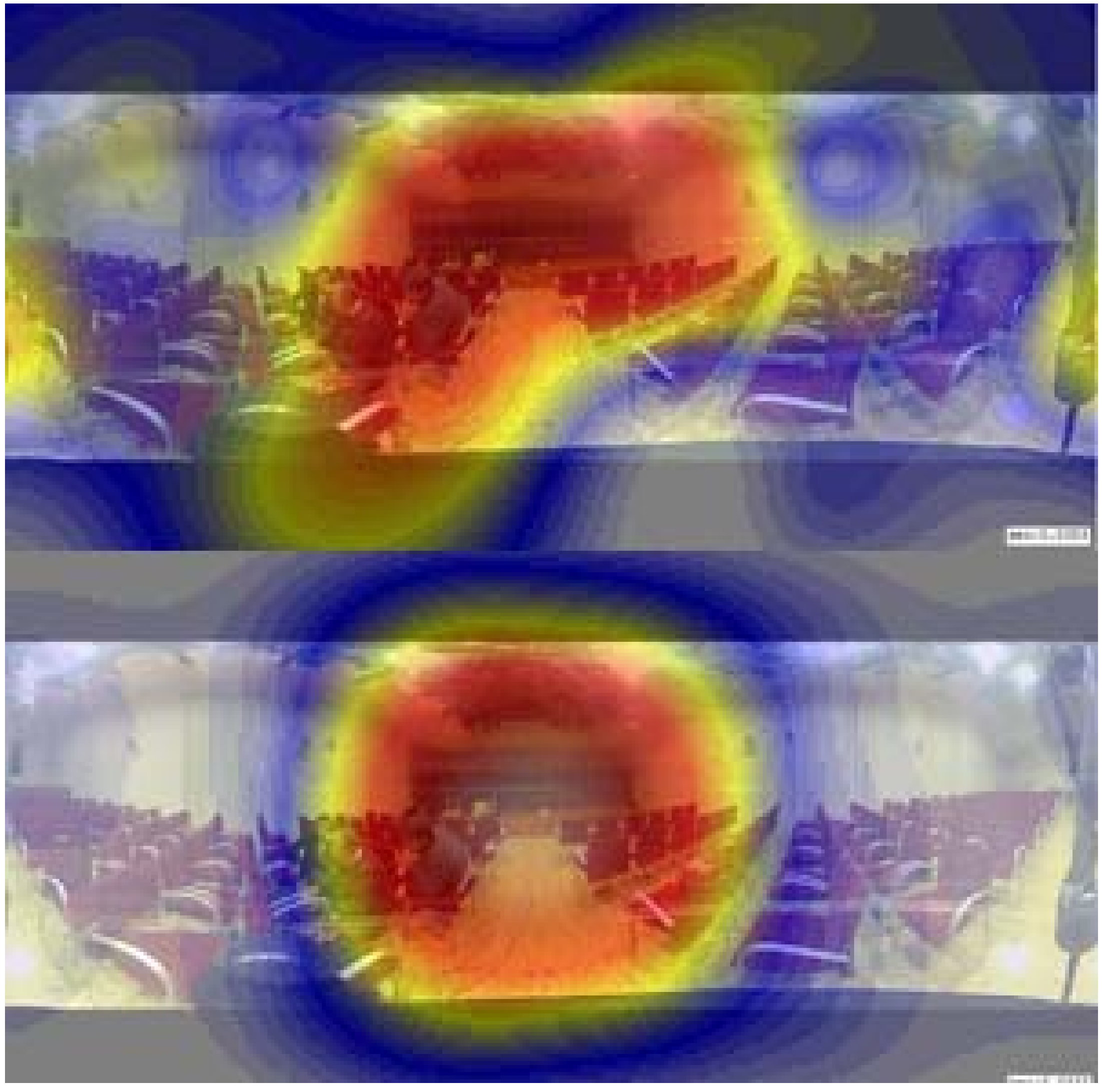
"Sala dei Concerti": 4 kHz – root2 – 8000 samples



The direct sound

500 Hz - the sound in this freq. band anticipates the direct sound. Is the effect of the radiation of the wooden structure of the stage

500 Hz



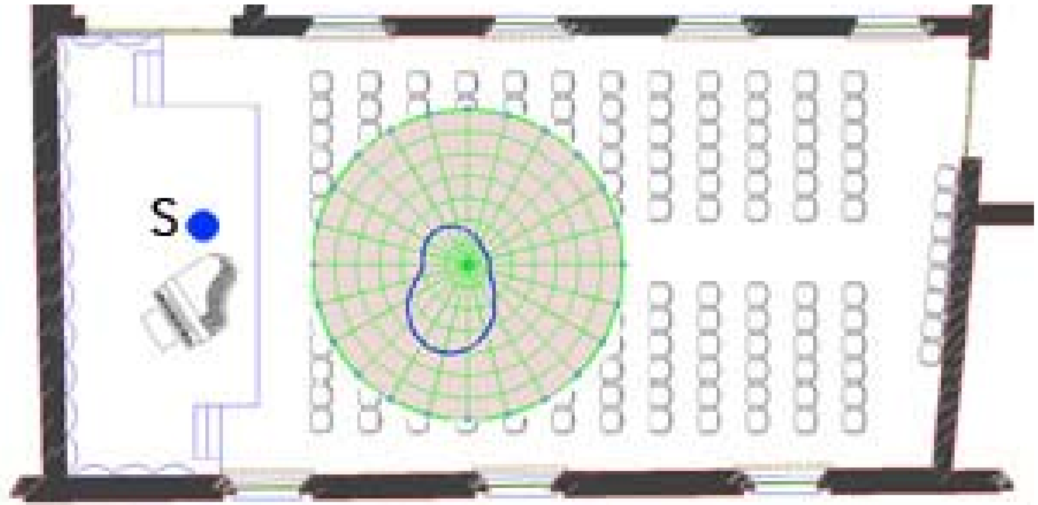
4000 Hz

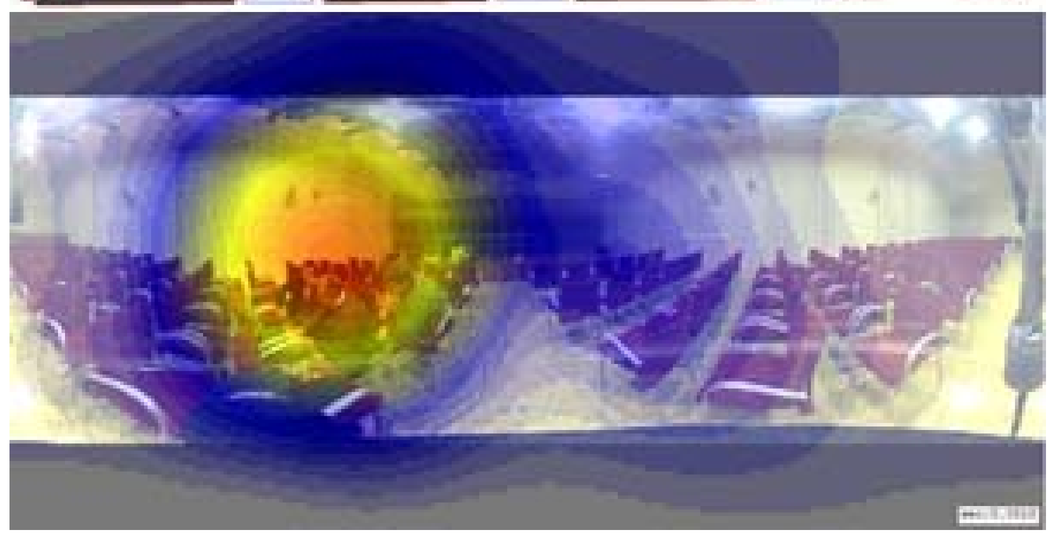
The first reflection from the floor is clearly visible, followed by the diffuse sound of the wooden diffusors.

21 ms

Strong lateral reflection (90°) coming from a plane even surface.

On the opposite side that reflection is not present because of an absorbent curtain.

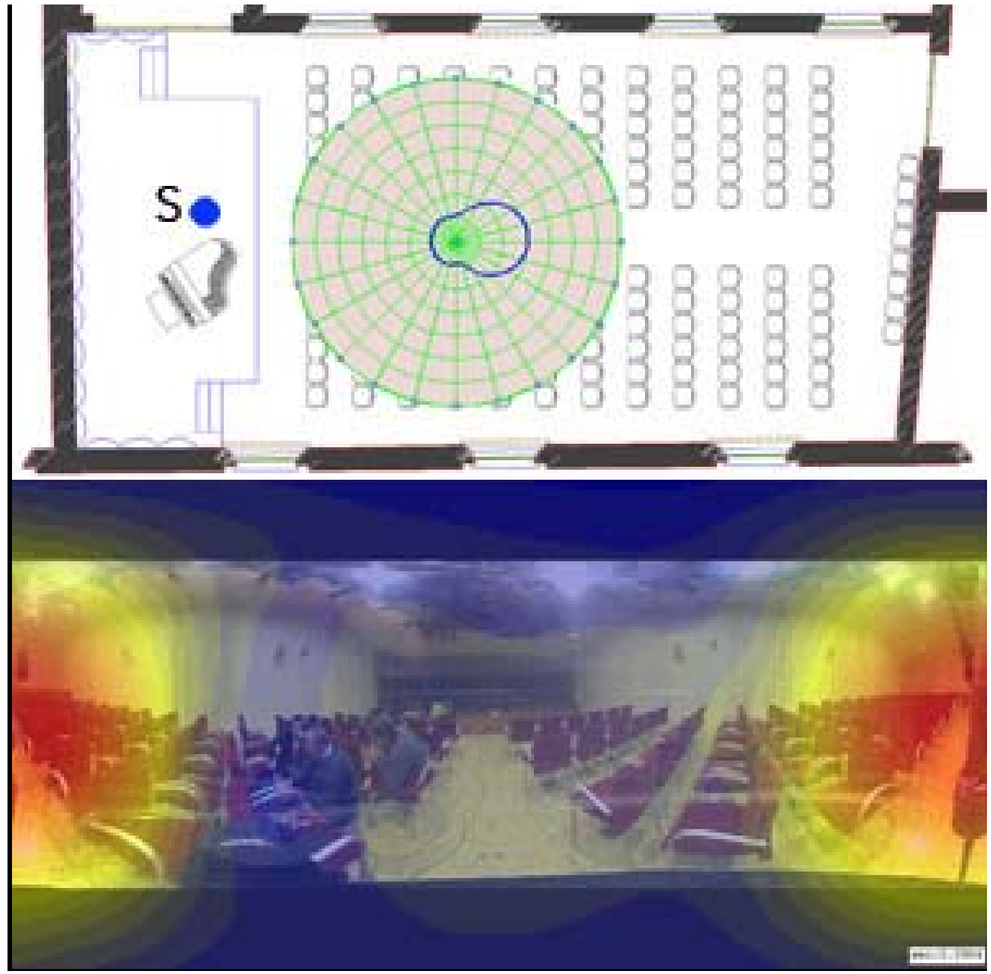




After this reflection the sound appears quite diffuse in the room apart from a little bounce between the lateral walls.

97 ms

Strong reflection from the back of the room. The effect is audible also from the stage and causes problems with high repeated notes to the performers



Conclusions

Today we presented a new approach to the impulse response measurements. It permits the dynamic view of the impulse responses plotted on a panoramic picture (360° x180°) by using 32 high directive virtual microphones.

Positive aspects

Easy visualization of undesired reflections

↓

Easy way for locating their arrival direction

↓

Easier way for correcting them

This is a first step in the research, a lot of work has to be done:

- Calibration of the probe
- Creation of a plug-in (VST or Audacity-based)
- IP-camera for taking the panoramic pictures

Thank you for the attention

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