A digitally controlled two dimensional loudspeaker array

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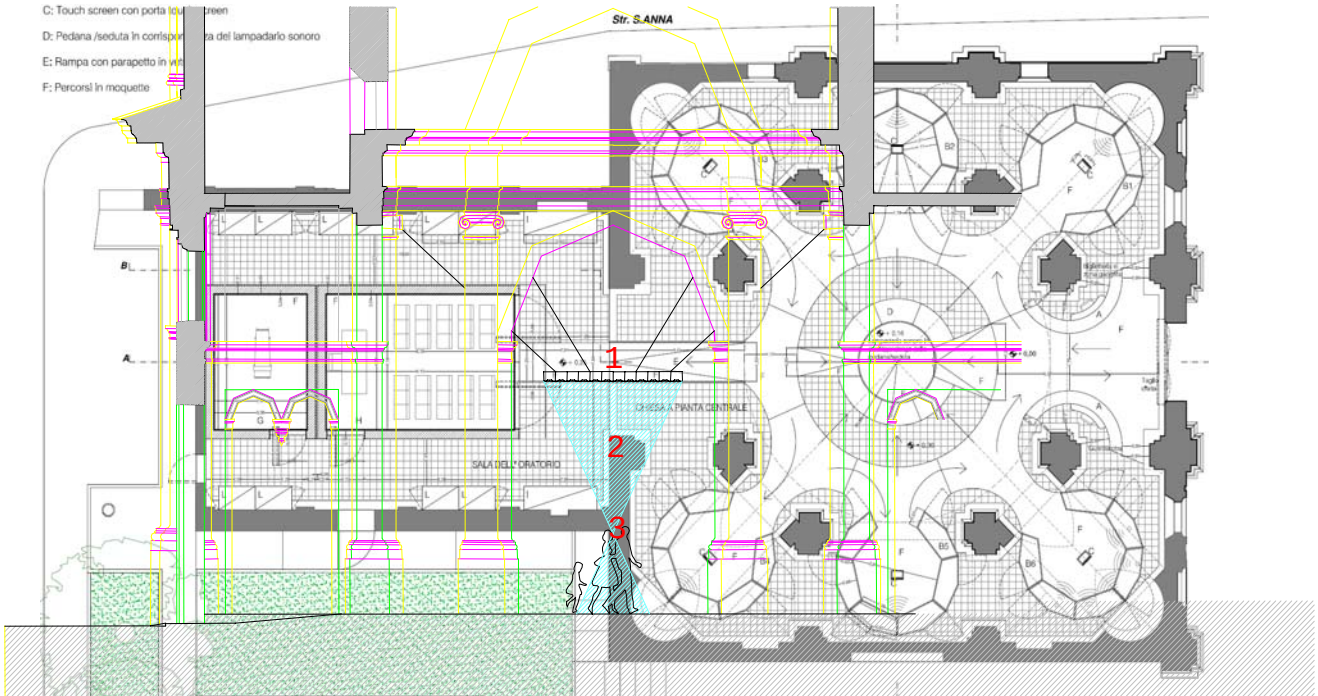
Daniele Torelli
Angelo Farina (LAE Group)

The full staff: LAE and..

• **Paolo Martignon**	Project management, geometry and filter design
• **Daniele Torelli**	SW development on Linux PC
• **Fons Adriaensen**	Consultance on SW, HW and algorithms
• **Roberto Zana**	Wiring design and realization
• **Audiolink srl and AIDA srl, Parma**	Place, instrumentation, hardware help and consultance
• **Aldo Piazza**	Chandelier iron structure realization

The project: a ”sonic chandelier”

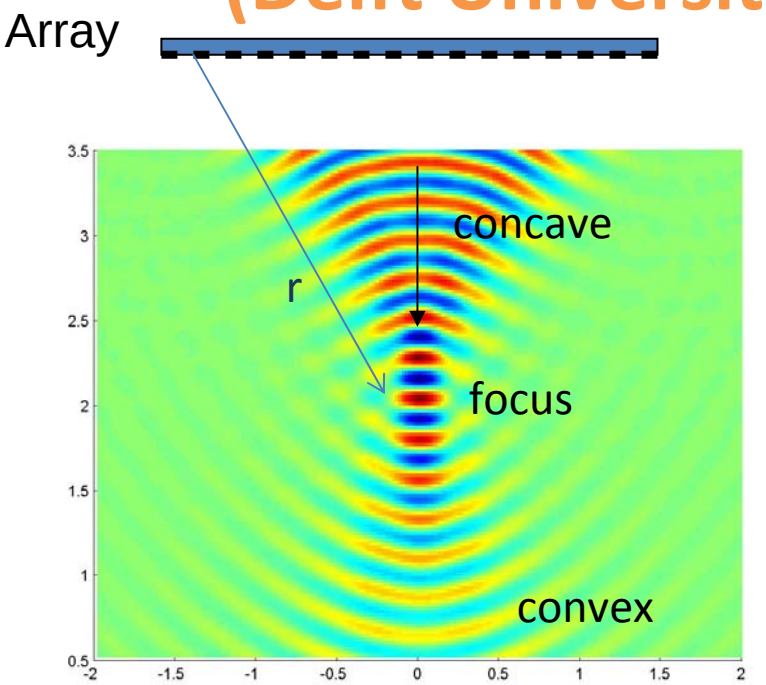
- S.Elisabetta church (reverb time 5 sec.)
- Sonic chandelier:
  - Moving virtual sources (WFS)
  - Active insulation



Presentation outline

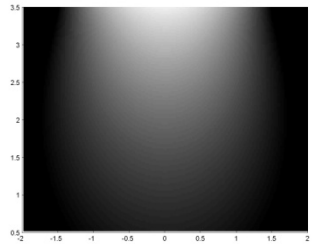
- Wave Field Synthesis concepts, spatial aliasing
- Speakers choice and line array prototype
- 2D array design and realization
- HW description and signal processing scheme
- Filters structure, design and implementation
- Validation test and measurement

Sound focalization by WFS
(Delft University of Technology, 90's)

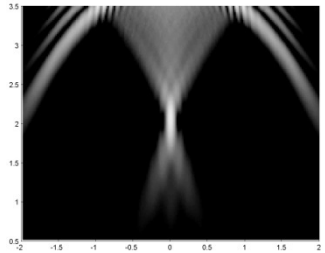


Sensible parameters:

$\frac{A}{\lambda}$ Set the beam width..



$\frac{\Delta x}{\lambda}$ *Spatial aliasing*, secondary lobes..



The front curvature is obtained by means of a gain-delay set ..

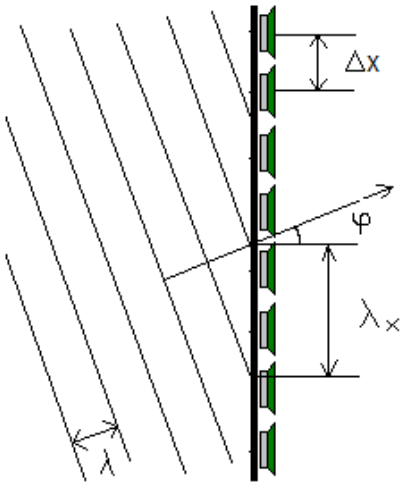
Common filter

$$Q_m^{foc}(x,\omega) = S(\omega)\sqrt{\frac{k}{2\pi i}}\sqrt{\frac{\Delta z_0}{\Delta z_0 - z_0}}\cos\varphi\frac{e^{+ikr}}{\sqrt{r}}.$$

Delays

Gains

The spatial aliasing problem



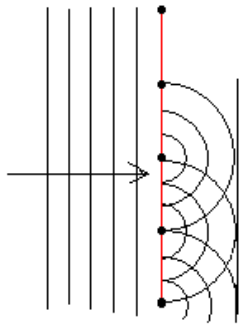
The spatial Nyquist theorem:

Sampling condition: $\lambda_x = \frac{\lambda}{sen\varphi} > 2 \cdot \Delta x$

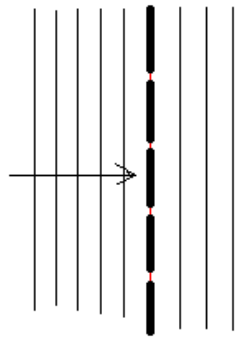
antialiasing sampling filter $\Rightarrow f_{\max} \leq \frac{c}{2\Delta x sen\varphi}$

Reconstruction condition:

$$sen\vartheta_{em}(f) \leq \frac{c}{2\Delta x f}$$

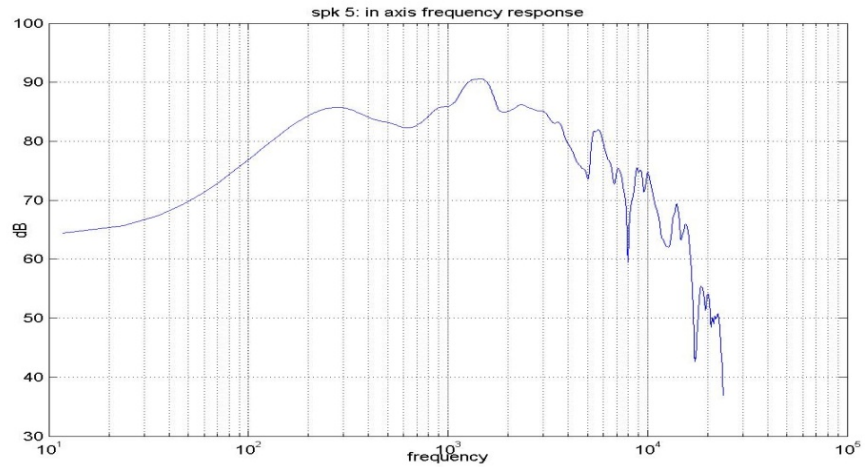


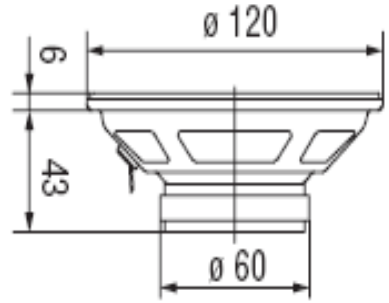
Omnidirectional

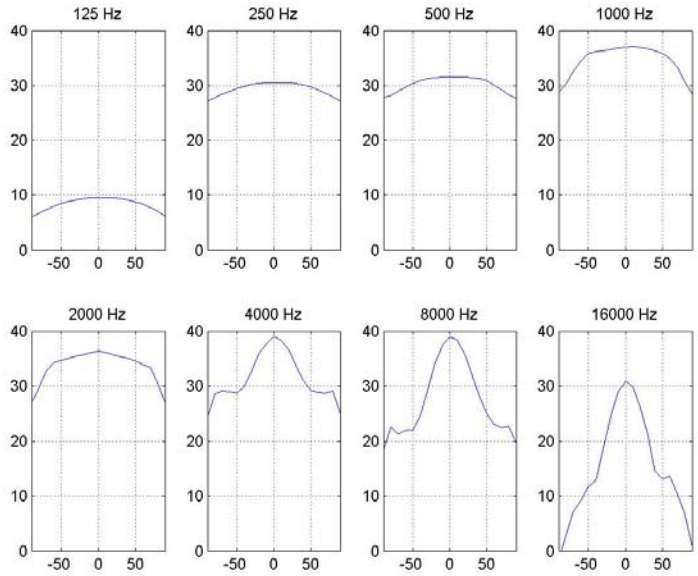


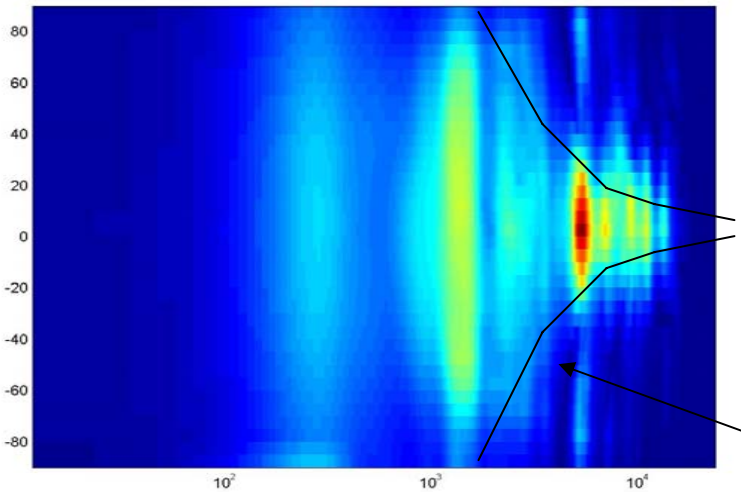
Rigid pistons

Our choice: single transducer, extended range



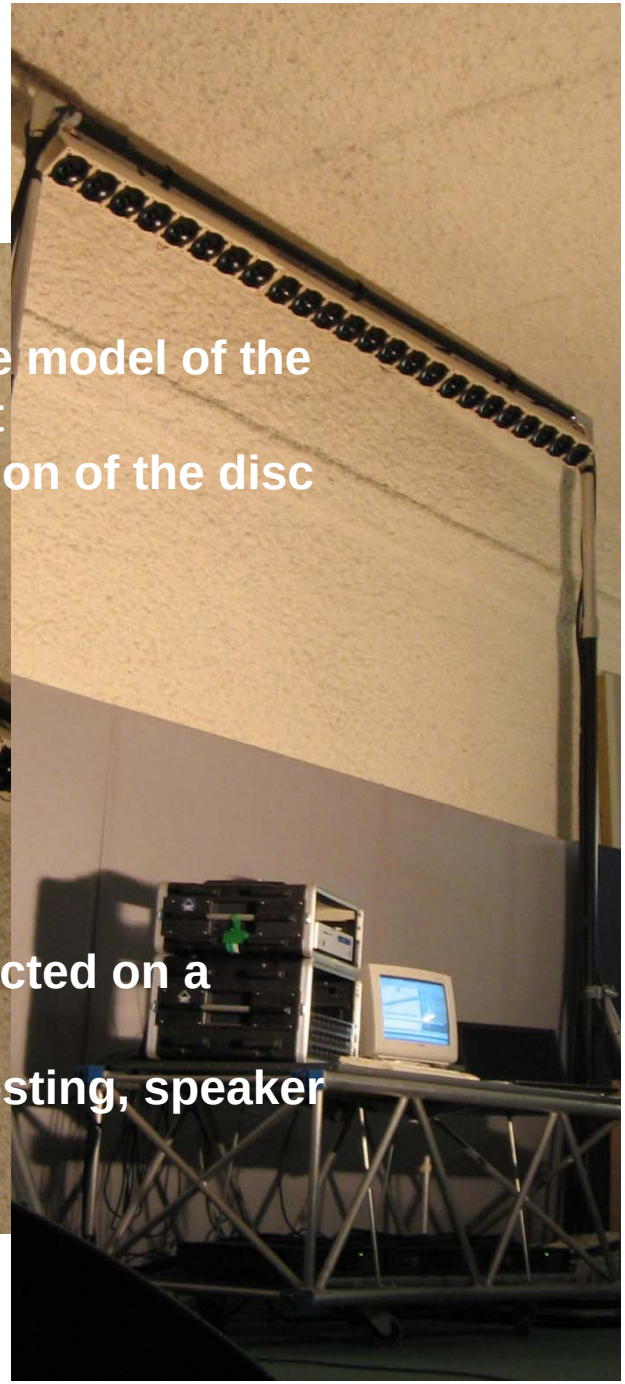


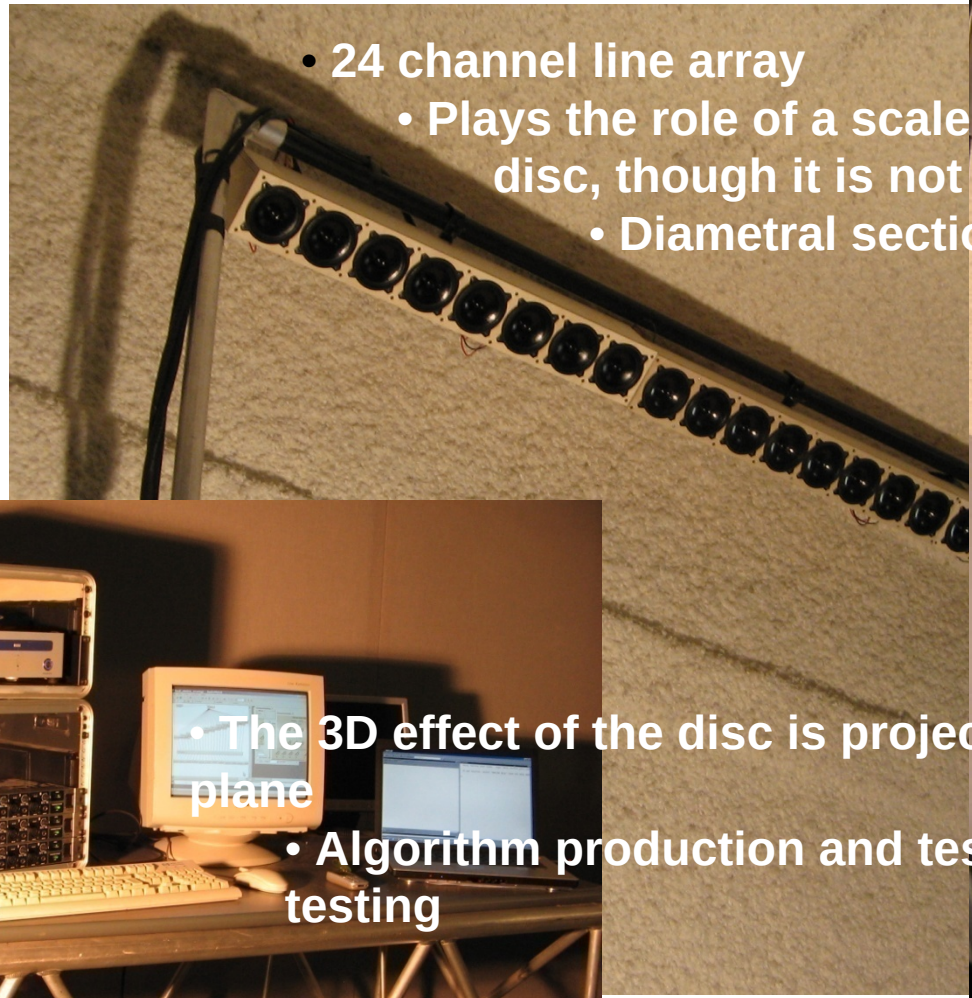




$$sen\,\vartheta_{em}(f) \le \frac{c}{2\Delta x f}$$

A simplified prototype

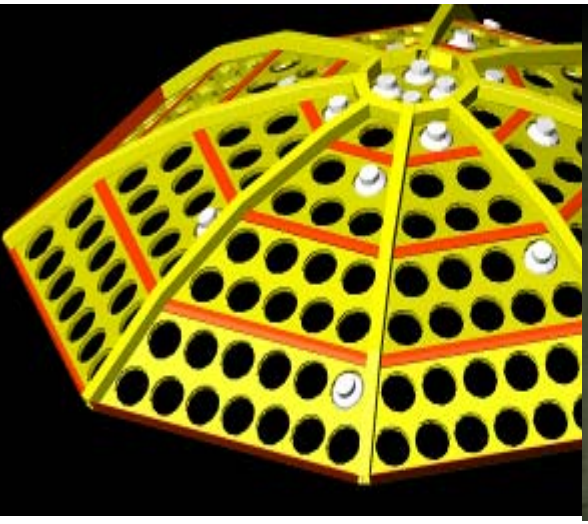




- 24 channel line array
- Plays the role of a scale model of the disc, though it is not
- Diametral section of the disc

- The 3D effect of the disc is projected on a plane
- Algorithm production and testing, speaker testing

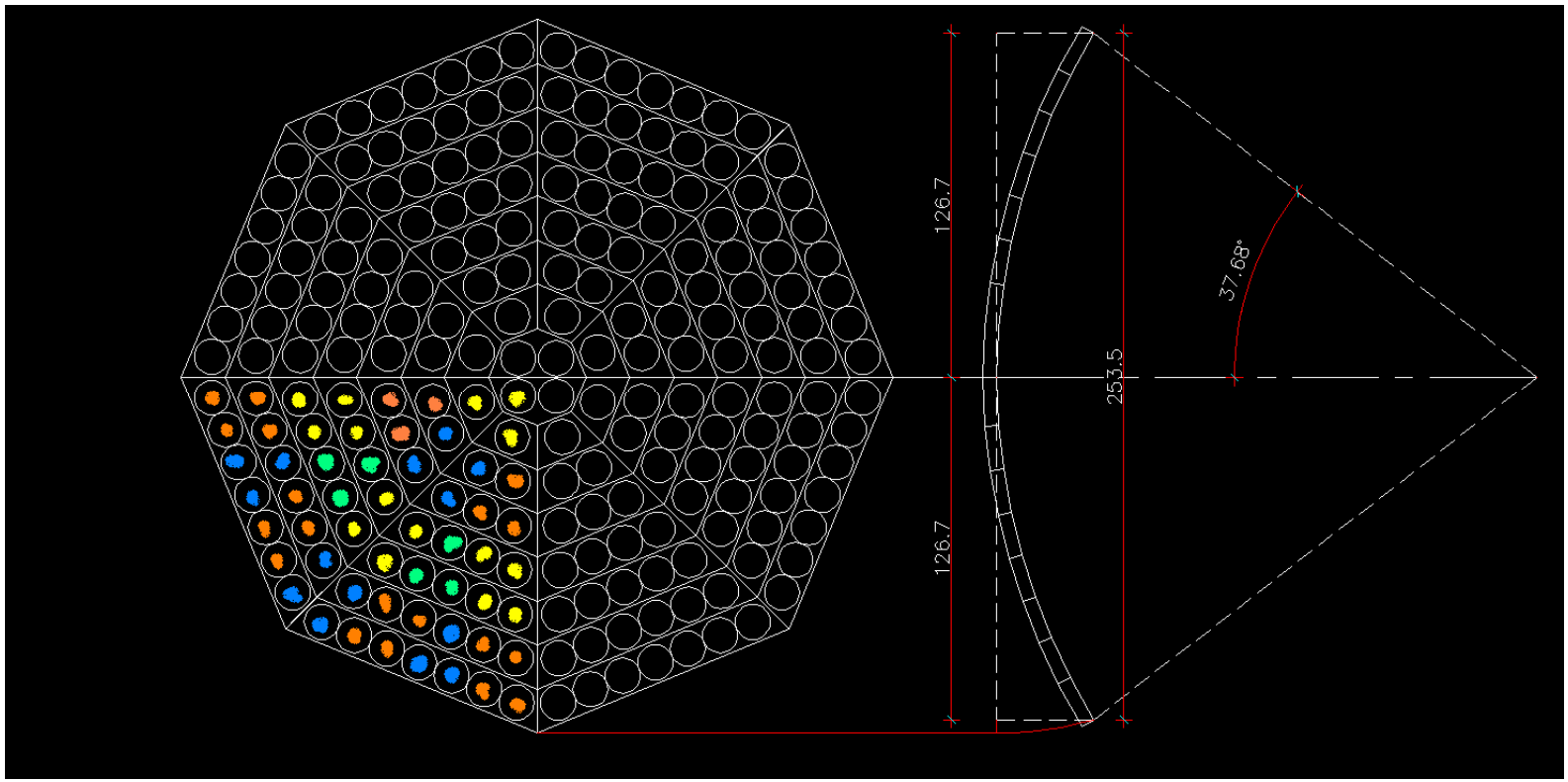
Chandellier: design, manifacturing and assembling

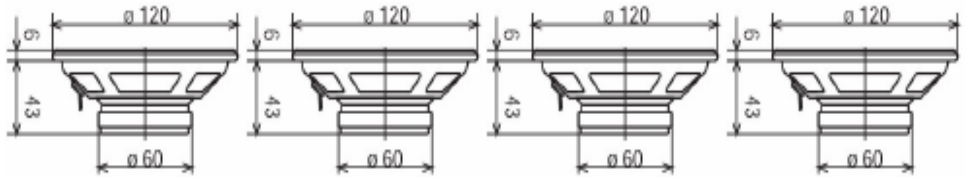





Lifting up..

Speakers to channel connection





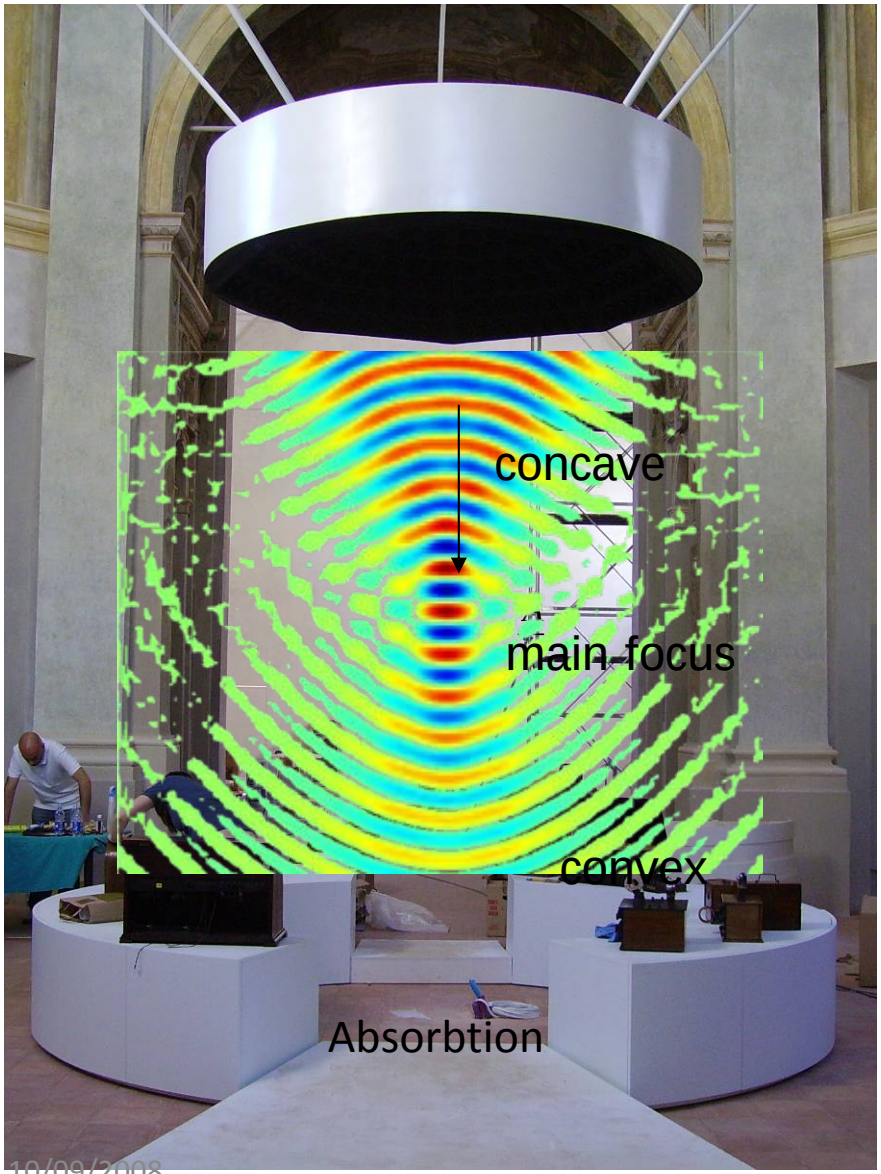
Special 32 Ohm
model by Ciare, Italy

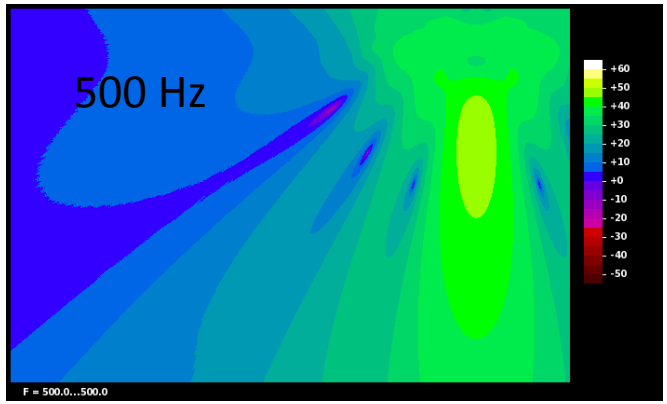
228 loudspeakers
64 channels

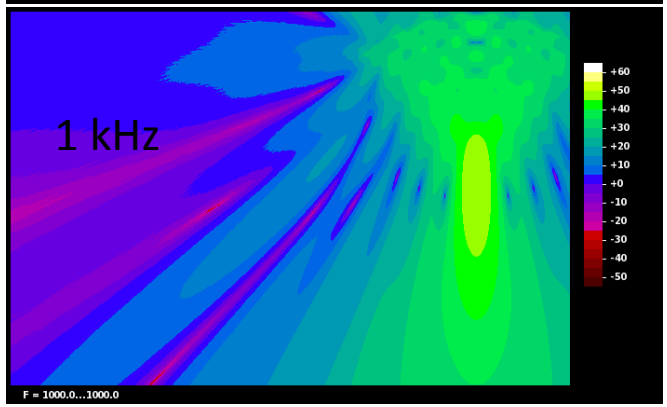
1 channel

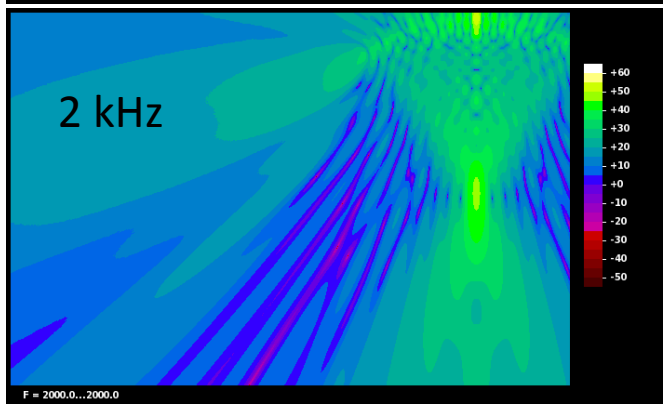
Frounhofer distance for a group of speaker at 10 kHz is about **4** meters

More on the sound field..

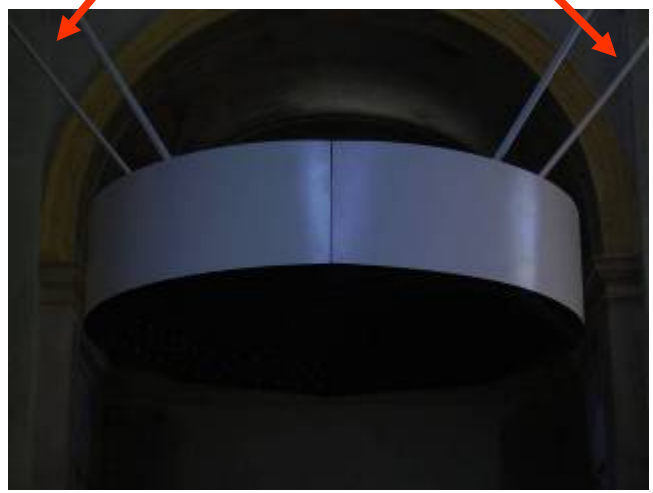


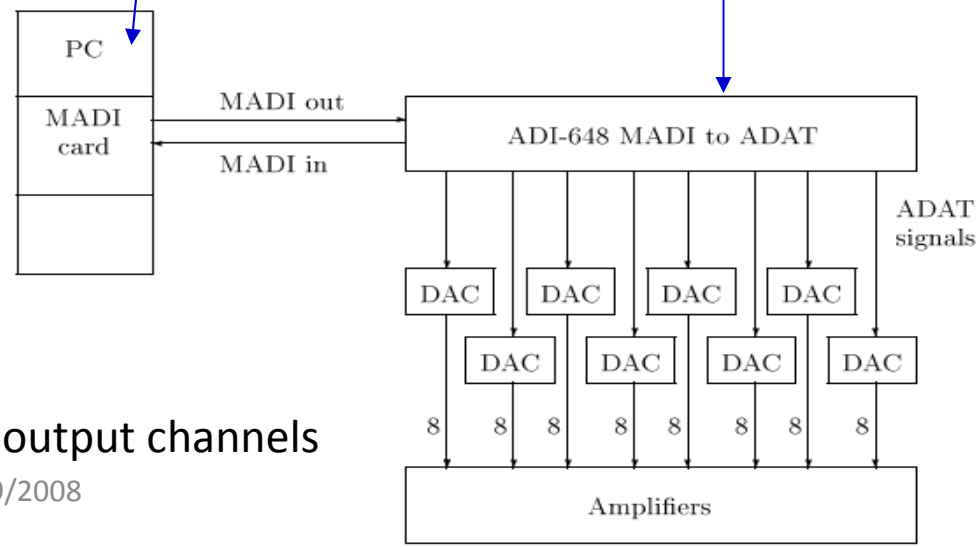






The feeding system

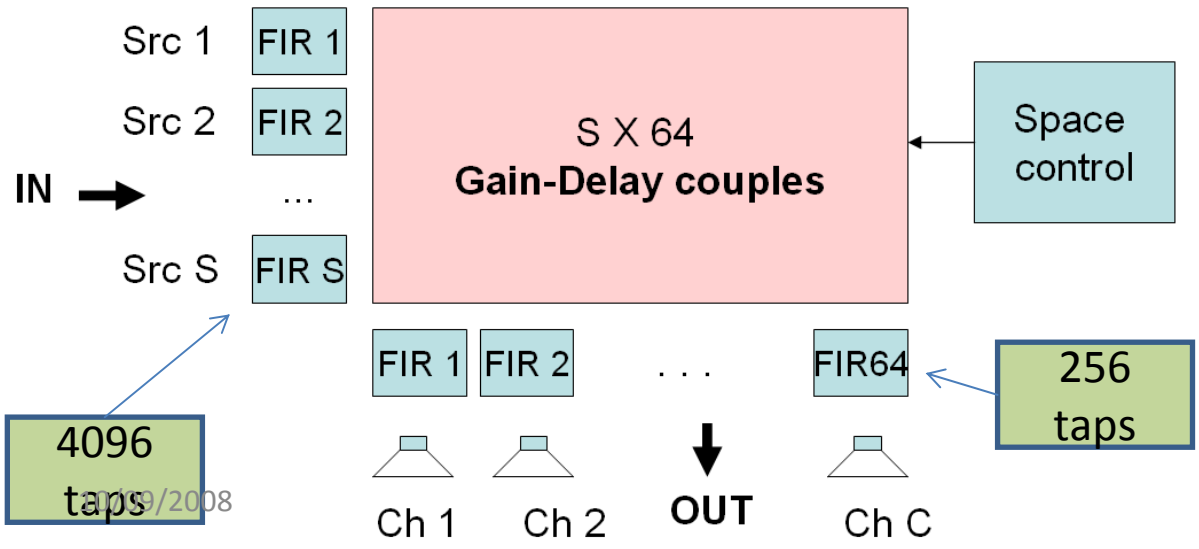


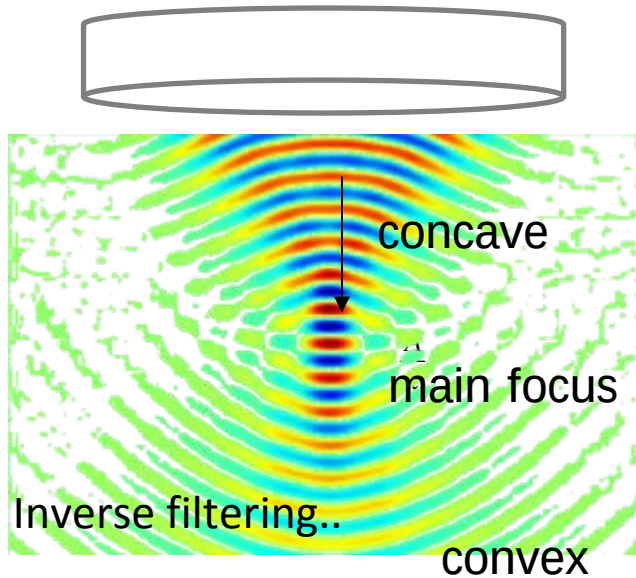


64 output channels

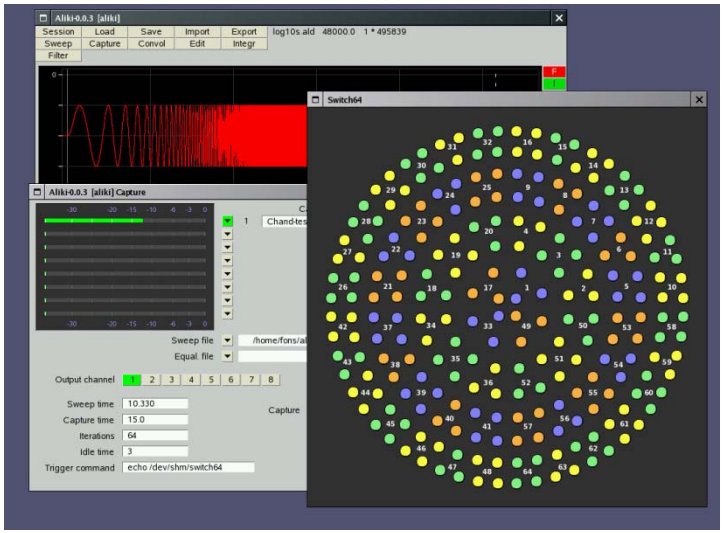
From WFS to filter structure

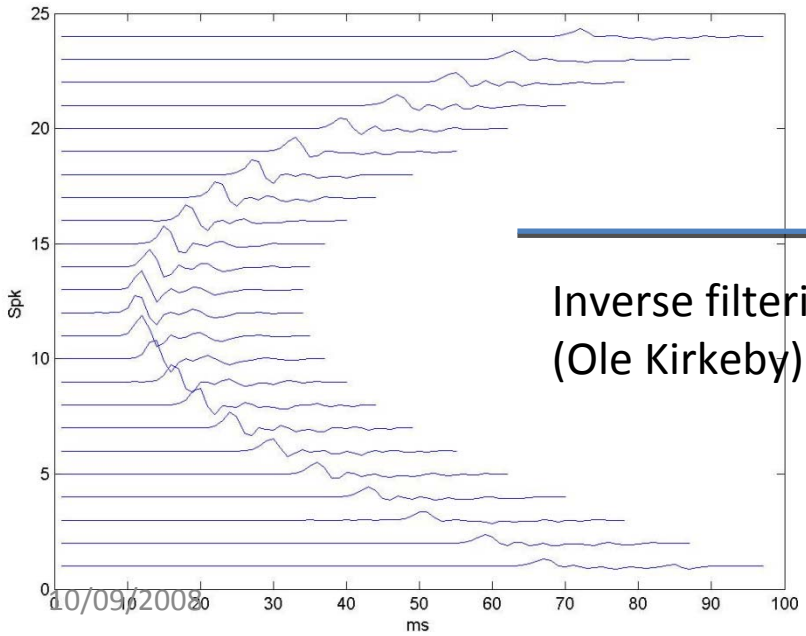
Common WFS EQ and speaker EQ (mag and phase)	Antialiasing sampling filter	Gains and delays	Antialiasing reconstruction filter	Single speaker relative EQ
Input FIR	Array shape	Dynamic delays-gains matrix , Output FIRs	Speaker directivity	Output FIRs



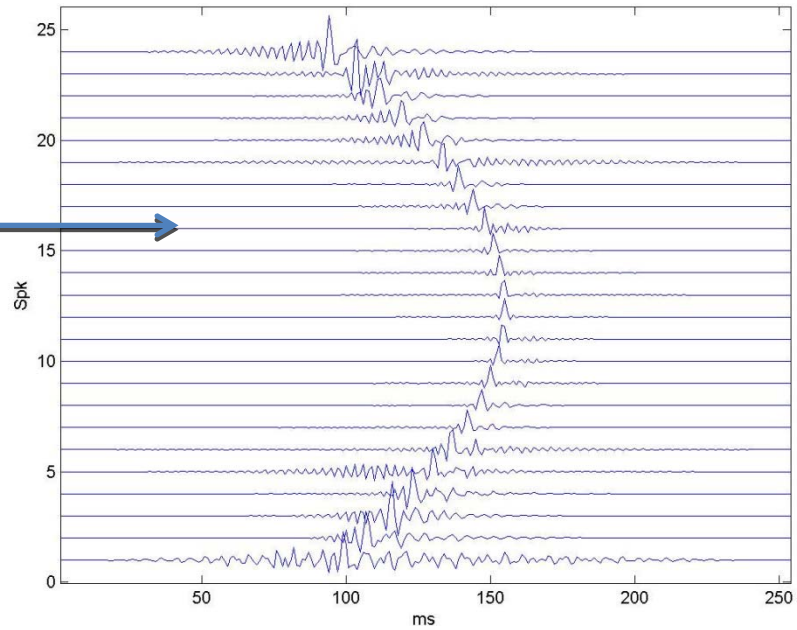


Output FIR design

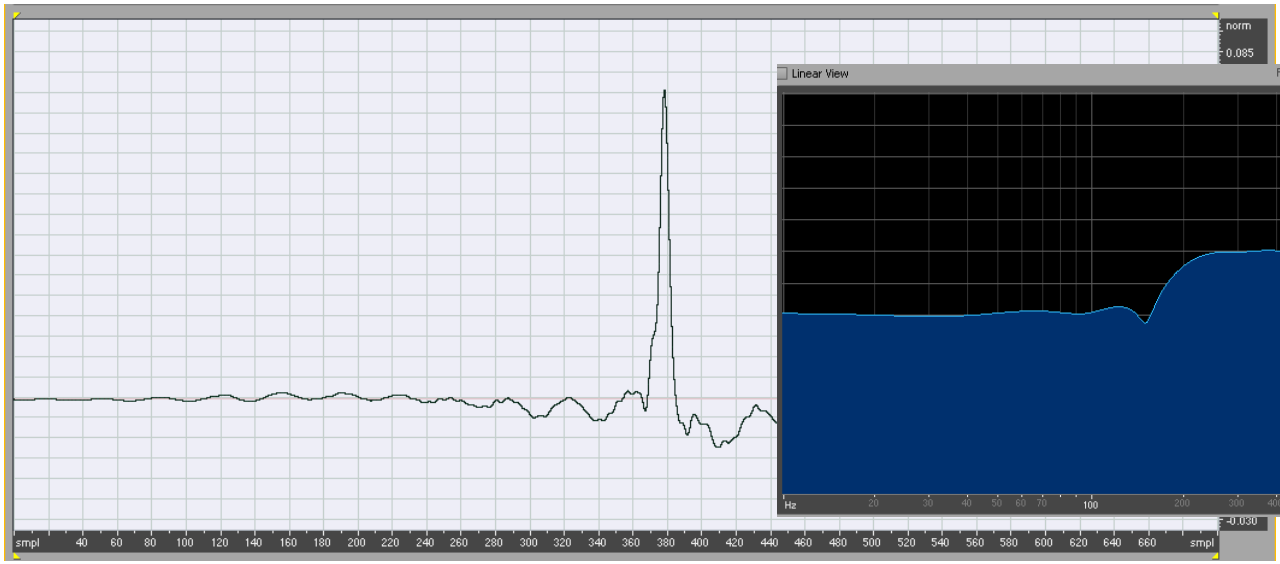


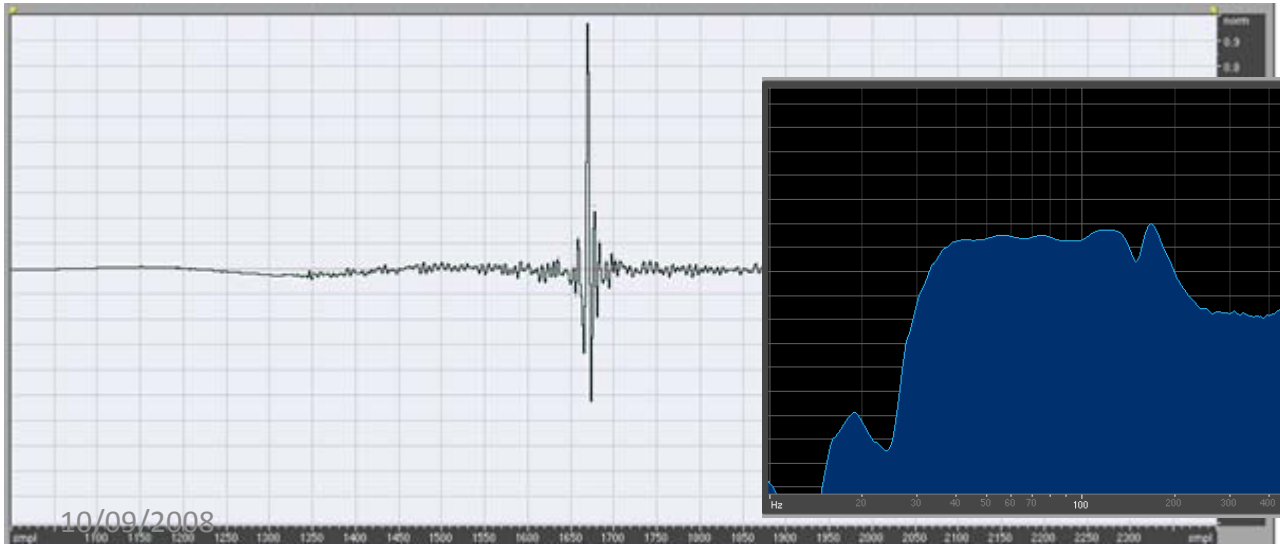


Inverse filtering
(Ole Kirkeby)

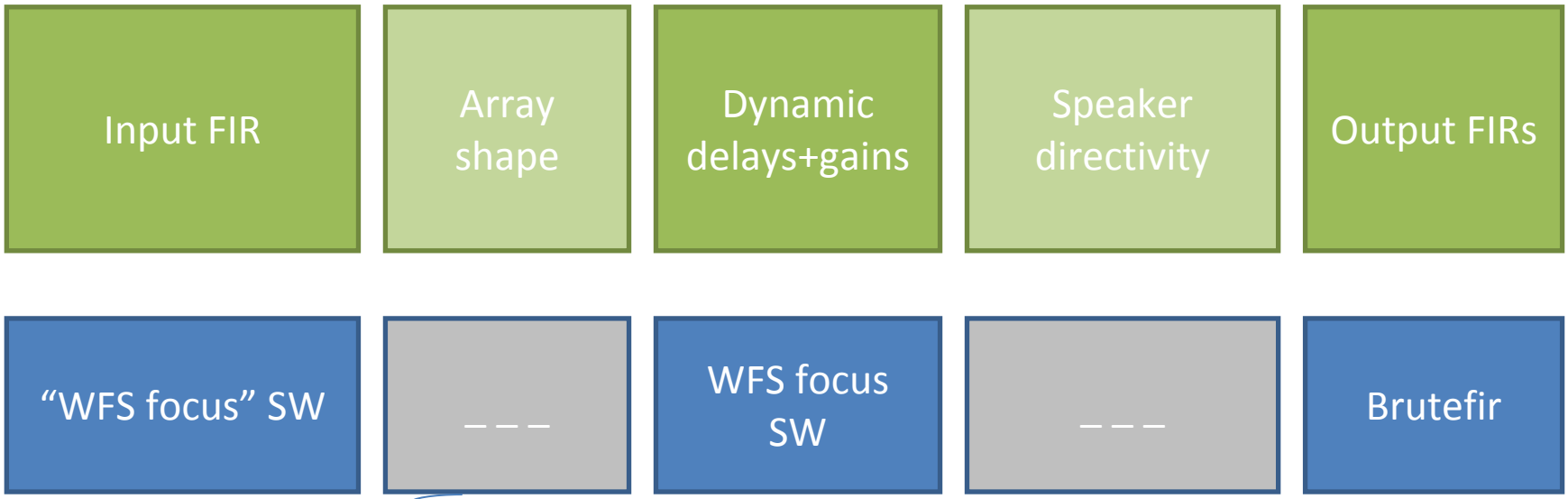


Input FIR design



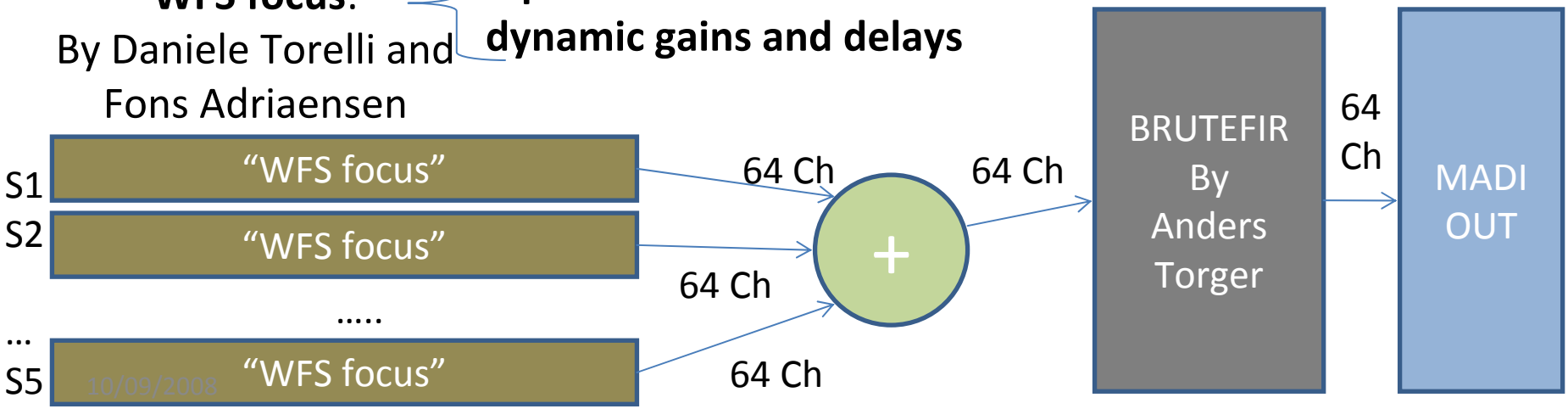


From filter to SW structure

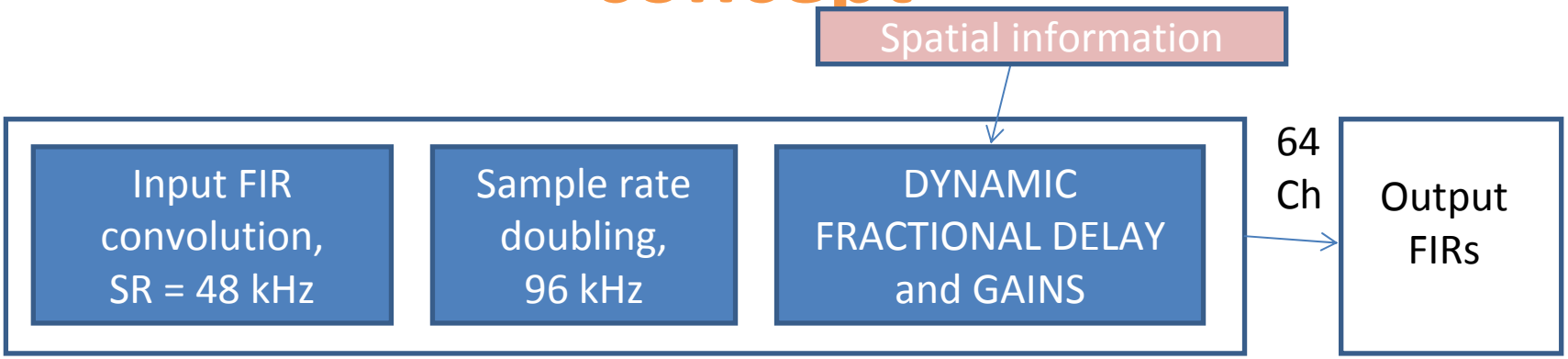


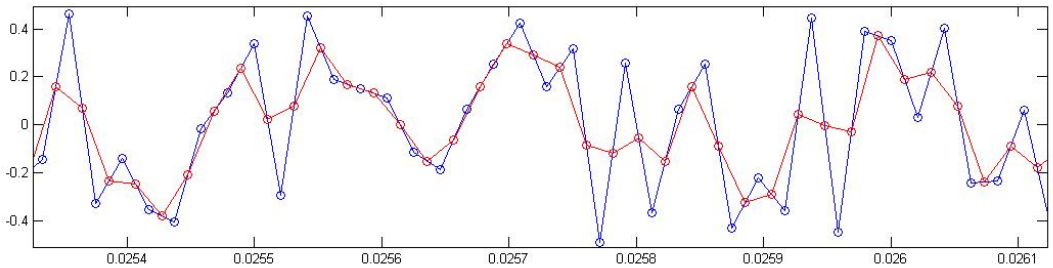
WFS focus:
By Daniele Torelli and Fons Adriaensen

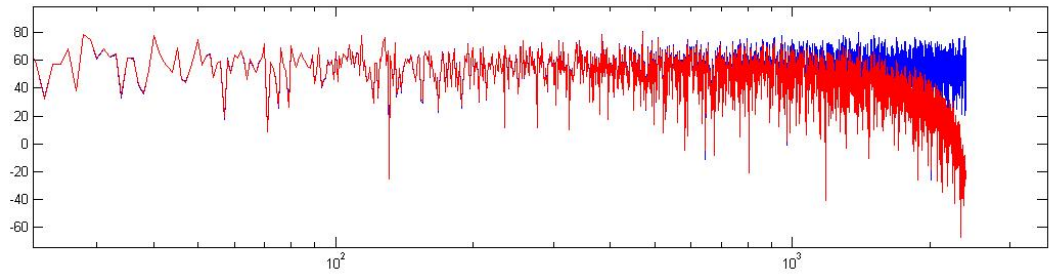
input FIR
dynamic gains and delays



Moving the focus: “WFS focus” concept

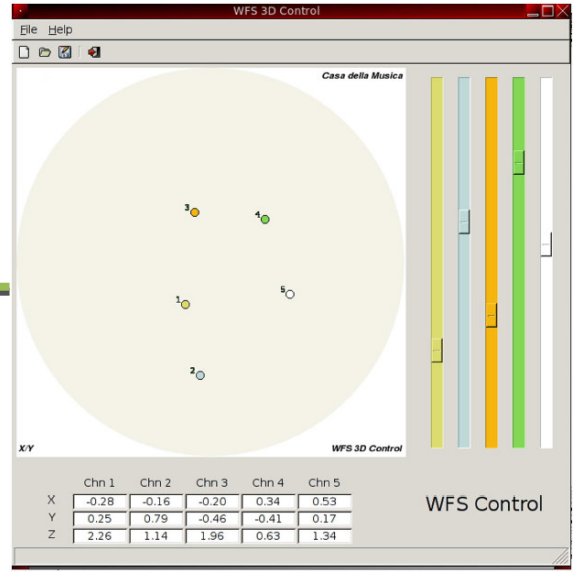






Effect of a fractional delay with linear interpolation.

User interfaces



MADI inputs (external sources)

MIDI controller

MIDI

OSC

Mono signals

"WFS focus"

"WFS focus"

.....

"WFS focus"

64 Ch

64 Ch

64 Ch

+

.....

Audio application, I.E. "ARDOUR"

OSC

ARDOUR "WFS focus" plugin

AUDIO signal

SPACE control

Spherical coordinates centered on main focus → fractional delay and gains

Results

- Precise and smooth, “click” free sound moving
- Appreciable Doppler effect
- “Objective” sound scene
- Good distance perception
- 22 dB decay at medium frequencies between the center and a peripheral point 5 m distant (center of one shell) . Tested with filtered pink noise.
- Very sensible increasing of the active insulation with people beneath the array

Thank you !