Institute of Acoustics

AUDITORIUM ACOUSTICS 2000
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Acoustics of the Teatro Arcimboldi in Milano. Part 2: Scale model studies, final results

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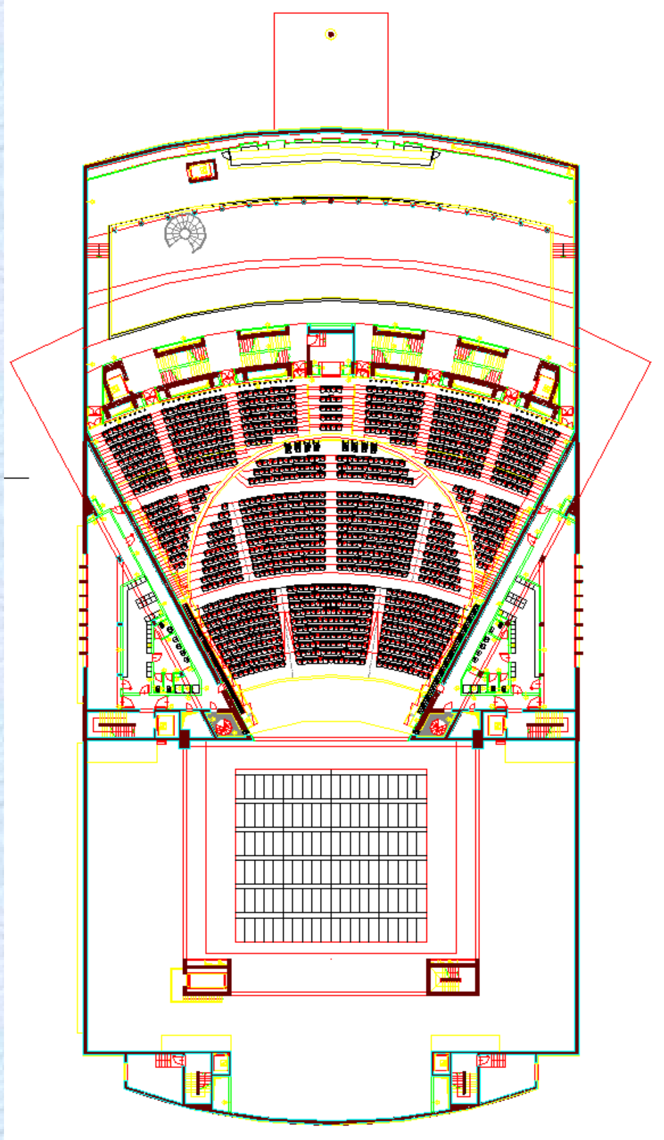
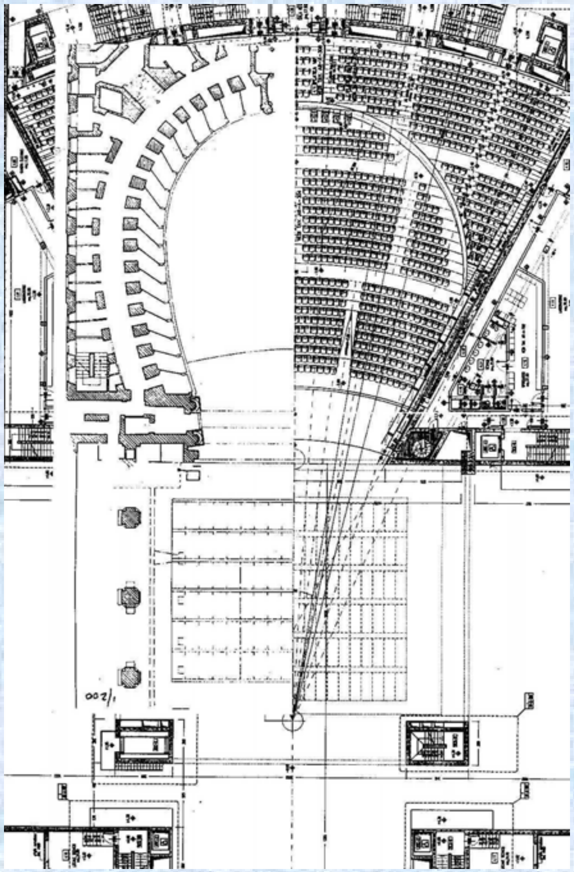
Teatro degli Arcimboldi: shape and dimensions



	Volume	N. seats	RTocc. mid
Paris, Opéra Garnier	10000	2131	1.15
Milano, La Scala,	11250	2135	1.2
Wien, Staatsoper	11600	1658	1.3
London, Royal Opera House	12250	2120	1.1
Milano, Arcimboldi	19500	2385	1.7
Buenos Aires, Teatro Colon	20570	2487	1.8
Paris, Opéra Bastille	21000	2700	1.5
New York, Metropolitan	24724	3816	1.8

Comparison between Teatro La Scala and Teatro degli Arcimboldi

La Scala Arcimboldi



	La Scala	Arcimboldi
Volume V	11252 m^3	19500 m^3
N. of seats N	2282	2385
Ratio V/N	5 m^3/seat	8 m^3/seat
Average height in stalls	19 m	15 m
Lenght of stalls in plan	32 m	32 m
distance of listener more far	37 m	39 m
Total internal surface (in plan)	1635 m^2	1980 m^2
Surface of the orchestra pit	125 m^2	130 m^2

Measurements

Scale Model

1:16 wood scale model

MLSSA system running at a sampling rate of 125 kHz

Piezoelectric “omnidirectional” source (freq, response 1-50 kHz)

Poliurethan foam dummies

Binaural ¼” microphones

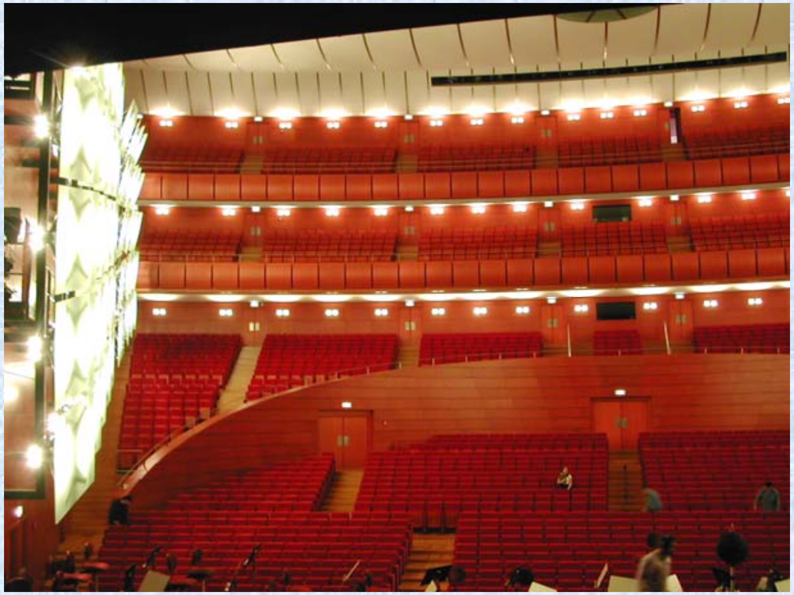
Real Room

Aurora system running at 48 kHz, 24 bits (Digigram sound card)

Wide-band dodechaedron loudspeaker (equalized to flat sound power between 60 - 16k Hz)

Sennheiser MKE2002 binaural microphone

Soundfield ST-250 microphone



Scale Model of Teatro degli Arcimboldi

Goals:

•Study of early reflections

•Research of echoes, focalizations and shadows

•Optimal alignment of reflective panels.

Technical details:

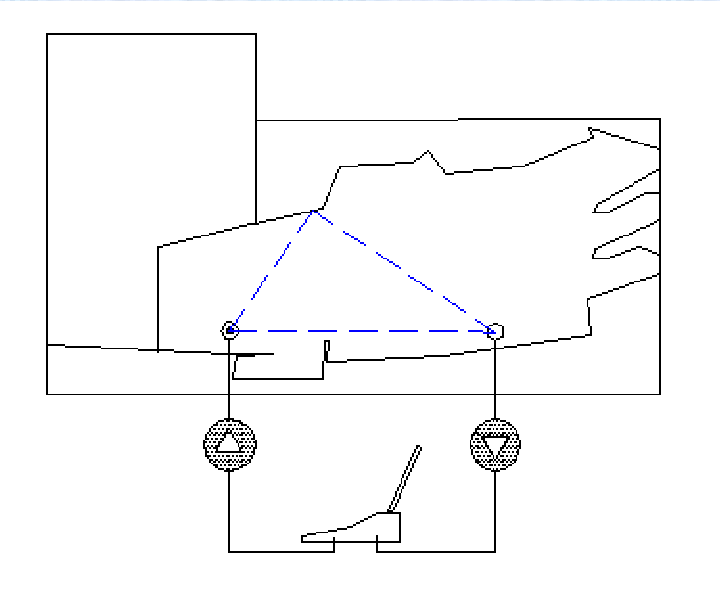
•The model is in scale 1:16

•Plywood, 20 mm thick

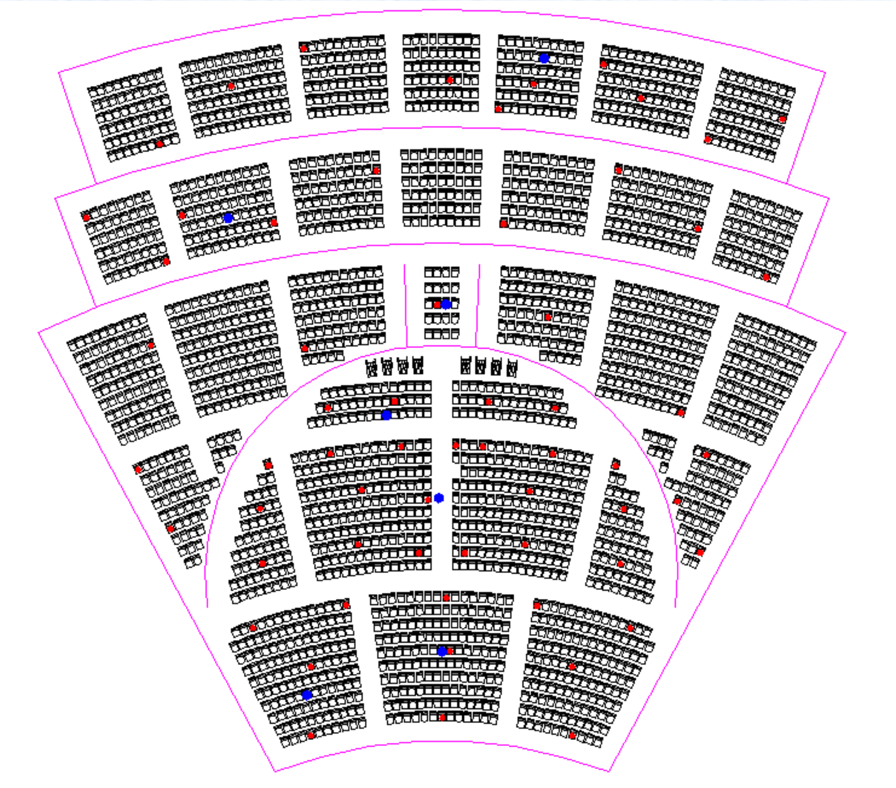
•Reflectors are built in plexiglass

•The seats are completely full of audience – the dummies are made of poliurethan foam, with wooden spherical head.

Scale Model measurements

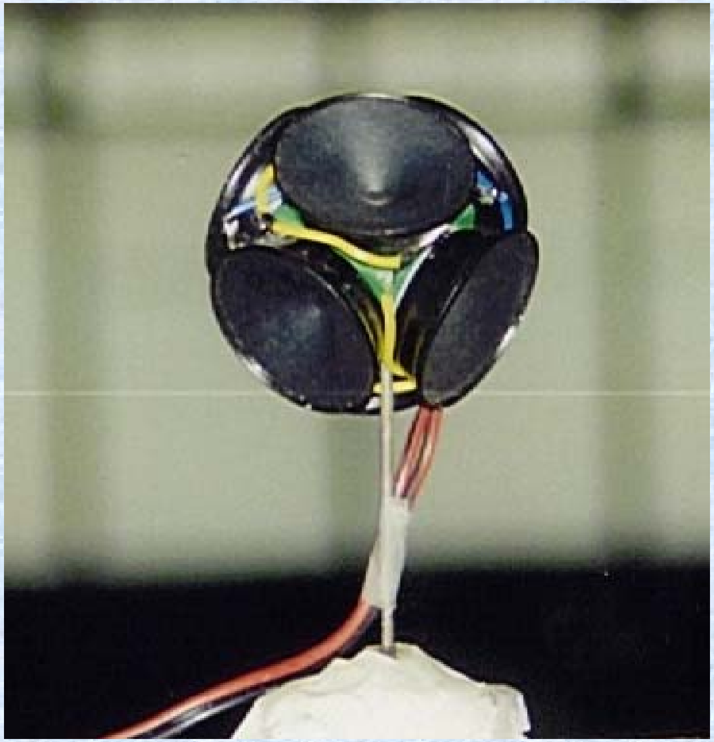


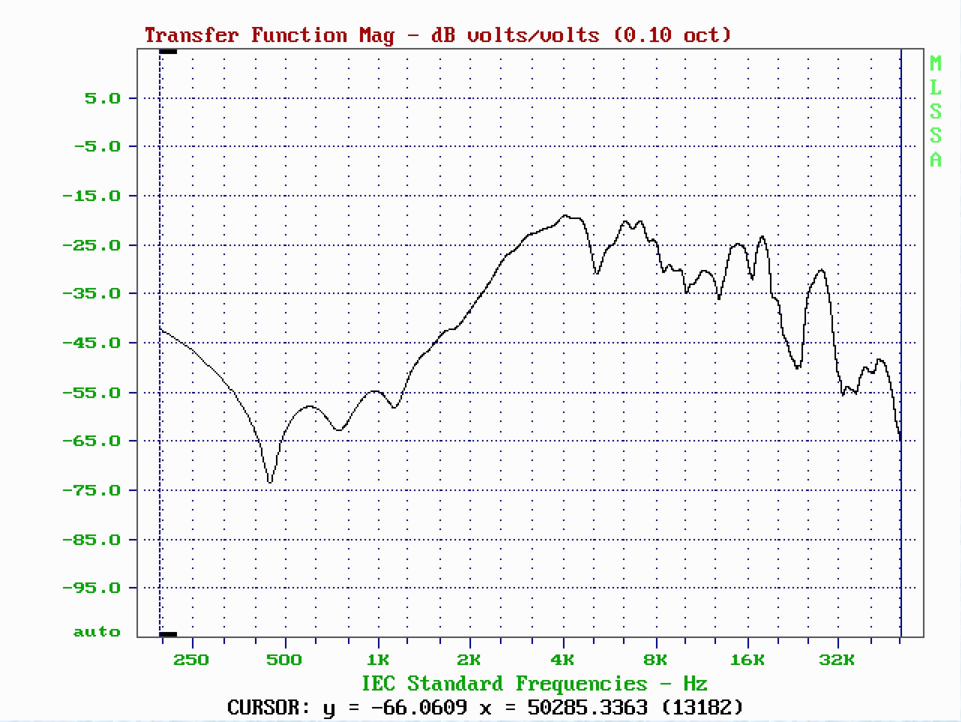
- Source in orchestra pit, curtain closed
- Source on the stage, with orchestra shell
- 7 binaural receivers, (blu dots)



Equipment employed – sound sources

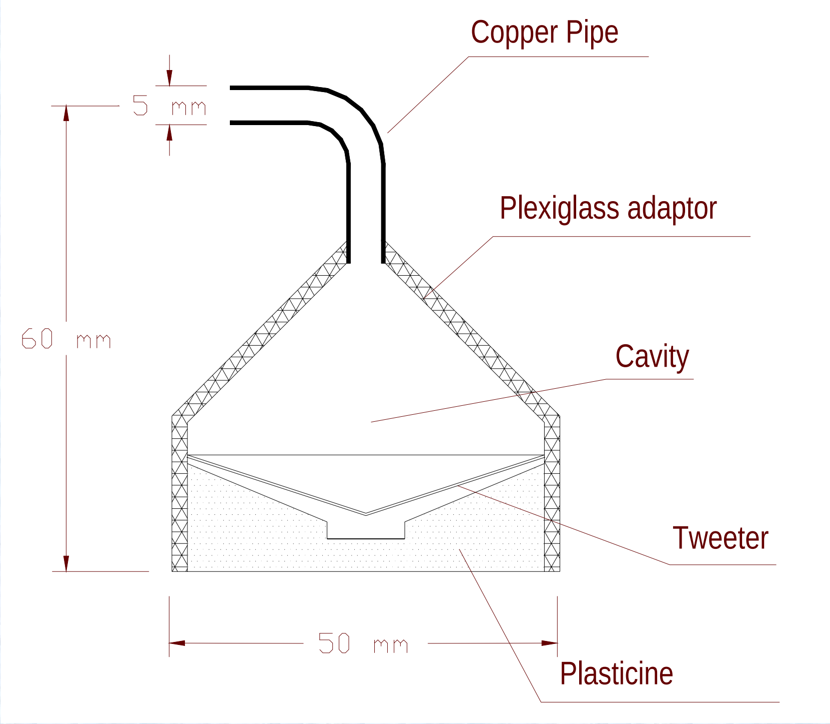
•First Sound Source: 6-ways piezoelectric tweeter

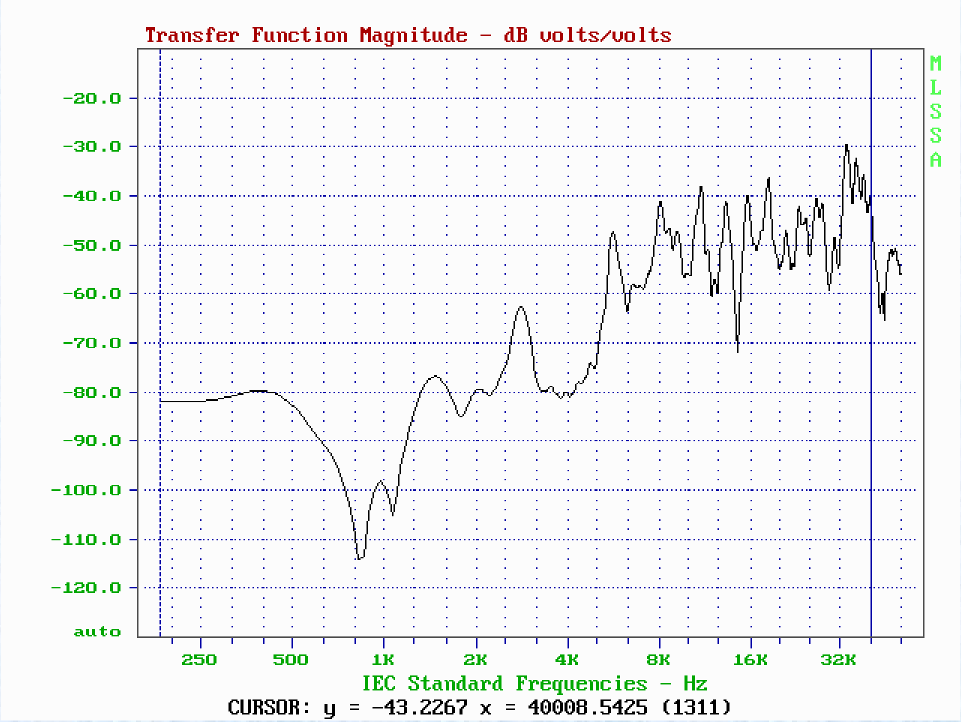




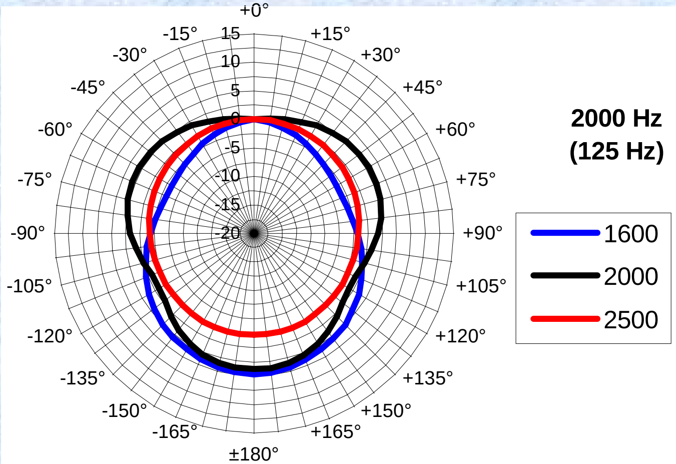
Equipment employed – sound sources

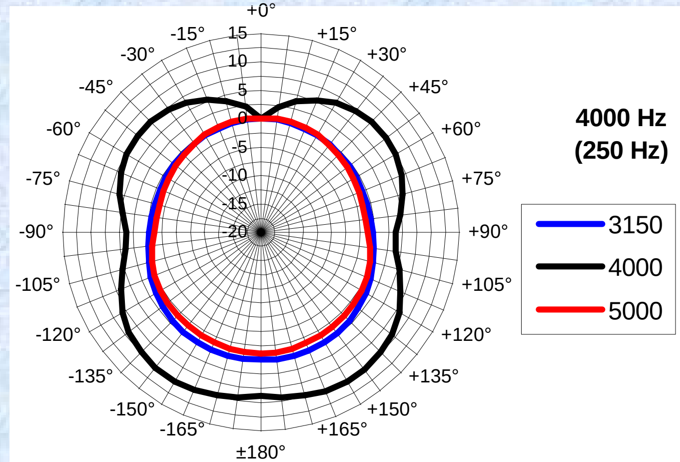
•Second Sound Source: piezoelectric tweeter with pipe adaptor

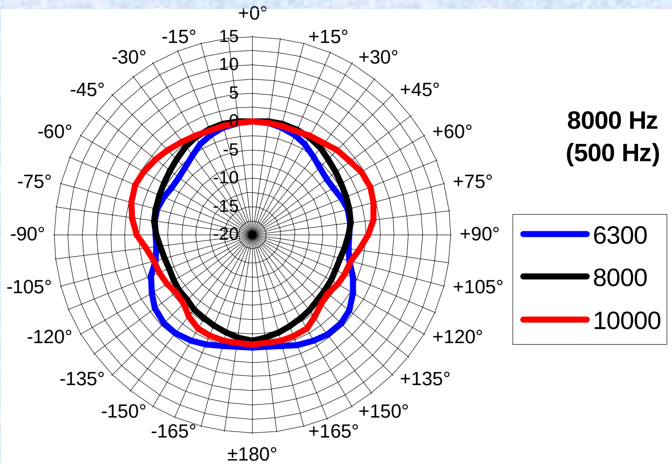


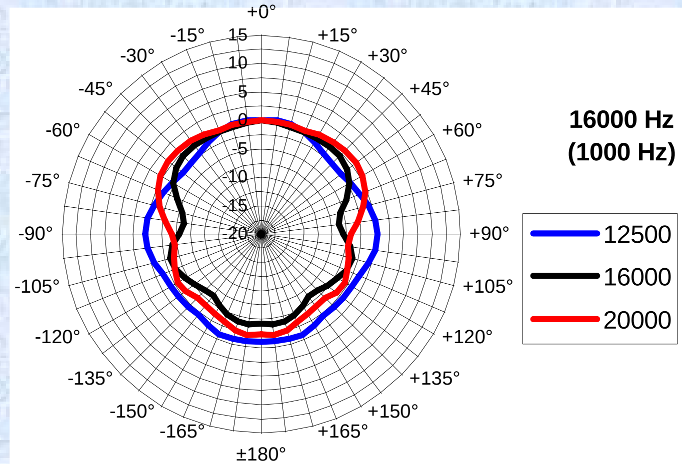


Directivity of the second sound source



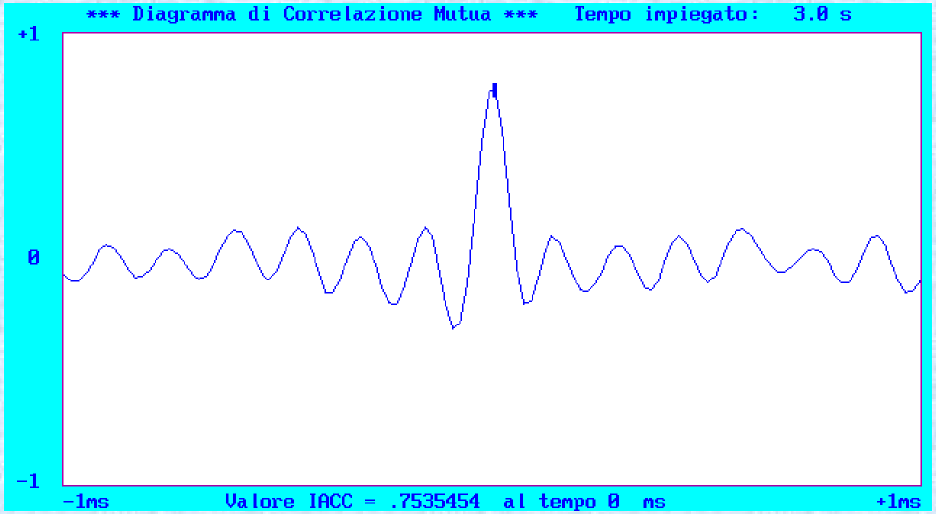




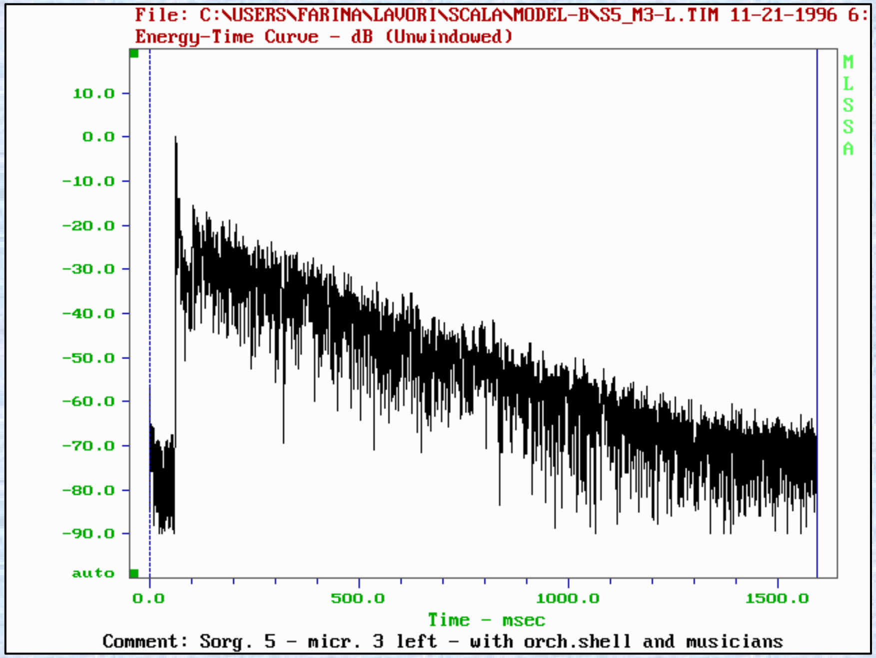


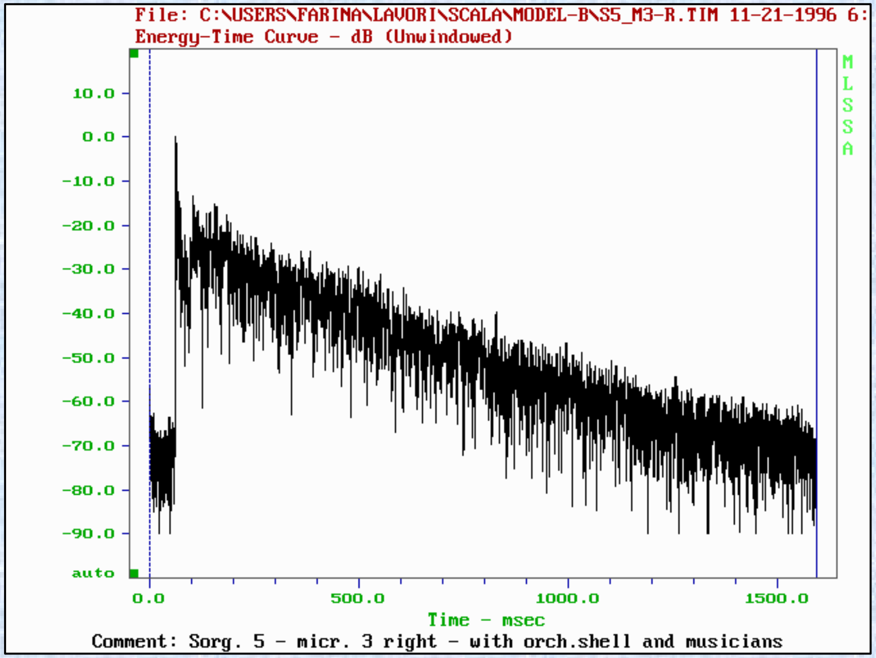
Equipment employed
binaural measurement system

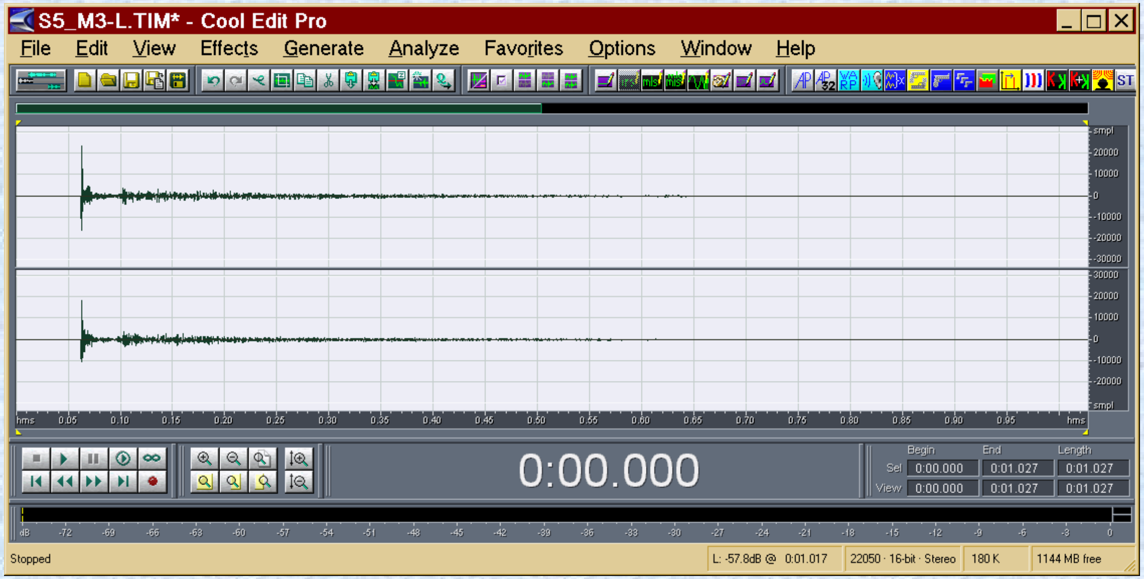
- Binaural microphone (1/4" capsules)
- MLSSA board in an Epson portable PC
- Home-made software for computing IACC



Typical impulse responses in the scale model







Measurements in the real room

Session	Source Position	n. receivers	Audience and musicians	Reflectin g panels	G map
A	Orchestra Pit, curtains closed	7 (62)	no	yes	Si
B	Orchestra Pit, curtains closed	7 (62)	no	no	si
C	Stage, orchestra shell	7	no	yes	no
D	Stage, orchestra shell	2	si	yes	no
E	Stage, opera scenery	7	no	yes	no

Measurements in the real room

Signal generation and emission	– Notebook PC with PCMCIA sound board (Digigram VX Pocket V2, 24 bits, 48 kHz) – CoolEdit with Aurora plugins (log sine sweep signal) – Dodechaedron loudspeaker with integrated power amplifier and wireless remote control (LookLine D300)
Binaural recording	– 2 Sennheiser MKE 2002 dummy heads – 1 Tascam DAP1 DAT recorder – 1 Sony TCD-D100 DAT recorder – Waveterminal U2A SPDIF-to-USB interface
B-format recording	– Soundfield ST250 microphone – Notebook PC with PCMCIA sound board (Digigram VX Pocket 4404 bits, 48 kHz, 4 channels)
Sound Pressure Level measurement	– Real-time, hand-held 1/3 octave spectrum analyzer (B&K 2260 Investigator)
Post processing software	– Cool Edit Pro with Aurora plugins – Surfer for G maps

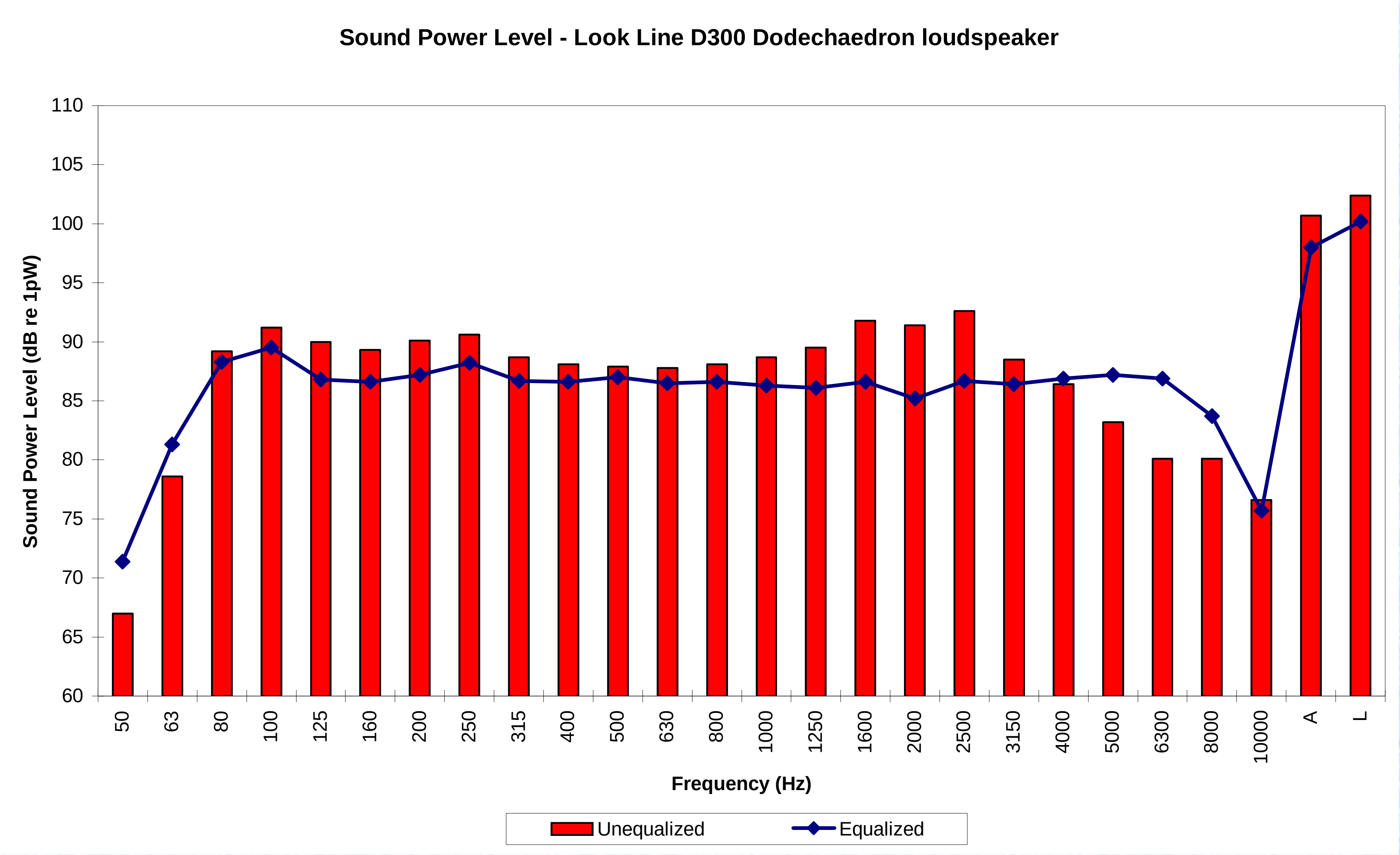
Sound Source

The loudspeaker on the stage

Amplifier with remote control

Measurement of the sound power with the Sound Intensity method (ISO-9614-II)

Sound Power Spectrum



Microphones

Soundfield ST-250

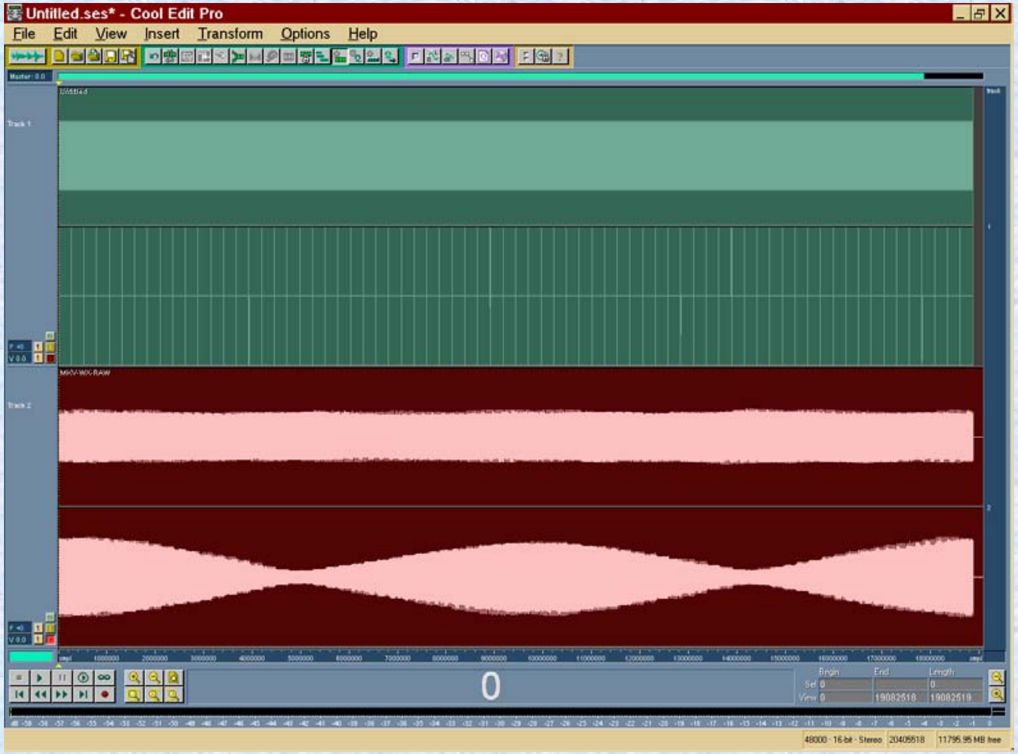
(B format)

Sennheiser MKE-2002

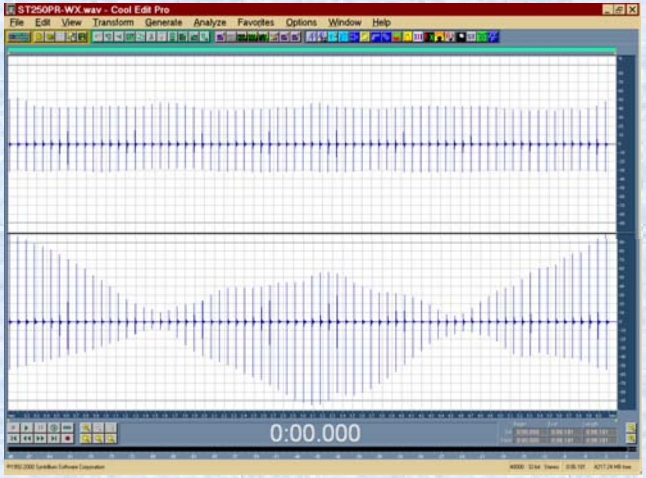
(binaural)

Measurement of the directivity of the Soundfield ST-250 microphone

Microphone on the automated rotating table

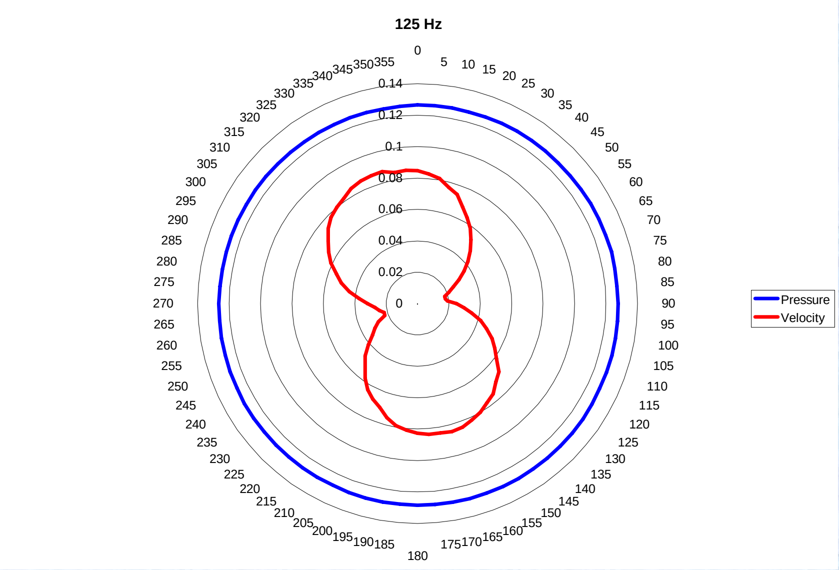


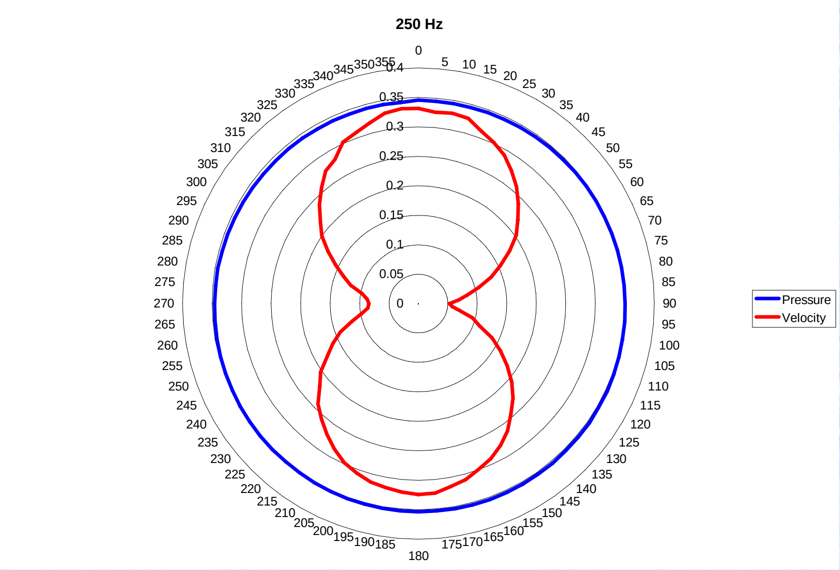
CoolEditPro generating the MLS test signal, the pulses for the rotating table, and simultaneously recording channels W (omni) and X (figure of eight)

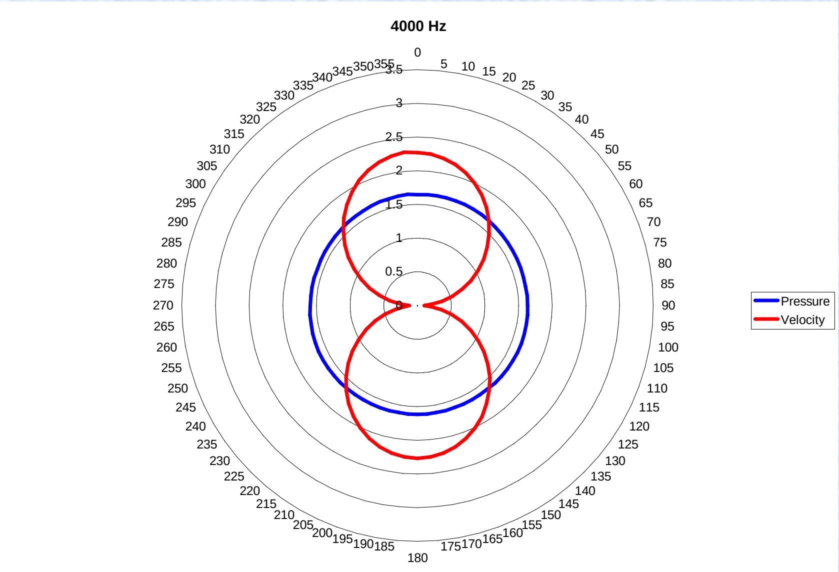


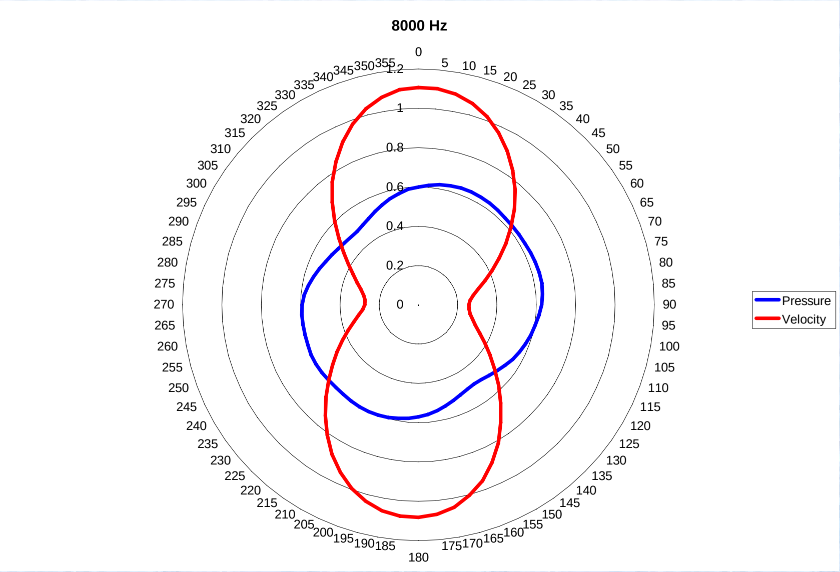
Deconvolved impulse responses

Polar plots of the ST-250 directivity



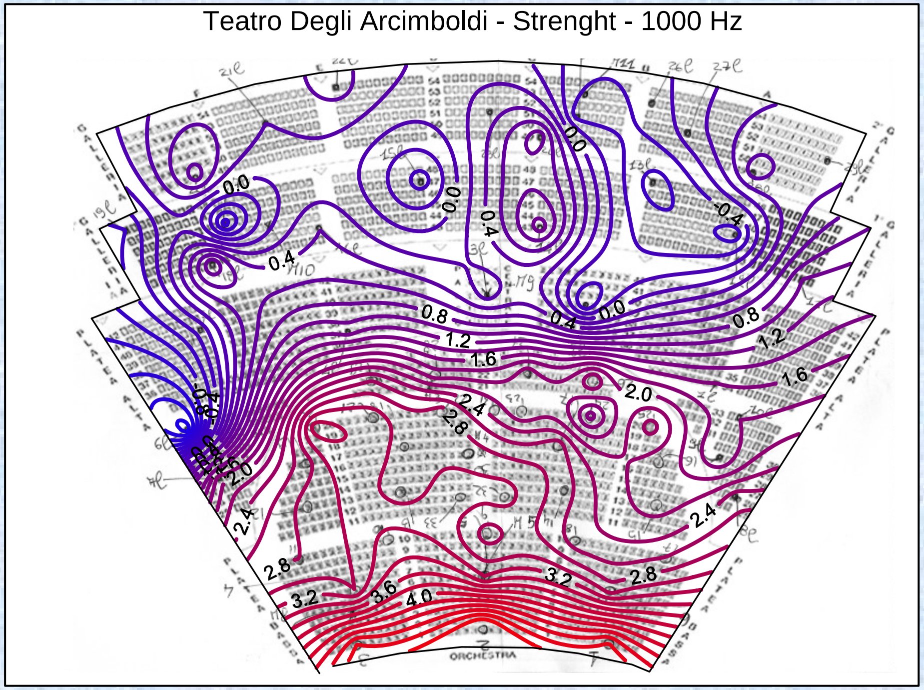


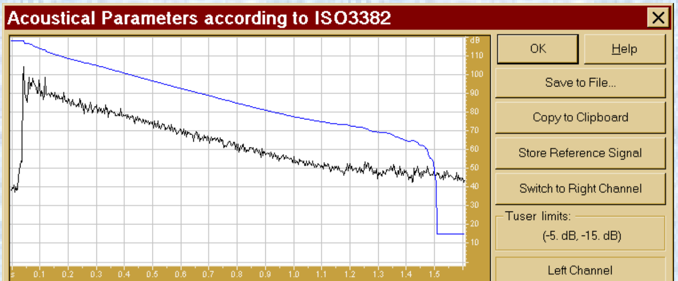




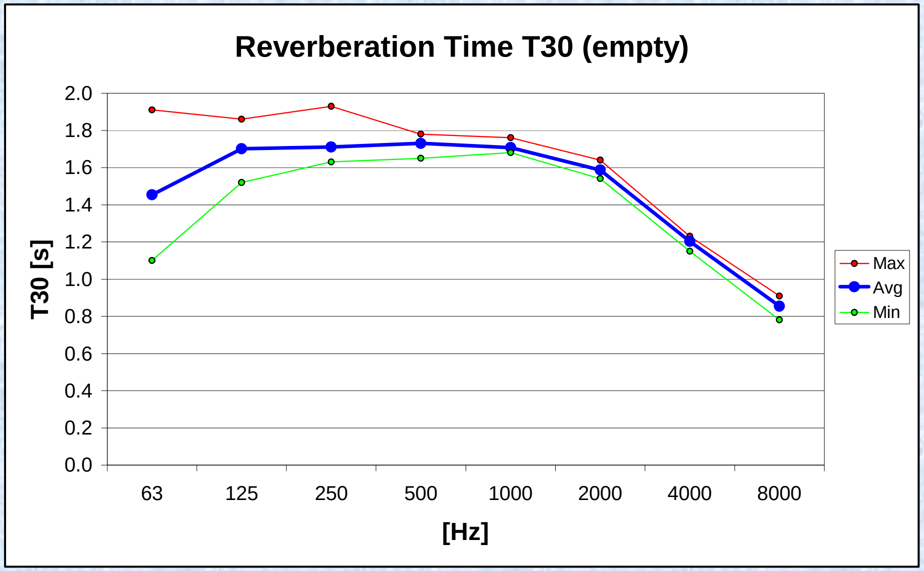
Measured acoustical parameters (averages)

Acoustical parameter	*Measured*	*Designed*
Rev. Time T30	1.7 s	1,8 s
Early Decay Time EDT	1.75 s	1,7 – 1,9 s
Clarity C80	0.5 dB	–1 to +3 dB
Strenght	0 to 4 dB	–2 to + 4 dB
I.A.C.C.	0.24	< 0.70
I.T.D.G.	25 ms	25 ms

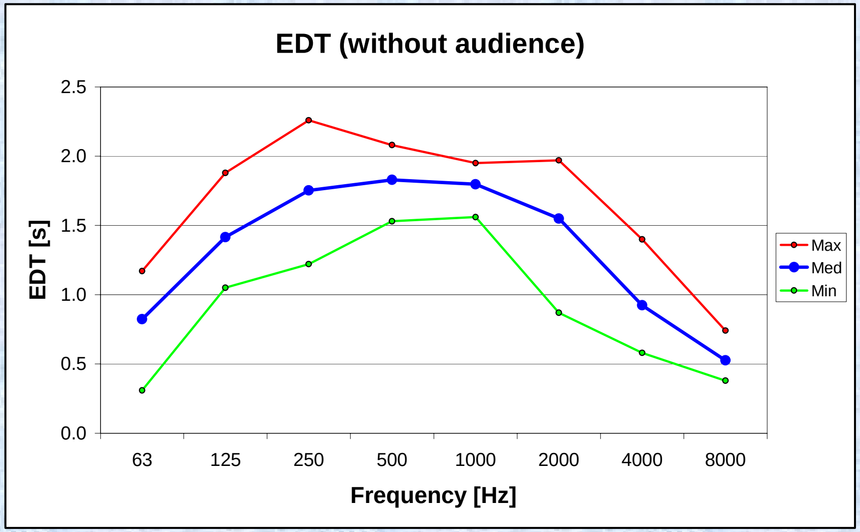


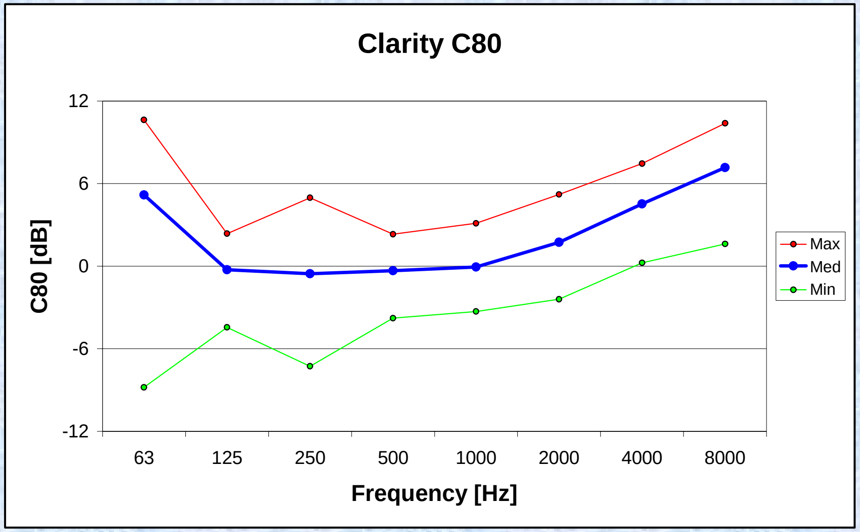

Acoustical Parameters according to ISO3382

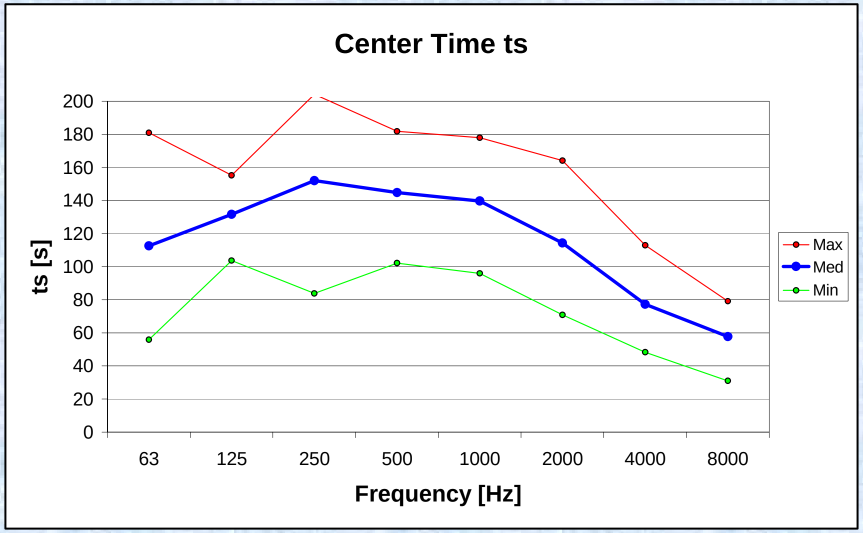
Freq. (Hz)	31.5	63	125	250	500	1k	2k	4k	8k	16k	Lin	A
Signal (dB)	47.11	60.56	52.31	59.75	67.41	72.80	76.86	81.08	79.13	78.52	85.40	85.51
Noise (dB)	28.31	27.43	29.49	31.49	34.70	41.92	38.47	41.85	41.72	27.81	47.88	48.09
strenGth(dB)	-21.89	-8.44	-16.69	-9.25	-1.59	3.80	7.86	12.08	10.13	9.52	6.40	8.51
C50 (dB)	-1.17	-1.56	-5.10	-3.16	-1.68	-1.02	-2.77	-2.07	7.24	12.09	1.06	0.03
C80 (dB)	5.63	3.81	0.94	-1.71	1.67	2.29	2.05	2.45	9.73	16.72	4.48	3.74
D50 (%)	43.31	41.12	23.61	32.59	40.45	44.17	34.57	38.30	84.10	94.18	56.08	50.15
Ts (ms)	113.45	88.14	125.01	150.83	107.40	87.48	103.20	93.15	28.14	18.66	69.24	77.58
EDT (s)	--	0.64	1.52	2.01	1.78	1.43	1.44	1.19	0.52	--	1.08	1.16
T20 (s)	2.26	0.80	1.60	1.72	1.48	1.61	1.60	1.43	0.75	0.41	1.47	1.48
r T20	0.94	0.95	0.99	1.00	0.99	1.00	1.00	1.00	1.00	0.97	1.00	1.00
T30 (s)	2.97	1.35	1.43	1.92	1.52	1.60	1.59	1.43	0.74	0.46	1.49	1.49
r T30	0.94	0.93	0.97	0.99	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00
Tuser (s)	1.68	0.36	1.62	1.63	1.76	1.76	1.70	1.44	0.75	0.24	1.49	1.50
r Tuser	0.86	0.95	0.97	0.99	0.97	0.99	1.00	1.00	0.98	0.94	1.00	1.00

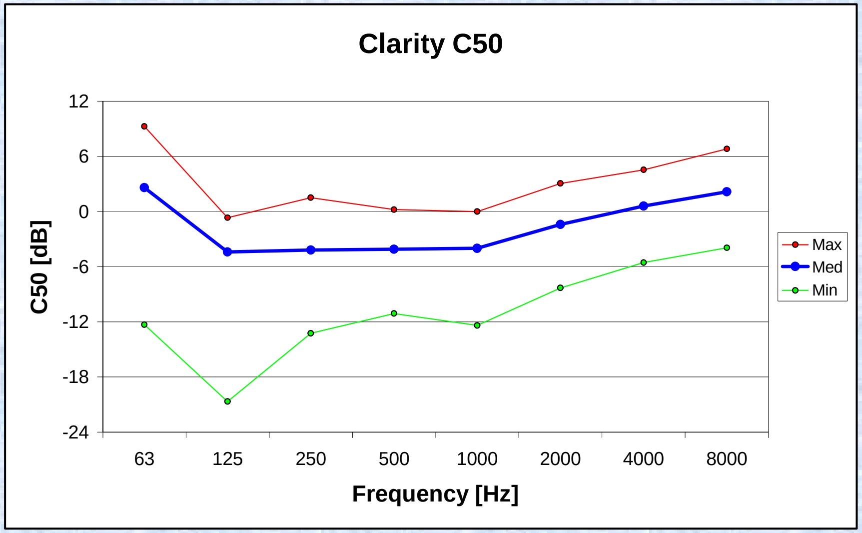


Other acoustical parameters





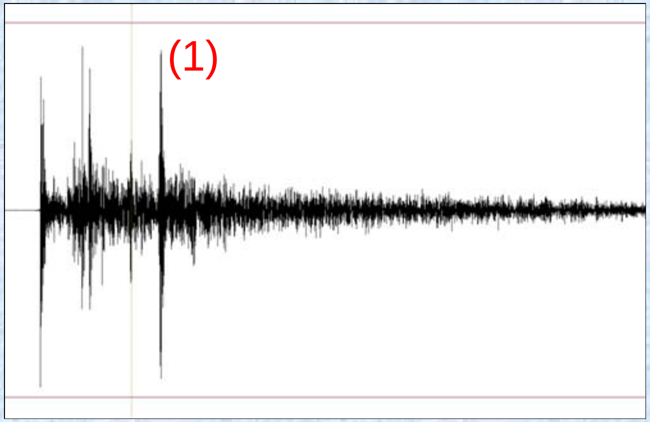




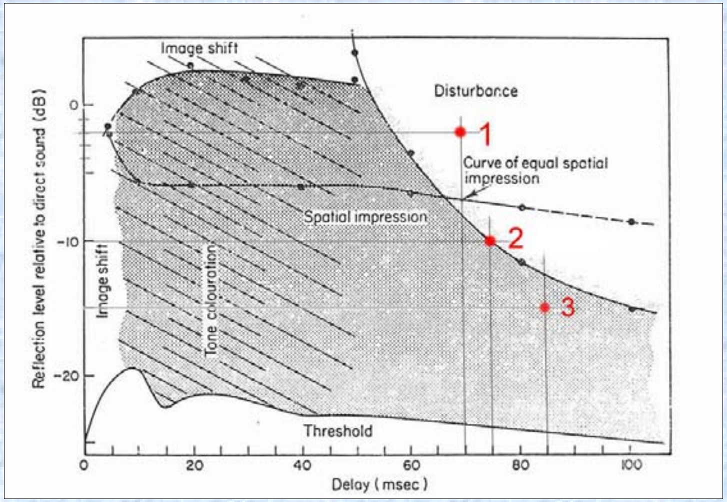
Research of possible echoes

Wall in back of the stalls

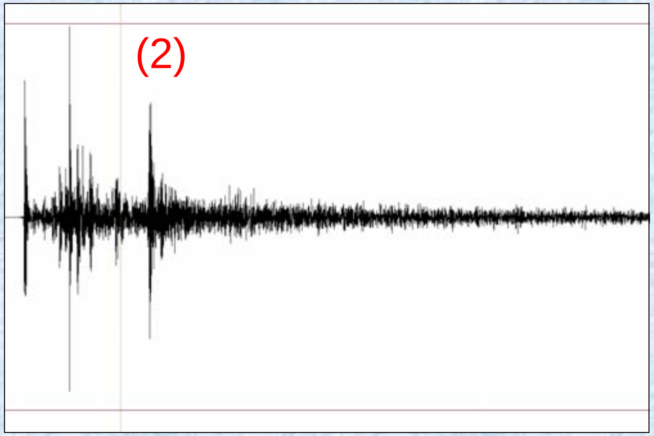
Session B2, center of stalls



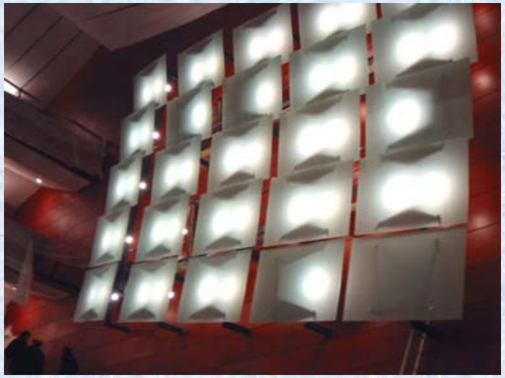
Barron's Echo criterion

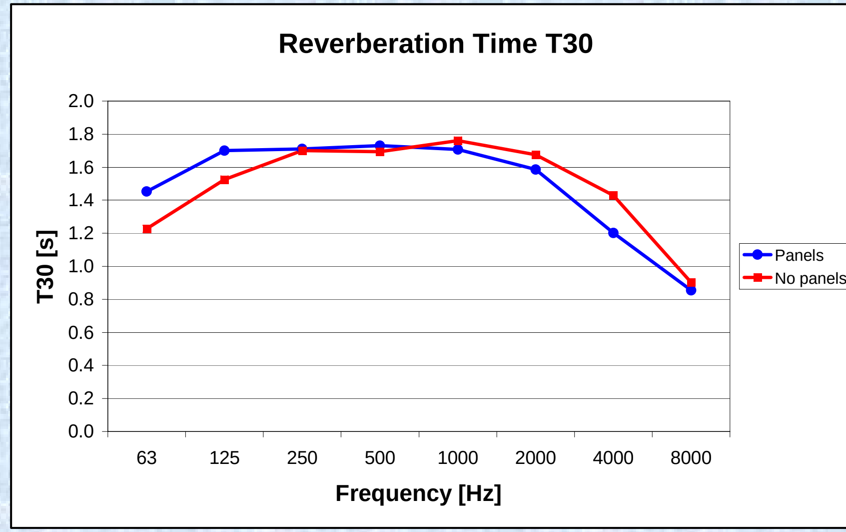


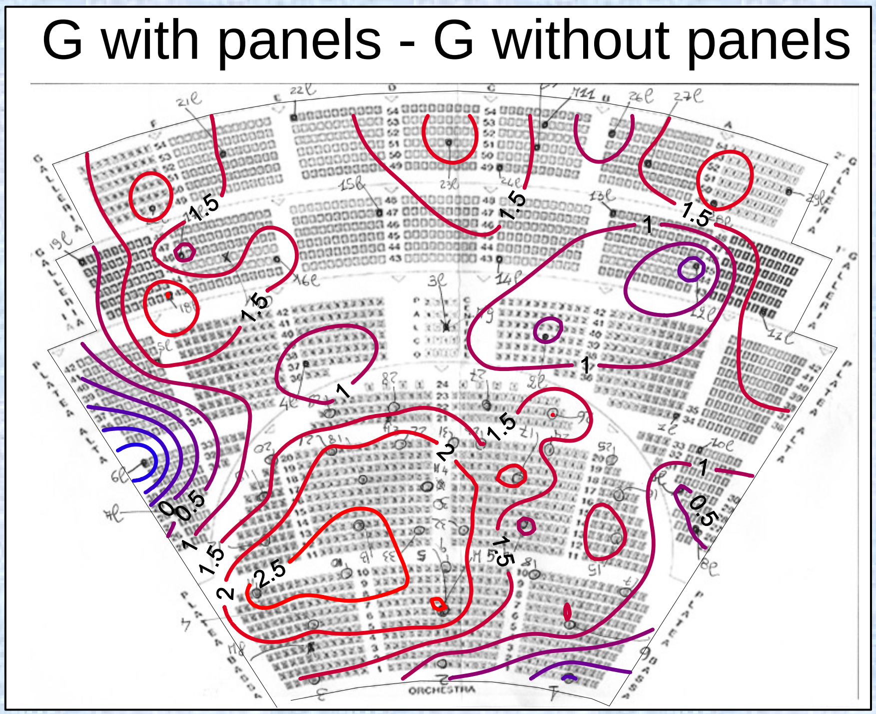
Session C. center of stalls

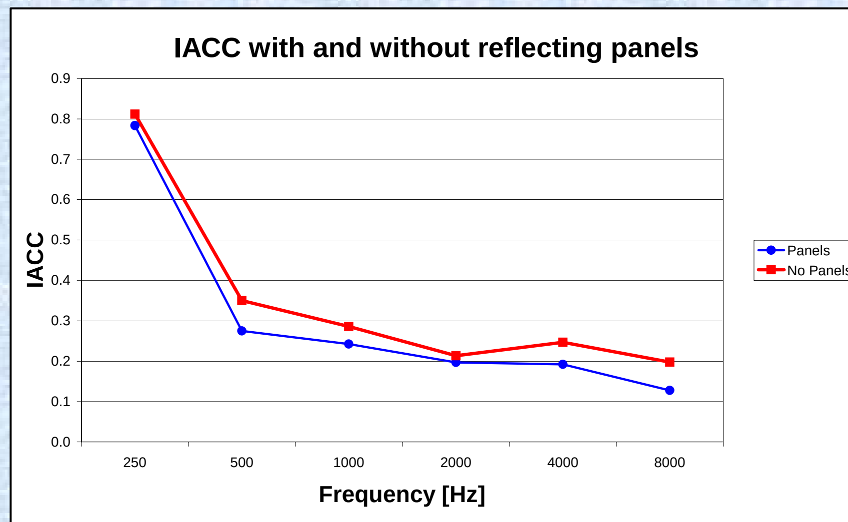


Comparison between measurements performed with and without lateral reflective panels



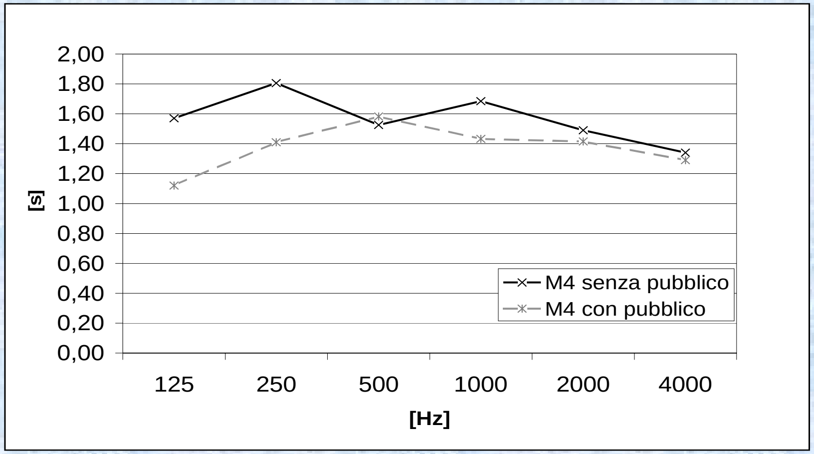




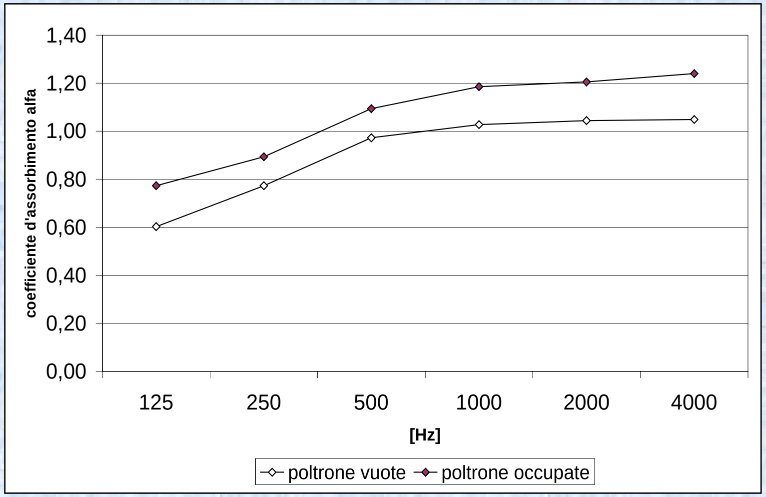


Comparison between measurements with and without audience

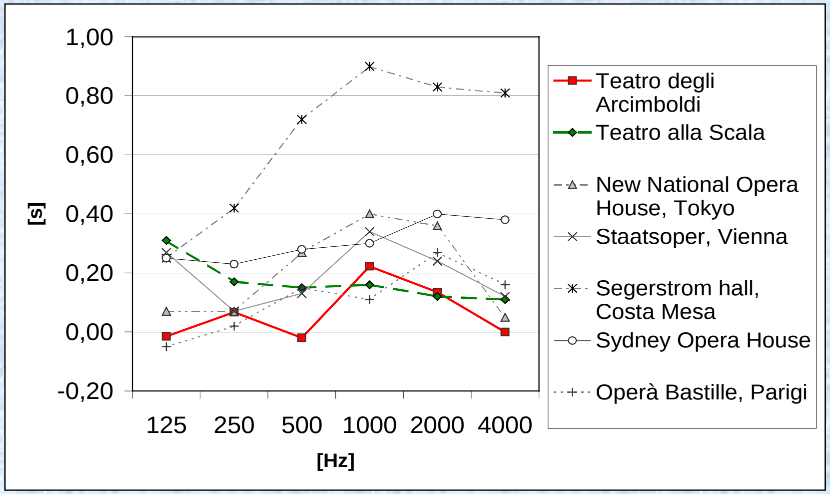
Reverberation Time T30



Absorption of seats

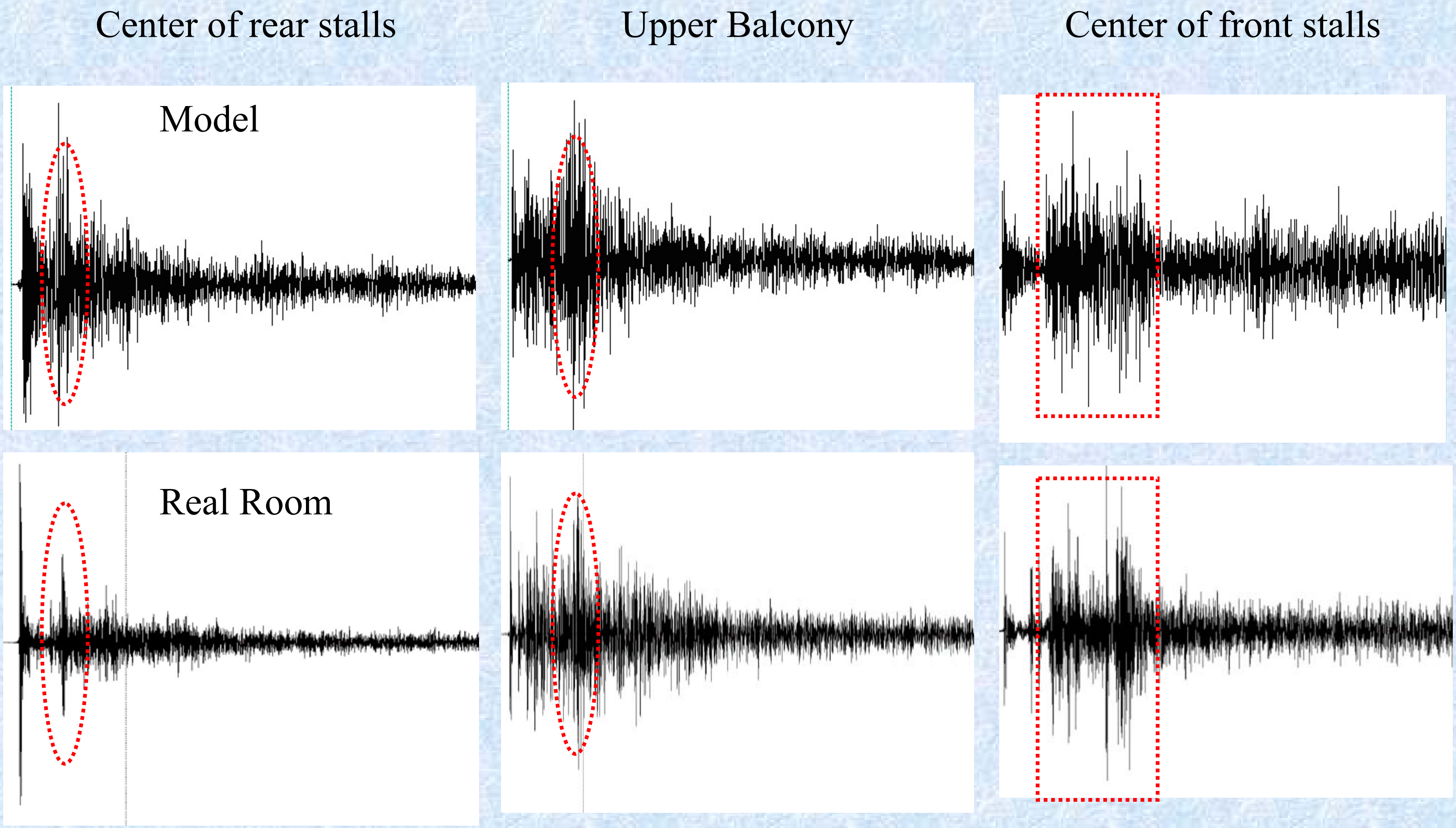


Variation of T30 in various theatres

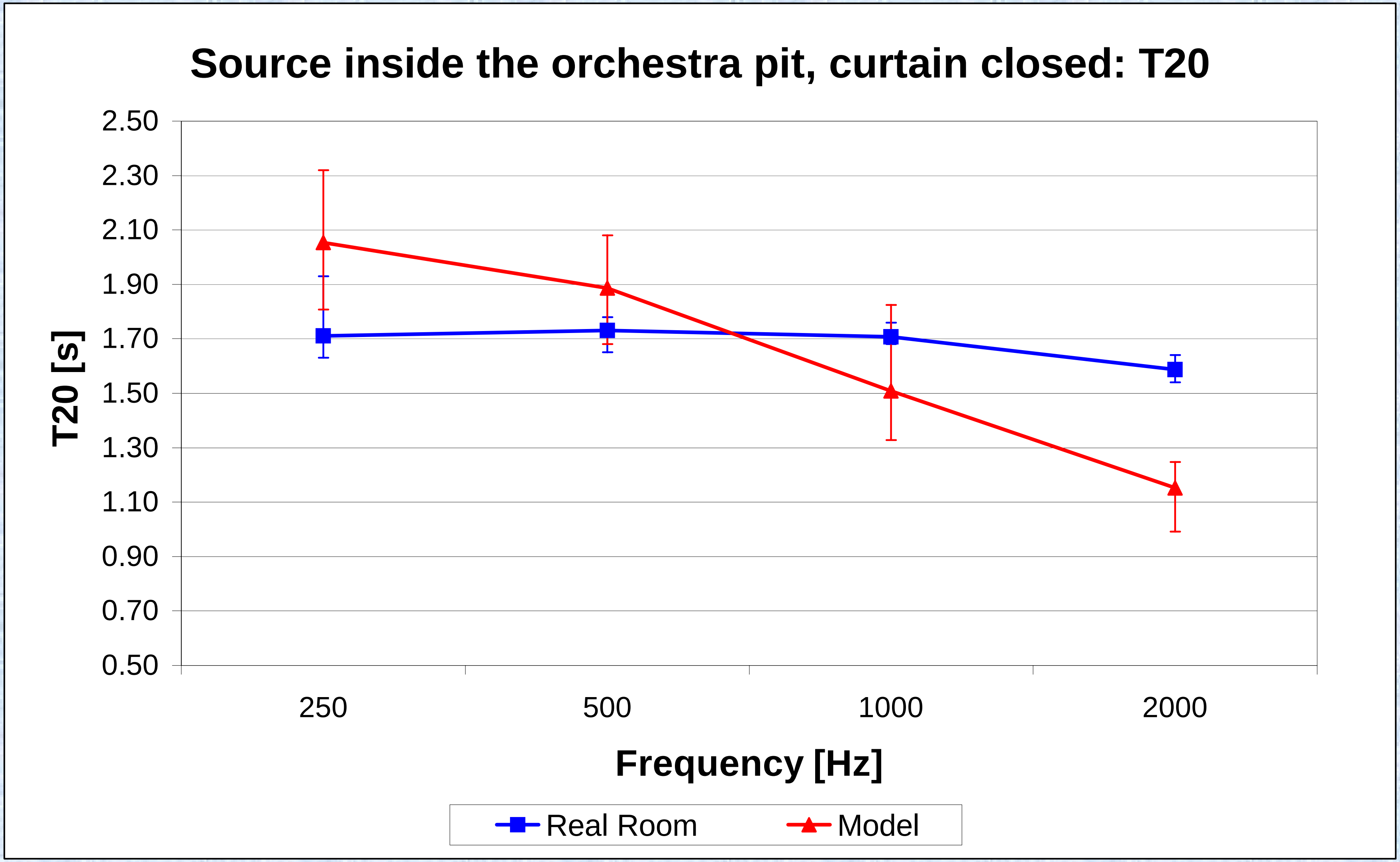


Comparison between scale model and real room

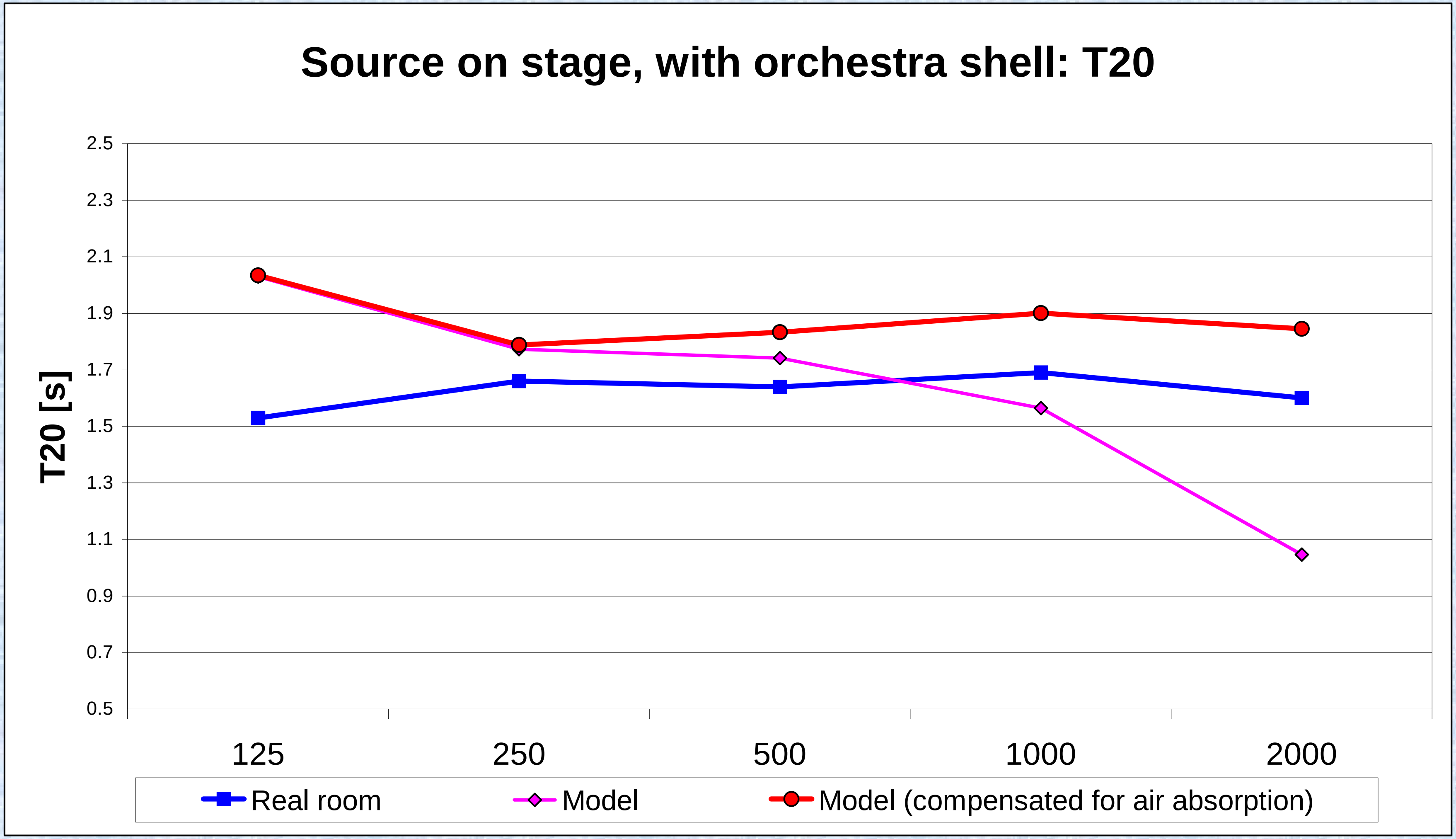
Reflection from the ceiling in three seats, source in the orchestra pit



Comparison between scale model and real room



Comparison between scale model and real room



Conclusions

- The scale model was used mainly for studying the early reflections and for orienting properly the lateral reflectors
- Reverberation time and clarity measured in the model were coincident with the real room only in two octave bands (500 and 1000 Hz)
- The measurements performed in the real hall resulted in acoustical parameters strictly close to the design goal
- The presence of the reflecting panels revealed to be strongly beneficial for the sound field in the stalls, even if they were not optimally oriented
- The effect of seat occupance revealed to be very little, confirming that the chosen seats give an absorption almost independent of the presence of the listener