RECORDING CONCERT HALL ACOUSTICS FOR POSTERITY

Angelo Farina [(1)] **– Regev Ayalon** [(2)]

[(1)] Dipartimento di Ingegneria Industriale, Università di Parma, Via delle Scienze 181/A Parma, 43100 ITALIA

HTTP://pcfarina.eng.unipr.it - mail: farina@unipr.it

[(2)] K.S. Waves Inc., Azrieli Center, Tel Aviv, ISRAEL

HTTP://www.waves.com - mail:regev@waves.com

Multichannel Audio - The New Reality

24th AES International Conference

June 26 - 28, 2003

Background

- The title of this paper is exactly the same employed by Michael Gerzon in its JAES paper (Vol. 23, Number 7, 1975)
- He first proposed to collect impulse responses measured in famous theatres, with a microphone capable of capturing the complete spatial information
- This paper is consequently basically a tribute to M.Gerzon, who had foreseen most of the modern multichannel audio applications, including impulse response measurements and auralization obtained by convolution.

Goals

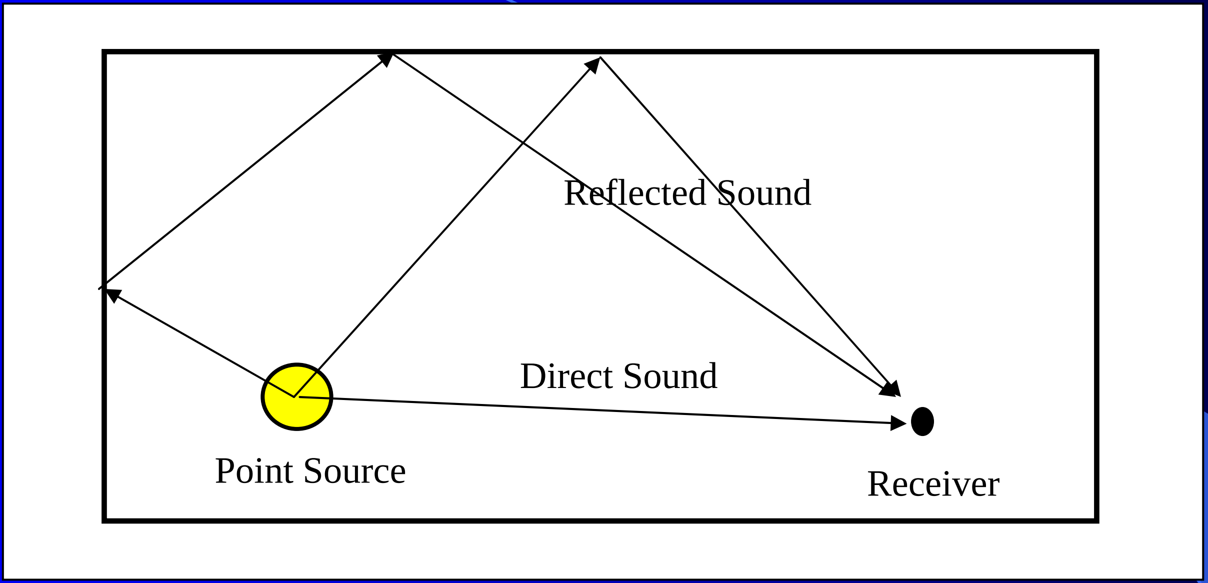
- The main goal is to measure an huge collection of impulse response in famous theatres, concert halls, cathedrals, etc.
- These impulse responses have two main uses:

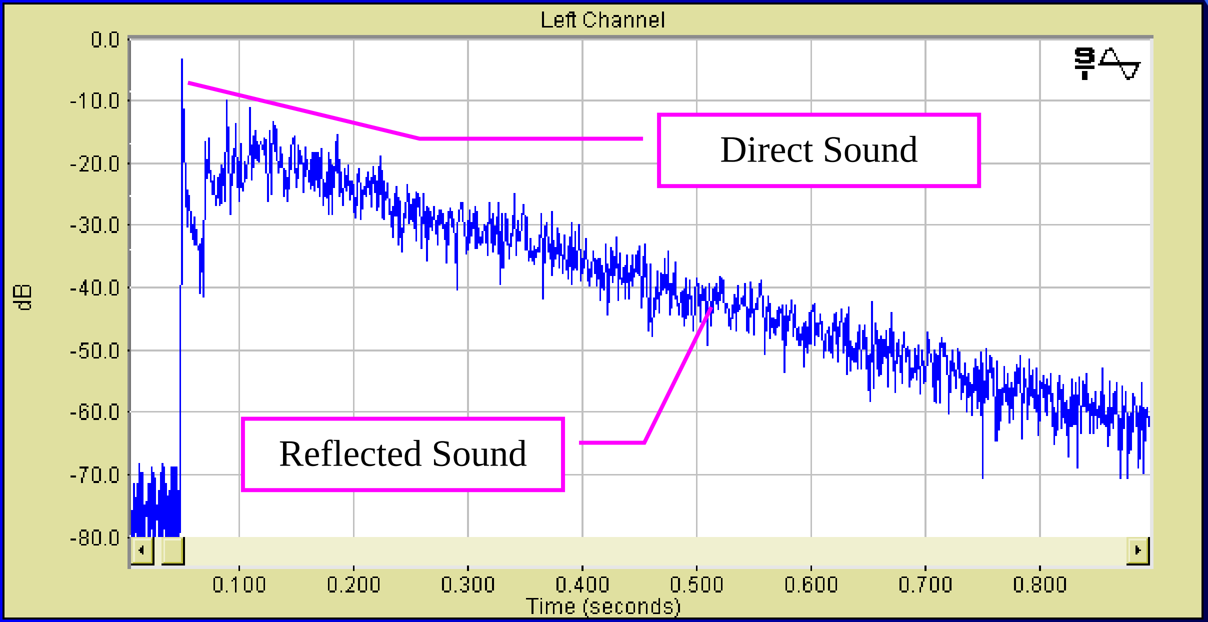
1. In case something happens to the original space (remember the case of La Fenice theater) they contain a detailed “acoustical photography” which is preserved for the posterity
2. They can be used for studio sound processing, as artificial reverb and surround filters for today’s and tomorrow’s musical productions

Topics

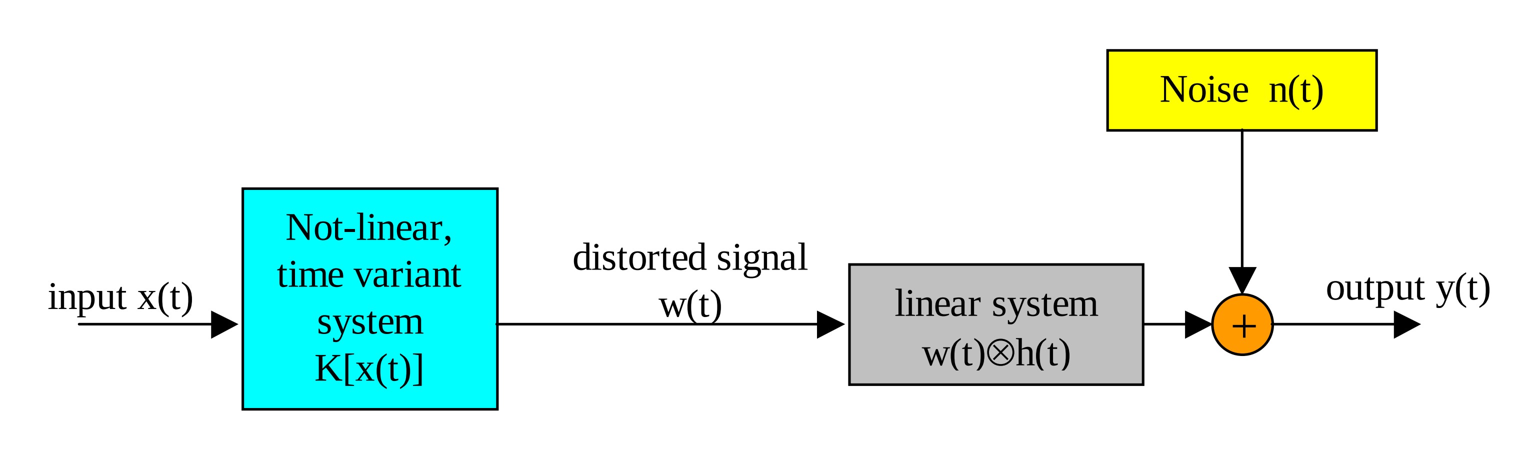
- Description of the measurement technique
- Analysis of some acoustical parameters of the first theaters already measured
- Description of the processing methods to be employed for transforming the measured data in audible reconstructions of the original spaces
- Description of the usage of the measured data for studio processing and production

Sound propagation in rooms





Measurement process



- The desidered result is the linear impulse response of the acoustic propagation h(t). It can be recovered by knowing the test signal x(t) and the measured system output y(t). It is necessary to exclude the effect of the not-linear part K and of the background noise n(t).

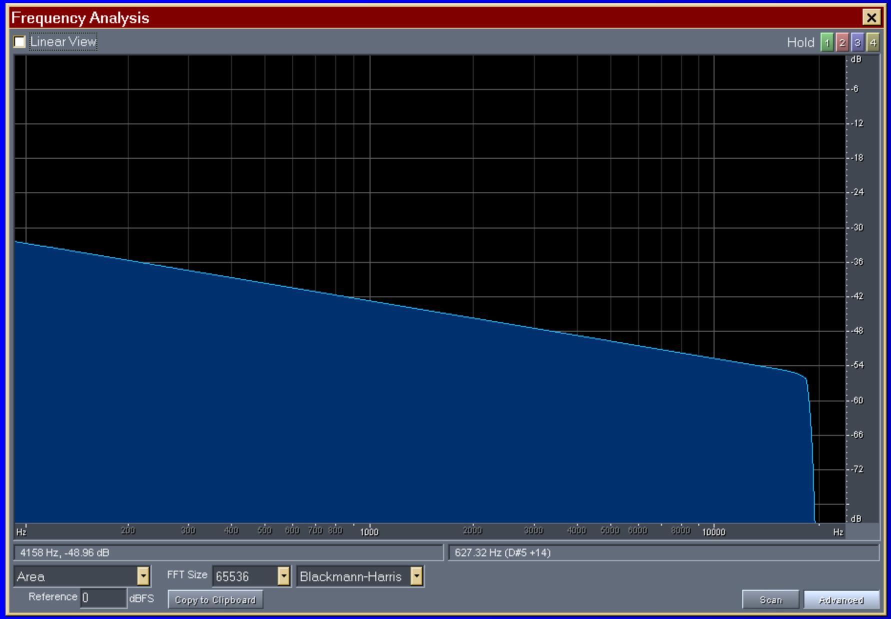
Test signal: Log Sine Sweep

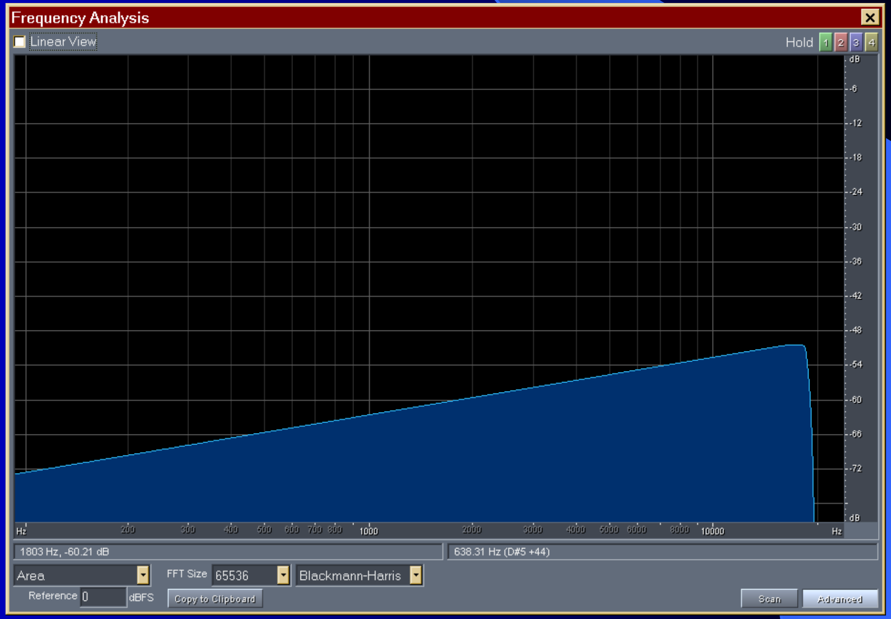
- $x(t)$ is a sine signal, which frequency is variable exponentially with time, starting at f_1 and ending at f_2.

$$x(t) = \sin\left[\frac{2\cdot\pi\cdot f_1\cdot T}{\ln\left(\frac{f_2}{f_1}\right)}\cdot\left(e^{\frac{t}{T}\cdot\ln\left(\frac{f_2}{f_1}\right)}-1\right)\right]$$

Deconvolution of Log Sine Sweep

- The “time reversal mirror” technique is emplyed: the system’s impulse response is obtained by convolving the measured signal y(t) with the time-reversal of the test signal x(-t). As the log sine sweep does not have a “white” spectrum, proper equalization is required

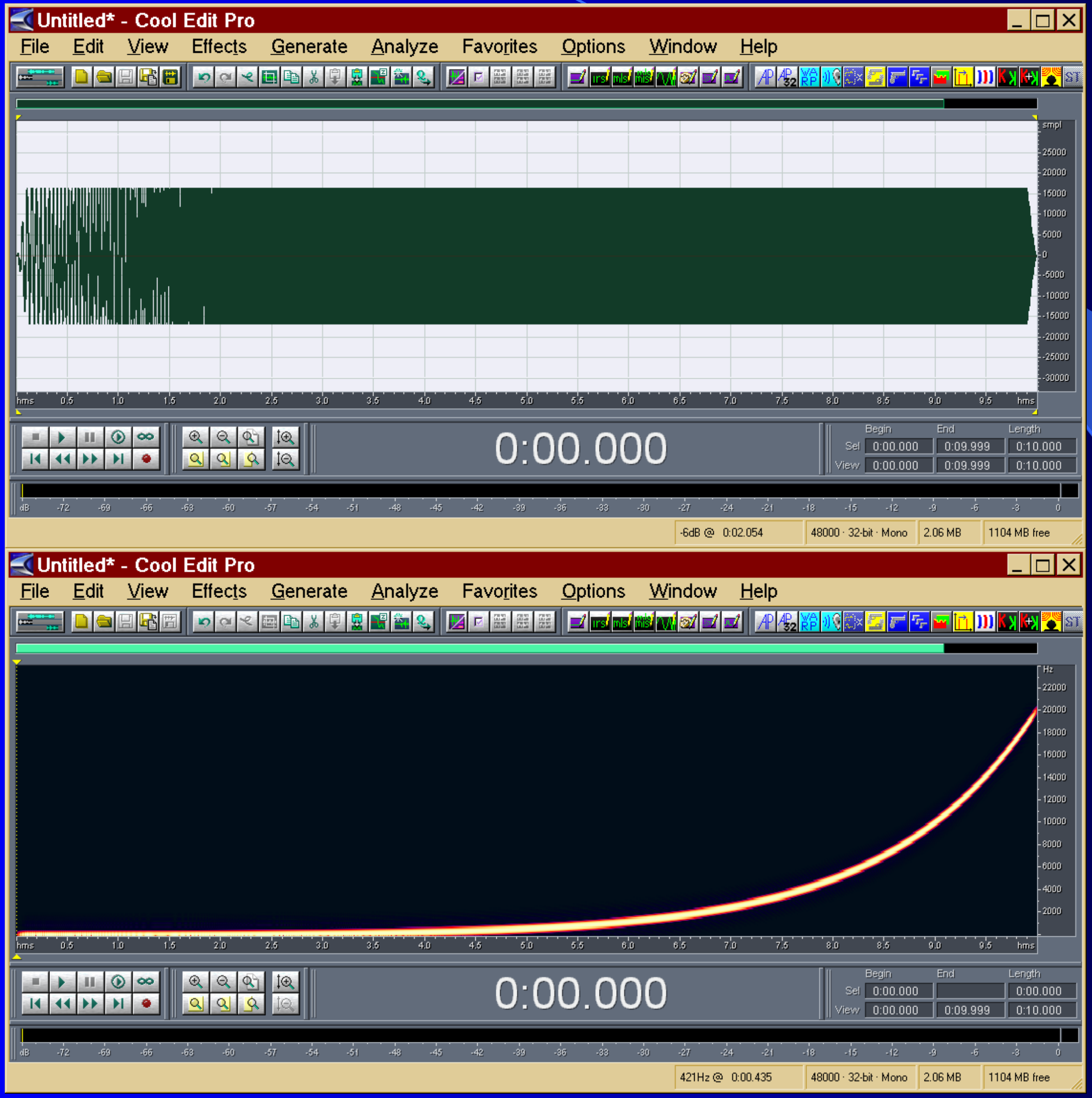




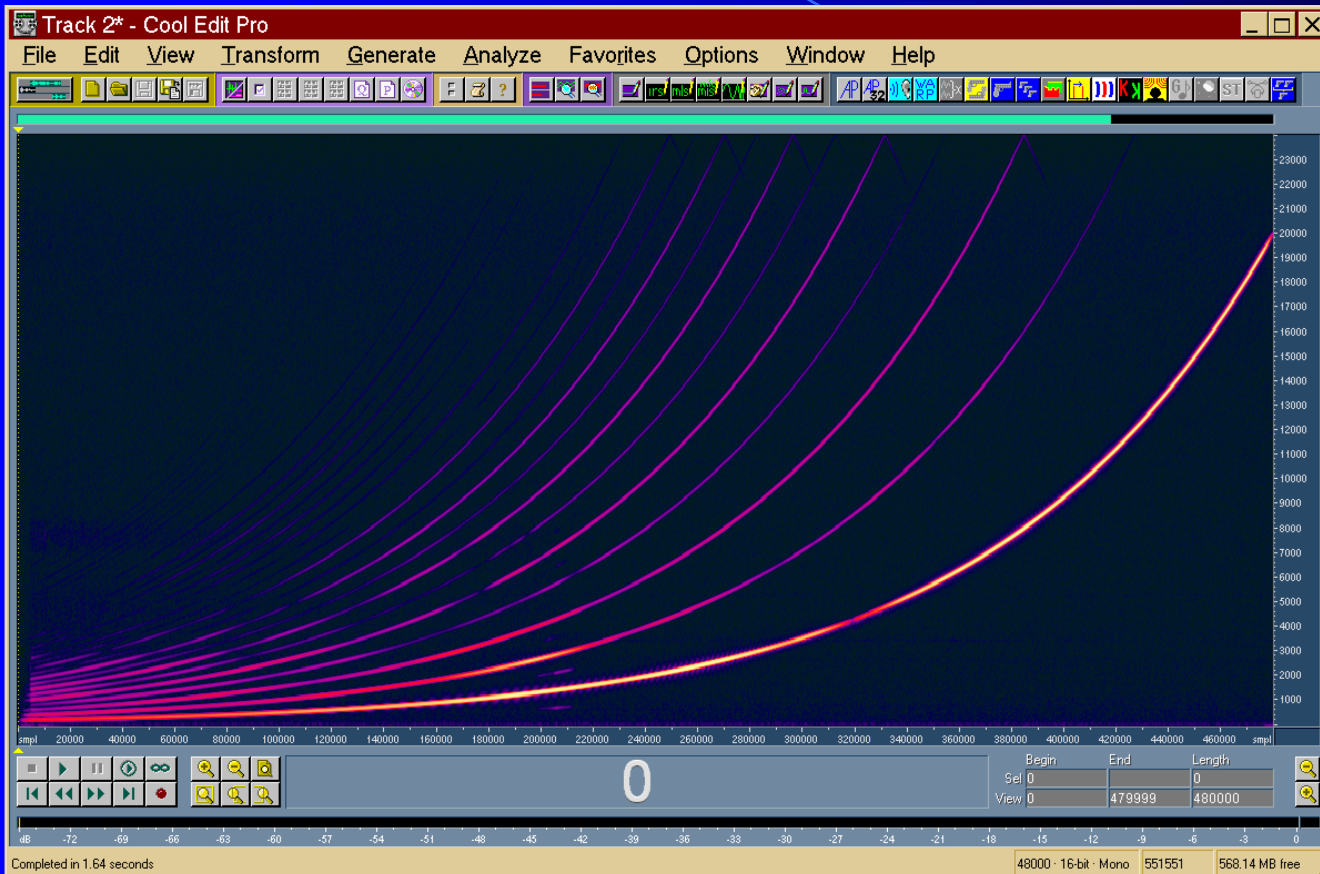
Test Signal x(t)

Inverse Filter z(t)

Test Signal – x(t)

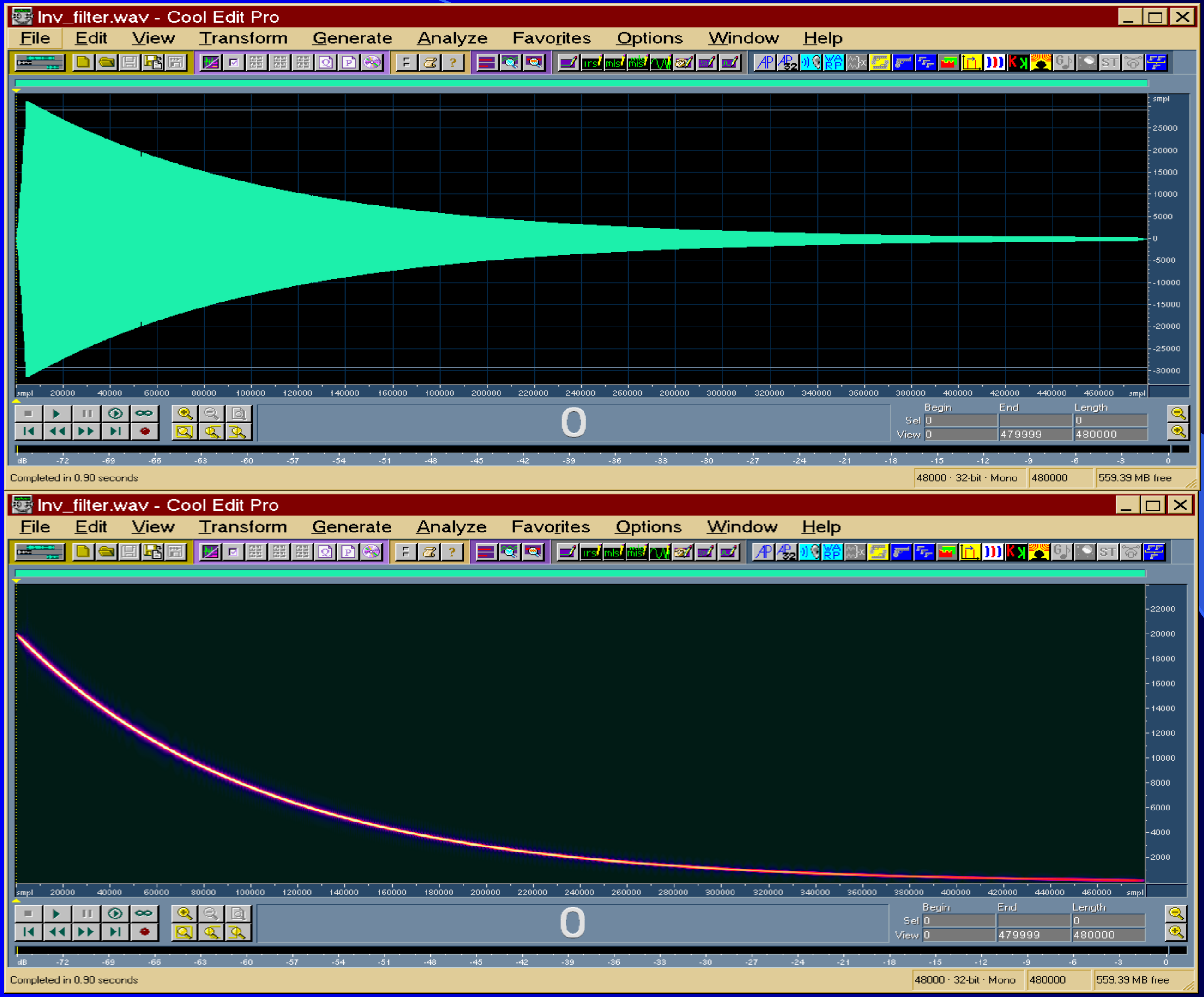


Measured signal - y(t)



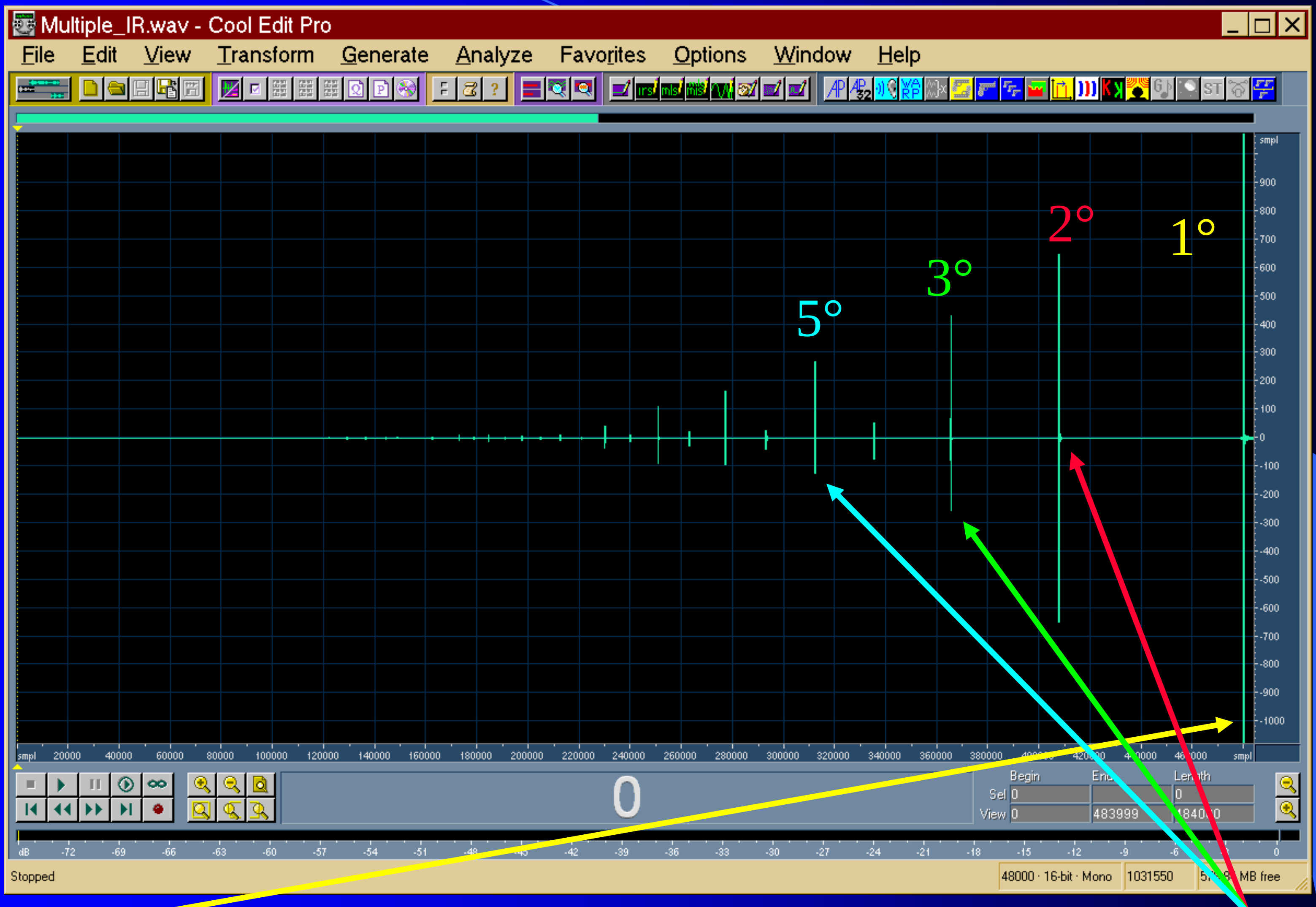
- The not-linear behaviour of the loudspeaker causes many harmonics to appear

Inverse Filter – z(t)



The deconvolution of the system’s impulse response is obtained convolving the measured signal y(t) with the inverse filter z(t) [equalized, time-reversed x(t)]

Result of the deconvolution



The last impulse response is the linear one, the preceding are the harmonics distortion products of various orders

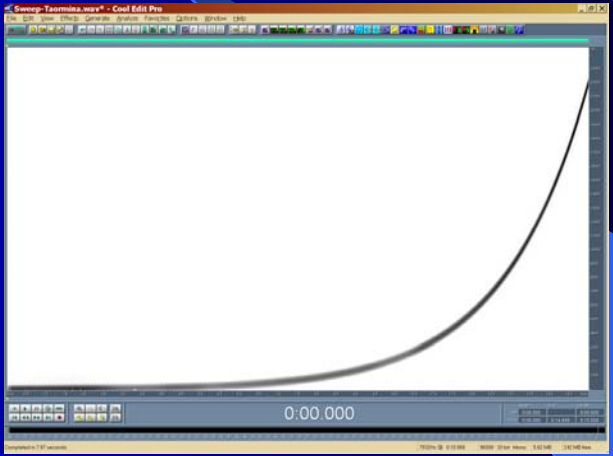
Measurement Setup

- The measurement method incorporates all the known techniques:
  - Binaural
  - B-format (1st order Ambisonics)
  - WFS (Wave Field Synthesis, circular array)
  - ITU 5.1 surround (Williams MMA, OCT, INA, etc.)
  - Binaural Room Scanning
  - M. Poletti high-order virtual microphones
- This measurement setup has been named “Waves2003”, as it is being employed for the collection of impulse response to be employed together with the new convolution software being developed by KS Waves ltd.

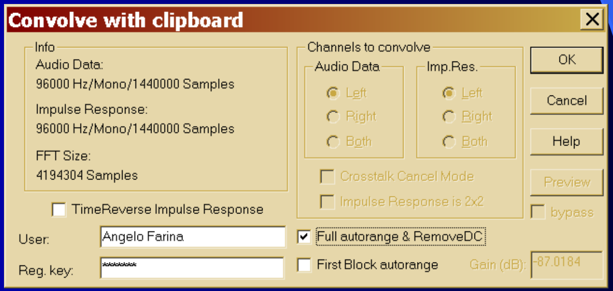
“Waves2003” Measurement Parameters

- Test Signal: pre-equalized sweep

Start Frequency	**22 Hz**
End Frequency	**22 kHz**
Sweep length	**15 s**
Silence between sweeps	**10 s**
Type of sweep	**LOG**

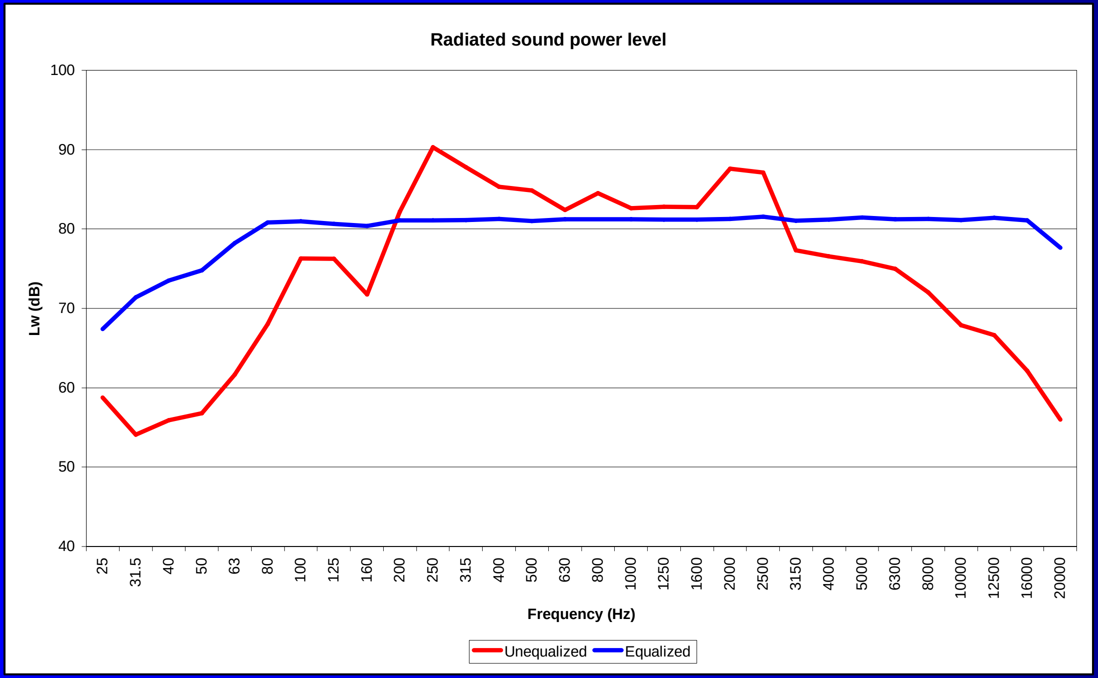


- Deconvolution:



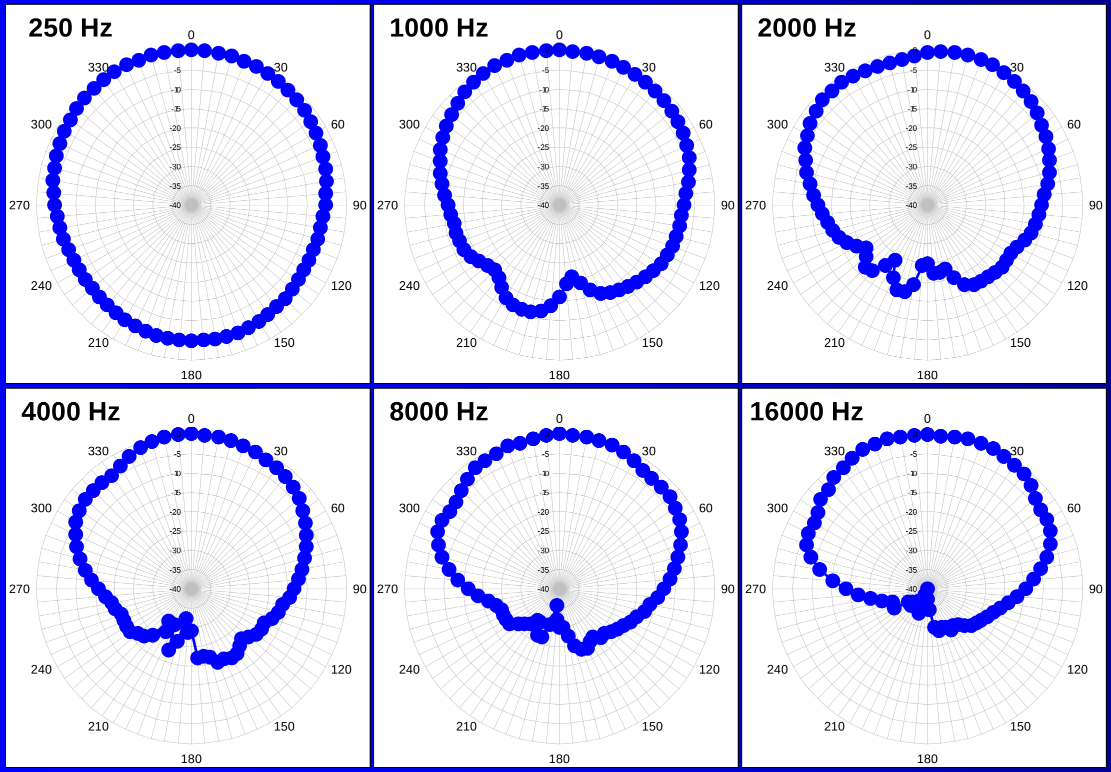
Transducers (sound source #1)

- Equalized, omnidirectional sound source:
  - Dodechaedron for mid-high frequencies
  - Subwoofer



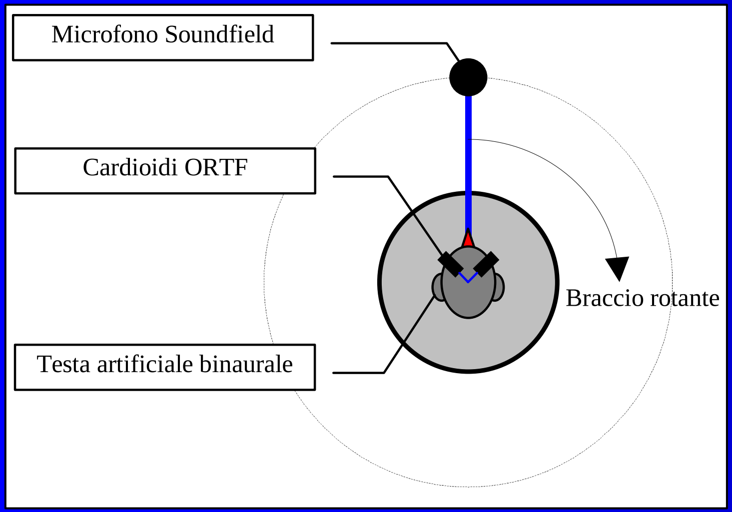
Transducers (sound source #2)

- Genelec S30D reference studio monitor:
  - Three-ways, active multi-amped, AES/EBU
  - Frequency range 37 Hz – 44 kHz (+/- 3 dB)



Transducers (microphones)

- 3 types of microphones:
  - Binaural dummy head (Neumann KU-100)
  - 2 Cardioids in ORTF placement (Neumann K-140)
  - B-Format 4 channels (Soundfield ST-250)



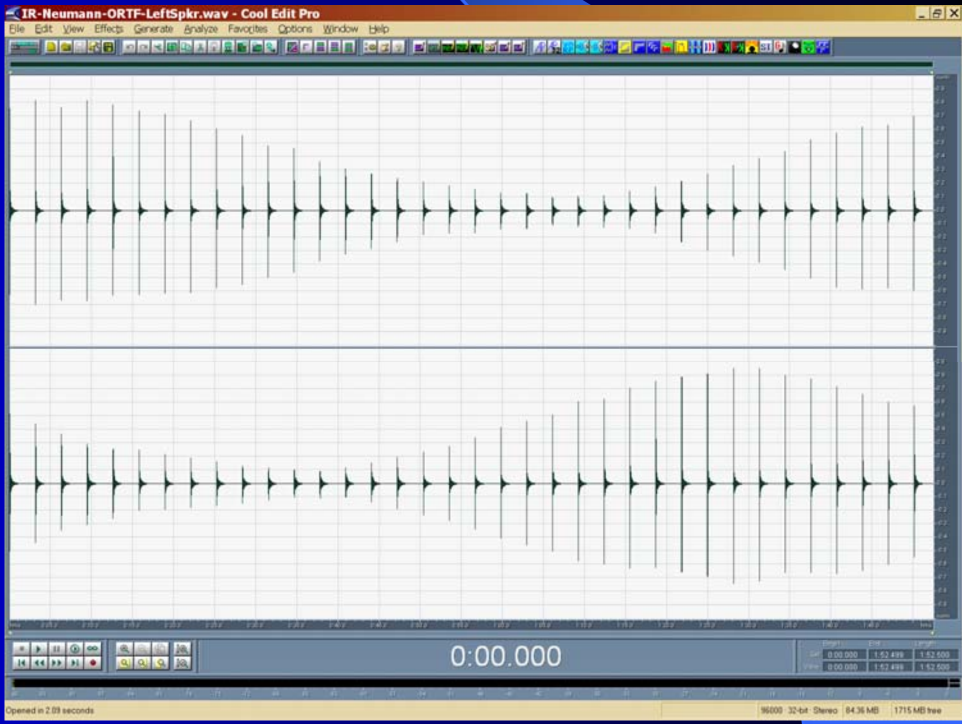
Other hardware equipment

- Rotating Table:
  - Outline ET-1

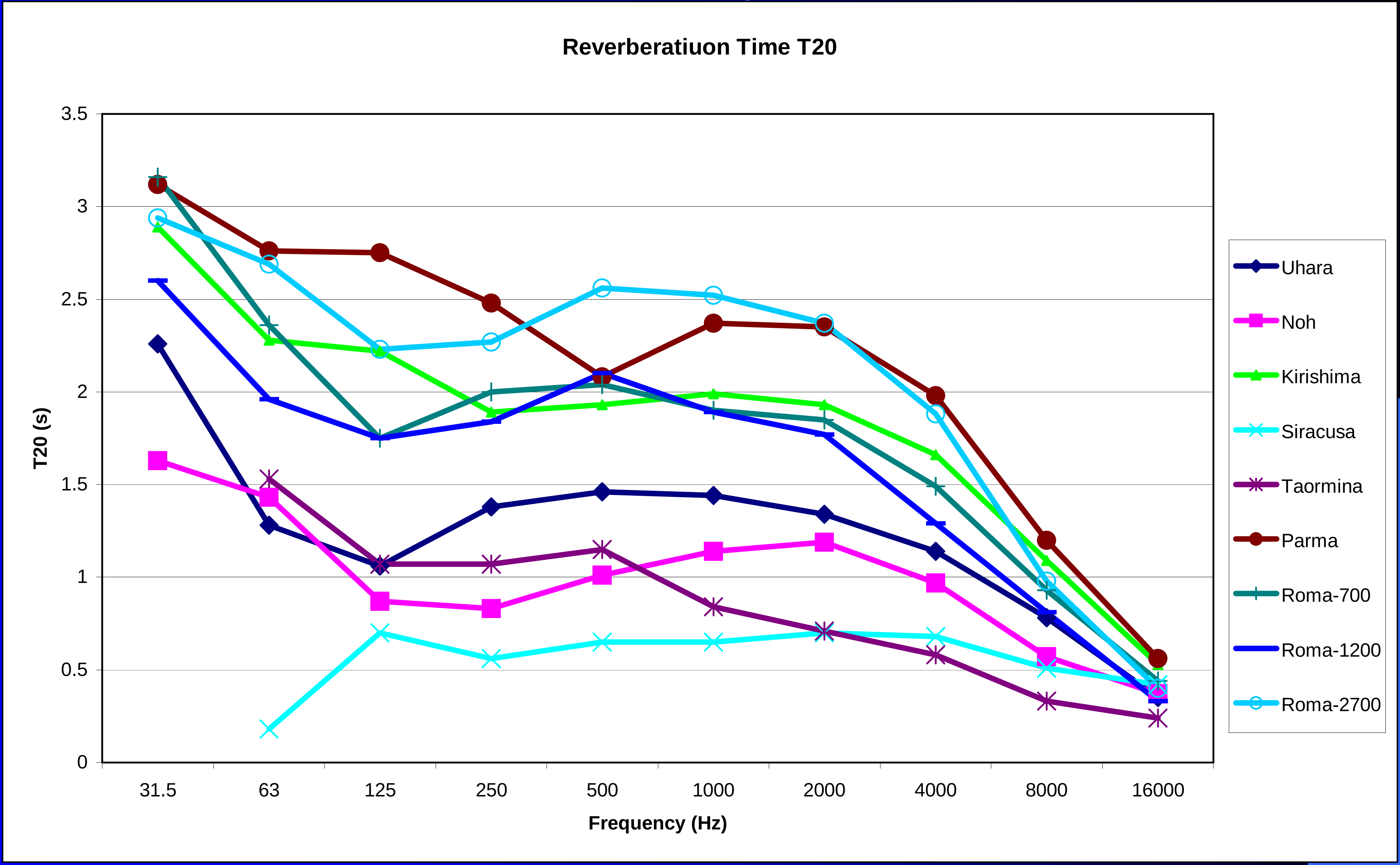
- Computer and sound card:
  - Signum Data Futureclient P-IV 1.8 GHz
  - Aardvark Pro Q-10 (8 ch., 96 kHz, 24 bits)

Measurement procedure

- A single measurement session play backs 36 times the test signal, and simultaneusly record the 8 microphonic channels

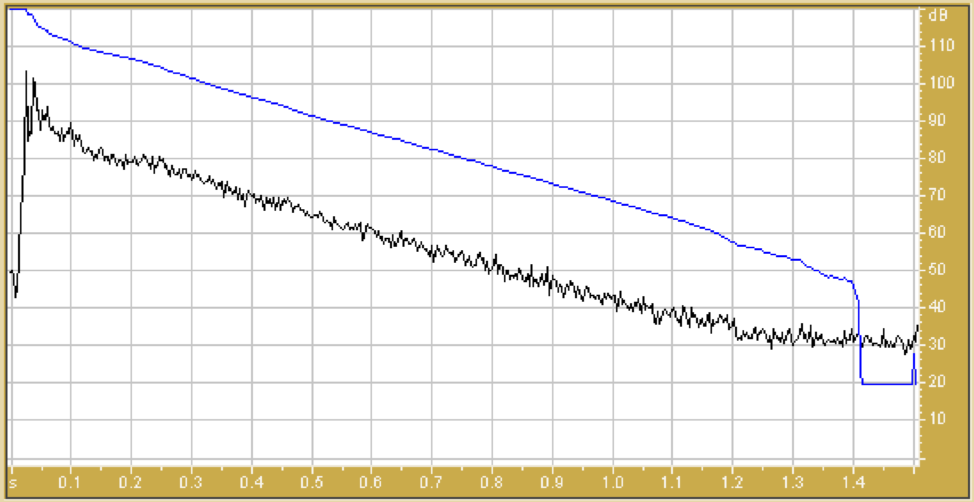


Theatres measured



Uhara Hall, Kobe, Japan

Acoustical Parameters according to ISO3382



OK | Help

Save to File...

Copy to Clipboard

Store Reference Signal

Switch to Right Channel

Tuser limits:

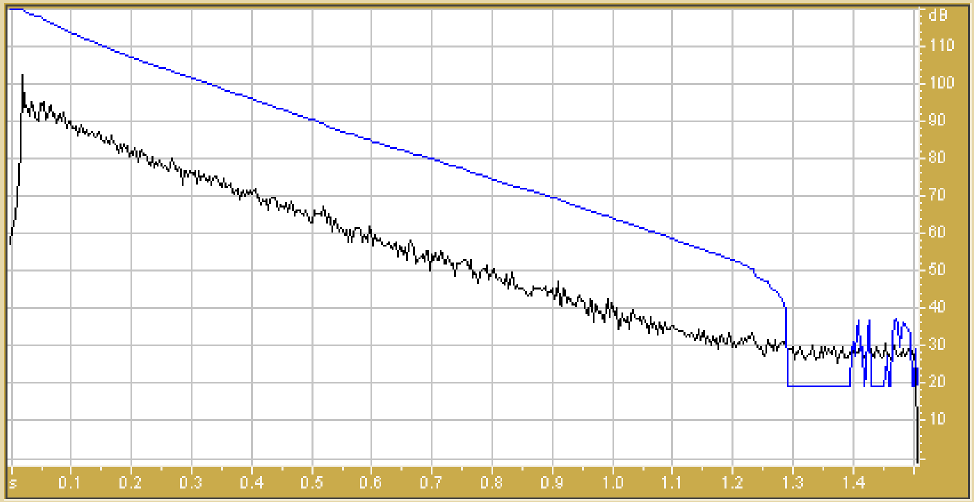
(-5. dB, -15. dB)

Left Channel

Freq. (Hz)	31.5	63	125	250	500	1k	2k	4k	8k	16k	Lin	A
Signal (dB)	38.62	63.15	70.39	65.09	69.61	71.06	73.56	76.88	76.40	78.76	82.91	82.44
Noise (dB)	17.37	24.72	25.25	16.20	15.28	18.54	19.71	17.71	20.31	29.34	32.80	28.99
strenGth(dB)	-30.38	-5.85	1.39	-3.91	0.61	2.06	4.56	7.88	7.40	9.76	3.91	5.44
C50 (dB)	3.39	7.02	0.54	2.16	5.01	4.77	4.02	6.51	8.64	13.60	6.24	6.30
C80 (dB)	4.91	8.67	4.69	4.83	7.83	6.37	5.73	9.11	11.64	17.92	8.68	8.58
D50 (%)	68.59	83.45	53.11	62.19	76.02	75.01	71.60	81.74	87.97	95.82	80.80	81.02
Ts (ms)	102.03	56.49	82.94	74.39	45.93	51.61	53.52	33.91	23.70	15.08	36.27	36.17
EDT (s)	1.36	--	0.88	1.35	0.86	1.26	1.30	0.63	0.38	0.20	0.64	0.67
T20 (s)	2.26	1.28	1.06	1.38	1.46	1.44	1.34	1.14	0.78	0.35	1.22	1.24
r T20	0.97	0.98	0.96	1.00	0.98	0.99	1.00	0.99	0.99	0.98	1.00	1.00
T30 (s)	2.13	1.40	1.17	1.33	1.34	1.43	1.34	1.08	0.73	0.42	1.23	1.23
r T30	0.96	0.99	0.98	1.00	0.99	1.00	1.00	1.00	0.99	0.98	1.00	1.00
Tuser (s)	1.61	1.21	1.18	1.42	1.74	1.72	1.51	1.22	0.61	0.27	1.26	1.31
r Tuser	0.97	0.94	0.96	0.98	0.96	0.99	0.99	0.98	0.98	0.94	0.98	0.98

Noh theater, Kobe, Japan

Acoustical Parameters according to ISO3382



OK

Help

Save to File...

Copy to Clipboard

Store Reference Signal

Switch to Right Channel

Tuser limits:

(-5. dB, -15. dB)

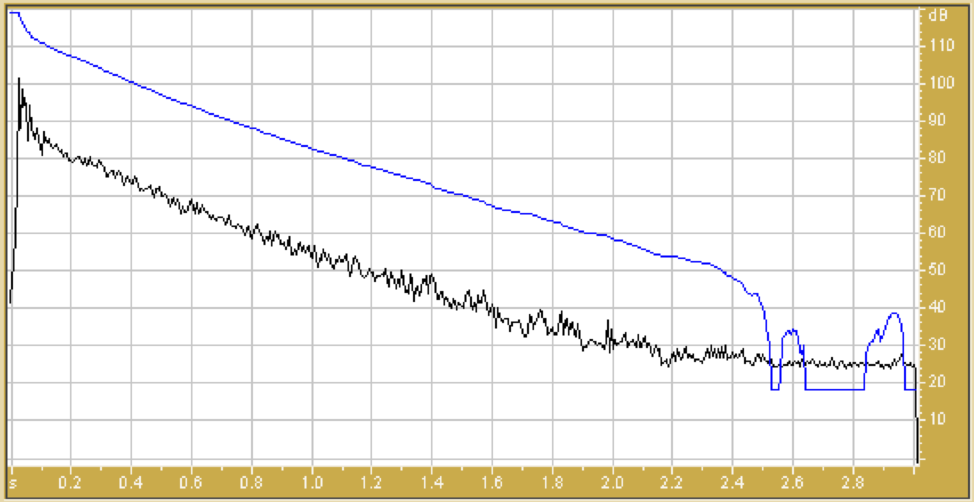
Left Channel

Freq. (Hz)	31.5	63	125	250	500	1k	2k	4k	8k	16k	Lin	A
Signal (dB)	41.61	61.05	70.09	66.51	68.33	71.62	75.65	76.58	77.81	80.23	83.62	83.28
Noise (dB)	15.45	20.46	19.40	11.83	15.17	17.23	23.32	18.80	20.99	26.39	30.14	28.54
strenGth(dB)	-27.39	-7.95	1.09	-2.49	-0.67	2.62	6.65	7.58	8.81	11.23	4.62	6.28
C50 (dB)	-2.00	5.19	3.00	2.32	1.23	-0.16	0.36	0.29	3.54	8.69	2.40	1.67
C80 (dB)	1.57	10.58	7.83	6.17	3.63	2.07	3.04	3.69	8.31	13.99	5.62	4.83
D50 (%)	38.69	76.77	66.61	63.07	57.06	49.08	52.07	51.68	69.30	88.09	63.48	59.51
Ts (ms)	143.48	63.84	49.94	54.27	73.70	79.21	74.89	69.56	38.04	17.51	52.26	58.60
EDT (s)	1.59	0.49	0.70	0.79	1.16	1.17	1.09	0.93	0.59	0.54	0.83	0.89
T20 (s)	1.63	1.43	0.87	0.83	1.01	1.14	1.19	0.97	0.57	0.37	1.03	1.05
r T20	0.94	0.93	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
T30 (s)	2.34	1.68	0.82	0.86	0.99	1.12	1.17	0.95	0.59	0.37	1.05	1.06
r T30	0.94	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Tuser (s)	1.07	--	0.48	0.79	1.08	1.17	1.17	0.93	0.53	0.36	0.92	0.97
r Tuser	0.97	--	0.95	0.99	0.99	0.99	1.00	1.00	0.99	0.98	1.00	1.00

Kirishima Concert Hall, Japan

Kirishima Concert Hall, Japan

Acoustical Parameters according to ISO3382



OK | Help

Save to File...

Copy to Clipboard

Store Reference Signal

Switch to Right Channel

Tuser limits:

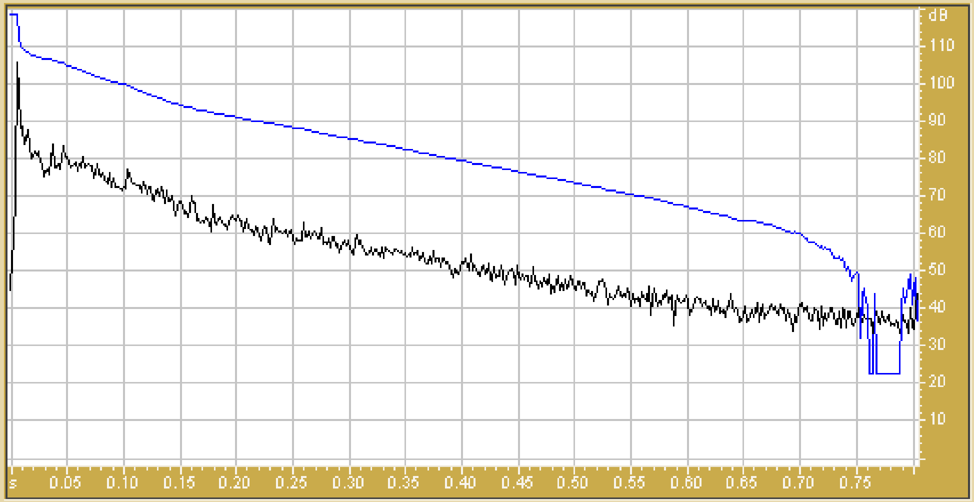
(-5. dB, -15. dB)

Left Channel

Freq. (Hz)	31.5	63	125	250	500	1k	2k	4k	8k	16k	Lin	A
Signal (dB)	41.00	61.66	67.66	63.99	65.79	68.49	74.16	76.06	78.93	81.19	83.37	83.00
Noise (dB)	10.48	20.70	14.89	12.06	12.97	14.80	18.12	19.52	22.64	28.87	30.09	27.92
strenGth(dB)	-28.00	-7.34	-1.34	-5.01	-3.21	-0.51	5.16	7.06	9.93	12.19	4.37	6.00
C50 (dB)	5.66	2.88	-4.28	-0.76	0.67	1.46	3.82	4.62	8.10	14.02	5.92	5.92
C80 (dB)	7.70	3.51	0.57	0.26	3.45	2.81	4.70	5.81	9.89	15.62	7.31	7.13
D50 (%)	78.63	66.00	27.18	45.63	53.87	58.31	70.65	74.33	86.60	96.19	79.62	79.64
Ts (ms)	109.92	101.24	163.59	136.38	89.78	94.58	62.37	53.25	27.46	14.07	44.01	43.36
EDT (s)	1.07	1.69	2.42	2.39	1.81	1.92	1.39	1.20	0.48	--	0.96	0.95
T20 (s)	2.89	2.28	2.22	1.89	1.93	1.99	1.93	1.66	1.09	0.53	1.73	1.67
r T20	0.97	0.97	0.99	0.99	1.00	1.00	1.00	1.00	0.99	0.96	1.00	1.00
T30 (s)	4.38	2.63	2.54	2.09	1.92	1.99	1.97	1.69	1.13	0.58	1.87	1.78
r T30	0.93	0.98	0.99	0.99	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00
Tuser (s)	4.09	1.99	1.94	1.61	1.95	2.04	1.80	1.67	0.95	0.29	1.66	1.56
r Tuser	0.93	0.97	0.98	0.99	1.00	1.00	1.00	1.00	0.96	0.86	0.99	0.99

Greek Theater in Siracusa

Acoustical Parameters according to ISO3382



OK

Help

Save to File...

Copy to Clipboard

Store Reference Signal

Switch to Right Channel

Tuser limits:

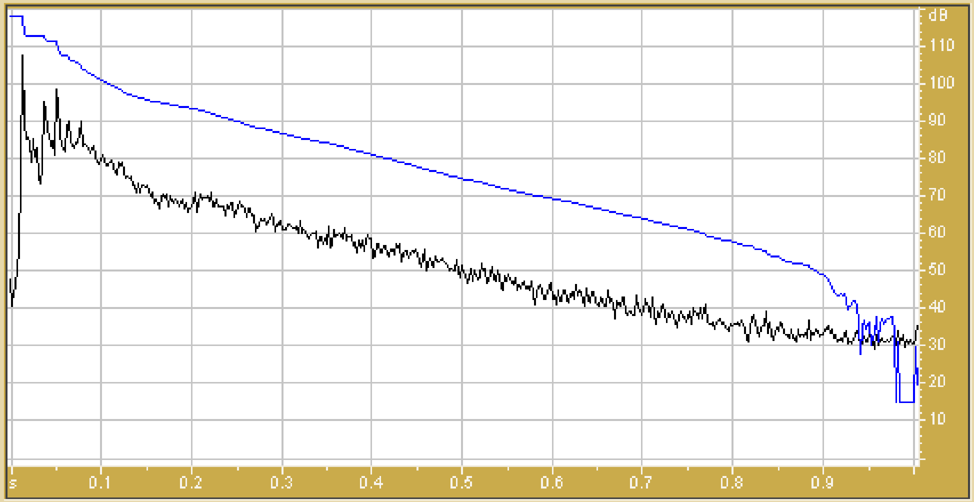
(-5. dB, -15. dB)

Left Channel

Freq. (Hz)	31.5	63	125	250	500	1k	2k	4k	8k	16k	Lin	A
Signal (dB)	-16.75	45.48	52.60	57.54	60.13	65.56	68.96	69.72	75.93	77.78	79.21	78.76
Noise (dB)	52.00	45.11	23.74	25.60	28.59	29.97	30.95	25.68	21.36	24.04	50.94	36.13
strenGth(dB)	-85.75	-23.52	-16.40	-11.46	-8.87	-3.44	-0.04	0.72	6.93	8.78	0.21	1.76
C50 (dB)	-14.13	-1.#J	3.27	9.91	12.74	13.03	13.08	11.61	14.91	17.70	14.26	13.93
C80 (dB)	-1.#J	-1.#J	9.08	12.72	15.70	15.84	16.01	14.94	18.59	22.95	17.80	17.33
D50 (%)	3.72	111.27	67.97	90.73	94.95	95.26	95.31	93.54	96.87	98.33	96.38	96.11
Ts (ms)	949.51	-73.36	45.37	18.75	12.36	8.27	7.47	9.18	5.07	2.50	5.25	5.71
EDT (s)	--	0.18	0.66	--	--	--	--	--	--	--	--	--
T20 (s)	--	0.05	0.70	0.56	0.65	0.65	0.70	0.68	0.51	0.42	0.55	0.57
r T20	--	0.90	0.98	0.96	0.98	0.99	0.99	0.99	0.99	0.98	1.00	1.00
T30 (s)	--	0.05	1.01	0.74	0.88	0.93	0.94	0.86	0.62	0.37	0.67	0.77
r T30	--	0.89	0.96	0.97	0.97	0.97	0.98	0.98	0.98	0.99	0.99	0.98
Tuser (s)	--	--	0.73	0.86	0.44	0.64	0.74	0.64	0.47	--	0.56	0.57
r Tuser	--	--	0.93	0.95	0.98	0.95	0.96	0.98	0.95	--	0.94	0.94

Roman Theater in Taormina

Acoustical Parameters according to ISO3382



OK | Help

Save to File...

Copy to Clipboard

Store Reference Signal

Switch to Right Channel

Tuser limits:

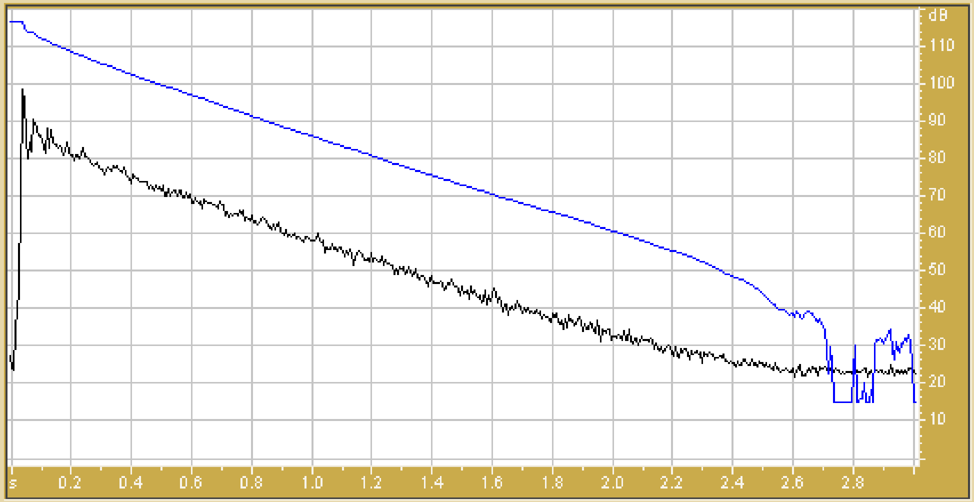
(-5. dB, -15. dB)

Left Channel

Freq. (Hz)	31.5	63	125	250	500	1k	2k	4k	8k	16k	Lin	A
Signal (dB)	34.89	52.35	60.71	64.11	64.73	68.79	73.13	75.78	78.99	74.23	82.86	82.05
Noise (dB)	37.40	24.47	23.02	24.00	26.52	25.38	22.14	21.45	25.15	29.60	37.59	31.62
strenGth(dB)	-34.11	-16.65	-8.29	-4.89	-4.27	-0.21	4.13	6.78	9.99	5.23	3.86	5.05
C50 (dB)	-1.85	0.80	-0.19	6.09	6.84	8.00	9.05	8.89	12.45	17.81	10.50	10.21
C80 (dB)	-2.18	5.56	13.17	12.41	11.20	13.09	14.79	14.59	18.58	27.80	16.38	15.94
D50 (%)	39.52	54.60	48.89	80.27	82.85	86.33	88.93	88.56	94.61	98.37	91.82	91.29
Ts (ms)	337.99	83.05	58.80	43.40	40.82	23.68	18.98	19.33	11.01	4.57	14.59	14.96
EDT (s)	--	0.74	0.63	--	0.39	0.49	--	0.45	--	--	--	--
T20 (s)	--	1.53	1.07	1.07	1.15	0.84	0.71	0.58	0.33	0.24	0.50	0.52
r T20	--	0.98	0.88	0.94	0.97	0.94	0.92	0.93	0.98	0.91	0.94	0.94
T30 (s)	--	1.23	1.11	1.11	1.22	1.08	0.89	0.76	0.46	0.22	0.75	0.74
r T30	--	0.97	0.97	0.98	0.99	0.97	0.96	0.96	0.95	0.98	0.94	0.94
Tuser (s)	--	--	0.18	0.44	0.59	0.43	0.32	0.32	0.36	--	0.34	0.35
r Tuser	--	--	0.88	0.93	0.96	0.97	0.97	0.98	0.86	--	0.94	0.95

Parma Auditorium, Italy

Acoustical Parameters according to ISO3382



OK

Help

Save to File...

Copy to Clipboard

Store Reference Signal

Switch to Right Channel

Tuser limits:

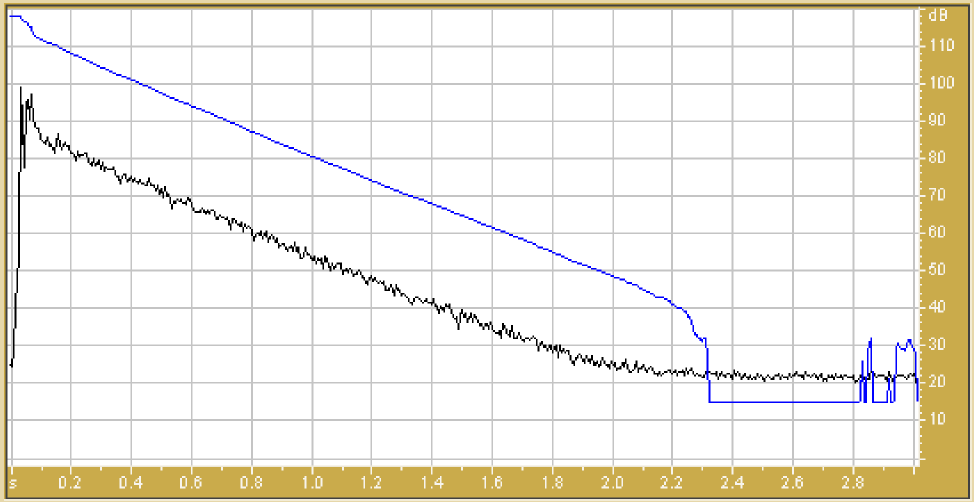
(-5. dB, -15. dB)

Left Channel

Freq. (Hz)	31.5	63	125	250	500	1k	2k	4k	8k	16k	Lin	A
Signal (dB)	40.84	57.24	68.80	66.26	67.20	70.03	73.41	74.09	77.50	75.02	82.52	81.08
Noise (dB)	20.40	26.31	23.57	24.89	22.64	20.25	19.91	17.27	23.54	20.46	33.16	28.11
strenGth(dB)	-28.16	-11.76	-0.20	-2.74	-1.80	1.03	4.41	5.09	8.50	6.02	3.52	4.08
C50 (dB)	2.38	-2.31	-5.27	-5.18	-1.30	1.21	1.29	0.09	4.29	8.19	2.33	2.04
C80 (dB)	4.35	-0.33	-0.29	-0.84	0.44	2.20	2.45	1.47	6.37	9.33	3.97	3.49
D50 (%)	63.36	37.01	22.92	23.29	42.57	56.89	57.36	50.51	72.87	86.82	63.12	61.53
Ts (ms)	145.30	159.46	155.87	138.71	122.80	98.06	94.93	100.07	44.10	15.99	69.01	75.79
EDT (s)	2.25	1.84	1.98	1.64	2.19	1.95	2.06	1.81	1.01	--	1.49	1.61
T20 (s)	3.12	2.76	2.75	2.48	2.08	2.37	2.35	1.98	1.20	0.56	2.05	2.08
r T20	0.99	0.99	0.97	0.99	1.00	1.00	1.00	1.00	1.00	0.96	1.00	1.00
T30 (s)	5.53	2.77	2.66	2.66	2.08	2.42	2.32	1.99	1.24	0.60	2.20	2.14
r T30	0.91	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	0.98	1.00	1.00
Tuser (s)	3.36	2.14	1.98	2.16	2.00	2.30	2.40	1.90	1.17	1.18	1.81	1.91
r Tuser	0.98	0.98	0.97	0.99	0.98	0.99	1.00	1.00	1.00	0.93	0.99	1.00

Rome Auditorium, 700 seats

Acoustical Parameters according to ISO3382



OK | Help

Save to File...

Copy to Clipboard

Store Reference Signal

Switch to Right Channel

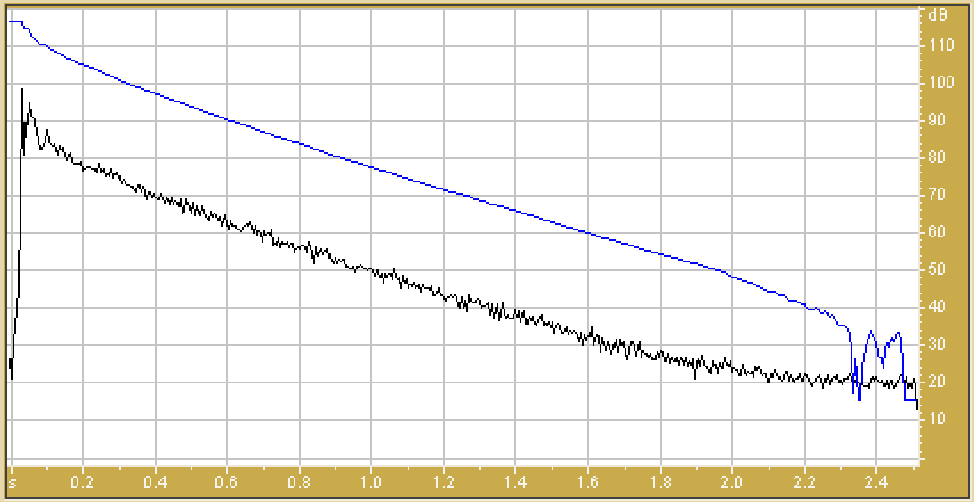
Tuser limits:
(-5. dB, -15. dB)

Left Channel

Freq. (Hz)	31.5	63	125	250	500	1k	2k	4k	8k	16k	Lin	A
Signal (dB)	37.50	58.10	69.58	67.65	69.29	70.45	74.74	78.03	76.63	74.34	83.48	82.62
Noise (dB)	17.10	19.19	23.26	19.21	18.71	16.64	18.07	20.72	21.58	19.77	30.42	26.83
strenGth(dB)	-31.50	-10.90	0.58	-1.35	0.29	1.45	5.74	9.03	7.63	5.34	4.48	5.62
C50 (dB)	-0.90	3.27	0.60	2.07	0.19	0.67	2.73	5.41	5.29	12.80	4.45	4.32
C80 (dB)	0.61	3.81	2.54	3.12	2.19	2.20	3.94	6.93	7.59	17.00	6.04	5.85
D50 (%)	44.81	67.98	53.45	61.70	51.11	53.86	65.24	77.67	77.16	95.02	73.58	72.99
Ts (ms)	181.27	107.51	111.52	100.03	108.51	104.34	81.09	48.46	39.77	15.22	57.02	58.14
EDT (s)	2.63	2.43	1.62	1.74	1.96	1.95	1.51	0.98	0.74	0.35	1.11	1.14
T20 (s)	3.16	2.36	1.75	2.00	2.04	1.90	1.85	1.49	0.93	0.44	1.72	1.68
r T20	0.97	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	0.96	1.00	1.00
T30 (s)	3.18	2.44	1.74	1.99	2.06	1.91	1.82	1.52	0.94	0.47	1.75	1.72
r T30	0.98	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00
Tuser (s)	2.91	2.77	2.00	2.14	2.05	2.15	1.82	1.49	0.93	0.23	1.64	1.60
r Tuser	0.96	0.99	0.97	0.99	0.99	1.00	1.00	1.00	1.00	0.97	1.00	1.00

Rome Auditorium, 1200 seats

Acoustical Parameters according to ISO3382



OK | Help | Save to File... | Copy to Clipboard | Store Reference Signal | Switch to Right Channel

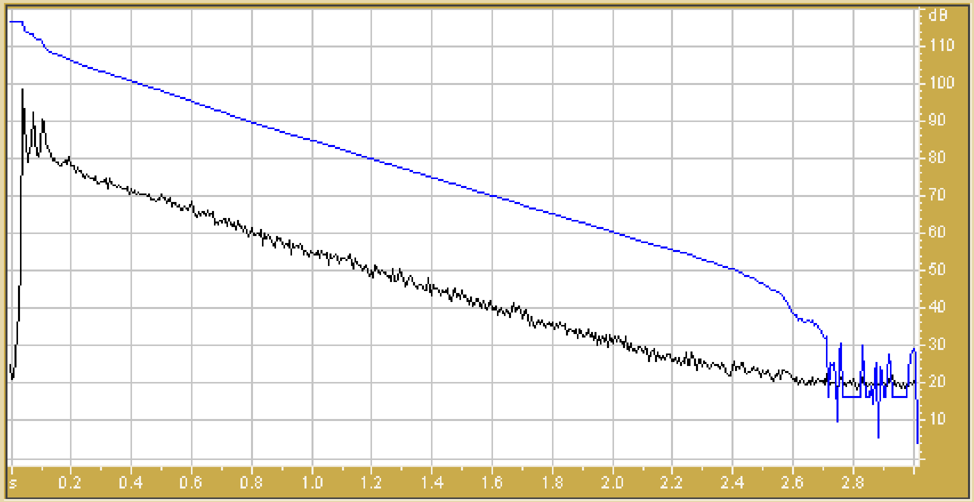
Tuser limits: (-5. dB, -15. dB)

Left Channel

Freq. (Hz)	31.5	63	125	250	500	1k	2k	4k	8k	16k	Lin	A
Signal (dB)	41.68	55.83	63.54	63.62	66.86	69.45	72.19	74.06	75.73	75.25	81.57	80.17
Noise (dB)	14.69	19.18	20.03	19.76	21.60	18.02	15.16	15.39	14.61	18.90	28.70	24.38
strenGth(dB)	-27.32	-13.17	-5.46	-5.38	-2.14	0.45	3.19	5.06	6.73	6.25	2.57	3.17
C50 (dB)	-0.12	0.32	1.54	-0.71	1.21	2.84	3.33	3.65	6.56	14.58	5.52	4.51
C80 (dB)	3.97	2.65	2.57	3.19	4.53	5.05	4.58	5.72	9.42	19.34	7.60	6.51
D50 (%)	49.33	51.82	58.78	45.91	56.94	65.81	68.28	69.83	81.90	96.63	78.10	73.87
Ts (ms)	118.18	106.65	112.36	109.72	77.08	71.11	66.21	53.80	30.77	9.37	41.90	49.13
EDT (s)	0.88	1.59	1.91	1.85	1.40	1.40	1.46	0.90	0.54	--	0.81	0.91
T20 (s)	2.60	1.96	1.75	1.84	2.10	1.89	1.77	1.29	0.81	0.33	1.55	1.54
r T20	0.93	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.99	1.00
T30 (s)	3.43	2.13	1.79	1.96	2.17	1.95	1.79	1.38	0.83	0.39	1.68	1.67
r T30	0.96	0.98	0.99	0.99	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00
Tuser (s)	--	1.19	1.67	1.94	1.99	1.94	1.65	1.23	0.73	0.26	1.34	1.38
r Tuser	--	0.92	0.99	0.98	0.99	0.99	1.00	0.99	1.00	0.95	0.99	0.99

Rome Auditorium, 2700 seats

Acoustical Parameters according to ISO3382



OK | Help

Save to File...

Copy to Clipboard

Store Reference Signal

Switch to Right Channel

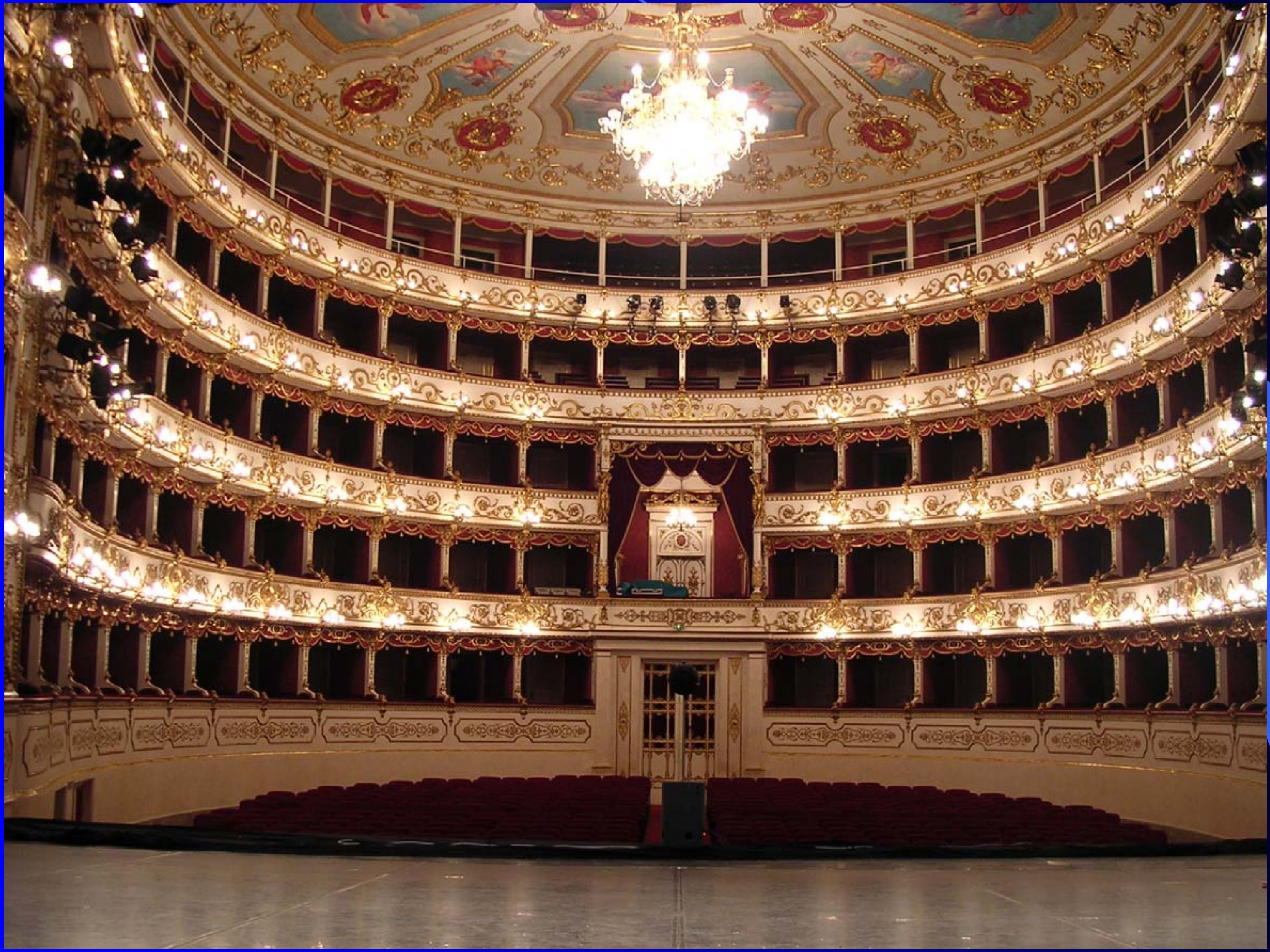
Tuser limits:
(-5. dB, -15. dB)

Left Channel

Freq. (Hz)	31.5	63	125	250	500	1k	2k	4k	8k	16k	Lin	A
Signal (dB)	40.58	59.81	66.22	64.73	66.68	68.14	72.38	73.32	74.61	73.03	80.75	79.52
Noise (dB)	19.20	19.22	22.29	20.72	18.69	15.32	14.60	19.69	17.64	21.56	29.76	25.03
strenGth(dB)	-28.42	-9.19	-2.78	-4.27	-2.32	-0.86	3.38	4.32	5.61	4.03	1.75	2.52
C50 (dB)	0.53	-2.67	-9.51	-4.67	1.95	-0.17	2.55	2.21	6.04	14.50	3.35	3.16
C80 (dB)	1.11	4.58	-1.16	1.18	4.65	4.47	5.96	6.04	10.09	20.48	6.98	6.87
D50 (%)	53.05	35.08	10.07	25.45	61.03	49.02	64.25	62.45	80.07	96.57	68.39	67.44
Ts (ms)	175.38	108.12	169.98	127.01	84.20	94.07	66.34	61.19	27.13	5.14	52.67	54.43
EDT (s)	2.65	0.83	2.13	1.81	1.58	1.76	1.44	1.04	0.74	--	1.11	1.07
T20 (s)	2.94	2.69	2.23	2.27	2.56	2.52	2.37	1.88	0.98	0.40	2.13	2.15
r T20	0.99	0.99	0.99	1.00	1.00	1.00	1.00	1.00	0.98	0.98	0.99	1.00
T30 (s)	--	2.61	2.13	2.29	2.63	2.59	2.37	1.86	1.05	0.45	2.24	2.23
r T30	--	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	1.00	1.00
Tuser (s)	3.09	2.56	2.48	2.34	2.31	2.59	2.44	1.76	0.78	0.47	1.84	1.91
r Tuser	0.96	0.92	0.98	0.99	0.99	1.00	0.99	0.99	0.96	0.93	0.97	0.98

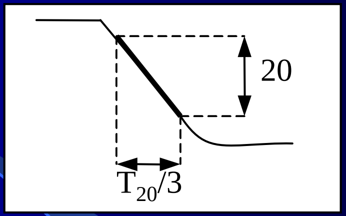
Bergamo’s Cathedral, Italy

Teatro Valli, Reggio Emilia, Italy



Acoustical Parameters

- Reverberation Time T_{20}:



- Clarity C_{80}:

$$C_{80} = 10 \cdot \lg \left[\frac{\int_{0}^{80ms} p^2(\tau) \cdot d\tau}{\int_{80ms}^{\infty} p^2(\tau) \cdot d\tau} \right]$$

- Definition D:

$$D = \frac{\int_{0}^{50ms} p^2(\tau) \cdot d\tau}{\int_{0}^{\infty} p^2(\tau) \cdot d\tau} \cdot 100$$

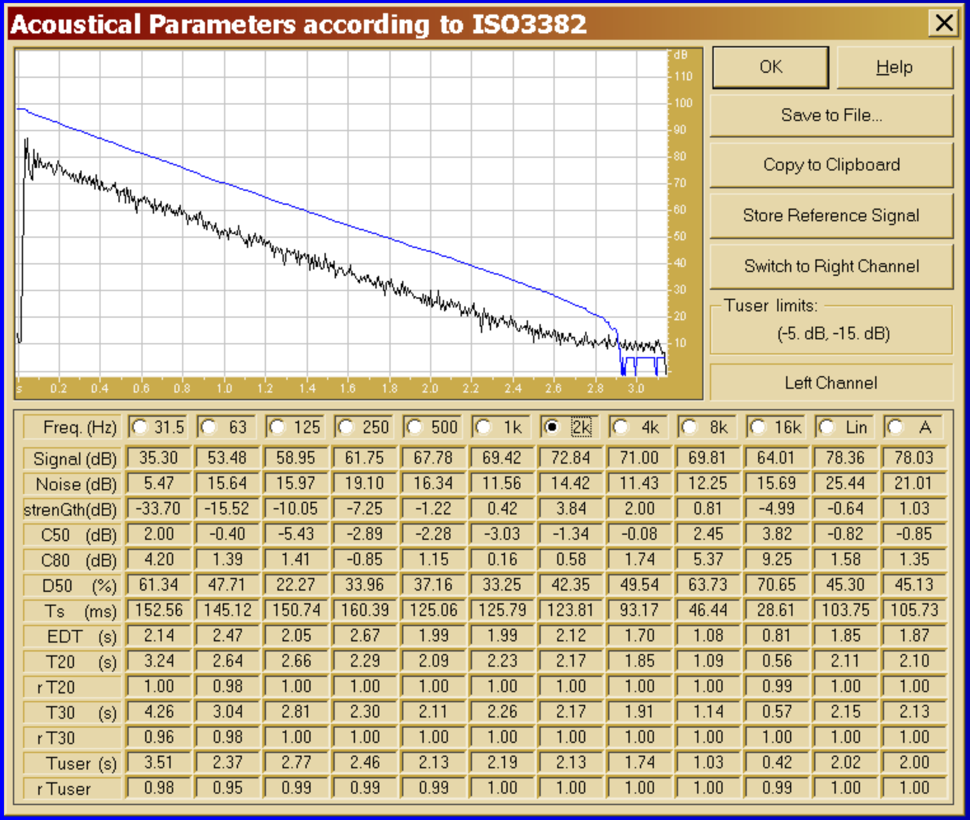
- Center Time T_S:

$$T_S = \frac{\int_{0}^{\infty} \tau \cdot p^2(\tau) \cdot d\tau}{\int_{0}^{\infty} p^2(\tau) \cdot d\tau}$$

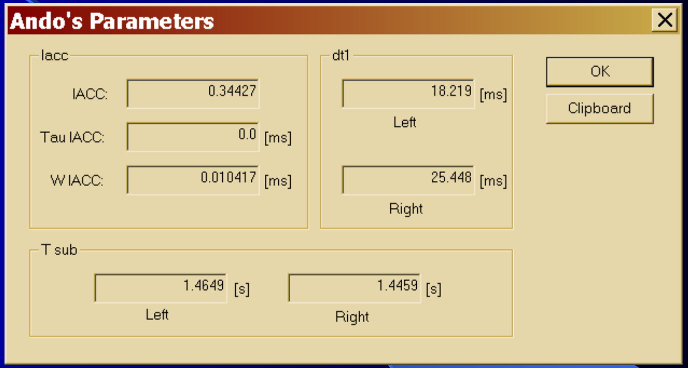
Acoustical Parameters

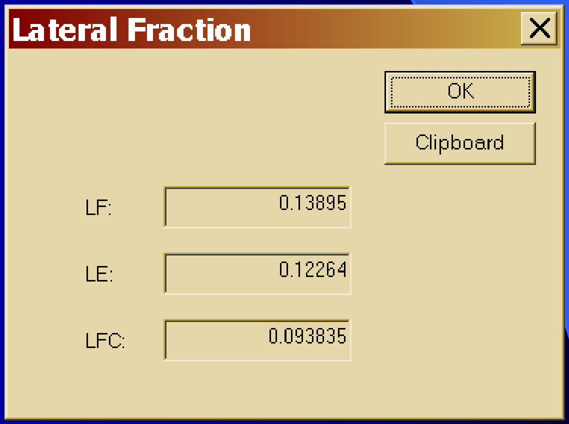
- Strenght: $G = SPL - L_W + 31 \quad dB$
- IACC: $$\rho(\tau) = \frac{\int_{-\infty}^{\infty} h_d(\tau) \cdot h_s(\tau + t) \cdot d\tau}{\sqrt{\int_{-\infty}^{\infty} h_d^2(\tau) \cdot d\tau \cdot \int_{-\infty}^{\infty} h_s^2(\tau + t) \cdot d\tau}}$$
- LF: $$LF = \frac{\int_{5ms}^{80ms} h_Y{}^2(\tau) \cdot d\tau}{\int_{0ms}^{80ms} h_W{}^2(\tau) \cdot d\tau}$$
- LFC: $$LFC = \frac{\int_{5ms}^{80ms} h_Y(\tau) \cdot h_W(\tau) \cdot d\tau}{\int_{0ms}^{80ms} h_W{}^2(\tau) \cdot d\tau}$$

Analysis of spatial attributes

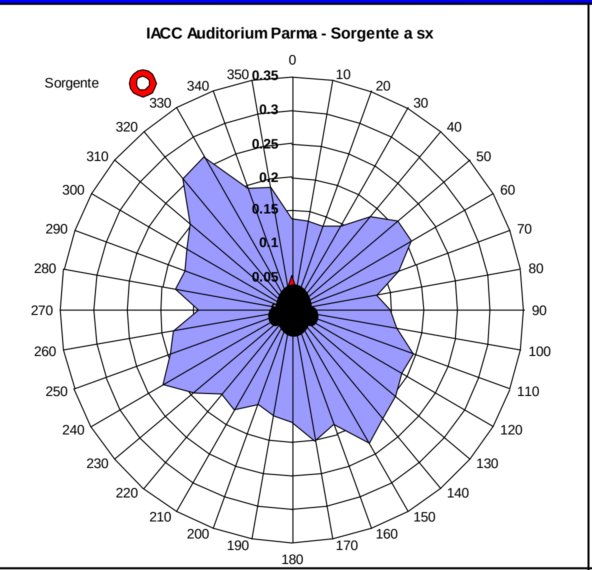


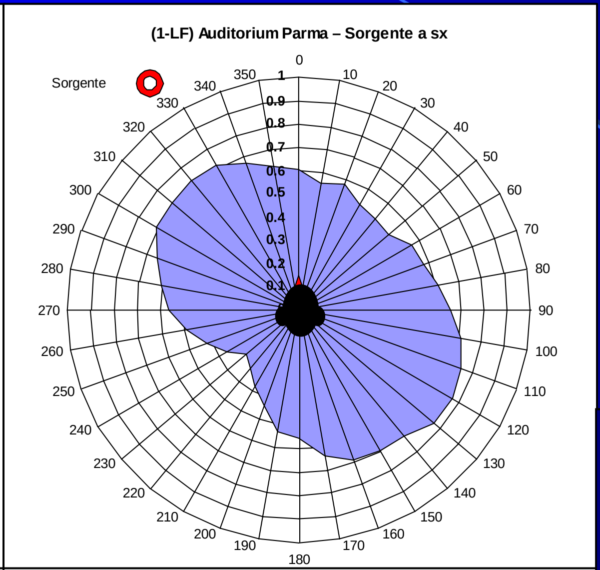
Freq. (Hz)	31.5	63	125	250	500	1k	2k	4k	8k	16k	Lin	A
Signal (dB)	35.30	53.48	58.95	61.75	67.78	69.42	72.84	71.00	69.81	64.01	78.36	78.03
Noise (dB)	5.47	15.64	15.97	19.10	16.34	11.56	14.42	11.43	12.25	15.69	25.44	21.01
strenGth(dB)	-33.70	-15.52	-10.05	-7.25	-1.22	0.42	3.84	2.00	0.81	-4.99	-0.64	1.03
C50 (dB)	2.00	-0.40	-5.43	-2.89	-2.28	-3.03	-1.34	-0.08	2.45	3.82	-0.82	-0.85
C80 (dB)	4.20	1.39	1.41	-0.85	1.15	0.16	0.58	1.74	5.37	9.25	1.58	1.35
D50 (%)	61.34	47.71	22.27	33.96	37.16	33.25	42.35	49.54	63.73	70.65	45.30	45.13
Ts (ms)	152.56	145.12	150.74	160.39	125.06	125.79	123.81	93.17	46.44	28.61	103.75	105.73
EDT (s)	2.14	2.47	2.05	2.67	1.99	1.99	2.12	1.70	1.08	0.81	1.85	1.87
T20 (s)	3.24	2.64	2.66	2.29	2.09	2.23	2.17	1.85	1.09	0.56	2.11	2.10
r T20	1.00	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00
T30 (s)	4.26	3.04	2.81	2.30	2.11	2.26	2.17	1.91	1.14	0.57	2.15	2.13
r T30	0.96	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Tuser (s)	3.51	2.37	2.77	2.46	2.13	2.19	2.13	1.74	1.03	0.42	2.02	2.00
r Tuser	0.98	0.95	0.99	0.99	0.99	1.00	1.00	1.00	1.00	0.99	1.00	1.00

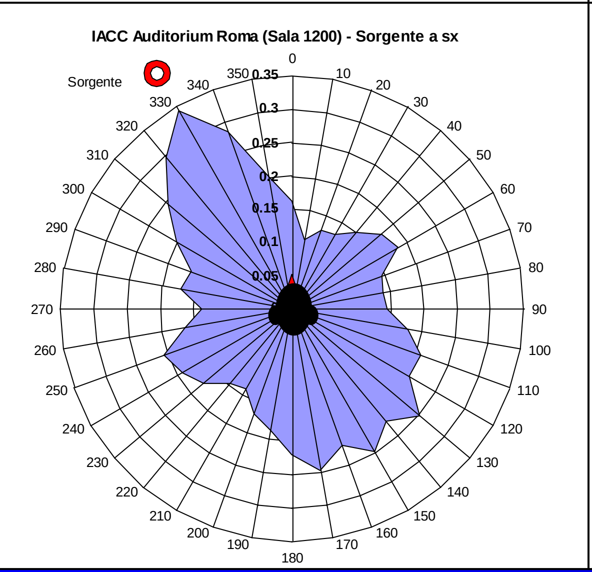


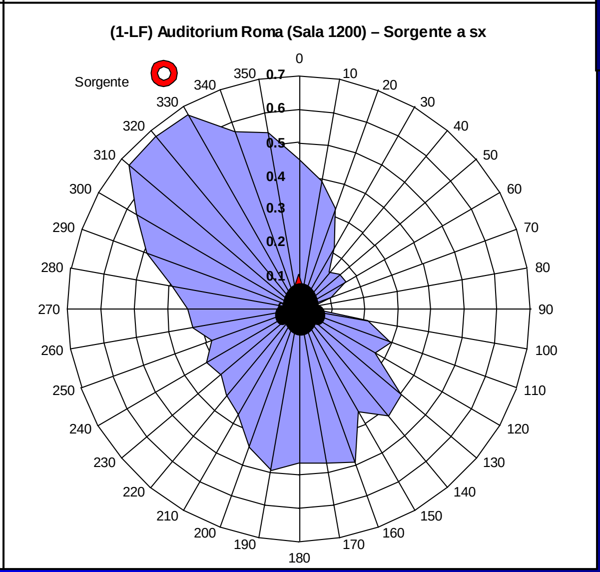


Polar diagrams of IACC and (1-LF)









Auditorium	1-LF	IACC
Parma	0.725	0.266
Roma	0.676	0.344

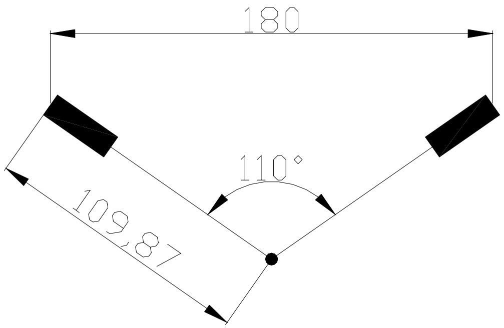
Auralization by convolution

- The basic method consists in convolution of a dry signal with a set of impulse responses corresponding to the required output format for surround (2 to 24 channels).
- The convolution operation can nowadays be implemented very efficiently on a modern PC through an ancient algorithm (equally-partitioned FFT processing, Stockam 1966).

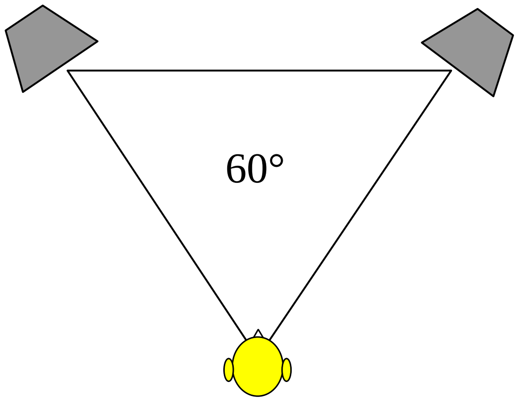
Auralization types

- Stereo (ORTF on 2 standard loudspeakers at +/- 30°)
- Rotation-tracking reproduction on headphones (Binaural Room Scanning)
- Full 3D Ambisonics 1st order (decoding the B-format signal)
- ITU 5.1 (from different 5-mikes layouts)
- 2D Ambisonics 3rd order (from Mark Poletti's circular array microphone)
- Wave Field Synthesis (from the circular array of Soundfield microphones)
- Hybrid methods (Ambiophonics)

ORTF Stereo



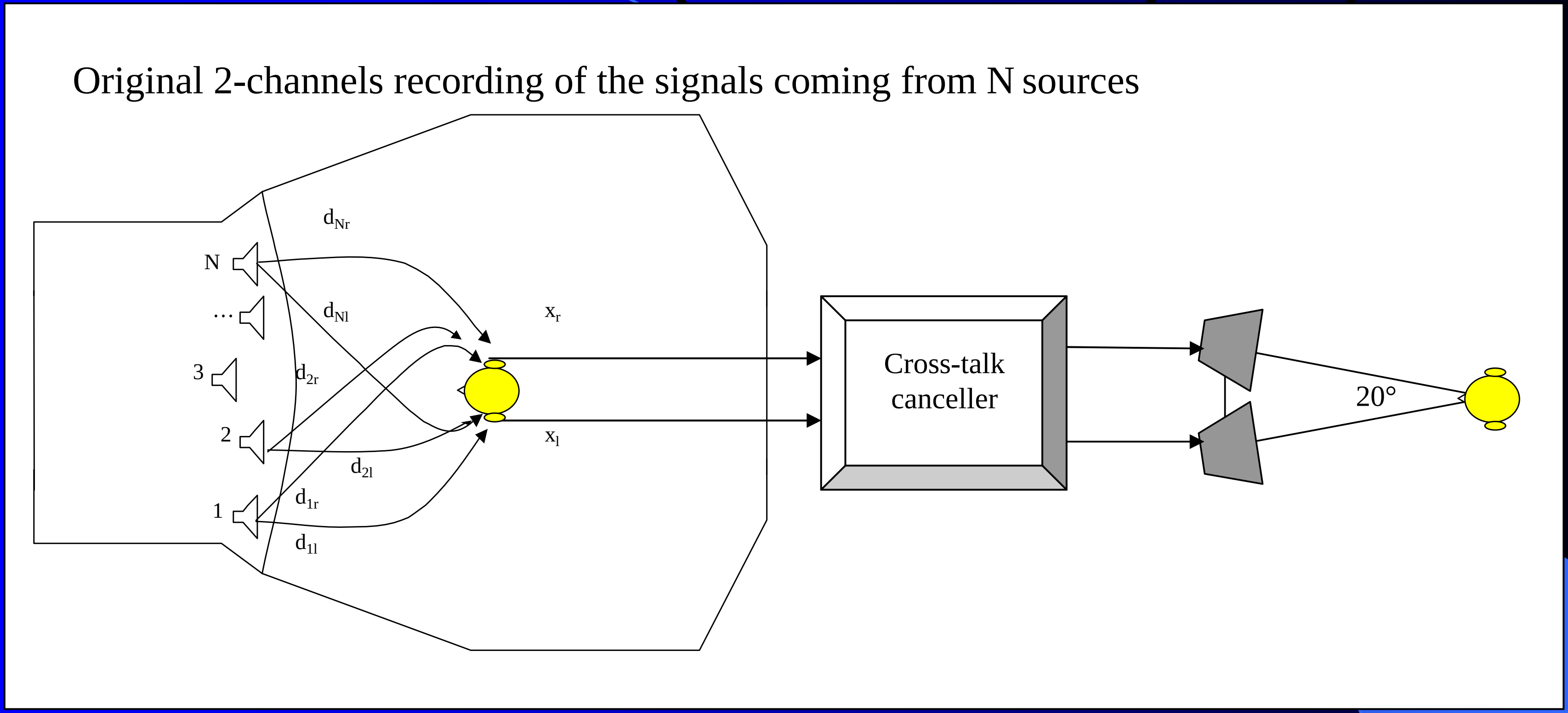
2 Microphones



2 Loudspeakers

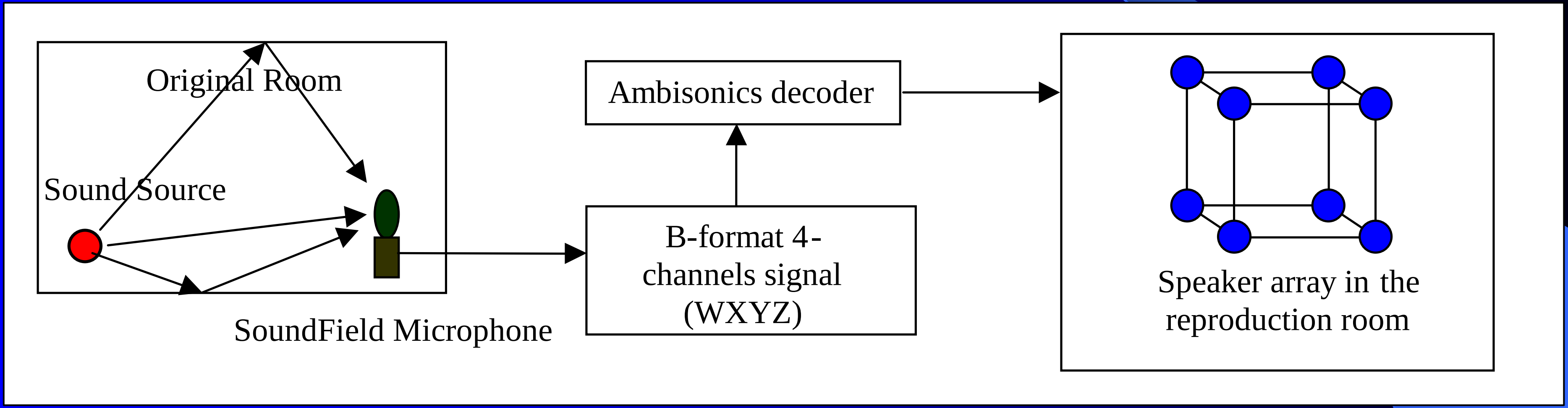
- Playback occurs over a pair of loudspeakers, in the standard configuration at angles of +/- 30°, each being fed by the signal of the corresponding microphone

Binaural (Stereo Dipole)



- Reproduction occurs over 2 loudspeakers angled at +/- 10°, being fed through a “cross-talk cancellation” digital filtering system

Ambisonics 3D 1st order

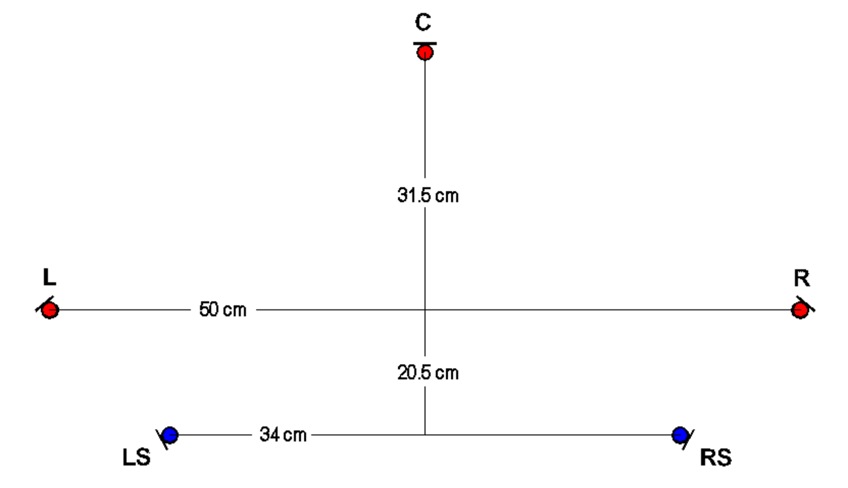


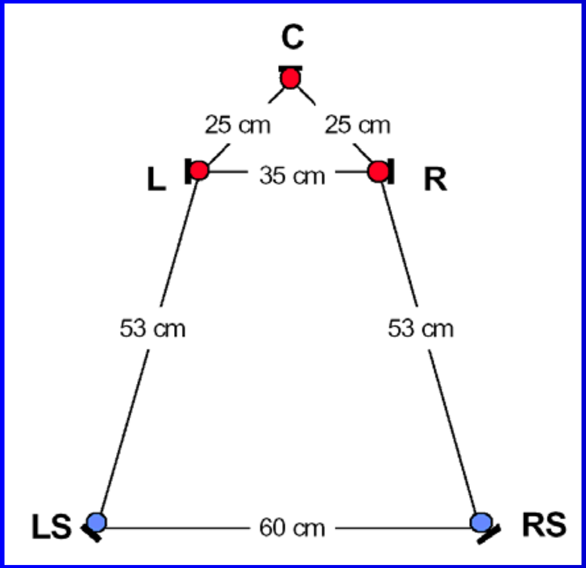
- Reproduction occurs over an array of 8-24 loudspeakers, through an Ambisonics decoder

ITU 5.1 surround

- Williams MMA

Schematic of the setup
C : Cardioid, 0°
L, R : Cardioid, ± 40°
LS, RS : Cardioid, ± 120°





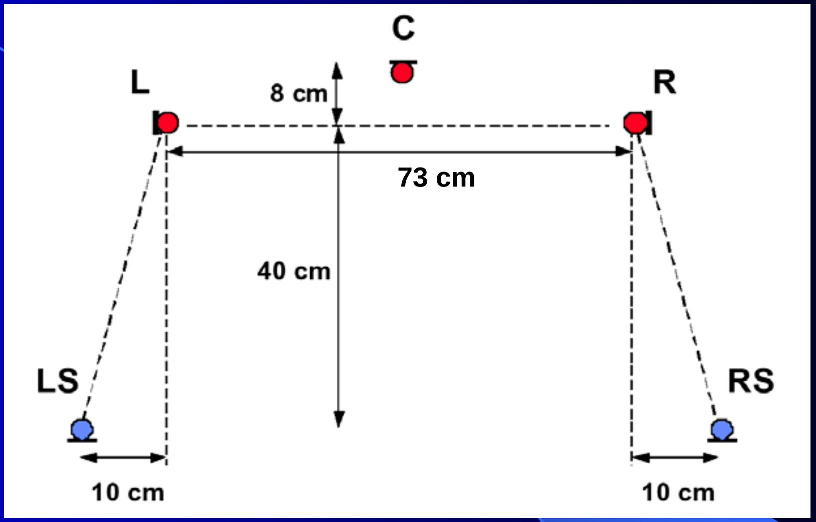
- INA-5

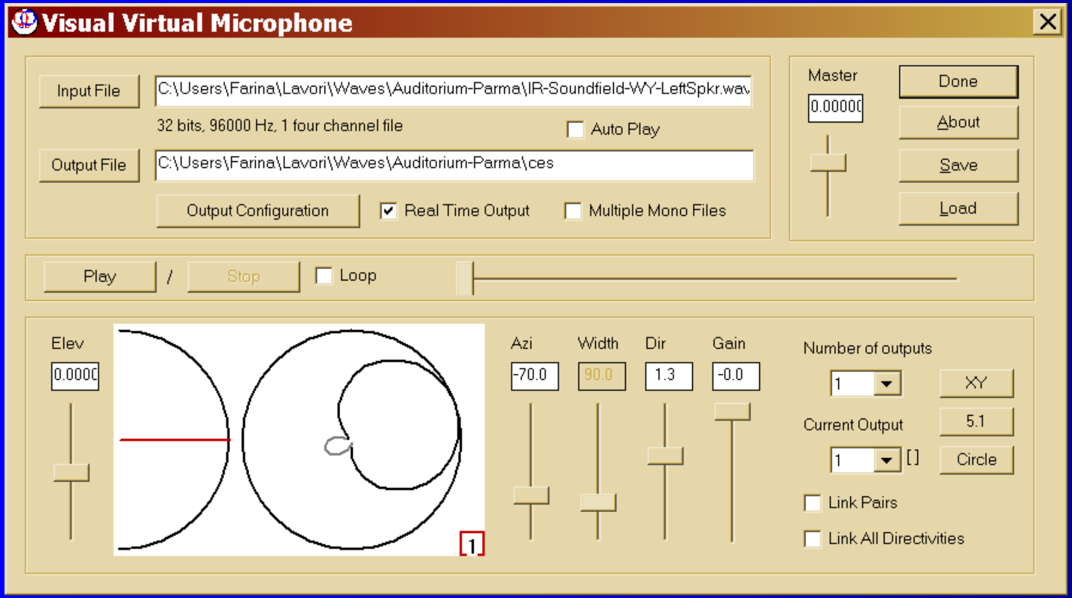
Schematic of the setup
C : Cardioid, 0°
L, R : Cardioid, ± 90°
LS, RS : Cardioid, ± 150°

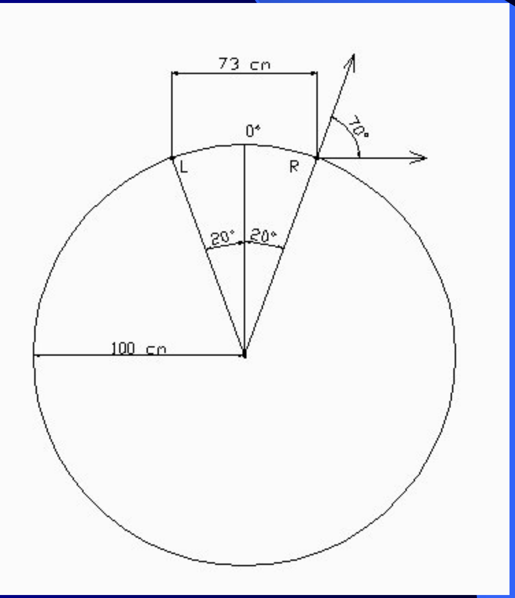
ITU 5.1 surround

- OCT

Schematic of the setup
C : Cardioid, 0°
L, R : Super Cardioid, ± 90°
LS, RS : Cardioid, ± 180°

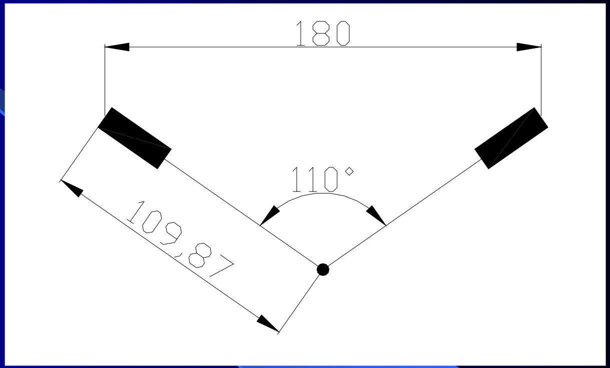




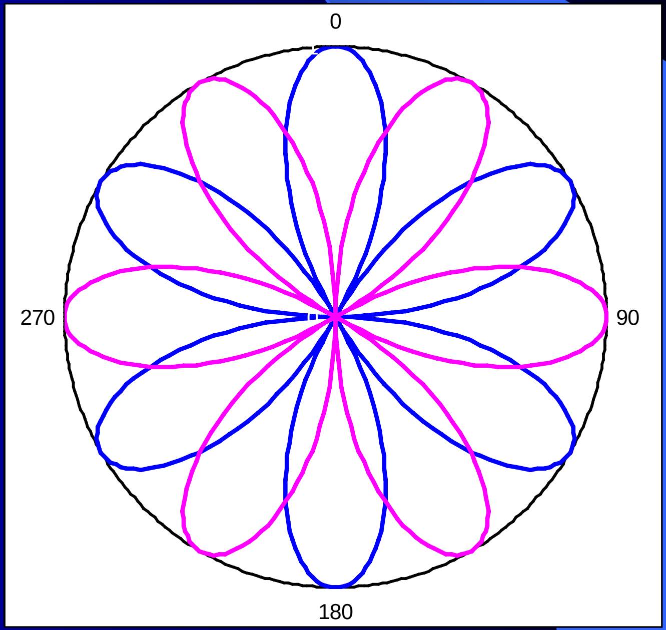


Virtual high-order microphones (M. Poletti)

- One of the two ORTF cardioid is employed, which samples 36 positions along a 100 mm-radius circumference

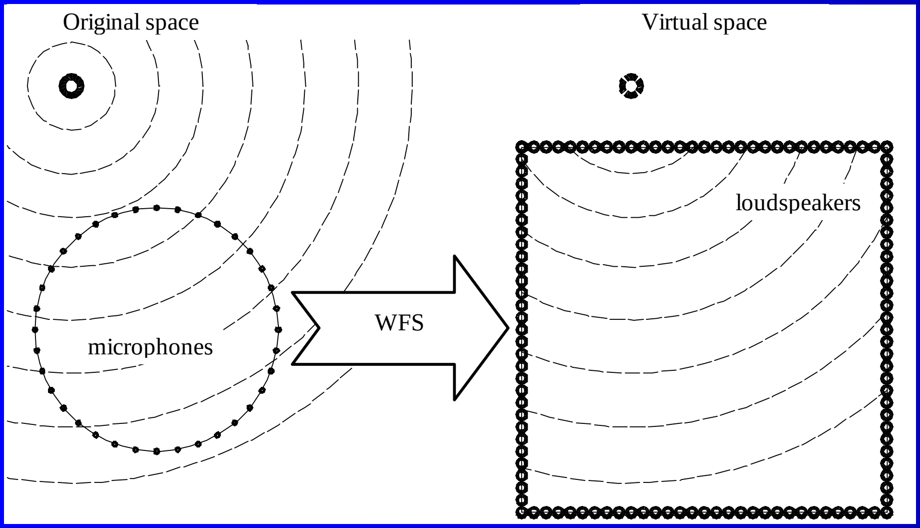


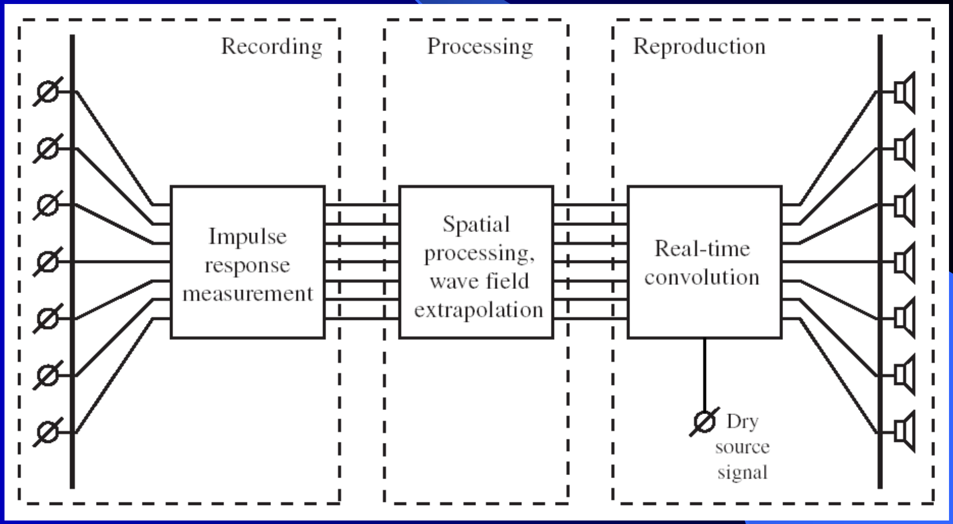
From these 36 impulse responses it is possible to derive the response of cylindrical harmonics microphones (2D Ambisonics) up to 5th order.



Wave Field Synthesis (WFS)

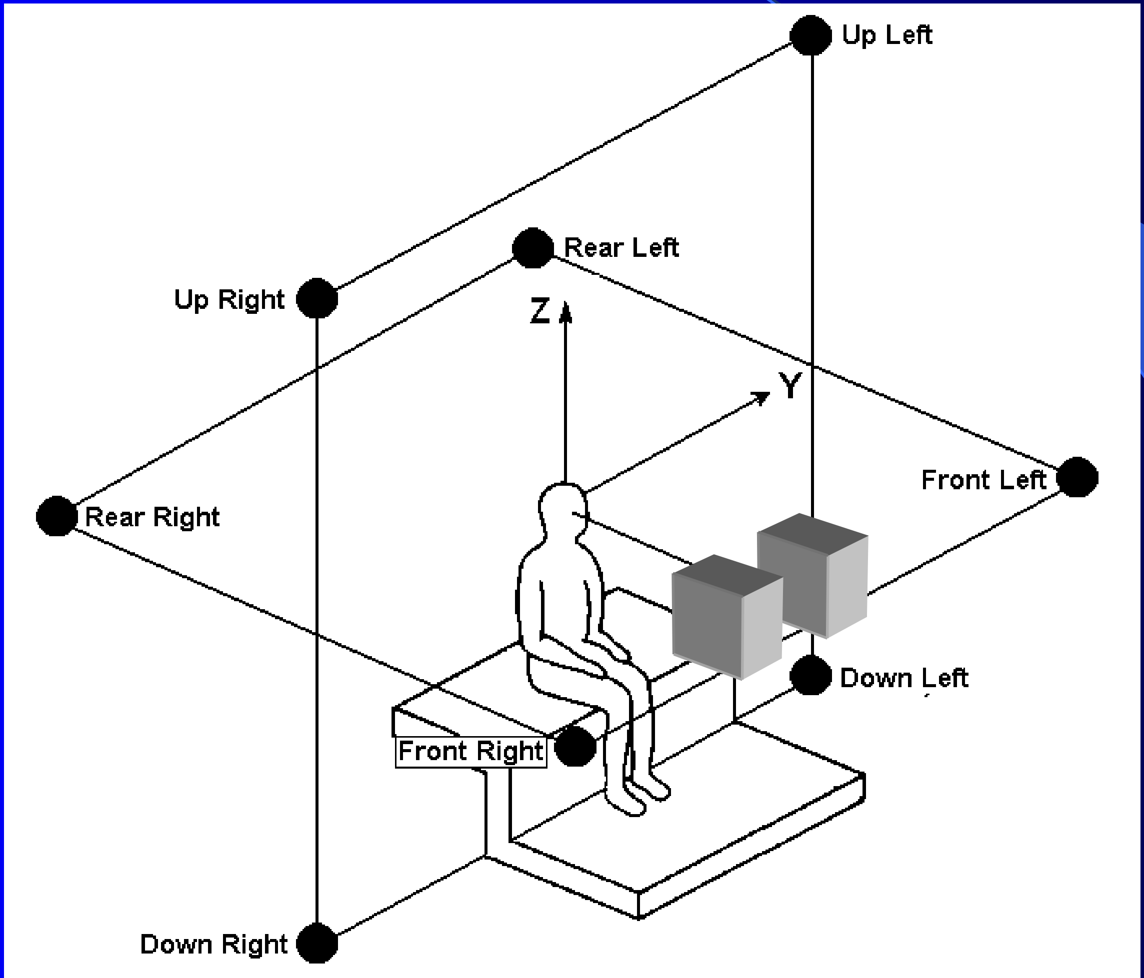
- Flow diagram of the process





Hybrid methods (Ambiophonics)

- Ambiophonics 3D (10 loudspeakers):



Conclusions

- Main advantages of the new measurement method “Waves 2003”:
  - Almost all previously known measurement techniques are incorporated in a single, coherent approach
  - The spatial informations are accurately sampled, making it possible to store, analyze and preserve these “3D acoustical photographies” of existing musical spaces for the posterity
  - The impulse response are stored in many different formats, allowing for their usage for surround productions with today technlogies (ITU 5.1, 1st order Ambisonics) and future, more advanced methods (high order Ambisonics, WFS, Ambiophonics)