Proceedings of the 5th WSEAS Int. Conf. on Instrumentation, Measurement, Circuits and Systems, Hangzhou, China, April 16-18, 2006 (pp62-67)

New acoustical techniques for measuring spatial properties in concert halls

LAMBERTO TRONCHIN and VALERIO TARABUSI

DIENCA – CIARM, University of Bologna, Italy

http://www.ciarm.ing.unibo.it

Abstract: -
The paper describes a new, hybrid method for measuring the spatial/temporal transfer function of a concert hall, which employs both a binaural probe and a B-format microphone.
It is shown how these two techniques can be complementary, both in terms of determination of objective parameters and for performing audible reconstructions (auralization).
The main advantage of this measurement method is that it makes it possible to conduct comparative listening tests with virtually zero delay for switching.
Consequently, the short-time perceptual memory of the subjects is employed, allowing for the detection of very subtle differences, which are not perceivable in normal listening tests, due to the excessive time delay between the presentation of the stimuli

Key words: - Acoustical measurements, Impulse Response, Acoustical Parameters, Spatiality, different techniques

.

INTRODUCTION

The goal of this paper is to exploit the complementarities of two ways of representing the spatial/temporal transfer function of a concert hall: the binaural approach and the B-Format approach. In the first case, the impulse response is measured or computed between an omnidirectional point source and two pressure microphones located at the entrances of the ear channels of a dummy head and torso.
In the second case, 4 impulse responses are measured or computed, starting again from an omnidirectional sound source, and reaching a so-called Soundfield microphone, which is a 4-channel probe, which captures the sound pressure (omnidirectional microphone) and the three Cartesian components of the particle velocity.
From these two different data sets, different acoustical quantities can be derived: from binaural measurements, IACC and derivations can be computed; similarly, from B-format measurements, quantities such as LF or Front-to-back ratio can be derived.

The paper does not focus on the counter-position between the two techniques, but instead on the possibility to employ both of them simultaneously. In fact, a modern technique was recently developed by Ralph Glasgal [1], called Ambiophonics, which aims to the reproduction of a realistic sound field by simultaneous usage of the binaural approach (from which a pair of closely-spaced loudspeakers, with cross-talk canceling filters, can be driven) and of the B-format approach (driving, by convolution with the B-format impulse response, a suitable 3D array of loudspeakers, employing an Ambisonics decoder or other decoding schemes).
It must be noted that the original Ambiophonics scheme introduced by Ralph Glasgal is substantially less constrained than the implementation described here. In fact, the Glasgal method is applied to generic stereo recording (made with any true stereo recording technique, such as ORTF, sphere-microphone, etc.), and the “surround” part of the system does not require a regular array of identical loudspeakers. In practice, the Glasgal approach

is mainly devoted to high-quality playback of existing music recordings, whilst the technique described here is focused to instrumentation-degree playback under controlled conditions of special recordings made for conducting psychoacoustical tests.

The experiments conducted by the authors about the Ambiophonics approach made it possible to establish the strong and weak points of each of the two techniques which constitute it, and to find the optimal combination, which maximizes the benefits of both. In practice, it resulted that the binaural approach is far superior for describing the direct sound and the early reflections coming from the stage enclosure, whilst the B-format approach is better for describing the late part of the reverberant tail and its surrounding (or enveloping) effect.

This means that, for optimal Ambiophonics reproduction, the measured or computed impulse responses should be edited: the binaural ones, employed for driving the frontal pair of close loudspeakers (Stereo Dipole), need to be cut just after the first reflections. Instead, the B-format IR should be smoothed in its first part, leaving only the late reflections and the subsequent diffuse tail. Although this editing is somewhat arbitrary, a series of subjective blind listening test clearly demonstrated that this hybrid approach is much superior to each of the two subsystems (Binaural->Stereo Dipole or B-format->Ambisonics). This holds true even when each of the two subsystems is employed with the whole, unedited impulse responses, within authors' experiments.

This means that an optimal characterization of an existing concert hall, or the simulations performed during the design of a new one, should include both the binaural and the B-format IRs. The tools for doing the measurements or simulations are now easily available, and the paper presents some of them, which were developed by the authors

METHODS FOR MEASURING SPATIAL PROPERTIES

First of all, what follows is applicable both to "live recordings", made during a musical performance, and to measurements of the impulse responses. In the second case, the musical performance can be reconstructed later, by convolution of properly recorded anechoic signals with the measured impulse responses.

These measurements/recordings are made with two complementary techniques: dummy-head binaural recordings and 4-channels, B-format recordings made employing a Soundfield microphone. This means that a total of 6 channels need to be recorded simultaneously.

Figure 1 shows one of the dummy heads employed (a B&K Type 4100), side-by-side with the Soundfield microphone (MK-V).

Fig. 1 the microphones

In this case, both are mounted on torso simulators, which can be easily placed on the chairs.

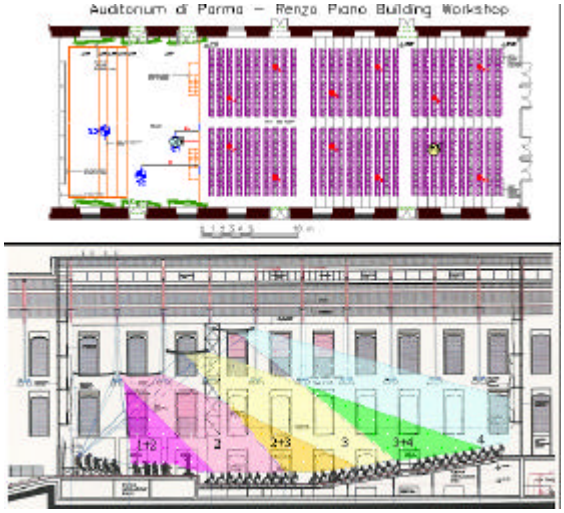
Fig. 2 the rack

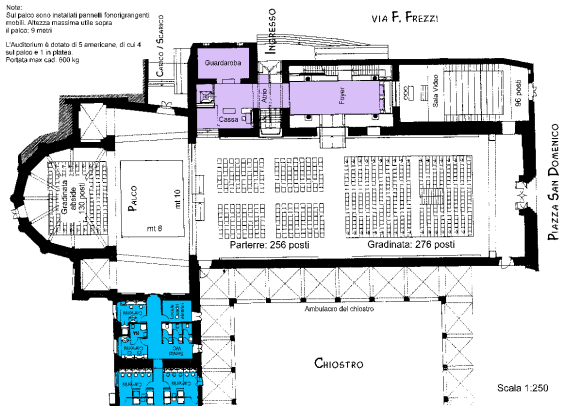
The signals coming from the dummy head and from the Soundfield microphone are recorded by means of a professional multichannel soundboard (Echo Layla), which is capable of recording up to 8 channels at 48 kHz, 24 bits. This is a rack-mounted unit, which is installed, together with the industrial PC and the other audio equipment, in a portable rack. This is shown in figure 2

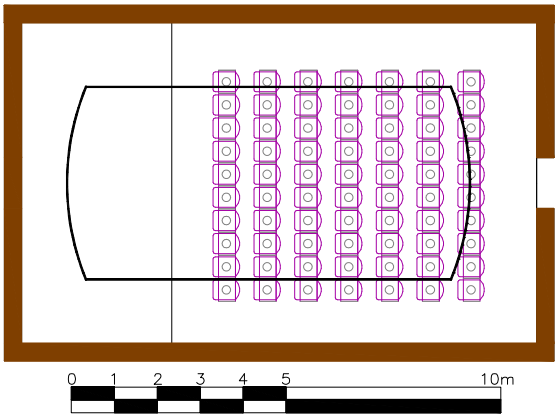
MEASUREMENTS IN CONCERT HALLS

M.Gerzon [2] first proposed to start a systematic collection of 3D impulse responses measured in ancient theatres and concert halls, for assessing their acoustical behaviour and preserving it for the posterity. His proposal found sympathetic response only very recently. This methodology allows both for Binaural and/or B-format measurements.
Gerzon proposed to measure B-format impulse responses, however nowadays it is better to always measure simultaneously both Binaural and B-format impulse responses.
Only a small number of theatres have yielded a complete three-dimensional, dual-format impulse response characterization up till now. Among them, we employed for the present work the IRs measured in three Italian theatres:

- Auditorium “Paganini” in Parma
- Auditorium “S.Domenico” in Foligno
- Theatre “Mazzacorati” in Bologna







Theater	Volume (m^3)	Plan Area (m^2)	Seats
Paganini – Parma	16300	850	780 (stalls)
S.Domenico - Foligno	18400	1050	532 (stalls) +130 (rear gradons)
Mazzacorati - Bologna	1000	90	70 (stalls) + 50 (balconies)

Fig. 3 The rooms: Paganini (up), Foligno (middle) and Mazzacorati (down)

Compared with their seat capacity and their volumes, these three rooms are quite live, much more than most Italian opera houses; in substance, these three performing spaces are among the few Italian theatres resembling the acoustical characteristics of north-European concert halls of the same size.
This is demonstrated by fig. 4, which shows the measured reverberation times in the three theatres (all measurements shown here were conducted with the room empty, but in the Parma Auditorium the measurements were also repeated with the room completely full, showing a reduction of the reverberation time

substantially constant with frequency, and less than 5%).

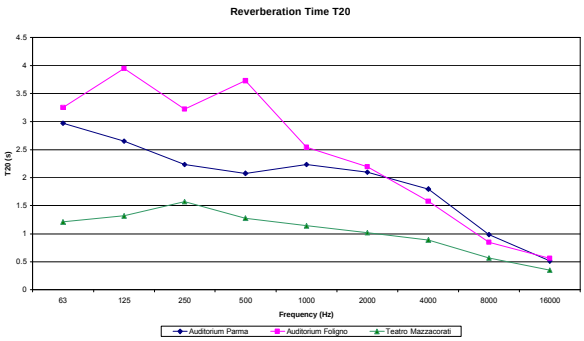
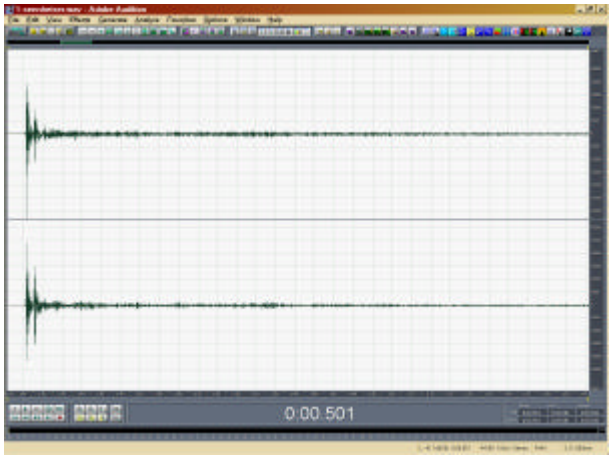


Fig. 4 – Reverberation time of the three theatres (unoccupied)

In the following pictures are reported the Impulse Responses measured in the three halls.



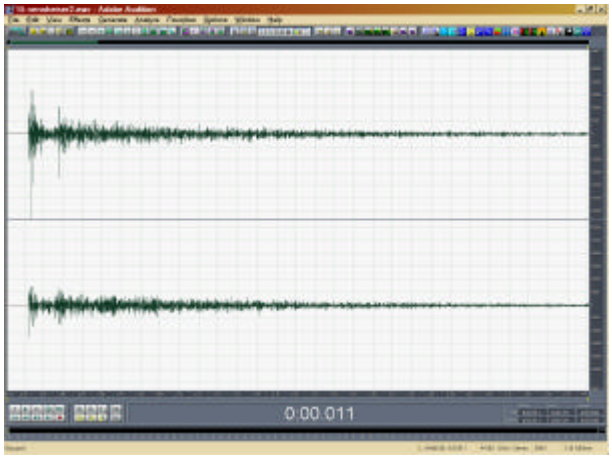


Fig. 5 – BIR measured in the three Halls: Parma, Foligno, Bologna (first 300 ms)

The following table contains the most important acoustical parameters (computed according to the ISO-3382 standard) in the three theatres (A-weighted band).

Parameter	Parma	Foligno	Mazzacorati
C50 [dB]	-0.64	6.44	0.6
C80 [dB]	1.00	7.45	3.09
Ts [ms]	176	47	80
EDT [s]	2.40	2.10	1.23
T10 [s]	2.23	2.42	1.13
T20 [s]	2.23	2.54	1.14
T30 [s]	2.25	2.63	1.15
IACC	0.24	0.54	0.09

Tab. 1 Acoustical parameters: average

CONCLUSIONS AND FUTURE WORK

This preliminary paper reported on the steps taken for setting up a recording/measurement and reproduction/simulation system capable of recreating a realistic reconstruction of the three- dimensional soundfield inside an existing concert hall.

The method can be applied either to multichannel “realtime” recordings, or to synthetically simulated sound samples obtained by convolution of anechoic music with measured impulse responses. These signals are replayed inside a special listening room, equipped with two integrated reproduction chains: a dual Stereo Dipole for “transaural” presentation of binaural signals, and an advanced Ambisonics decoder for

periphonic (3D) presentation of B-format signals.
The two systems can be operated separately or simultaneously, provided that, in the latter case, a proper correction for the gain and for the processing delay of the two systems is applied.
Even if this paper is specially focused on the experimental equipment, the measured impulse responses have been utilised starting from the theoretical principles of Ambisonics and Stereo Dipole, implementing a method for the reproduction of sound characteristics of the auditoria. The reproduction of the sound samples employed for the listening tests was driven by specially-written software, which also enabled for the automatic collection of questionnaires.
The hybrid Ambiophonics system resulted in very natural and convincing listening experience, and consequently this opens the possibility to comparatively assess minor acoustical differences between halls very far each other, particularly with reference to the spatial perception (envelopment, source imaging, depth, etc.) and to the temporal factors (Initial Time Delay Gap, difference between EDT and the subsequent reverberation time, etc.).
The encouraging results obtained by the first comparative experiments allows for the continuation of the research, which will move to the execution of several listening tests, aimed principally to defining the optimal listening conditions in terms of spatial attributes of the sound field and of system's frequency response, which are actually the less-explored perceptual aspects for a concert hall

ACKNOWLEDGEMENTS

The authors are in debt with Angelo Farina, for his help during the measurements and the analysis of the results.

REFERENCES

[1] R. Glasgal, K. Yates, "Ambiophonics – Beyond Surround Sound to Virtual Sonic Reality", Ambiophonics Institute, 1995.

[2] M.A. Gerzon, "Recording Concert Hall Acoustics for Posterity", *J. Audio Eng. Soc.*, vol. 23, pp. 569, 571 (1975 Sept.).

[3] R Miller, "Contrasting ITU 5.1 and Panor-ambiophonic 4.1 Surround Sound Recording Using OCT and Sphere Microphones," Proceedings of AES 112th International Convention, Munich, Germany 2002, preprint #5577.

[4] H. Moller – "Fundamentals of Binaural Technology" – Applied Acoustics vol. 36 (1992) pp. 171-218.

[5] O. Kirkeby, P. A. Nelson, and H. Hamada – "Virtual Source Imaging Using the Stereo Dipole"", Pre-prints of the 103rd AES Convention, New York, 26-29 September 1997.

[6] O. Kirkeby, P. A. Nelson, H. Hamada – "The "Stereo Dipole"-A Virtual Source Imaging System Using Two Closely Spaced Loudspeakers" – JAES vol. 46, n. 5, 1998 May, pp. 387-395.

[7] O. Kirkeby and P. A. Nelson – "Digital Filter Design for Virtual Source Imaging Systems", Pre-prints of the 104th AES Convention, Amsterdam, 15 - 20 May, 1998.

[8] A. Farina, E. Ugolotti - "Spatial Equalization of sound systems in cars" - Proc. of 15th AES Conference "Audio, Acoustics & Small Spaces", Copenhagen, Denmark, 31/10-2/11 1998.

[9] A. Farina, F. Righini, 'Software implementation of an MLS analyzer, with tools for convolution, auralization and inverse filtering', Pre-prints of the 103rd AES Convention, New York, 26-29 September 1997.

[10] Farina, E. Ugolotti, "Automatic Measurement System For Car Audio Application", Pre-prints of the 104rd AES Convention, Amsterdam, 15 - 20 May, 1998.

[11] Gerzon M., "Ambisonics in Multichannel Broadcasting and Video" - *Journal of Audio*

Engineering Society, Vol. 33, Number 11 pp. 859 (1985).

[12] Moorer J.A., "Music recording in the age of multi-channel" - Pre-prints of the 103rd AES Convention, New York, 26-29 September 1997.

[13] A. Farina, E. Ugolotti, "Subjective comparison between Stereo Dipole and 3D Ambisonics surround systems for automotive applications", 16th AES Conference, Rovaniemi (Finland) 12-14 April 1999.

[14] J. Daniel, J.B. Rault, J.D. Polack - " "Ambisonics encoding of other audio formats for multiple listening conditions" - Pre-prints of the 105th AES Convention, S.Francisco, 26 - 29 September, 1998

[15] Tronchin L., Farina A.: Acoustics of the former Teatro "La Fenice" in Venice, Journal of the Audio Engineering Society, New York, 45(12), 1051-1062, 1997.

[16] International Standard ISO 3382, Acoustics – Measurement of the reverberation time of rooms with reference to other acoustical parameters, 1997

[17] Cocchi A., Tronchin L., Farina A., Cesare-Consumi M., A comparison between some measurement techniques in the Foligno auditorium, Proc. of Auditorium Acoustics: Historical and contemporary design and performance, IOA, Imperial College, London, 2002.

[18] Farina A., Simultaneous measurement of impulse response and distortion with a swept-sine technique, 110th AES Convention, Paris, 2000.