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Modern Auralization Routines as Design Tools

Wolfgang Ahnert
AFMG Technologies GmbH

ABSTRACT

Auralization was developed as a tool in the 30ties. The historic overview over this development starts by using scale models as a design tool which is used until now. Here the needed components are explained and the pros and cons will be discussed. With the use of computer simulation in the end of the 60ties the presentation of auralized files started around 1990 first considered as a toy. The paper describes the development of the technical tools presenting auralized signals available for binaural reproduction without and with head tracker and by using loudspeaker reproduction without and with crosstalk cancelation. Nowadays Acoustic labs with Ambisonics reproduction or similar technologies are used.
A post-processing software for EASE allows reproducing music or speech signals convolved not only with calculated simulation files but in comparison also with measured files by using the microphone Ambeo VR. Additionally VR glasses generate realistic 3D-visuals in the same model as used for acoustic simulation. Finally the misuse of auralization is discussed by using some examples.

INTRODUCTION

Auralization routines are used more and more often:

- To evaluate the quality of room acoustic design
- To make acoustic effects or misconceptions clearly audible
- To convince a client or an architect to realize some needed treatment in rooms or open spaces
- To demonstrate insufficient sound isolation of walls or ceilings in the design phase
- To demonstrate design solutions for excellent speech intelligibility

All these activities may be performed in a professional way with the needed professional background or only for impressing a client without the guarantee that the demonstrated sound will be later also reproduced and perceived as expected.
The development of auralization routines to a useful tool will be shown below.

FIRST ATTEMPTS IN AURALIZATION

In the 30ties first attempts have been made by using physical scale models /1/, Friedrich Spandöck used simple rooms in an original scale and a 1:5 scale for comparisons, see figure 1. This way he made investigations in a frequency range from 2.5 to 4 kHz in the scale model which did correspond to 500 to 800 Hz in the original scale.
In figure 2 some oscillogram figures are shown for comparisons of results in the original room and in the model. The time scale in these figures is different and the existing air attenuation was not yet compensated for, so direct comparison was rather difficult.

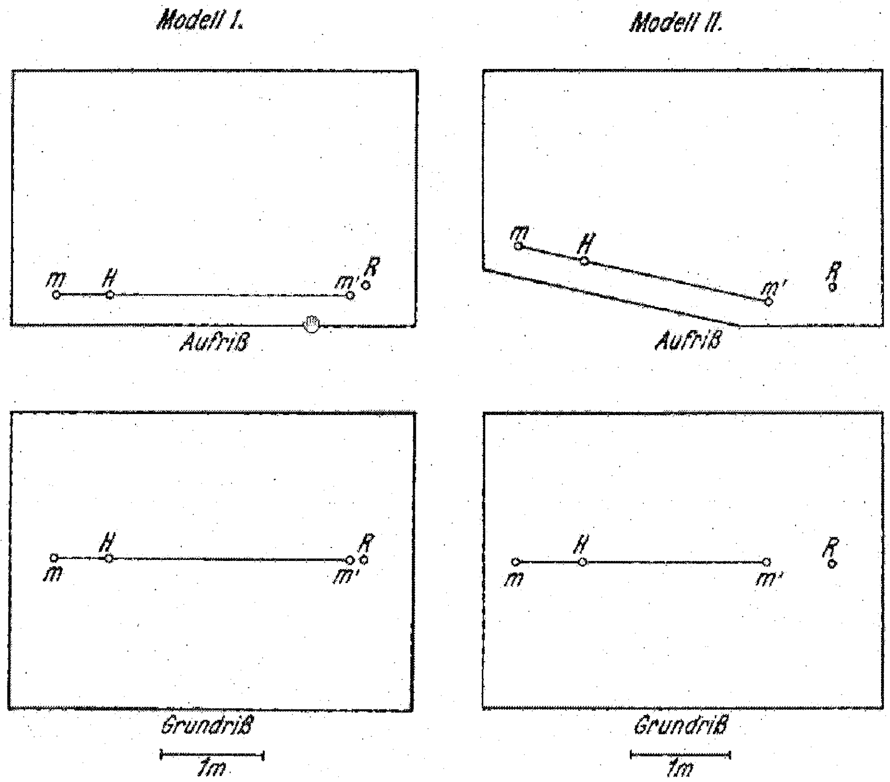


Fig. 1: Simple 3D Model used by F. Spandöck

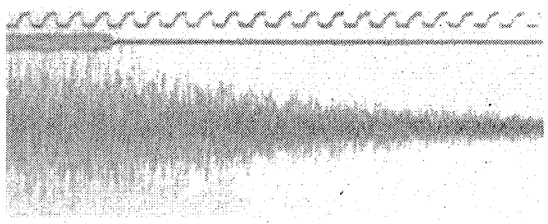


Fig. 7. Nachhall im ungedämpften Rotundenmodell III, Lautsprecher in R, Mikrophon in H; $f_0 = 2500$, $\Delta f = 1500$, $\alpha = 25$

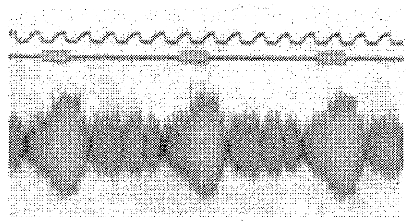


Fig. 9. Tongruppen in Modell I, Lautsprecher in R, Mikrophon in H; $f = 4000$

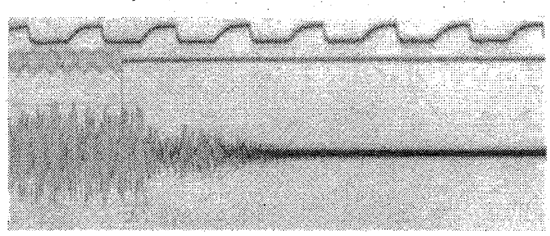


Fig. 8. Nachhall im gedämpften Rotundenmodell III, Lautsprecher in G, Mikrophon in W; $f_0 = 2200$, $\Delta f = 1000$, $\alpha = 200$

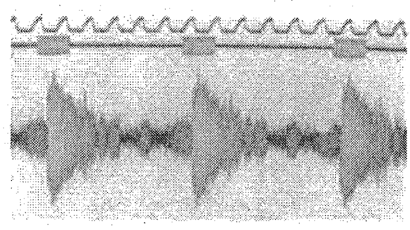


Fig. 10. Tongruppen in Modell II, Lautsprecher in R, Mikrophon in H; $f = 4000$

Fig. 2: Oscillograms of sound decay in an original room (left) and in the respective modelled room (right)

F. Spandöck writes at that time in 1934: One can radiate the speech or music of a gramophone record, which in our case runs at five times the normal speed and then sounds a bit over two octaves higher in pitch, at the location of the speaker or musician in the model room. Then record it by a phonograph on a second disc at the location of the listener. If you consequently run this phonograph disc on a gramophone for the reproduction of the sound now five times more slowly, you will hear again the music or speech in normal pitch and ordinary tempo, but with the acoustic effect of the model space and so, as one would expect in the original room. Because of the war this promising research work was only continued in the 1950ties and Spandöck publishes a patent /2/ in 1959 accordingly. The next figure 3 shows a sketch of his invention.

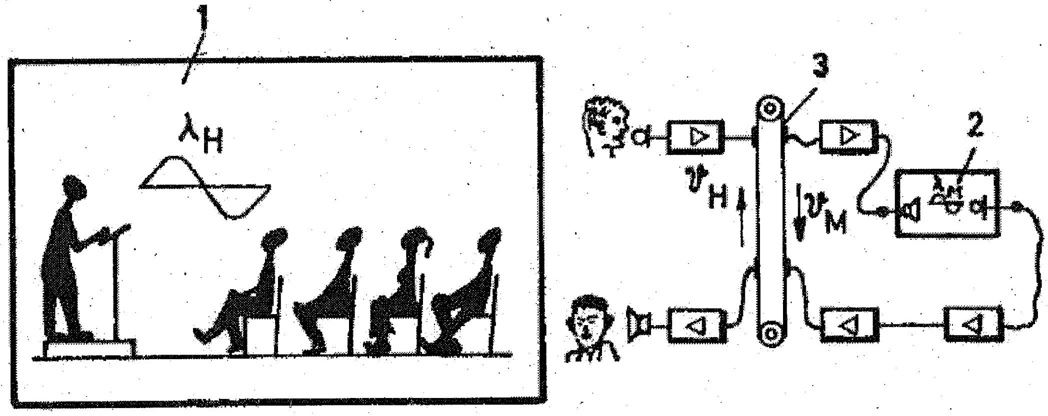


Fig. 3: Auralization procedure by Spandöck

1 is the reproduction room
2 is the model room
3 is a tape machine with Recording and Reproducing Head

When the tape runs in normal speed it shows the value ν_H, for the Model M it runs n times faster with the speed υ_M. The model recordings must be played back then n times more slowly, to listen the result in the reproduction room. The ratio n between the original and the model size is the following:

$$\frac{\lambda_H}{\lambda_M} = \frac{v_M}{v_H} = n \qquad \text{with}$$

λ = wave length of the real (H) and the model room (M)
ν = speed of the tape
n = model scale

The method has been used between 1960 and 1990. Models of the halls for auralization purposes have been constructed in scales 1:10 or even for smaller halls 1:8. In 1983 the author could listen to such auralizations created during the design phase of the Gasteig hall in Munich. At that time the results were very impressive.

AURALIZATION BASED ON COMPUTER SIMULATION

The time of the late 60ties may be considered as the start of computer simulation /3/, cumbersomly using mainframe computers mainly at universities and other institutions. But only with the advent of Personal Computers (PCs) in the 80ties the required software simulation tools have been properly developed as a precondition for auralization.
1985, Bose Modeler, by Bose Cooperation, USA
1988, CATT-Acoustic, by Dalenbaeck, Sweden
1990, EASE, by Ahnert/Feistel, Berlin/Germany

1991, ODEON, by Naylor & Rindel, Denmark
1994, RAMSETE, Faria, Italy

Binaural Auralization

In 1993 EASE started with computer auralization

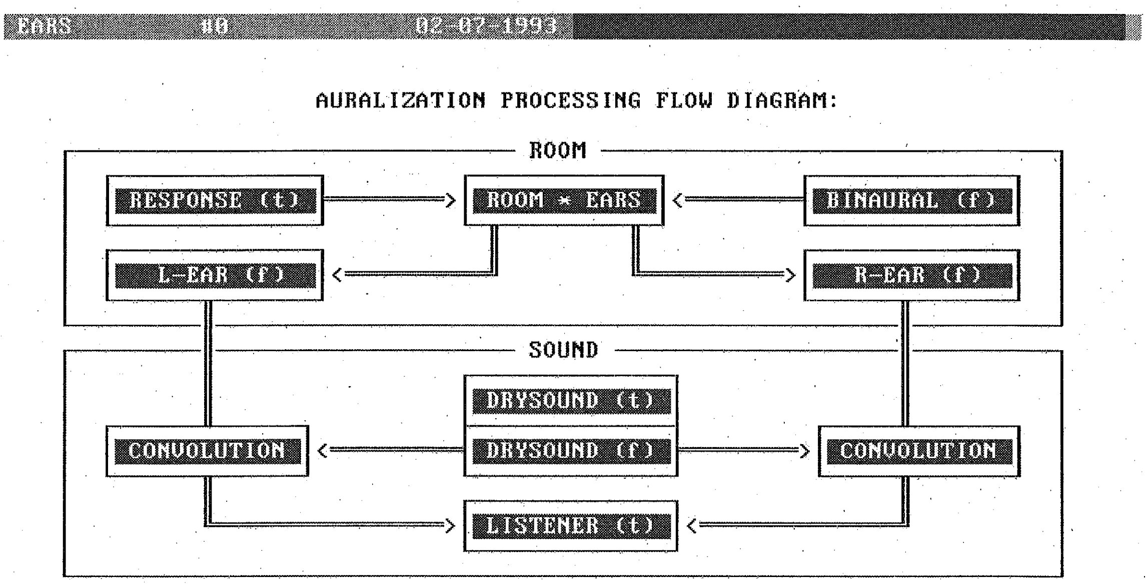


Fig. 4: First computer based Auralization in EASE in 1993

Impulse Response files that were calculated in EASE (or other software tools) could then be convolved with Head Related Transfer Functions (HRTF) to obtain binaural transfer functions. These functions were then convolved with dry sound samples in the frequency domain. An inverse FFT created the auralized file for reproduction. At that time a 20 sec music sample did take up almost one hour to process, even without calculating the response file in EASE (plus another hour or more).

Today streaming music or speech files can be auralized that way in real time.

What are the pros and cons of binaural auralization?

Pros:

- Two-channel reproduction system
- Widely used version, simple to realize
- Used for fast checks and demonstrating effects

Cons:

- Incorrect because of in-head localization of signal components in the median domain
- Echo and signal component detection is only well perceivable in the lateral domain
- For detail investigations not usable, only increase of reverberation may be evaluated

Improvements of Binaural Auralization with Headtrackers

For this procedure the binaural impulse responses are calculated in advance by using HRTF curves in a selected angular resolution surrounding the listener's head.

With 5° angular resolution 2.522 HRTF curves are required and the calculation takes a certain time. With 1° resolution even 64.442 HRTF curves have to be recorded and used for calculations. A simplified angular resolution of 10° still requires 614 HRTFs. These HRTFs are now convolved with the selected monaural response at the selected listener seat in the computer model and so *n* binaural impulse responses are stored. The number *n* depends on the selected angular resolution.

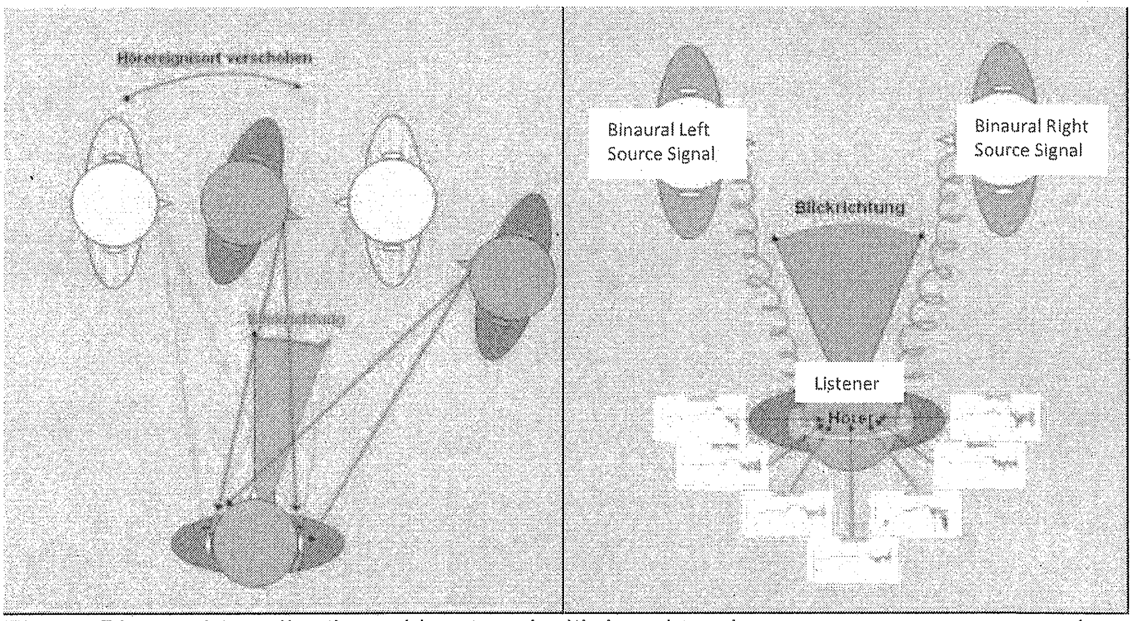


Fig. 5: Binaural auralization without and with head tracker

In the right part of figure 5 some of the *n* stored binaural transfer functions are shown. For the real time auralization the head tracker picks the respective binaural file depending on the actual head position and convolves it with the dry speech or music signal in real time for immediate reproduction.

What are the pros and cons of binaural auralization employing a head tracker?
Pros:

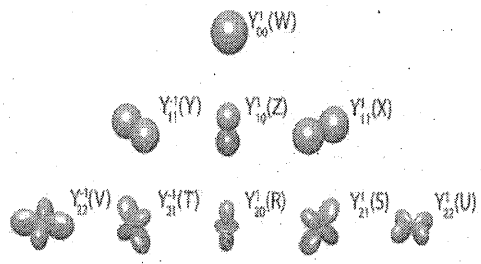
- Also two-channel reproduction system
- Realistic impression, the sound source localization is perceived correctly
- Recommended for quality checks of acoustic parameters

Cons:

- Not widely introduced
- Playback quality depends on the time and angular resolution of the available measured Head-related Transfer Functions
- With great efforts usable only for one listener

Auralization with Multichannel Reproduction

Ambisonic reproduction is used for the evaluation of correct reproduction of sound quality. . The B-Format is a special way of encoding **ambisonic** information. The first order in B-Format uses four audio streams: one channel to capture the indirected sound pressure (W), and three channels to capture the X (front-to-back), Y (left-to-right), and Z (top-to-bottom) directivity of it. The second order adds 5 additional directions for sound pressure capture in higher angular resolution.



Higher order B-Format files increase the angular resolution of the reproduction process.
The enhanced AURA algorithm in EASE was extended to calculate the B-Format impulse responses right now only of the 2nd order, higher orders are planned in the next generation of EASE

Fig. 6: Top to bottom: Null, First and Second Order B-Format

The reproduction of the signals occurs in a simple AcousticLab, see next figure 7.

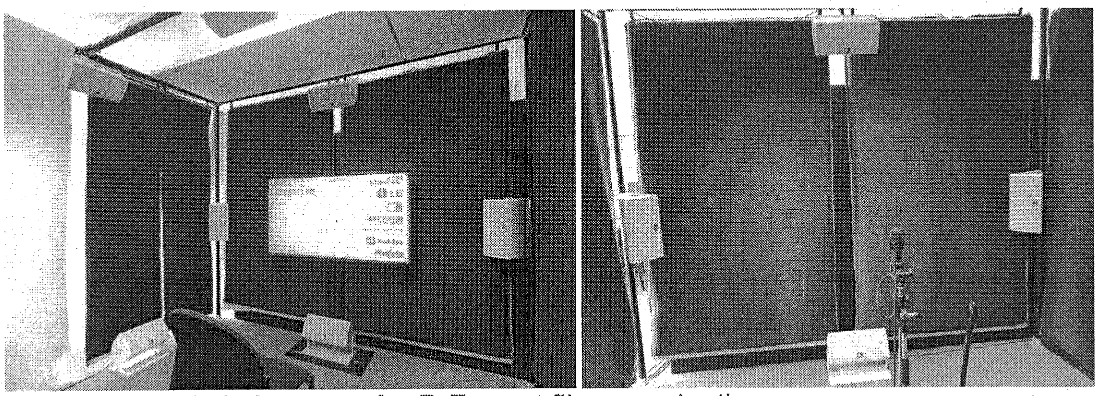


Fig. 7: Acoustic Laboratory for B-Format file reproduction

With a special software tool the nine B-Format files calculated in EASE are convolved with the dry music and speech source signals and hence reproduced there with using the 13 loudspeakers in the lab.
The listener is located in the center of that space in more or less equal distance to all loudspeakers; he may freely turn his head in all axes and has the correct sound impressions and localizations for all head positions. Additional VR Glasses will support the acoustic impressions by visual ones, see figure 8. The listener will listen to the simulated correct sound impression on a seat by "sitting" on this seat in a virtual environment. He may even turn his head with the glasses to listen to sound impressions from all directions while also seeing the correct visual representation of the space in question.

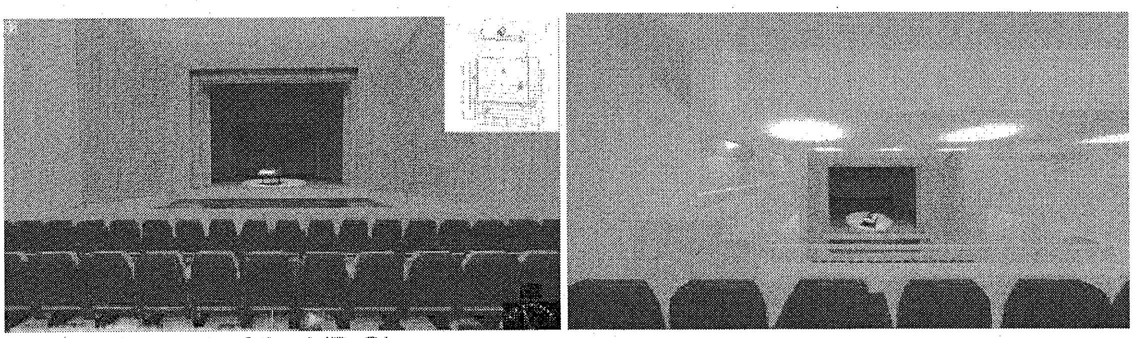


Fig. 8: View out of the VR Glasses

What are the pros and cons of binaural auralization in a dedicated listening room / AcousticLab?
Pros:

- Depending on the size of the reproduction space suitable for more than one listener
- With 12 and more monitor speakers good impression of the auralized signals
- By use of VR glasses perfect room impression correctly combined with the acoustic reproduction of the auralized signals
- Head movements with the VR glasses allow the acoustic and geometrical localization of specific acoustic effects or echoes
- Method is usable for final decisions by the architect or client without the need to understand acoustical parameters

Cons:

- A considerable effort is required to calculate all files necessary
- Need to have a suitable listening room or AcousticLab for signal reproduction
- Even more effort (higher B-Format order and more reproduction loudspeakers) is needed for higher angular resolution to avoid the interpolation of sound impressions

Misuse of Auralization

As acoustical simulations and thereby often also auralizations are becoming standard tools for acoustic analysis of a project during the design phase, a number of pitfalls need to be carefully avoided. A selection follows below:

As commonplace auralizations are, they are not practical factors to derive final decisions on the base of just two auralization results of e.g. competing projects. Therefore it is recommended to

- Reject auralization competitions in tenders
- Utilize these first preliminary auralization to convince an architect or building contractor to spend more money to take the correct decision on the base of further auralization
- Demonstrating auralization results to musicians is generally less recommended, they have different weightings in their perception of sound that can hardly be transferred by auralizations.

The use of Auralisation for acoustic design work alone must be avoided because of following issues

- Because of lack of diffraction during simulation in computer programs it is not recommended to use simulation and auralization technique alone to design halls with high quality demands in acoustics. Currently, it is still recommended to use scale models (in addition to mathematical models) for opera house or concert hall design.
- Because of lack of knowledge of correct absorption coefficients to be used in computer models it is not recommended to trust so-called „perfect comparisons“ in sound coloration of auralized files; simulation still remains simulation!
- Also quite often source data is not entirely known and results of simulations therefore might be questionable, specifically concerning multiple sources and, how the directivity of loudspeakers or natural sources is modelled. These uncertainties should not be underestimated in auralization procedures.

SUMMARY

Auralization routines are more and more important to verify the acoustic design issues during architectural design and acoustic planning phases. In the 90ties the existing auralization methods had to be considered as toys. Serious feedback for the selected design could not be expected and the acoustician is well advised to demonstrate the auralization with caution.

However, over the years this has been significantly developed and the quality of auralized results can become more and more realistic. Auralization in small Laboratories with loudspeaker arrangements surrounding the listener including the use of VR glasses supply an almost perfect impression of the sound quality to be expected in a particular space. Similar results will be reached with binaural reproduction including head tracker and also VR glasses.
But anyway, a 100% real demonstration of the future sound quality of a space is not yet possible and may be never achieved; the nature is too complex and the influence factors for "perfect Acoustics" are manifold. Simulating this complex behavior and then to auralize it will certainly take more time and research within the next years.

LITERATURE

/1/ Spandöck, F.: Akustische Modellversuche. Annalen der Physik, 5. sequence, volume 20, issue 4, July 1934, pp. 345-360
/2/ German Patent Nr. 3.139.151
/3/ Krokstad, A., Strøm, S. and Sørsdal, S.: Calculating the acoustical room response by the use of a ray tracing technique. J. Sound Vibration 1968, 8: pp. 118-125