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Design of a lightweight acoustical measurement room

Juha Backman[1]

[1] *AAC Technologies Solutions Finland, Lemminkäisenkatu 46, Turku, Finland*

Correspondence should be addressed to Juha Backman (juha.r.backman@gmail.com)

ABSTRACT

The paper presents the design principles of an acoustic test chamber, where the insulation requirements of typical measurement rooms are relaxed and so constructing the surfaces using very lightweight materials, consisting only of absorbents and a simple frame, is possible. The test chamber constructed according to these principles shows good absorption characteristics down to 200Hz and has a significantly larger free space for measurements than a conventional chamber designed using wedges and solid walls.

1 Introduction

Conventional anechoic chambers aim at achieving the contradictory requirements of good acoustical insulation and wide-band absorption, which unfortunately implies that the test chamber needs to be constructed as a heavy room-in-room structure, and that the free measurement space is significantly smaller than the space taken up the chamber. This often means that a chamber either cannot be constructed in an existing laboratory or office space, or the low-frequency absorption and working distance are severely limited

If a compromise is allowed in sound insulation, then the starting point for the design changes completely. In our specific design case further relaxation from the conventional design targets comes from limiting the main application area to telecom audio device testing, which implies that the loudspeaker frequency range is typically from 200 Hz upwards and the typical test distances for full devices can be less than 1 m. In this new design approach the sound field inside the chamber is attenuated at high frequencies (above a few hundred Hz) by attenuation mechanisms, while at low frequencies the radiation to the exterior space becomes an important attenuation mechanism. This implies that the wall design has to go towards the other extreme, avoidance of any sound-reflecting materials in the design. The design choice for our experiment was to use only flat sheets of polyester fibre acoustic absorbent, density about 24 kg/m^3. If stronger attenuation of high frequency reflections is desired then wedge-shaped or other structured surface materials can be used, but since the main purpose of wedge material is to ensure a smooth impedance transition at the lowest frequencies, then in this case a flat sheet made of softer material than typical anechoic chamber wedges provides reasonably good high-frequency attenuation.

2 A very short history of anechoic chambers

The basic design principles of the conventional anechoic chamber, a heavy room-in-room construction with wedge-shaped absorbers were laid out by a team led by Leo L. Beranek during the second world war, when the U.S. army needed a facility for testing high power loudspeakers. The team found from about thousand alternatives the air-backed wedge structure to be the most efficient [1]. The first laboratory of this type was built at the Harvard University in 1942, and a second with almost similar performance was built at Bell Labs' Murray Hill facility [2].

There have been proposals for other basic designs, such as Lothar Cremer's 1952 proposal for the use of hanging cubic absorbers [3] [4], but the wedge shape has remained popular. Recently melamine-based lossy, lightweight foams [5] have enabled significantly thinner absorbent structures [6], but still with the Beranek's basic principle of wedges backed by a heavy wall. Recent work has addressed methods for constructing simpler anechoic chambers, but still starting from the same requirements of sound isolation and good wide-band absorption for general research use [7] and for quality assurance [8].

3 Simulation results

The basic design assumptions were verified by a FEM simulation using COMSOL Multiphysics with the Acoustics Module. The challenge of numerical simulations was the usual problem of insufficient material data. Numerical models of porous or fibrous absorbents would require parameters generally unavailable from any manufacturer, so typical values had to be substituted.
The question this simulation addressed was whether the absorbent can decouple the interior and exterior spaces, and what material thickness is sufficient (100 or 200mm). The results (reproduced only partially here) indicated that 100mm provides some low-frequency control, and 200mm is preferable. The practical design compromise, also supported by the simulations, was to apply a 200mm layer on the floor and on the walls nearest to the surrounding room walls, while the ceiling and the walls towards the open space were covered with a 100mm layer.

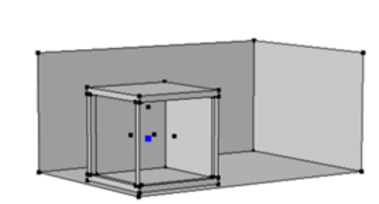

Figure 1. Geometry of an absorbent-walled cube in a hard-walled room used for simulations; source points (black) and receiver point (blue larger dot).

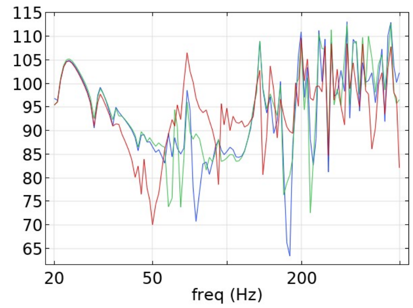

Figure 2. Low frequency responses from different source points in Figure ? to the receiver point, indicating that the modes of the exterior space have an effect on the interior space (absorbent 200 mm).

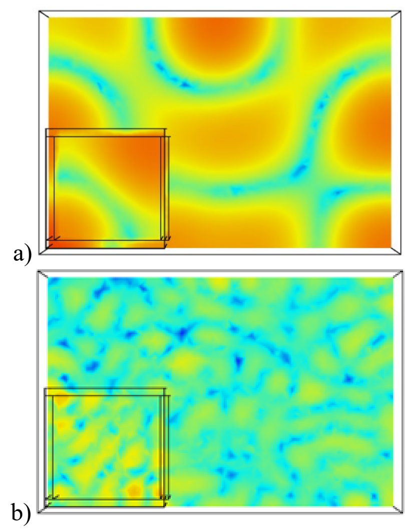

Figure 3. Sound pressure level distribution at a) low (80Hz) and b) at middle (315Hz) frequencies. At low frequencies the decoupling of internal and external spaces is insufficient, and the field in the test chamber is determined by the larger space modes, while at higher frequencies the two fields are essentially decoupled.

4 Practical room structure

The practical construction choices were determined by the available space, a need to have a selfsupported floor (the frame could not be attached to the concrete floor of the surrounding space), and a desire to leave a substantial air space between the test chamber and the closest surrounding walls in order to increase the low frequency absorption. The exterior dimensions of the test chamber were approximately $2*2*2m^3$. The 40 cm space between the chamber and the solid walls serves also well as a cable space for the measurement systems. The floor was built of 2*18mm plywood screwed on a frame built of $100*50mm^2$ timber (Figure 5), standing on insulation feet. It is essential to have both acoustical and structural damping material in the floor structure, especially if the inner floor absorbents are removed and the chamber is used as a half-anechoic space.

Figure 4. Absorbents under the plywood floor and the foam strips used to dampen the floor resonance.

The wall and ceiling frame was also constructed of $50*100mm^2$ timber. Flat sheets of 100 mm thick polyester fibre acoustical absorption material were placed inside the frame, and on the walls close to the also the spaces between in the frame were filled to yield a total absorbent thickness of 200 mm (impulse response measurements with a 100 mm absorbent thickness indicated low-level reflections from the closest walls).

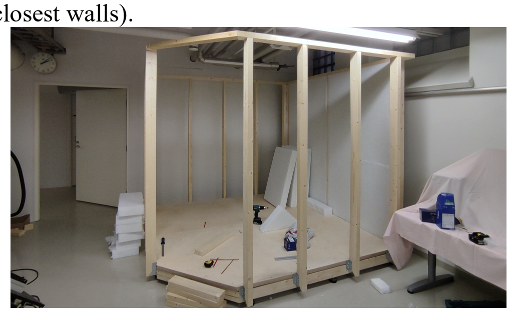

Figure 5. The timber frame of the test chamber.

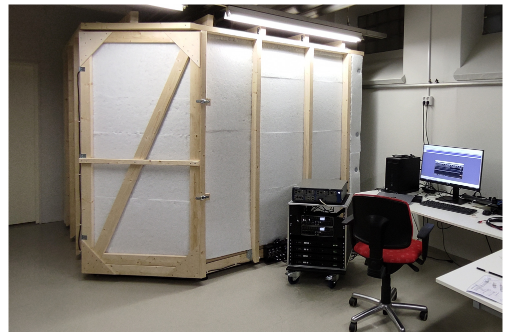

Figure 6. The complete test chamber.

5 Measured performance

An anechoic chamber is typically evaluated by measuring how precisely the distance attenuation of a sound source generated by an isotropic source follows 1/r-law [9] [10] [11]. In this case the verification measurements were made using a 2" Tymphany wideband loudspeaker in a small sealed enclosure. Since the room is intended for audio system measurements it is also instructive to take a look at the narrow-band behaviour by displaying the frequency responses of the test speaker, normalized to 0.4m (Figure 9).

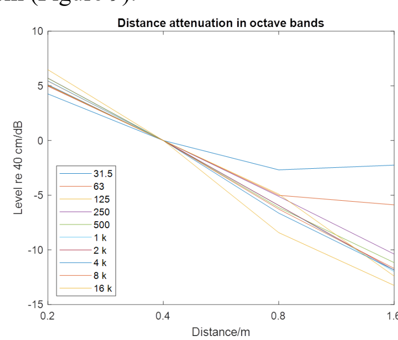

Figure 7. Octave band sound pressure level as a function of distance, normalized to 0.4m.

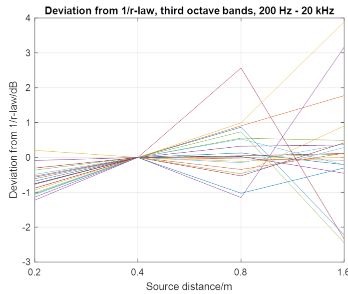

Figure 8. Third-octave band deviation from 1/*r*-law from 200Hz to 20kHz, normalized to 0.4m.

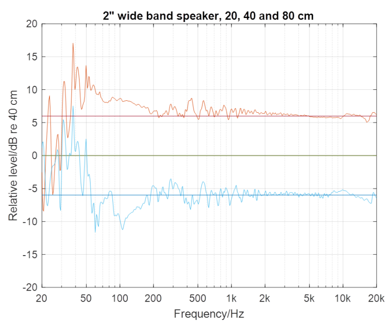

Figure 9. Responses of a 2” wideband speaker at 0.2, 0.4, and 0.8m, normalized to 0.4m.

Although the chamber does not have a reverberation time in the conventional sense (there is no diffuse field where the reverberation is properly defined), a reverberation time measurement is a good indicator that the modes of the exterior space do not affect the interior acoustics.

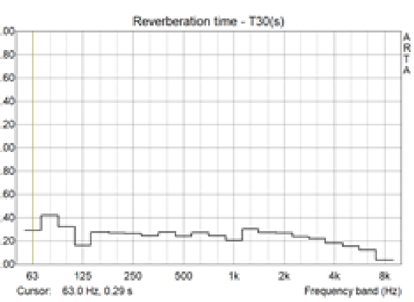

Figure 20. Reverberation time (T30). As opposed to conventional anechoic chambers the value does not increase at the very low frequencies.

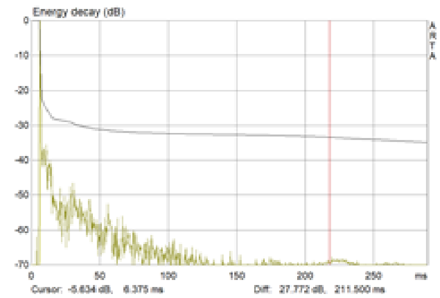

Figure 31. Broadband energy-time function.

Sound insulation of an anechoic space is not properly defined using the standard room acoustics criteria based on diffuse field average sound pressure levels of the receiving and transmitting spaces. A more appropriate criterion is the difference the sound pressure level just outside the wall and inside the wall. The insulation measured with this method is, as expected, quite low, about 5 dB over most of the frequency range, but some attenuation is provided even at the lowest frequencies. The results for background noise outside and inside the test chamber indicate that the structure is sufficient to attenuate the narrow-band spectral components (probably mostly due to ventilation) and the noise is mostly defined by microphone and preamp noise (1/2" G.R.A.S.). Increasing the insulation moderately would be easy by adding a second absorbent layer to the walls and the ceiling, preferably with an air space between the layers.

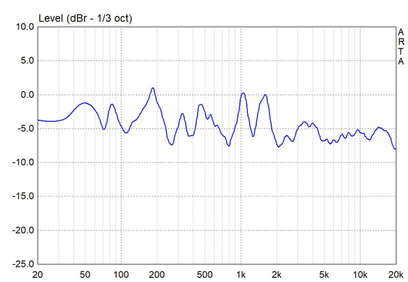

Figure 43. Difference between the sound pressure level outside and inside the test chamber wall.

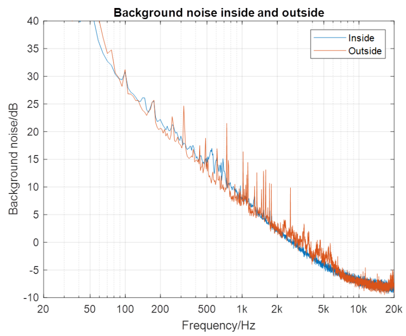

Figure 54. Background and microphone noise spectra outside and inside the test chamber.

6 Conclusions

This paper has described how an acoustical test chamber can be constructed with substantially lower size, weight, and cost than conventional anechoic chambers if high sound insulation can be ignored as a design factor. The proposed design has been shown to be well functional within the target frequency and measurement distance range (>200 Hz, up to 1 m), and the design can be well scaled. Similar ideas could be well applied to modular, easily removable acoustical spaces, e.g. creating a very dry recording space within a studio.

7 Acknowledgements

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