The Audiolab at the Institute for Data Processing, TUM

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Contents

Abstract

This technical report presents information regarding the audio-lab at the Institute for Data Processing (LDV), Technische Universität München. The report gives detailed information about construction considerations of our semi-anechoic chamber, the underlying acoustic basics and the characteristics of the lab environment.

1 Semi-Anechoic Chamber

Figure 1 shows the semi-anechoic chamber at our institute (walls and ceiling are insulated). The purpose of the chamber is to terminate reflexions and diffractions as well as noise around our institute in order to evaluate algorithms and techniques for (binaural) sound localization and separation as well as the measurement of head-related transfer functions (HRTFs).

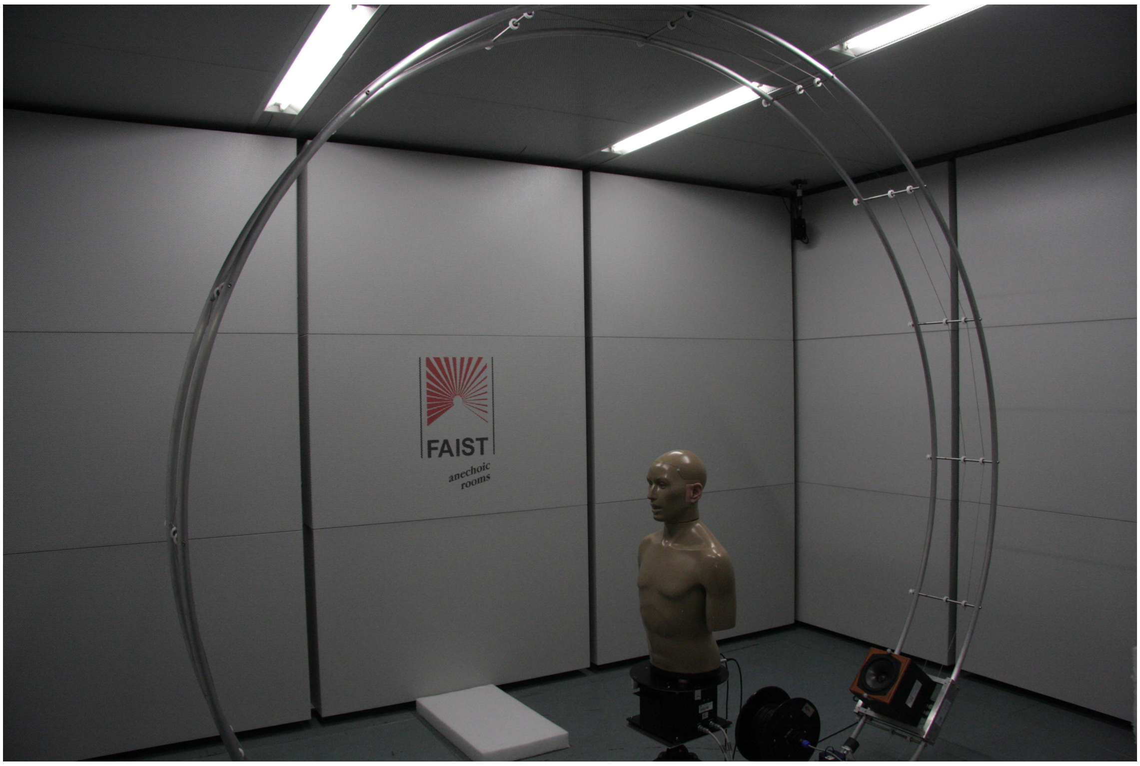

Figure 1: Audiolab

1.1 Acoustics Basics

Sound pressure level is given by

$$L = 20 \log_{10} \frac{p}{p_0} dB, \tag{1}$$

where p is the sound pressure and $p_0 = 20\mu Pa$ is the reference sound pressure. Beside the sound pressure level, the verlocity potential $\vec{v}$, which describes the oscillation velocity of a particle around its position of rest. The sound intensity is then computed by

$$\vec{I} = p(t)\vec{v}. \tag{2}$$

Anonther important factor is the acoustic impedance, which is given by

$$Z = \frac{p}{v}. \tag{3}$$

[2]

Contrary to sound field propagation under free field conditions, sound waves are diffracted and reflected in echoic conditions e.g. in buildings. Reflexions and diffractions make it very difficult to measure HRTFs and to evaluate sound localization and separation algorithms, therefore an audio-laboratory was constructed at our institute that provides a good compromise between costs, required space and anechoic conditions. In the following, acoustic basics about anechoic chambers is discussed.

To start with, the dimensions of a room have strong influence on its acoustic properties, i.e. resonance properties. The room's standard frequencies, the so-called room modes f_n can be calculated by

$$f_n = \frac{c}{2}\sqrt{(\frac{n_x}{l_x})^2 + (\frac{n_y}{l_y})^2 + (\frac{n_y}{l_y})^2}, \tag{4}$$

where l_x, l_y and l_z are the dimensions of a room and $n_x \in \mathbb{Z}$, $n_y \in \mathbb{Z}$ and $n_z \in \mathbb{Z}$. Room modes are resonances when sound waves excite the room. The sound pressure distribution Ψ of the room modes f_n at a certain position (x, y, z) within the room is

$$\Psi(x, y, z) = cos\frac{n_x \pi x}{l_x} cos\frac{n_y \pi y}{l_y} cos\frac{n_z \pi z}{l_z}. \tag{5}$$

Depending on the values of n_x, n_y and n_z there are locations within the room without any reflexions ($n_x = 0$, $n_y = 0$ and $n_z = 0$) and positions, where stationary waves arise [3].

The aim of an anechoic chamber is to reduce echoes to a minimum in order to achieve free-field conditions within a room [5, 7, 8]. Low frequencies state a problem and can't be terminated below a certain room dependent threshold

$$f_{thr} \sim \frac{1}{\sqrt[3]{V}}, \tag{6}$$

where V is the volume of a room.

Basically, there are two main factors, that influence the sound-wave absorption in order to minimize reflextions: the material of the absorbers and the geometry of the construction [4].
With infinitely expanded porous material, the acoustic impedance is given by

$$Z_p = \frac{1}{\sigma}\sqrt{\frac{\Xi\sigma + j2\pi f\rho}{j2\pi f\kappa}}, \tag{7}$$

where σ is the porosity, Ξ is the flow resistance for air, ρ describes the density and κ the compressibility of the insulation material [9]. According to (7), porous material is more effective for high frequencies than for low frequencies. Furthermore, in real world scenarios, the material has finite dimensions and the sound is reflected by the walls where the porous material is mounted. Therefore, it is necessary to maintain a distance d between the absorber and the wall, ideally with $d = \frac{\lambda}{4}$. For example, for a frequency $f = 100\,\mathrm{Hz}$ the absorber has to be mounted 85 cm before a reflecting wall, which means a high reduction of the volume of the room. To overcome this problem, Helmholtz resonators are applied.

One of the most used methods is to use pyramid shaped absorbers (wedge absorbers) made of porous material. Beside the absorbing properties of the porous material, the geometry of the absorbers is important. The pyramid shape of the absorbers increases the surface making the usage of this shape advantageous for low frequencies [12]. A disadvantage of this technique is the high place requirement, which renders this method useless for our rooms.
Finally, we chose a combination of porous material and resonance absorbers for our semi anechoic chamber. Between porous materials, that are effective for high frequencies, resonance absorbers are placed to work on low frequencies. The method provides good anechoic properties while still beeing compact. We installed absorbers, developed by Fraunhofer [1] and built by Faist [2].

www.ibp.fraunhofer.de
www.faist.de

1.2 Measurement Procedure

This section gives an overview about the evaluation of our semi-anechoic chamber. The measurements were done using:

- USB audio interface: Cakewalk UA-25 EX
- Microphone: G.R.A.S. Type 46AE 1/2”
- Sound source: KSdigital C5 Tiny

We measured the sound pressure indirectly by recording the signal x and compute the energy E_s, which is proportional to the sound pressure level, over a time window by

$$E_s = \sum_{n=1}^{N} (x(n))^2, \tag{8}$$

where N is the time window length. The sound pressure difference between two sound energies E_{s1} and E_{s2} is given by

$$\Delta L = 10log_{10}\frac{E_{s1}}{E_{s2}}. \tag{9}$$

The absolute sound pressure level can be determined by

$$L = 10log_{10}E_s + C, \tag{10}$$

where C is a constant value that can be determined with a calibrator. The sound pressure level calculation is done in frequency domain.

Reverberation time

One characteristic property of anechoic chambers is the reverberation time. the reverberation time is the period of time where density of the sound field energy is reduced to a millionth of its initial value. Given a temperature of 20° and a barometric pressure of 1000 hPa, the reverberation time T_r is computed by

$$T_r = 0.163V\frac{1}{-ln(1-\overline{\alpha}A)}, \tag{11}$$

where V the volume of the chamber, A the room’s surface and $\overline{\alpha}$ is the mean absorption factor. In practice, the reverberation time is often measured by the so-called switch-off method. Using the switch-off method, a sound source generate a sound field with a

constant noise level, then the source is switched off and the time is measured till the noise level is reduced by 60 dB [9].
We generated a Gaussian distributed white noise signal presented by a speaker, which is switched off after one second. The speaker and the microphone were placed 140 cm above the ground in the middle of the room with a distance of 1 m between the speaker and the microphone. The measured reverberation time is $T_r = 0.08\,\mathrm{s}$

Directional Characteristics of the Speaker

To determine the suitability of our speaker for the eavaluation of the semi-anechoic chamber, the directional characteristics has to be measured. The speaker has to be placed in the middle of the room, then 32 positions on a semi-sphere are chosen (azimuth $\in (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°)$ and elevation $\in (20°, 40°, 60°, 80°)$). The mean value is then determined for every third-octave band [11]. The maximum deviation can be seen in Table 1.

Third-octave band mean frequency [Hz]	Maximum deviation [dB]
≤ 630	± 1.5
800 bis 5000	± 2.0
6300 bis 10000	± 2.5
> 10000	± 5.0

Table 1:

As seen in Figure 2, a microphone, which has a distance of $120cm$ from the speaker , records the sine signals of the respective third-octave bands at the 32 mentioned positions. Our speaker matches teh limitations given in Table (referenz) within $80Hz....200Hz$. A detailed overview of the directional characteristics measurement of the speakers can be found in the appendix.

1.3 Anechoic Properties of the chamber

To evaluate the semi-anechoic properties of the chamber, the sound pressure level is measured at several positions in the room. In accordance with [11], the speaker is placed on

Figure 2: Measurement setup for directional characteristics determination of the speaker.

the floor in the middle of the room. ISO 3745 defines the maximum height of the speaker to be 15 cm above the floor, which was in our setting not possible because of the physical dimensions of the speaker. The middle of the con of our speaker is placed 23 above the ground. The test signal could be a noise signal or a single note. Then a microphone records the signal and the sound pressure level is calculated. The microphone is fixed at a cable as seen in Figure 3 and can be moved to different positions on the cable-path. As illustrated in Figure 4, five paths are chosen. The sound pressure is dependent on the distance between the speaker and the microphone. The sound power is given by

$$P_A = \int_A \vec{I}\,\mathrm{d}A, \tag{12}$$

where $\vec{I}$ is the sound intensity (2) and A is the considered surface. For the spherical surface with distance r between the sound source and the surface, the sound power can be computed by

$$P_A = I \cdot 4\pi r^2. \tag{13}$$

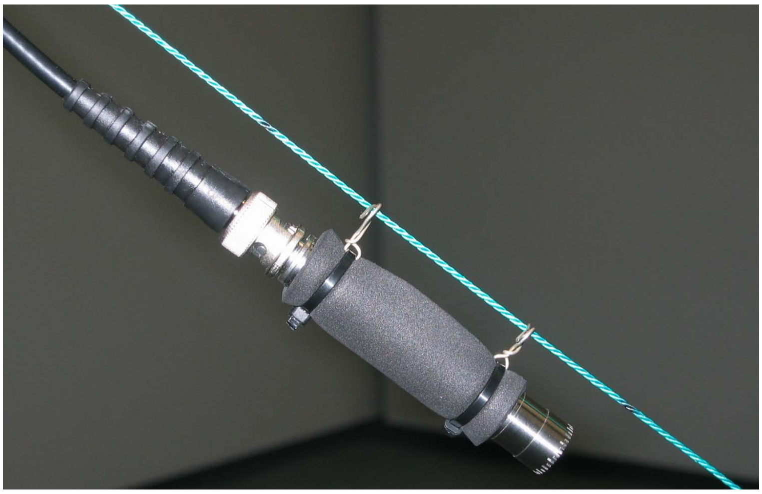

Figure 3: Microphone setup

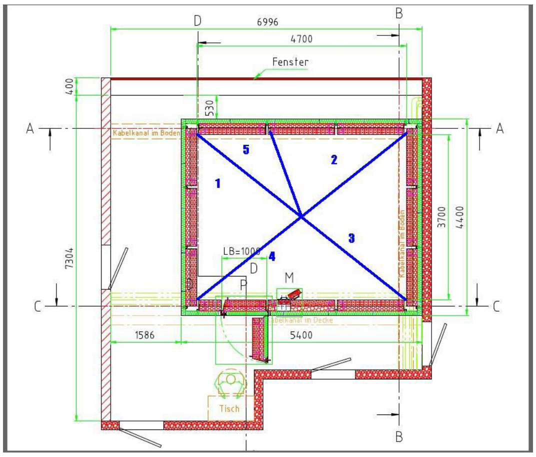

Figure 4: Microphone paths

The so-called inverse square law

$$I \backsim \frac{1}{r^2} \tag{14}$$

is used in the ISO 3745 norm to evaluate properties of low reverberant rooms. For evaluation, the sound pressure level difference ΔL of the microphone measurements on the afore mentioned paths are compared with the sound pressure level differences in free field. In free-field, the sound pressure level difference between two positions with a distance between the sound source r_1 and r_2 can be determined by

$$\Delta L = 10log_{10}\frac{I_{r1}}{I_{r2}} = 10log_{10}\frac{r_2^2}{r_1^2} = 20log_{10}\frac{r_2}{r_1}. \tag{15}$$

If, for example, $r_2 = 2r_1$ the level difference is 6.02 dB. For measurement, the microphone is fixed to a microphone-path with a distance of 0.5 m between the microphone and the speaker. The sound is recorded and the microphone is moved in 10 cm steps to the next measure point of the path. In accordance with [15], the sound pressure level differences ΔL for the corresponding distances are computed and compared with the free-field differences. We constrain the frequency region to $80Hz....200Hz$ due to the directional characteristics of our sound source. The tolerance for this frequency region is ± 2.5 dB.

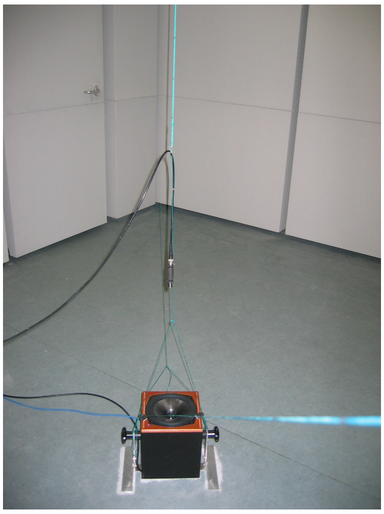

Figure 5: Measurement without floor-insulation.

We have conducted measurements for three settings:

- Measurement 1: Floor without any insulation as seen in Figure 5.
- Measurement 2: One $150cm \times 100cm$ piece of insulation between the speaker and the microphone as mentioned in (5)
- Measurement 3: Floor completely insulated as seen in Figure 8

To sum it up, the reverberation time of our semi-anechoic chamber is $T_r = 0.08$ s and the lower cut-off frequency is 160 Hz within a distance of 1.3 m from the center of the room. Due to the directional characteristics of our sound source, only frequencies from $80Hz....200Hz$ could be considered in accordance with ISO 3745. Analogous to [5, 16, 17, 18] we expect higher frequencies also to meet the norm.

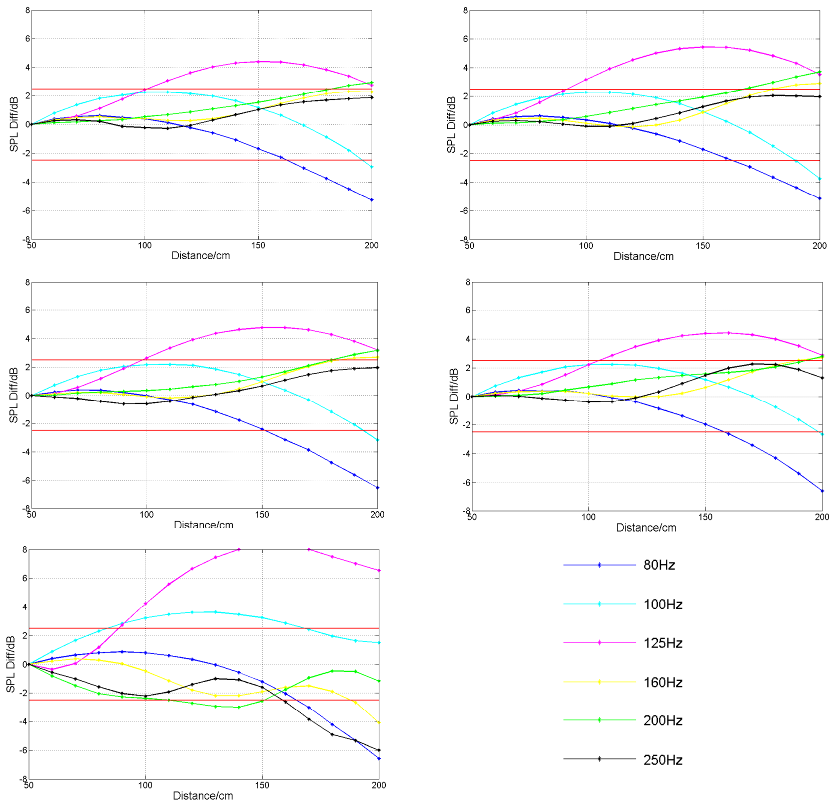

Figure 6: The graphs show measurement results without floor-insulation. The red horizontal lines describe the 2.5 dB sound pressure level difference tolerance region for the measurement.

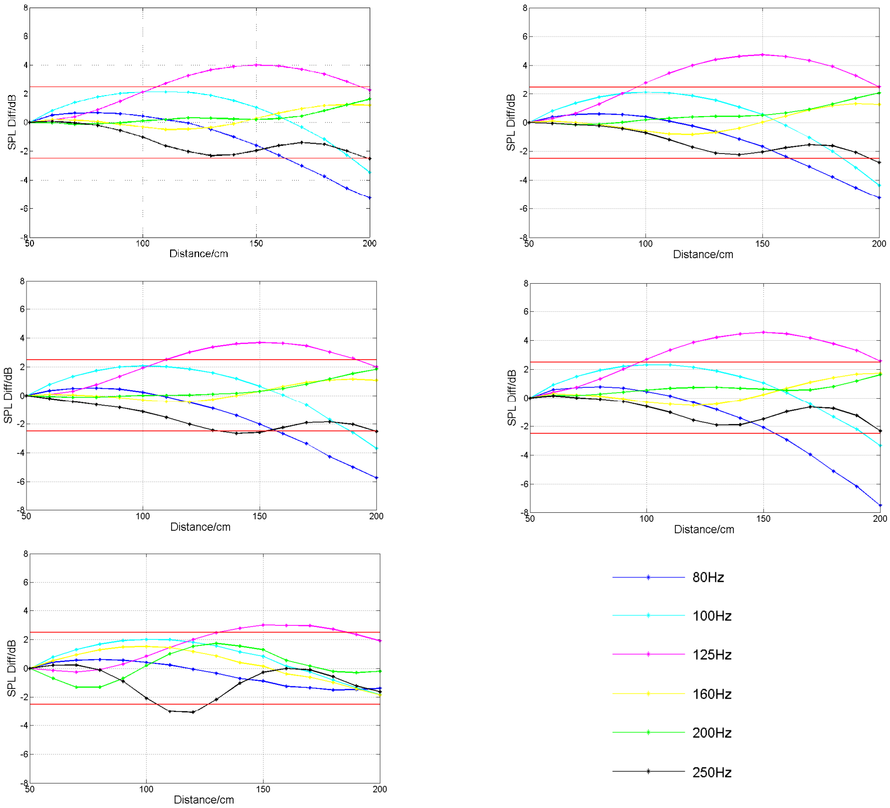

Figure 7: The graphs show measurement results with a $150\,cm \times 100\,cm$ piece of insulation between the speaker and the microphone. The red horizontal lines describe the 2.5 dB sound pressure level difference tolerance region for the measurement.

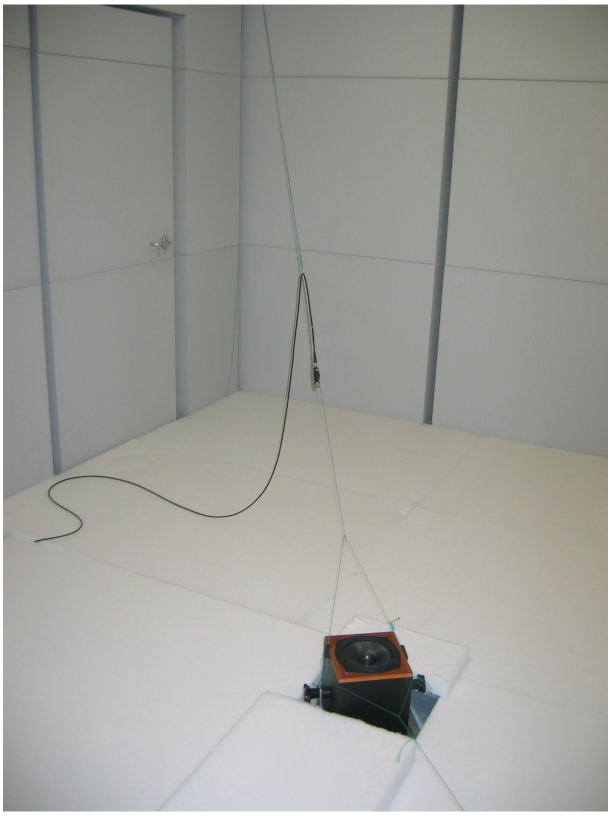

Figure 8: Measurement with floor-insulation

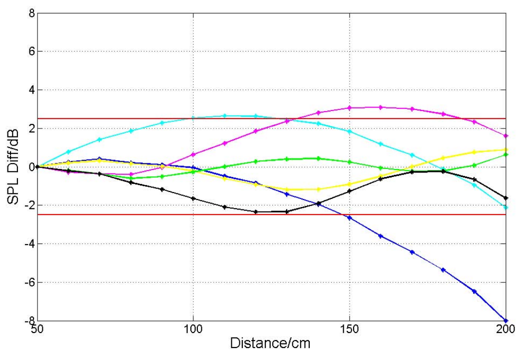

Figure 9: The graphs show measurement results with completely insulated floor. The red horizontal lines describe the 2.5 dB sound pressure level difference tolerance region for the measurement.

Bibliography

[1] Blauert, Jens, "'Spatial Hearing", The MIT Press, 1997

[2] Fastl, Hugo und Zwicker, Eberhard, "Psychoacoustics", 3.Auflage, Springer, 2007

[3] Beranek, Leo L., "'Noise and Vibration Control"', McGraw-Hill, 1971

[4] Möser, Michael, "'Technische Akustik"', 8. Auflage, Springer, 2009

[5] Fuchs, Helmut V., "'Schallabsorber und Schalldämpfer"', Springer, 2009

[6] Henn,Hermann, Sinambari, Gh. Reza und Fallen, Manfred "'Ingenieurakustik - Physikalische Grundlagen und Anwendungsbeispiele"', 4. Auflage, Vieweg + Teubner, 2008

[7] Normenausschuss Materialprüfung, "'DIN 52 212 Bestimmung des Absorptionsggrades im Hallraum"', Beuth, 2009

[8] Cremer, Lothar und Müller, Helmut, "'Die Wissenschaftlichen Grundlagen der Raumakustik Bd 1"', Hirzel, 1978

[9] Blauert, Jens und Xiang, Ning, "'Acoustics for Engineers", 2. Auflage, Springer 2009

[10] Lerch, Reinhard, Sessler, Gerhard und Wolf Dietrich, "'Technische Akustik: Grundlagen und Anwendungen"', Springer 2009

[11] Normenausschuss Akustik, Lärmminderung und Schwingungstechnik im DIN und VDI, "'Akusitik - Bestimmung der Schallleistungspegel von Geräuschquellen aus Schalldruckmessungen - Verfahren der Genauigkeitsklasse 1 für reflexionsarme Räume und Halbräume (ISO 3745:2009); Deutsche Fassung EN ISO 3745:2009"', Beuth Verlag, 2009

[12] Beranek, Leo L. und Sleeper, Harvey P. Jr., "'The Design and Construction of Anechoic Sound Chambers"', The Journal of the Acoustical Society of America, 1946

[13] Dreyer, Jason, Jangale Ashish S. und Rao, Mohan D., "'Design and Analysis of an Hemi-Anechoic Chamber at Michigan Technological University"', Noise-Con, 2005

[14] Gomez-Alfageme, J.J., Sanchez-Bote, J.L. und Blanco-Martin, E., "’Design, Construction and Qualification of the New Anechoic Chamber at Laboratorio de Sonido, Universidad Politécnica de Madrid"’, AES Convention Paper 7153, 2007

[15] Cunefare, Kenneth A., Biesel, Van B., Tran, John, Rye, Ryan, Graf, Aaron, Holdhusen, Mark und Albanese, Anne-Marie, "’Anechoic Chamber Qualification: Traverse Method, Inverse Square Law Analysis Method and Nature of Test Signal"’, The Journal of the Acoustical Society of America, 2003

[16] Zha, X., Späh, M., Fuchs, H.V., Eckoldt, G. und Babuke, G., "’Neuer Reflexionsarmer Raum für den gesamten Hörbereich"’, IBP MItteilung 321, Fraunhofer Institut für Bauphysik, 1997

[17] Babuke, G., Zha, X. und Schneider, W., "’Das neue Volkswagen-Akustik-Zentrum in Wolfsburg"’, IBP-Mitteilung 436, Fraunhofer Institut für Bauphysik, 2004

[18] Zha, Xueqin, Fuchs, Helmut V., Späh, Moritz, "’Ein neues Konzept für akustische Freifeldräume"’, Rundfunktechnische Mitteilungen, 1998

[19] www.me.mtu.edu/courses/meem4704/images, accessed: 01.09.2013

[20] Møller H., Sørensen M.F., Hammershøi D. und Jensen C.B., "Head-related transfer functions of human subjects", Journal of the Audio Engineering Society, 1995

[21] Muller S. and Massarani P., "Transfer-function measuremnt with sweeps", Journal of the Audio Engineering Society, 2001

[22] Lindau A., Maempel H.J. and Weinzierl S., "Minimum BRIR grid resolution for dynamic binaural synthesis", Journal of the Acoustical Society of America, 2008