


**COVER PAGE**

***Document downloaded by @DAEL***

***Sat Nov 28 04:33:30 2026***
***For personal use***

When automatic English translation is provided, only the original document is authentic.
The EAA cannot be held responsible of any translation error

Bibliographical reference

*Acoustical Behavior of the Large Anechoic Chamber at the Laboratoire de Mécanique et d'Acoustique in the Low Frequency Range*, S. Schneider and C. Kern, Acta Acustica **vol. 94** (Number 1), 2008, pp. 141-147

DOI
https://doi.org/10.3813/AAA.918016

ACTA ACUSTICA UNITED WITH ACUSTICA
Vol. 94 (2008) 141 – 147



DOI 10.3813/AAA.918016

# Acoustical Behavior of the Large Anechoic Chamber at the Laboratoire de Mécanique et d'Acoustique in the Low Frequency Range

S. Schneider
CNRS/LMA, 31 chemin Joseph-Aiguier, 13402 Marseille Cedex 20, France. schneider@lma.cnrs-mrs.fr

C. Kern
Technische Universität Dresden, Institut für Festkörpermechanik, 01062 Dresden, Germany

**Summary**
It is of vital importance to have detailed information about the characteristics of an anechoic chamber, since any imperfections lead to deviations from free-field conditions and will perturb measurements. In the present paper the behavior of the large anechoic chamber at the LMA is studied in the 20 to 200 Hz frequency range. The response to pure-tone excitation, generated by an open vented box, was recorded along two lines parallel to the walls. A numerical model for the radiating sound source was used to determine the strength of the source and its center. The region in the chamber where the deviation from free-field conditions was less than the allowed 1.5 dB was determined, based on the experimental data. Its was established that even above the cut-off frequency, deviations greater than the allowed 1.5 dB occurred. A door in the anechoic chamber was identified as at least one of the sources of these imperfections.

**PACS no. 43.55.Pe, 43.58.Bh**

## 1. Introduction

In the present study, the acoustical behavior of the large anechoic chamber at the Laboratoire de Mécanique et d'Acoustique (LMA) was investigated in the low frequency range. The 20 to 200 Hz frequency range of interest is even below the 75 Hz cut-off frequency of the room. This frequency range is of particular interest for determining the characteristics of sound sources used for audio applications and for active sound control purposes.

Earlier measurements carried out in the anechoic chamber in the frequency range above have shown that in addition to perturbations occurring below the cut-off frequency, significant deviations from free-field conditions occur in the 120 to 160 Hz frequency range [1]. Experiments were carried out here to quantify these deviations and to predict the regions in the chamber which are the least subject to these perturbations. The sound pressure radiated by an open vented box was recorded along two traverse lines, running parallel to the walls, and discontinuous, pure-tone traverses measurements were carried out (see [2]). To characterize the anechoic chamber the properties of the sound source – acoustic center and source strength – must be known. Instead of using an analog compensation method [3, 4] or a mathematical compensation method [5, 6] here a numerical model for the entire bass reflex box was used to obtain the acoustic free-field of the sound source. The precise knowledge of the acoustic source enables the determination of the sound field reflected by the acoustic lining. Detailed information about these reflections would make it possible to correct the measurements carried out in this non-anechoic environment. In addition, the data obtained on the reflected sound field can be used to study the feasibility of performing active control operations in the entire anechoic chamber to eliminate any remaining reflections from the walls at low frequencies. The active control of the wall reflections in an anechoic chamber at low frequencies is part of an ongoing project at the LMA [7], called CARLA project.

Received 15 June 2007,
accepted 4 November 2007.

## 2. Determination of the room characteristics

The anechoic chamber at the LMA has inner dimensions of 5.4 × 6.3 × 11.4 $m^3$ measured from wedge tip to wedge tip. Outer walls of the chamber are made of reinforced concrete. The acoustic lining consists of 3720 melamine wedges. Each wedge consists of a rectangular parallelepiped measuring 0.3 × 0.3 × 0.4 $m^3$ forming the base of the wedge and a tapering section of 0.7 m in length. The base of the wedges is clamped in an iron wire frame leaving a 0.25 m air gap behind the lining. The acoustic lining was designed and installed in 2003 by

© S. Hirzel Verlag · EAA

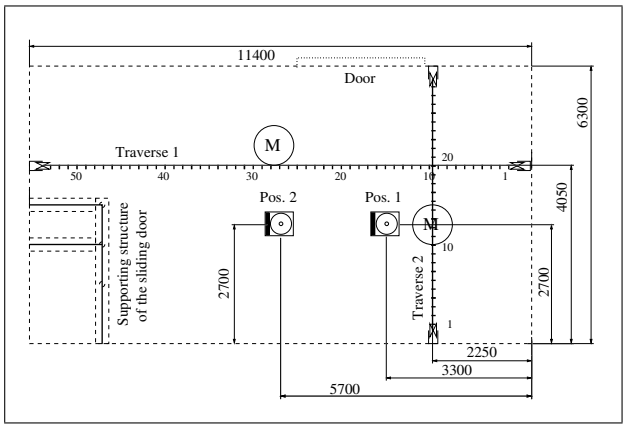


Figure 1. Positions of the traverse lines and the sound sources in the anechoic chamber. The encircled M indicates the position of the stepping motor which controls the microphone.

`decibel france` [8]. The cut-off frequency of the chamber of 75 Hz was determined by `decibel france` using impedance tube measurements on the acoustic lining elements but neglecting the iron wire frame.

The need to study the characteristic of the anechoic room arose when imperfections in the room were observed in earlier experiments above the cut-off frequency and reliable experimental data were also required even below the cut-off frequency, when studying the behavior of the sound sources used for audio applications and for active sound control procedures at very low frequencies. The typical frequency range involved in applications of this kind is 20 to 200 Hz. Detailed knowledge of the characteristics of the sound sources is essential to efficient active control procedures.

Contrary to what has been done in previous studies on the determination of the room characteristics [2, 9, 5], all the traverse lines here were parallel to the walls. The authors are aware that this configuration is not in keeping with ISO 3745 standard [10]. However, this set-up is seemed to be better suitable for determining the characteristics of the chamber at positions where measurements are often carried out. Measurements are in general performed in planes that are parallel to the chamber walls, and traverse line data can therefore be used to correct these measurements.

A 1 inch Brüel & Kjaer microphone was used to record the sound pressure at 1.6 m above the tips of the bottom wedges with a spatial resolution of $\Delta s = 0.2$ m along two traverse lines. This resolution was assumed to be fine enough to resolve the acoustic field up to a frequency of 200 Hz [11]. The two traverses cover the whole length and width of the anechoic room. A second microphone placed .25 cm above the plane of the suspension of the membrane of the loudspeaker was used as a reference microphone to verify the stability of the sound source. A diagram of the measurement set-up, including the two source positions, is given in Figure 1. The minimum distance between the first traverse line and the sound source was 1.5 m, and the traverse therefore covered a range of $r = 1.5$ m to $r = 5.4$ m from the source; whereas the second traverse, where the minimum distance between the traverse line and the source was 3.5 m covered only a range of $r = 3.5$ m to $r = 4.2$ m. The microphones were connected to a NEXUS preamplifier feeding a STANFORD SR 785 signal analyzer used in synchronous-demodulation mode to eliminate the influence of other than the frequency of excitation. Data were post processed using `Scilab 2.7`.

A YAMAHA SW 118IV bass reflex box with a 18" membrane [12], emitting a pure sine tone, was used as the sound source. The membrane was facing the ceiling of the anechoic chamber and was situated at 0.9 m above the tips of the bottom wedges for both source positions. Although this source, is not in line with ISO 3745 standard, which specifies that a closed box should be used, it was chosen among the closed boxes available because it generates a higher sound level at low frequencies and a higher signal to noise ratio was obtained. To determine the reflected sound field, detailed information about the characteristics of the source was of great importance. When a closed box is used, the sound source is generally modeled in the form of a monopole source. As an open vented box can hardly be modeled using a single monopole sound source, two monopole sources were used here [13]. One monopole placed between the vents and one placed in front of the membrane were used to model the acoustic sound field radiated by the bass reflex box. The spatial positions of the centers of the two monopoles were assumed to be frequency-independent. The sound pressure $p_{\text{inc}}$ emitted by the source was therefore modeled using

$$p_{\text{inc}}(x,k) = s_1(k)\frac{\mathrm{e}^{\mathrm{j}k|x-x_1|}}{|x-x_1|} + s_2(k)\frac{\mathrm{e}^{\mathrm{j}k|x-x_2|}}{|x-x_2|}, \qquad (1)$$

where $x_1$ stands for the spatial position of the center of the membrane in the plane of the suspension of the membrane. The point $x_2$ is located between the two vents. To determine the frequency dependent source strengths $s_1$ and $s_2$ in equation (1), a numerical model for the bass reflex box was used. The sound pressures $p_{\text{int}}$ in the box ($\Omega_{\text{int}}$), $p_{\text{ext}}$ in the ambient fluid ($\Omega_{\text{ext}}$) and the displacement $x_{\text{mem}}$ of the membrane must satisfy the following set of differential equations:

$$\Delta p_{\text{int}} + k^2 p_{\text{int}} = 0 \quad \text{in } \Omega_{\text{int}}, \qquad (2)$$

$$\left[-\omega^2 M_{\text{ms}} - \mathrm{j}\omega\left(R_{\text{ms}} + \frac{Bl^2}{R_{\text{e}}}\right) + \frac{1}{C_{\text{ms}}}\right] x_{\text{mem}} = A_{\text{mem}}(p_{\text{int}} - p_{\text{ext}}) + \frac{Bl}{R_{\text{e}}}U_{\text{e}}, \qquad (3)$$

$$\Delta p_{\text{ext}} + k^2 p_{\text{ext}} = 0 \quad \text{in } \Omega_{\text{ext}}, \qquad (4)$$

$$\lim_{r\to\infty} r\left(\frac{\partial p_{\text{ext}}}{\partial r} - \mathrm{j}k p_{\text{ext}}\right) = 0, \quad r = |x|. \qquad (5)$$

Sound propagation in the domains $\Omega_{\text{int}}$ and $\Omega_{\text{ext}}$ was modeled using the time harmonic Helmholtz equation Eqns. (2) and (4). The electro-mechanical behavior of the loudspeaker was modeled using the model by Thiele and Small [14], which is a one mass-spring-damper system

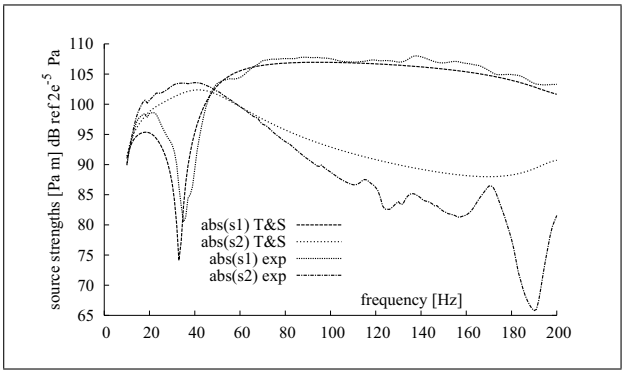


Figure 2. Modulus of the source strengths $s_1$ and $s_2$ obtained from measurements (labeled "exp") and numerical simulation (label "T&S").

describing the displacement $x_{\mathrm{mem}}$ of the membrane. The following parameters of the loudspeaker were used: $M_{\mathrm{ms}} = 0.105$ kg, $R_{\mathrm{ms}} = 4.51$ kg/s, $C_{\mathrm{ms}} = 0.35$ mm/N, $Bl = 19.8$ T, $R_{\mathrm{e}} = 5.1\ \Omega$ and $U_{\mathrm{e}} = 2.3$ V. The supply voltage $U_{\mathrm{e}}$ has been measured when performing the experiments. The walls of the wooden box are assumed to be motionless. This hypothesis has been verified by measuring the displacement of the walls. Eqns. (2) and (3) were solved using the finite element method. To solve equation (4) the boundary element method was used, as this method implicitly accounts for the unbounded exterior domain $\Omega_{\mathrm{ext}}$ represented by the Sommerfeld radiation condition equation (5). Eqns. (2), (3) and (4) are linked up via a continuity condition for the sound pressure and the normal velocities at the membrane and at the outlet of the vents. The source strengths $s_1$ and $s_2$ in equation (1) were identified by minimizing the difference between the sound pressure created by the two monopole model and the results of the numerical simulation. A set of points lying on a circle with a radius of 1.3 m from the center of the membrane in the plane of its suspension were used for this identification. The remaining error of the model equation (1) with respect to the complete model Eqns. (2) to (5) was less than 1% over the entire frequency range after the source strength $s_1$ and $s_2$ had been identified. In the same way, but using experimental data, these source strengths have been evaluated. Experimental data were obtained by measuring the sound pressure at a distance of 1.3 m from the center of the membrane in the plane of its suspension while rotating the sound source in the anechoic chamber. The modulus of the two source strengths obtained from the numerical simulation superimposed with experimental results are shown in Figure 2. The impact of the chamber on the measured data is clearly visible. The left sub-figure of Figure 3 compares the sound pressure recorded by the reference microphone with the sound pressure created by the dipole model equation (1). Good agreement over the entire frequency range is observed. For the microphone position on the traverse line closest to the sound source the recorded sound pressure and direct sound pressure of the numerical model are shown in the lower sub-figure of Figure 3. Perturbations are clearly visible in the experimental data but the mean

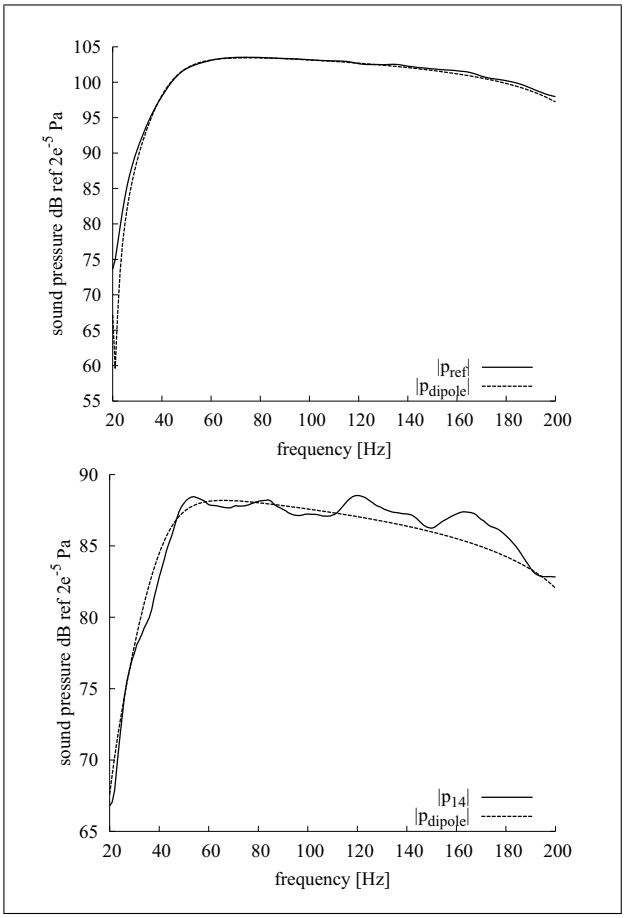


Figure 3. Sound pressure recorded in the anechoic chamber by the reference microphone (labeled '$p_{\mathrm{ref}}$') and at the microphone position on the traverse line closest to the sound source (labeled '$p_{14}$') superimposed with the sound pressure created by the numerical model of the vented box (labeled '$p_{\mathrm{dipole}}$') at the corresponding positions.

source strength of sound source is correctly represented by the numerical model. It can therefore be assumed that the dipole model equation (1) of the bass reflex box YAMAHA SW 118IV represents its free-field behavior with acceptable accuracy over the frequency range of interest.

Once the source location and its characteristics have been determined the reflected sound field $p_{\mathrm{reflected}}$ and the free-field deviation $L_{\mathrm{p}}$ in the anechoic chamber can be calculated via

$$p_{\mathrm{reflected}}(x) = p_{\mathrm{exp}}(x) - p_{\mathrm{inc}}(x), \tag{6}$$

$$L_{\mathrm{p}}(x) = 20\log\left(\left|\frac{p_{\mathrm{exp}}(x)}{p_{\mathrm{inc}}(x)}\right|\right) \tag{7}$$

from the measured sound pressure $p_{\mathrm{exp}}$.

The maximum allowed difference between the measured and theoretical free-field levels according to ISO 3745 and ANSI S12.35 is ±1.5 dB at frequencies lower than 630 Hz. A region where the difference is smaller than the required ±1.5 dB will be called the 1.5 dB region. The size of this region may depend on the frequency and the location of the acoustic source in the chamber. Figure 4

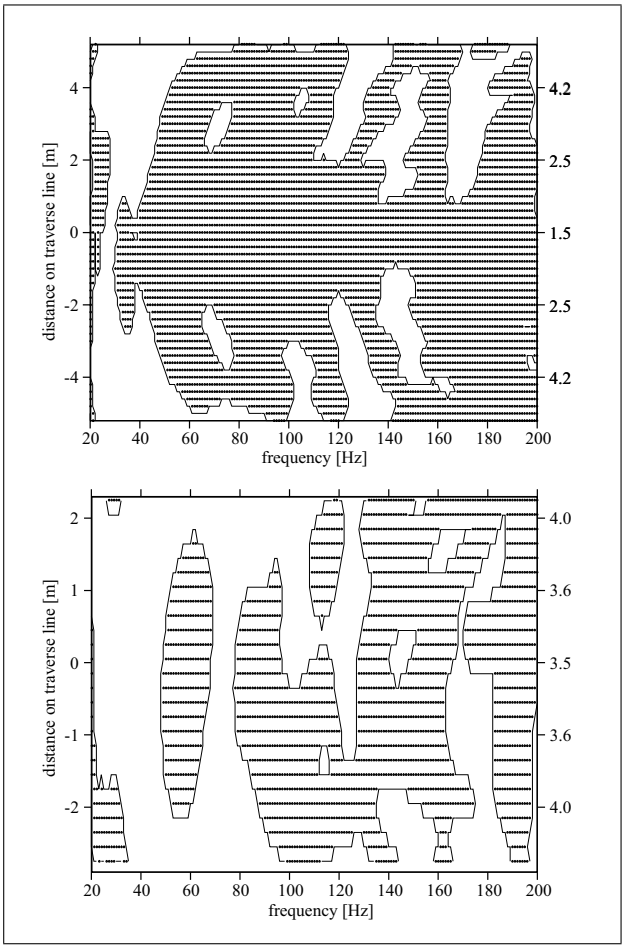


Figure 4. 1.5 dB regions obtained on traverses one and two with source position two.

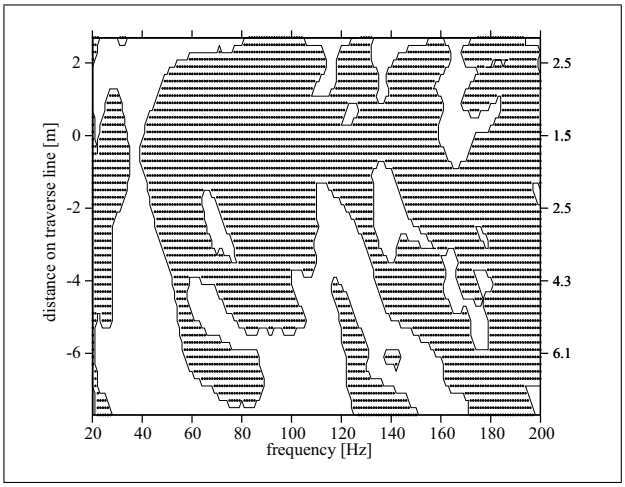


Figure 5. 1.5 dB region obtained on traverses one with source position one.

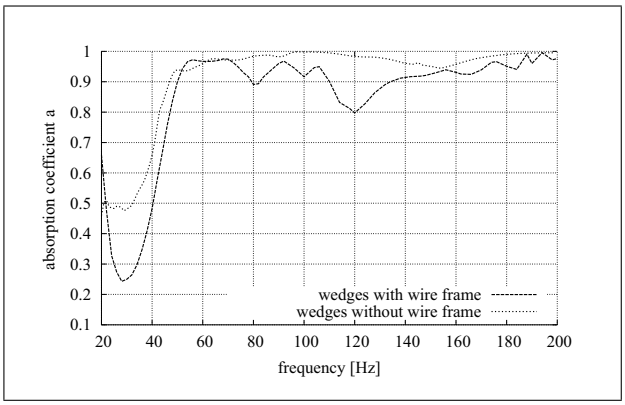


Figure 6. Absorption coefficient of the acoustic lining under different mounting conditions.

shows this 1.5 dB region in the large anechoic chamber at the LMA, as established from the measurement obtained on traverse one and two with the sound source at position two. A pair of frequency and position on the traverse line, where the free-field deviation is smaller than ±1.5 dB, is marked with a point in Figure 4 and the 1.5 dB region is bounded by a continuous line. The length scale on the left of each sub-figure gives the distance on the traverse line with ”0” at the position closest to the sound source. Length scale on the right of each sub-figure gives the total distance between microphone and sound source. Upon analyzing the 1.5 dB region with respect to the length of the room, it was observed that above 50 Hz, in addition to the distance $r = 1.5$ m, which is the smallest distance between the traverse line and the sound source, in a region ±4 m on the traverse line, the deviation from free-field conditions was smaller than 1.5 dB. The 1.5 dB region therefore covers the entire length of the chamber. This holds true except for the 110 to 160 Hz frequency range, where a larger deviation than the 1.5 dB allowed was measured. It is worth noting that this frequency range is above the cut-off frequency of the chamber. In addition, the chamber was found to be asymmetric in the 170 to 190 Hz frequency range at a distance of 1 m to 4.5 m on the traverse line. This position corresponds approximately to the position of a door in the anechoic chamber (see Figure 1). The observed perturbations in the 110 to 190 Hz frequency range could have been expected upon analyzing the absorption coefficient of the acoustic lining. Figure 6 gives the absorption coefficient for normal incidence of plane waves of a sample of 3 × 3 wedges held in place by the iron wire frame which is the configuration installed in the anechoic chamber at the LMA. Up to a frequency of 70 Hz the acoustic lining shows an acceptable absorbing behavior. But fewer absorption was found to occur at higher frequencies. In particular, a significant breakdown was observed in the 110 to 180 Hz frequency range. This breakdown can be made responsible for the poor performance of the chamber in the corresponding frequency range. Note that this wire frame, which is used to hold the wedges in place, has been neglected so far when assessing the quality of the lining and the chamber. For this reason 75 Hz was determined as the cut-off frequency of the chamber out of measurements in an impedance tube experiment without the iron wire frame as the experimental data did not show such a significant breakdown in the absorption coefficient (see Figure 6).

Across the width of the anechoic room only a very small 1.5 dB region was found to exist. This was mainly attributable to the large distance ($r \geq 3.5$ m) between the sound source and the traverse line. Again, an asymmetry was observed in the 80 to 110 Hz frequency range (see Figure 4). Toward positive distances on the traverse line a smaller 1.5 dB region was found to exist than toward negative distances. In addition, traverse two was situated in the region where perturbations between 170 to 190 Hz were found to occur in the case of traverse one, causing a further asymmetric perturbation. Measurements at low frequencies should therefore not be performed at this position. If, however, experiments have to be carried out at this position, microphones should be placed closer than $r = 3.5$ m to the sound source to keep perturbations introduced by the imperfections of the chamber as small as possible.

The objective of the further analysis of the experimental data is to quantify the perturbation that occur in the chamber. The results can be used to judge the reliability of other experimental results or even to correct them. Therefore, either the spatial position of the microphone or frequency of excitation was kept constant.

Firstly, the spatial position was fixed and the response of the chamber with respect to frequency was studied. This reflected the properties of the chamber at a single fixed microphone position. The deviation from free-field conditions recorded in the chamber at a distance of $r = 1.6$ m and $r = 3.5$ m on traverse one and $r = 3.5$ m on traverse two are shown in Figure 7. The experimental data obtained, showed that on both traverses, even above the cut-off frequency of 75 Hz, significant perturbations occurred. At the frequencies 40 and 120 Hz they can reach -5 to -7 dB and even at 145 and 175 Hz perturbations are in the order of 2 dB.

Secondly, the excitation frequency was kept constant and the acoustic field in the chamber was analyzed with respect to the spatial position on each traverse line. On traverse one, four frequencies, 40, 50, 120 and 145 Hz were chosen and the deviation from the free-field condition are shown in Figure 8. At 40 Hz over the entire distance analyzed a constant offset of -1 dB and an increasing difference between the measured and expected sound field was observed. By contrast, the experimental data obtained at 50 Hz show a wide range in the chamber with almost no deviation followed by a rapidly increasing deviation toward the walls of the chamber. Hence when measurements are carried out at a distance of ±3 m from the sound source experimental data will be less subject to perturbations caused by reflections from the walls. Experimental results for 120 and 145 Hz show highly varying perturbations with respect to the position on the traverse line.

These variations reach -4 to 1 dB within a distance of 2 m at 120 Hz. The same holds true for traverse two, at 120 and 145 Hz (see Figure 9), perturbations are highly varying with respect to the spacial position and a correction of acquired experimental data is almost impossible. Therefore, when carrying out measurements in the 120 to

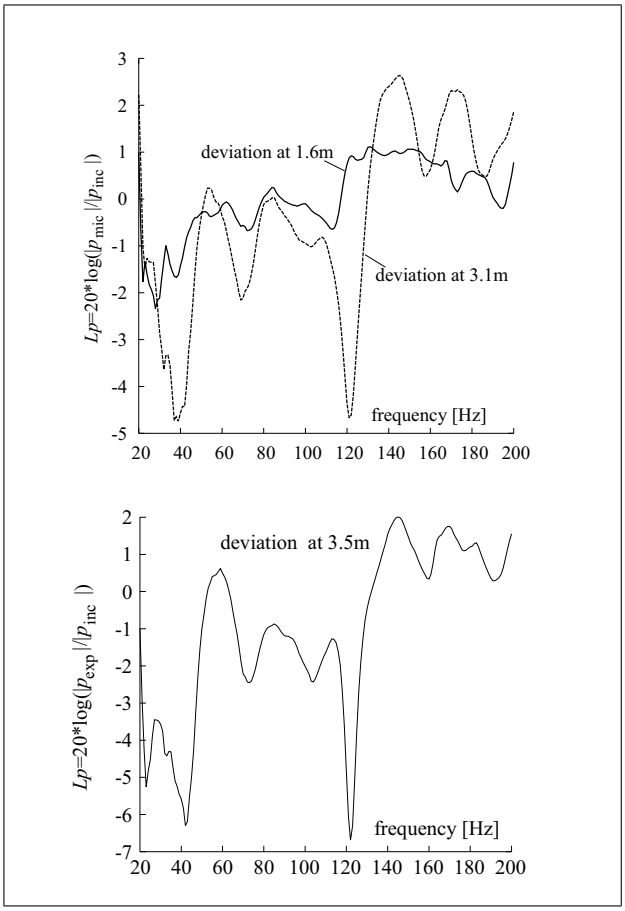


Figure 7. Deviation from free-field conditions with respect to the frequency at a distance of 1.6 m, 3.1 m and 3.5 m. Left sub-figure shows results for traverse one and right sub-figure for traverse two.

160 Hz frequency range experimental results will be subject to significant perturbations caused be the chambers imperfections. The results of the measurements carried out in the anechoic chamber at the LMA, can be summarized as follows.

On traverse one, that is along the length of the chamber, the cut-off frequency of 75 Hz of the chamber was confirmed in a sense that over the entire length of the chamber the deviations from free-field conditions are smaller than 1.5 dB. However, deviations larger than 1.5 dB were found to exist between 110 and 160 Hz. An additional region of deviations larger than 1.5 dB was detected between 170 to 190 Hz at the location of a door in the wall of the anechoic chamber. Traverse two was located exactly at this location, and the traverse data therefore show the presence of perturbations over the entire traverse between 170 and 190 Hz. These perturbations, along with deviations observed between 110 and 160 Hz result in a very small 1.5 dB region at the position of traverse two. Measurements at this position at frequencies lower than 200 Hz should therefore be avoided.

In these premises, the cut-off frequency of the chamber rather lies at 200 Hz than at 75 Hz. Impedance tube measurements on the acoustic lining that respect the mounting

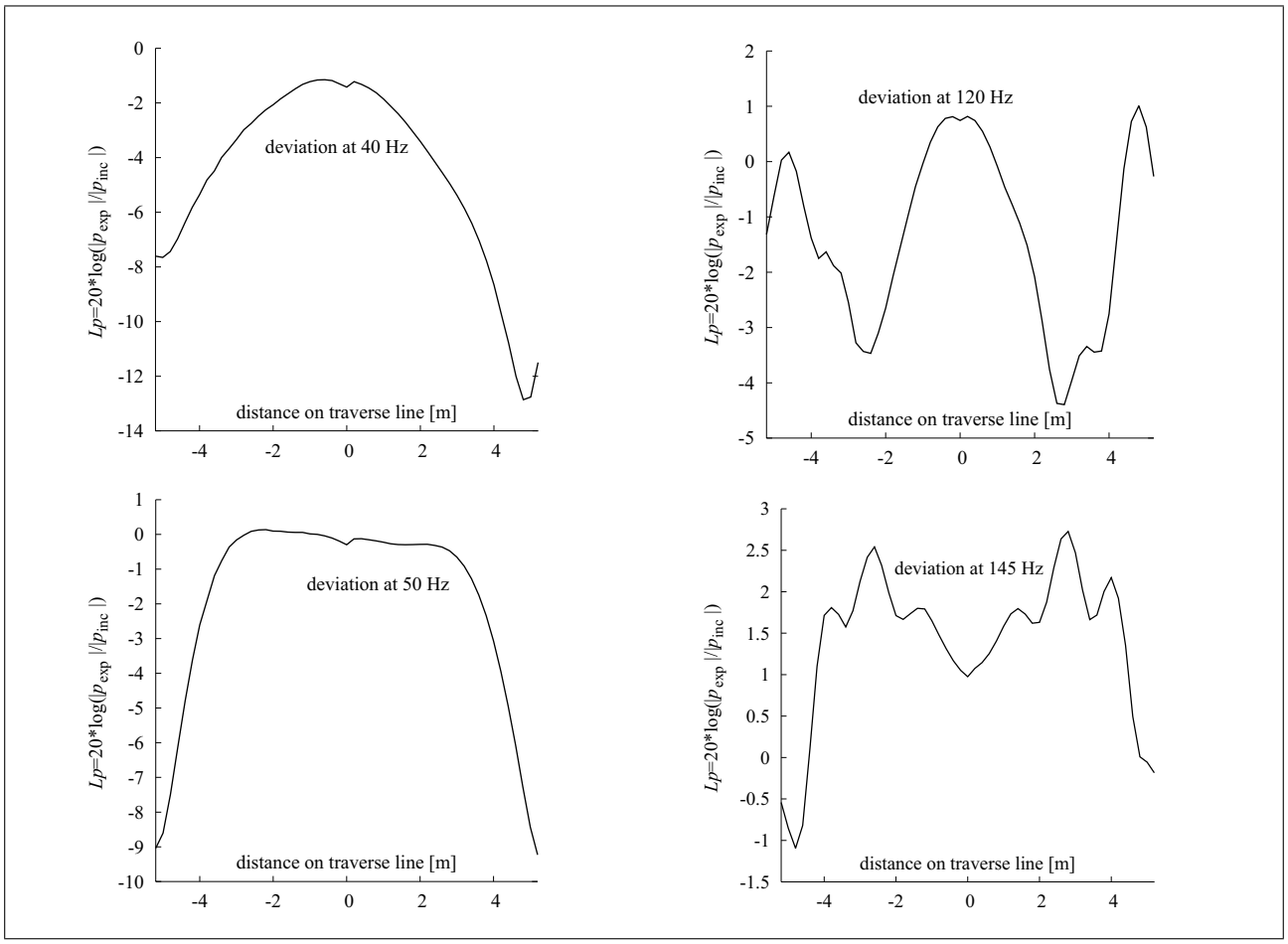


Figure 8. Deviation from free-field conditions with respect to the distance on the traverse line in the case of traverse one and source position two.

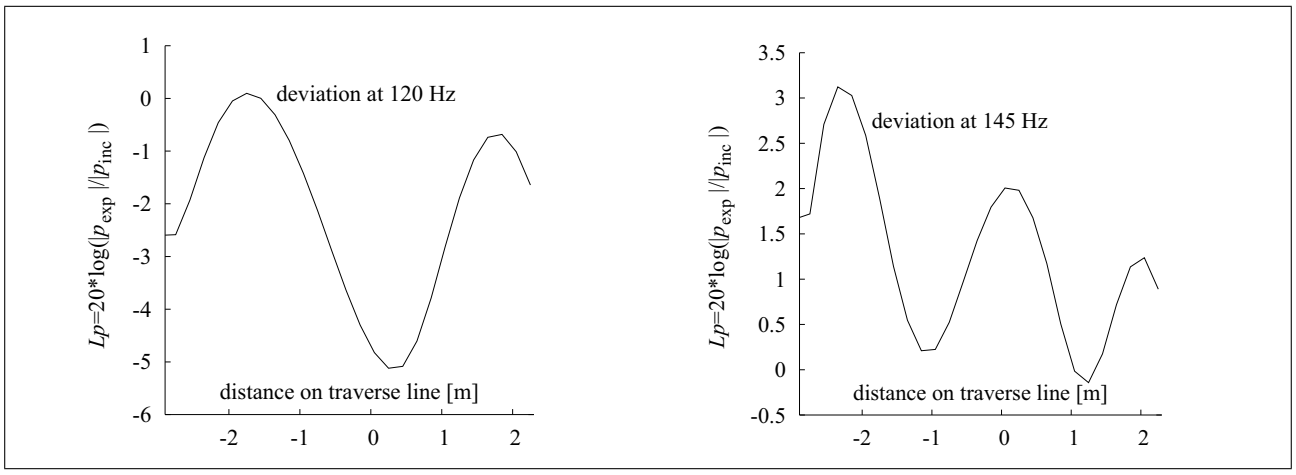


Figure 9. Deviation from free-field conditions with respect to the distance on the traverse line in the case of traverse two and source position two.

conditions of the melamine wedges in the anechoic chamber – an iron wire frame where wedges are clamped in – are showing a fall of the absorption coefficient down to $\alpha \approx .8$ in the 110 to 160 Hz frequency range (see Figure 6). Such a behavior has not been observed when the absorption coefficient of the acoustic lining has been measured without the iron wire frame and thus an incorrect cut-off frequency of the chamber has been determined out of these experimental data. The acoustical behavior of a material like Melamine is dominated, at least in the low frequency range, by the displacement of its frame. Therefore mounting conditions have a significant impact on the

material's behavior and must be carefully respected when carrying out experiments in the impedance tube [15, 16].

## 3. Conclusions

Two traverse lines parallel to the walls of the anechoic chamber of LMA were used to record the sound field created by a bass reflex box. To characterize the response of the chamber to a pure-tone excitation, by determining the reflected sound field, the sound field emitted by the box under free-field conditions was calculated numerically. Using this model for the sound source the 1.5 dB region of the chamber was determined on two traverse lines running parallel to the walls. The results show that even above the cut-off frequency of 75 Hz, the perturbations occurring in the chamber were greater than the permitted value of 1.5 dB. These perturbations were found to occur in the 110 to 160 Hz frequency range. The reason for these imperfections is the fall of the absorption coefficient of the acoustic lining below a value of $\alpha \approx .9$ in the 110 to 160 Hz frequency range. Therefore, the cut-off frequency of the anechoic chamber of the LMA rather lies at 200 Hz than at 75 Hz.

A door in the anechoic room, although it was equipped with an acoustic lining, was identified as of on the causes of imperfections in the chamber at a frequency of around 170 Hz.

### Acknowledgments

The authors would like to thank P. Herzog for fruitful discussions and for providing the parameters of the loudspeaker.

S. Schneider (joint author of this paper) was financed by a grant from the "Deutsche Forschungsgemeinschaft". Numerical simulations were run on a SGI Origin3800 at the Center for Information Services and High Performance Computing at the Technische Universität Dresden, Germany.

### References

[1] M. Melon, C. Langrenne, D. Rousseau, B. Roux, P. Herzog: Comparison of four subwoofer measurement techniques. 120th AES Convention, Paris, France, number 6833.

[2] K. A. Cunefare, V. B. Biesel, J. Tran, R. Rye, A. Graf, M. Holdhusen, A.-M. Albanese: Anechoic chamber qualification: Traverse method, inverse square law analysis method, and nature of test signal. Journal of the Acoustical Society of America **113** (2003) 881–892.

[3] E. C. Bell, L. N. Hulley, N. C. Mazumder: The steady-state evaluation of small anechoic chambers. Applied Acoustics **6** (1973) 91–109.

[4] F. Ingerslev, O. J. Pederson, M. P. K. Moller: New rooms for acoustical measurements at Danish Technical University. Acustica **19** (1968) 185–199.

[5] W. Koidan, G. R. Hruska: Acoustical properties of the national bureau of standards anechoic chamber. Journal of the Acoustical Society of America **64** (1978) 508–516.

[6] R. R. Boullosa, A. P. Lopez: Some acoustical properties of the anechoic chamber at the Centro de instrumentos, Universidad nacional autonoma de Mexico. Applied Acoustics **56** (1999) 199–207.

[7] E. Friot: Control of low-frequency wall reflections in an anechoic room. Active 2006, Adelaide, 18-20 septembre 2006, pages on CD–ROM.

[8] Decibel France insonorisation. Salle anéchoïque du LMA, 616 rue de la Dombes, Z.I. de Rosarge - Les Échets F–01706 Miribel Cedex, 2003. www.decibelfrance.com.

[9] H. C. Hardy, F. G. Tyzzer, H. H. Hall: Performance of the anechoic room of the parmly sound laboratory. Journal of the Acoustical Society of America **19** (1947) 992–995.

[10] ISO 3745-2003: Acoustics – Determination of sound power levels of noise sources - Precision methods for anechoic and semi-anechoic rooms.

[11] J. Duda: Inverse square law measurements in anechoic rooms. Sound and Vibration **32** (1998) 20–25.

[12] YAMAHA corporation: YAMAHA Speaker System: Subwoofer SW118IV. Pro Audio & Digital Musical Instrument Division, P.O. Box 3, Hamamatsu, 430-8651, Japan.

[13] L. L. Beranek: Acoustics. American Institute of Physics, New York, 1993.

[14] R. Small: Vented-box loudspeaker systems-part 1: Small-signal analysis. J. Aud. Eng. Soc. **21** (1973) 363–372.

[15] D. Pilon, R. Panneton, F. Sgard: Behavioral criterion quantifying the edge-constrained effects on foams in the standing wave tube. Journal of the Acoustical Society of America **114** (2003) 1980–1987.

[16] D. Pilon, R. Panneton, F. Sgard: Behavioral criterion quantifying the effects of circumferential air gaps on porous materials in the standing wave tube. Journal of the Acoustical Society of America **116** (2004) 344–356.